Gutiérrez-Dávila, M.; González, C.; Giles, F.J.; Gallardo, D. y Rojas, F.J. (2016). Efecto de sobrecargas ligeras sobre el rendimiento del salto vertical con contramovimiento / Effect Of Light Overloads On Countermovement Vertical Jump Performance. Revista Internacional de Medicina y Ciencias de la Actividad Física y el Deporte vol. 16 (64) pp. 633-648 Http://cdeporte.rediris.es/revista/revista64/artefecto770.htm
DOI: http://dx.doi.org/10.15366/rimcafd2016.64.002

ORIGINAL

EFFECT OF LIGHT OVERLOADS ON COUNTERMOVEMENT VERTICAL JUMP PERFORMANCE

EFECTO DE SOBRECARGAS LIGERAS SOBRE EL RENDIMIENTO DEL SALTO VERTICAL CON CONTRAMOVIMIENTO

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Código UNESCO / UNESCO code: 2406.04 Biomecánica / Biomechanics.
Clasificación del Consejo de Europa / Council of Europe classification: 3. Biomecánica del deporte / Biomechanics of sport

Recibido 27 de febrero de 2014 **Received** February 27, 2014
Aceptado 24 de mayo de 2014 **Accepted** May 24, 2014

ABSTRACT

The purpose of this study was to determine the effect of different light overloads on the vertical impulse, velocity of center of mass and peak power during two consecutive maximum vertical jumps. 28 athletes practicing different sports where vertical jump is a basic skill have participated. A force platform, operating at 500 Hz, temporally synchronized to a video camera, which recorded at 210 Hz the sagittal plane of the jumps were used for the analysis. The results have shown that when overloads of 7,5% of body weight were used , the time used for the counter- phase increased. The vertical impulse and peak power did not vary with the use of different levels of light overloads used in this study, however, the take-off velocity the CM was reduced with a similar percentage that increased the overload.

KEYWORDS: Biomechanics, force, impulse, overweight, vertical jump.

RESUMEN

El propósito de este estudio ha sido determinar el efecto de diferentes sobrecargas ligeras sobre el impulso vertical, la velocidad del centro de masas y el máximo pico de potencia, durante la realización de dos saltos verticales máximos consecutivos. Han participado 28 deportistas practicantes de modalidades deportivas donde el salto vertical constituye una habilidad básica. Se ha utilizado una plataforma de fuerza, operando a 500 Hz, sincronizada temporalmente a una cámara de vídeo, que registraba a 210 Hz el plano sagital de los saltos realizados sobre la plataforma. Los resultados indican que, cuando se utilizan sobrecargas del 7,5% del peso corporal, el tiempo utilizado durante la fase de contramovimiento se incrementa. El impulso vertical y el pico de potencia no varían con el uso de los diferentes niveles de las sobrecargas utilizadas, sin embargo, la velocidad de despegue se reduce un porcentaje similar al incremento de la carga.

PALABRAS CLAVE: Biomecánica, fuerza, impulso, sobrepeso, salto vertical.

INTRODUCTION

From a biomechanical perspective, in complex explosive movements, coordination of partial impulses produced by different muscle groups is one of the most important factors in terms of effectiveness. Furthermore, we must consider that both muscle strength and speed of contraction are dependent on the mass and inertia to which this force opposes. From this biomechanical theory, by increasing the mass we reduce the speed of muscle shortening and, consequently, the dynamic performance of muscle contraction would be modified.

For example, it is known that when muscle activity is geared towards handling heavy loads, the maximum static force tends to increase, while the top speed of muscle contraction remains unchanged or may even decrease. As a result, in addition to increased muscle strength there is a shift of the maximum peak power (PP) to accommodate heavier loads. (Fitts and Widick, 1996; Shoepe, et al. 2003). Conversely, when lighter loads are handled, muscle strength also increases, but PP does not move (Kaneko et al., 1983). Specifically, for vertical jumps, the previous investigations seem to confirm a general hypothesis where the optimal load for maximum energy production and peak power, normally active in person, occurs accelerating the body itself (Dugan et al., 2004; Cormie et al, 2007a;. Markovic and Jaric, 2007; Cormie, et al. 2008; Jaric and Markovic, 2009; McBride et al, 2010). Although the hypothesis set seems to be sufficiently proved when analyzing the various methodologies, types of jumps and the samples used in these investigations, it is necessary to be cautious with the results.

Generally, when it is reported that the optimal load for maximum energy production and peak power in vertical jumps is body mass itself, it has not been taken into account that the feet and legs represent 12% of body mass and these remain static for much of the vertical jump. Thus, some research has suggested an adjustment in the mass, considering only the moving mass (Cormie et al., 2007b). Moreover, during the vertical jumps, the mass of the upper segments is subject to certain acceleration. As a result, they produce an additional force that modifies the external load (inertial force). For example, in vertical jumps performed with segmental participation (arm action), net vertical force, application of strength time and takeoff speed off the center of mass (CM) are increased (Aragón-Vargas, 2000; Feltner , et al., 1999; Hara et al., 2006; Lees et al., 2004; Gutiérrez-Dávila et al, 2012). In order to avoid this, most of the researches supporting the proposed hypothesis have used protocols where the accelerations of the upper segments are restricted during the jump, which is a limitation that keeps us away from reality.

Regarding the samples used, it has been found that the load which provides the maximum PP is different in trained athletes with regard to non-trained athletes (Driss et al., 2001; Stone et al., 2003). This evidence allows us to consider that training can vary certain mechanical properties of muscles that are closely related to the dynamic performance. In this regard, Driss et al., (2001), by using the protocol for jumping starting from squatting with segmental restriction (Squat Jump) have confirmed that the maximum PP is achieved by accelerating its own mass in sedentary people, whereas for athletes trained in strength and power, light loads (5-10 kg), had no effect on the PP.

The use of small overloads in the field of sports training has been associated with the use of weighted vests and belts. On some occasions it has been incorporated as an additional load in order to study its effects on activities that involve quick movements (Cronin et al, 2008; Clark et al, 2010) and in other cases, to determine its effect on the ability to jump (Faigenbaum, et al., 2006; Thompsem, et al., 2007; Khlifa et al, 2010.). However, while these devices do not restrict movement, there is few data that confirms their effect on situations of vertical jump with countermovement and free segmental involvement, ie, situations in which the protocols used are similar to real competitive situations.

As stated above, the purpose of this study was to determine the effect of the use of weighted vests with different light overloads (2.5%; 5% and 7.5% of body mass) on the drive, the speed of CM and the maximum peak power while performing two consecutive maximum vertical jumps without segmental restriction. This is considered to be one of the most appropriate protocols in terms of vertical jumping for the analysis of plyometric activities involving the stretch-shortening cycle (Wallace et al. 2010)

METHOD

Participants

Twenty-six students of the Faculty of Physical Activity and Sport (age = 21.4 ± 2.1 years, height = 1.79 ± 0.05 m; mass = 71.2 ± 6.9 kg; BMI = 22.3 ± 1.8 kgm^{-2}) have participated in this study. It was a requirement for the selection that they have participated regularly in sports in which vertical jump is a basic skill (volleyball, basketball, handball, football and athletics). All participants were informed and asked for their consent to participate in this study following the guidelines of the Ethics Committee of the University of Granada (Spain).

Materials and Procedures

We used a 0.6 x 0.37 m force platform, Dinascan/IBV, which operated at 500 Hz and was temporarily synchronized to a video camera Casio EX - FH20, which recorded at 210 Hz the sagittal plane of jumps performed on the platform. After a standard fifteen minutes warm-up, the participants had to perform two consecutive maximum vertical jumps (Figure 1) starting from a standing position on the platform and implemented with a vest weighted with a variable overload with respect to its mass (0%, 2,5%, 5% and 7.5% of body mass).

Before recording sessions, a learning process to get familiar with the jumping model was performed, as well as to adapt to the registration systems. Following Schmidt and Lee (2011), this learning process ended when the takeoff times of the second jump were stable. One session of five valid rehearsals for each load condition, with a recovery of 2 minutes between every rehearsal and 10 minutes between sessions was conducted. Rehearsals recording the highest and lowest flying time for the first jump and among the remaining three were discarded and only the average recording of the flying time of the second jump was analyzed. The order of the conditions proposed for each session was altered between subjects.

Figure 1. Graphical representation of the model used for the two consecutive maximum vertical jumps.

Calculation of the biomechanical variables

For each rehearsal, the potential bias from the platform forces was determined by the average of the vertical force ($\boldsymbol{F}_Y$) of 20 successive registers after the takeoff of the first jump. After subtracting the possible bias and weight of the subject in each experimental situation ($\boldsymbol{m}_{(0)}$; $\boldsymbol{m}_{(2.5)}$; $\boldsymbol{m}_{(5)}$ y $\boldsymbol{m}_{(7.5)}$, respectively), the vertical acceleration of CM was determined by the $\boldsymbol{F}_Y$ and mass of the jumper for each situation.

Finally, successive records of vertical velocity and vertical positions taken by the CM ($\boldsymbol{v}_{(Y)CM}$ y Y_{CM}, respectively) were determined by means of the integration of the vertical components of the acceleration-time and velocity-time functions respectively and we used for this the trapezoidal method with a temporary increase of 0.002 s. As constant of integration for the first jump we used the CM height in the initial position of each participant and zero speed. For the second jump we used the height and vertical velocity of the CM at the time of making contact with the platform.

The calculation of the constants of integration was made from video images (2D). To do this, before the registration of jumps, a reference system consisting in a bucket of 2 x 2 x 0.5 m which allowed the conversion of the digitized coordinates on real data was used. To determine the initial position of the CM of the first jump, an image previous to the start of the movement was manually digitized by using the model and inertial parameters proposed by Zatsiorsky and Seluyanov (1983) and adapted by De Leva, (1996). To determine the position of the CM touchdown in the second jump, twelve consecutive images were digitized during the start of the second jump, where the sixth image corresponded to making contact with the platform. Thus, the contact occurs in the interval between the 5th and 6th image (an interval of 0.0047 s). The plane coordinates of the twelve images were smoothed by using a digital lowpass filter, 8 Hz (Winter, 1990). CM positions for each image were determined by using the same model and inertial parameters that were used for the first jump.

Finally, the initial position of the CM for the second jump was the average value of positions of the CM corresponding to the 5th and 6th image. The instantaneous vertical speed of the CM is determined by the first derivative of the vertical position of the CM with respect to time (midpoint of the interval between the 5th and 6th image); we used for this the quintic spline functions with zero smoothing (Wood and Jennings, 1979).

The temporal analysis of the two jumps is divided into three phases, according to the methodology proposed by Feltner et al, (2004): *a) Countermovement*, ranging from the beginning of the movement until the vertical velocity of the CM acquires its closest to zero value (t_{0Y}); *b*) *Propulsion* ($t_{(PROPULSION)}$), comprising a temporary period between t_{0Y} and the instant at which the vertical velocity of the CM reaches its maximum value (t_{MV}) and *c)*: *Before takeoff* ($t_{(PREVIOUS\text{-}TAKEOFF)}$), which covers from the t_{MV} to the instant of takeoff (t_{DE}).

The phases mentioned are shown in Figure 2 together with the normalized vertical force with regard to body weight ($F_{(Y)}$), the vertical velocity component of the CM ($v_{(Y)}$) and the normalized power during the propulsion with respect to time, for one of the subjects analyzed. For a detailed analysis of the first jump, the *countermovement* phase is divided into two time periods: a_1: *initial countermovement* period, ranging from the beginning of the movement until the moment when the CM vertical speed reaches its maximum negative value (t_{NV}) and a_2: Period of final countermovement, ($t_{(COUNTERMOV.\text{-}FINAL)}$) ranging from t_{NV} to t_{0Y}. Due to the difficulties in locating the instant when the beginning of the movement occurs, the period of initial countermovement has not been considered.

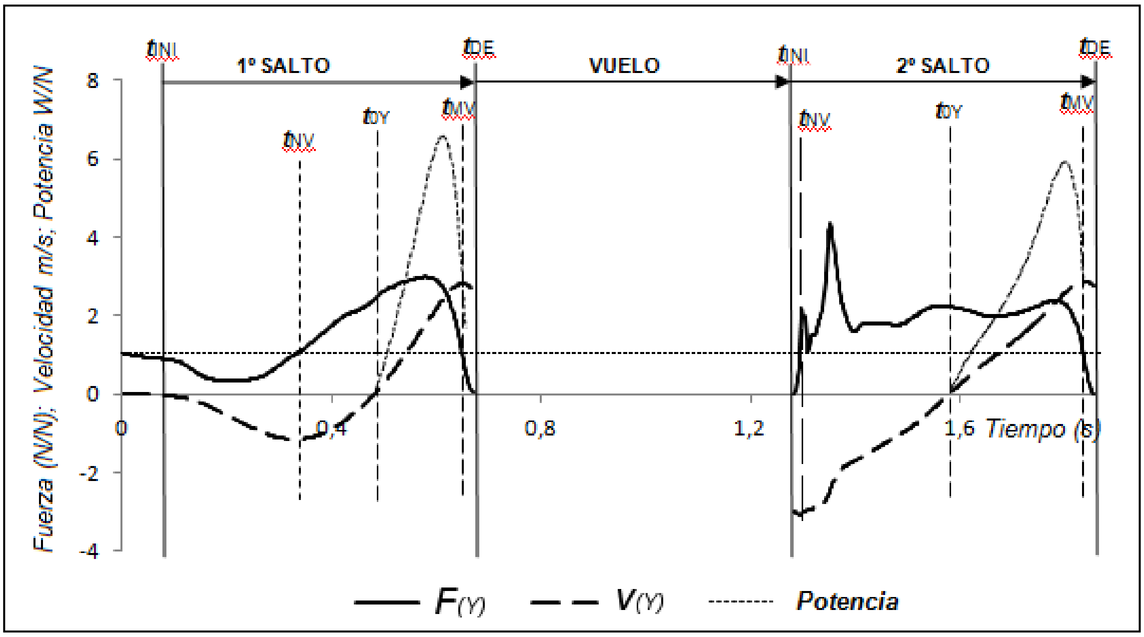

Figure 2. Graphic representation of the phases in which the vertical jump has been divided by using the normalized vertical force with regard to body weight ($\mathbf{F}_{(Y)}$ and the vertical component of the CM speed ($\mathbf{v}_{(Y)}$). The normalized power developed during the propulsive phase is also shown in the figure.

The vertical momentum for the countermovement phase of the second jump and the propulsive phases in combination with those prior to the takeoff, for the two jumps ($\boldsymbol{I}v_{(COUNTERMOV)}$ and $\boldsymbol{I}v_{(PROP.+PREVIOUS-TAKEOFF.)}$, respectively), were determined by integration of the $\boldsymbol{F}_{(Y)}$ function with regard to the lenght of the respective phases, using the trapezoidal method for it with a temporary increase of 0.002 s. The maximum power peak during the propulsion phase ($PP_{(PROPULSION)}$) has been considered as the maximum value of the product of the net force and the vertical speed during the propulsion phase. The time at which the maximum peak power ($t_{(PP-PROPULSION)}$) occurs is expressed as a percentage of the lenght of the propulsive phase.

Statistical Analysis

After checking the normal distribution of the data and in order to evaluate the reliability of the evidence we applied an analysis of variance for repeated measures to all rehearsals in the four experimental conditions (five rehearsals for each condition), using the takeoff time of the second jump ($\boldsymbol{t}_{(COUNTERMOV.)}+\boldsymbol{t}_{(PROPULSION)}$) as dependent variable. No significant differences between rehearsals were observed. The intraclass correlation coefficient for this same variable was 0.984 ($p < 0.001$) for the condition without additional load (0%), 0.987 ($p < 0.001$) for 2.5% ($p < 0.001$), 0.988 ($p < 0.001$) for 5% and 0.982 ($p < 0.001$) for 7.5%. We calculated the mean and standard deviation for each variable in each experimental situation and we determined the differences between the means of the four levels of the variable (0%, 2.5%, 5% and 7.5% of body mass) through an analysis of variance for repeated measures (ANOVA). A subsequent multiple analysis of contrasts determined what groups showed statistically significant differences. The significance level was set at $p < 0.05$. We used the statistical package Statgraphic Plus 5.1. y SPSS v. 20.0.

RESULTS

Table 1 shows the numerical data of the most significant factors that determine the effectiveness of the first vertical jump. Final countermovement time ($\boldsymbol{t}_{(COUNTERMOV.-FINAL)}$) was significantly greater when using an overload of 7.5% of the body mass ($p < 0.05$) with respect to lower loads (0%, 2,5% and 5% of the mass), whereas no statistically significant difference existed between the mean when compared side-by-side overloads lower than 7.5% of the mass. Similar results were obtained for the time of the pre-takeoff, where $\boldsymbol{t}_{(PRE-TAKEOFF)}$ was significantly higher when using a load of 7.5% of the mass ($p < 0.01$), with regard to the use of lower loads. The vertical velocity of the CM at takeoff decreased as the load ($p < 0.001$) increased.

Contrasts test applied to this variable confirms this fact, statistically significant differences between means exist when the four experimental conditions are crossed pair-wise. Although there have been no statistically significant differences between the averages for the maximum peak power during the propulsive phase ($PP_{(PROPULSION)}$), the values of central tendency tend to decrease as the load increases. There were no differences between the averages for the other variables analyzed.

Table 1.- Descriptive statistics and multivariate analysis of variance (ANOVA of repeated measures) for the biomechanical variables in the four conditions of load (0%, 2.5%, 5% and 7.5% with regard to the mass of each participant) for the first jump.

Variables	0% mass[1]	2,5% mass[2]	5% mass[3]	7,5 mass[4]	*F*
$t_{(COUNTERMOV.-FINAL)}$ (s)	0,163 ± 0,033	0,166 ± 0,031	0,167 ± 0,029	0,185[1,2,3] ± 0,041	*3,94**
$t_{(PROPULSION)}$ (s)	0,248 ± 0,050	0,257 ± 0,052	0,256 ± 0,042	0,259 ± 0,040	1,20
$t_{(PRE-TAKEOFF)}$ (s)	0,024 ± 0,004	0,024 ± 0,003	0,024 ± 0,004	0,027[1,2,3] ± 0,005	*5,29***
$v_{(Y)CM}$ in t_{NV} (ms^{-1})	-1,131 ± 0,177	-1,108 ± 0,182	-1,114 ± 0,175	-1,074 ± 0,196	0,86
Y_{CM} takeoff (m)	1,234 ± 0,064	1,227 ± 0,079	1,236 ± 0,066	1,226 ± 0,060	0,46
$v_{(Y)CM}$ takeoff(ms^{-1})	2,758 ± 0,183	2,698 ± 0,189[1]	2,653 ± 0,202[1,2]	2,568[1,2,3] ± 0,196	*23,18****
$I_{V(PROP.+PRE-TAKEOFF.)}$ (Ns)	196,5 ± 23,8	197,4 ± 26,6	198,6 ± 25,9	196,9 ± 25,5	0,47
$PP_{(PROPULSION)}$ (W)	4197 ± 667	4185 ± 712	4134 ± 686	4060 ± 682	1,48
$t_{(PP-PROPULSION)}$ (%)	84,2 ± 3,9	84,1 ± 3,8	84,6 ± 3,0	85,0 ± 3,0	1,19

**** p < 0,001; ** p < 0,01; * p< 0,05; [1,2 3] indicates the different meanings between conditions (p<0,05).*

Table 2 shows the data of central tendency and level of significance of the variables analyzed for the second jump. Regarding temporary variables, there have been only certain statistically significant differences in the time spent in the countermovement phase ($t_{(COUNTERMOV.)}$), being lower when the jump is performed without any overloading (0%) with respect to the rest situations ($p < 0.05$). The vertical velocity of the CM at the time of making contact for the second jump ($v_{(Y)CM}$ reception) tends to decrease as overload ($p < 0.001$) increases.

The test of contrasts applied to this variable shows that there are statistically significant differences when using multiple pair-wise comparison between all situations except for jumps when compared with overloads of 2.5% - 5% of the mass. Similar to the data presented for the first jump, the vertical velocity of the CM on takeoff ($v_{(Y)CM}$ takeoff) tends to decrease when increasing the load ($p < 0.001$).

The test of contrasts revealed that there were significant differences when performing multiple pair-wise comparison between all situations except for jumps when compared to overloads of 5% - 7.5% of the mass. There were no statistically significant differences between the averages for the maximum peak power during the propulsive phase ($PP_{(PROPULSION)}$), although it should be noted that the values of central tendency tend to decrease as the load increases. There were no differences between the averages for the other variables analyzed.

Table 2.- Descriptive statistics and multivariate analysis of variance (ANOVA of repeated measures) fpr the biomechanical variables in the four conditions of load(0%, 2.5%, 5% and 7.5% compared to the mass of each participant) for the second jump.

Variables	0% mass[1]	2,5% mass[2]	5% mass[3]	7,5 mass[4]	*F*
$t_{(COUNTERMOV)}$ (s)	0,293 ± 0,075	0,324[1] ± 0,093	0,322[1] ± 0,094	0,329[1] ± 0,093	*2,83**
$t_{(PROPULSION)}$ (s)	0,268 ± 0,051	0,275 ± 0,053	0,275 ± 0,053	0,281 ± 0,053	0,70
$t_{(PRE-TAKEOFF)}$ (s)	0,025 ± 0,004	0,027 ± 0,003	0,026 ± 0,004	0,026 ± 0,005	1,67
Y_{CM} reception (m)	1,195 ± 0,081	1,191 ± 0,099	1,198 ± 0,079	1,188 ± 0,082	0,18
$v_{(Y)CM}$ reception (m)	-2,881 ± 0,219	-2,819[1] ± 0,236	-2,774[1] ± 0,218	-2,706[1,2,3] ± 0,226	*15,60****
Y_{CM} takeoff (m)	1,222 ± 0,068	1,220 ± 0,075	1,216 ± 0,075	1,209 ± 0,064	*0,65*
$I_{V(COUNTERMOV)}$ (Ns)	205,3 ± 25,7	205,9 ± 26,7	207,4 ± 25,4	207,2 ± 26,3	0,73
$v_{(Y)CM}$ takeoff(m)	2,668 ± 0,183	2,599[1] ± 0,200	2,563[1,2] ± 0,181	2,493[1,2] ± 0,219	14,42***
$I_{V((PROP.+PRE-TAKEOFF.)}$ (Ns)	190,1 ± 22,6	189,8 ± 24,8	189,7 ± 23,0	191,2 ± 27,0	0,53
$PP_{(PROPULSION)}$ (W)	3869 ± 633	3856 ± 634	3851 ± 586	3816 ± 631	0,12
$t_{(PP-PROPULSION)}$ (%)	85,2 ± 4,4	85,1 ± 4,4	86,0 ± 3,1	85,8 ± 3,3	0,53

**** p < 0,001; ** p < 0,01; * p< 0,05; [1,2,3] indicates the different meanings between conditions (p<0,05).*

Figure 3 graphically presents a comparative analysis between the two jumps (first jump and second jump) in the four experimental conditions (0%, 2.5%, 5% and 7.5% of body mass), for the following variables: a) Vertical speed at takeoff ($v_{(Y)CM}$ takeoff), b) Time propulsion ($t_{(PROPULSION)}$) c) maximum peak power achieved during the propulsion phase ($PP_{(PROPULSION)}$). It can be stated from the data exposed that the vertical velocity of the CM at takeoff was greater for the first jump in all load conditions. However, the average time used for the propulsion phase ($t_{(PROPULSION)}$), is higher for the second jump in all load conditions. Finally, the maximum peak power during the propulsive phase is higher for the first jump in all load conditions.

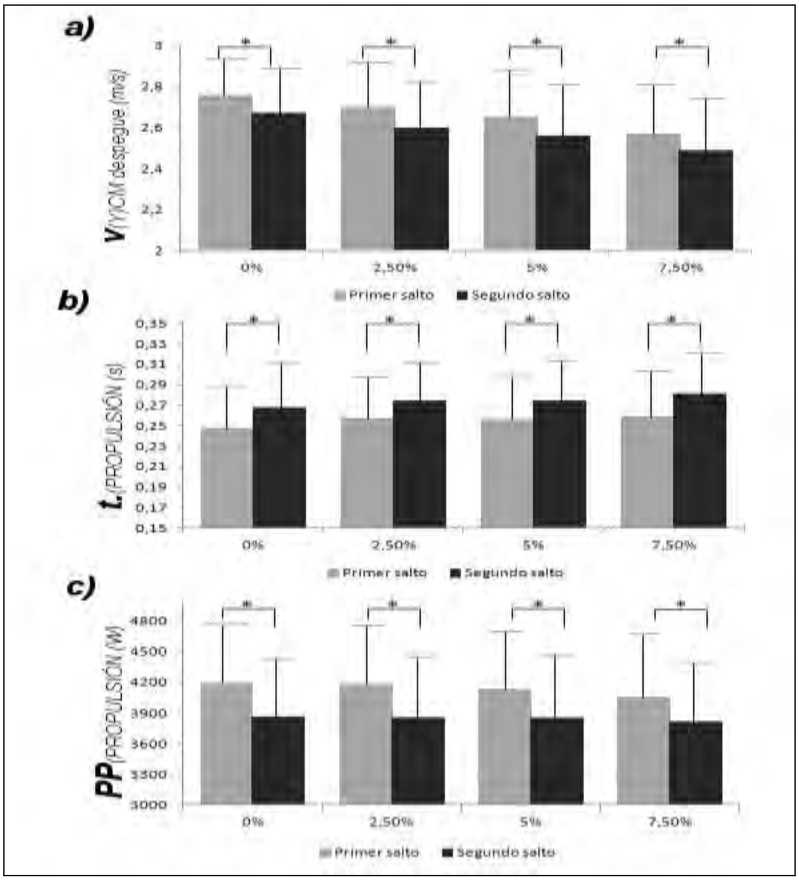

Figure 3. Graphical analysis compared between the two jumps (first jump and second jump) in the four experimental conditions (0%, 2.5%, 5% and 7.5%), for vertical takeoff speed ($v_{(Y)CM\ takeoff}$) (a); propulsion time ($t._{(PROPULSION)}$) (b) and the maximum power peak reached during the propulsion phase ($PP_{(PROPULSION)}$) (c).

DISCUSSION

In the first jump, the average time taken to curb the countermovement ($\boldsymbol{t}._{(COUNTERMOV.-FINAL)}$) tends to increase as the load increases, but there have only been some statistically significant differences for the jumps performed with an overload of 7.5% of body mass. Whereas the maximum negative vertical velocity of the CM was similar in all conditions ($\boldsymbol{v}_{(Y)CM}$ en $\boldsymbol{t}_{NV}$, see table 1), increased time to slow down the movement of the CM downwards (eccentric phase) must obey the need to increase the vertical braking impulse, due to the increase of the displaced mass.

The temporal analysis for the second jump is similar to that described for the first, although the causes may be different. Thus, the time used for the countermovement phase ($\boldsymbol{t}._{(COUNTERMOV.)}$) is smaller for jumps performed with their own mass (0%), compared to those made with any of the other loads. However, the negative vertical velocity of the CM at the beginning of this phase is smaller as load ($\boldsymbol{v}_{(Y)CM}$ *reception*, see table 2) increases.

This fact has a simple physical explanation: By analyzing takeoff speed of the first jump ($\boldsymbol{v}_{(Y)CM}$ *takeoff*, see table 1) it is possible to know that the average height reached by the CM during flight tends to decrease as the load (0.388 m 0.371 m, 0.359 m, 0.336 m, for 0%, 2.5%, 5% and 7.5%, respectively) increases. By reducing the height reached by the CM during the flight of the first jump also the height when dropping for the second jump is reduced. Thus, taking into account that the position of the CM, at the time of reception, is similar for all loads (Y_{CM} *reception*, see table 2), the negative vertical velocity at the reception will also be reduced.

However, there were no significant differences in the vertical momentum developed during the countermovement ($\boldsymbol{I}_{V(COUNTERMOV)}$, see table 2), which allows us to suggest that the reduction in time for the countermovement phase when the mass itself moves (0%) will cause some increase in the net vertical force ($\boldsymbol{F}_{(Z)}$), regarding the use of overloads. It is also possible to explain this rise $\boldsymbol{F}_{(Z)}$ during the countermovement phase in the 0% condition from a muscular perspective. Thus, the highest negative vertical velocity of the CM at the time of reception will produce some increase in the speed of stretching of the muscles and consequently, the eccentric force that might derived from the muscles involved in the countermovement will be increased (Komi 1984). As stated above, we may conclude that the shortest time used during the countermovement phase is due to having started from a previous greater height and not because of the effect of overloading.

One of the most important contributions of this research is related to the vertical velocity of the CM on takeoff ($\boldsymbol{v}_{(Y)CM}$ *takeoff*). This variable has been reduced with the increase of mass for the two jumps. From a purely mechanical point of view, according to the following expression: $\boldsymbol{v}_{(Y)CM} = (\boldsymbol{I}_{V(PROP.+PRE\text{-}TAKEOFF.)}/m)$, the vertical takeoff speed is related to the vertical impulse and the displaced mass. Whereas the vertical momentum ($\boldsymbol{I}_{V(PROP.+PRE\text{-}TAKEOFF.)}$) has been similar in all load conditions (see Tables 1 and 2) and the displaced mass increases by 2.5% in each condition, the vertical speed at the end of the propulsion impulse ($\boldsymbol{v}_{(Y)CM}$ *takeoff*) should be reduced by the same percentage.

Indeed, the data presented confirms that, by increasing loading of 2.5% for each condition, average vertical velocity is reduced an average of 2.25% in the first jump and 2.20% in the second (see Table 1 and 2). Therefore, we could say that the vertical momentum remains similar in all conditions, while the vertical velocity of the CM is reduced to a similar percentage of the increase in load, coinciding with McBride, et al., (2010).

The peak power during the propulsive phase ($PP_{(PROPULSION)}$) has been one of the most used indicators to determine the vertical jump performance and the most used to demonstrate that in the vertical jumps, the optimal load is the body itself (Cormie et al, 2007b;. Cormie, et al. 2008; Jaric and Markovic, 2009; McBride et al, 2010.). However, this research has not found significant differences in the $PP_{(PROPULSION)}$ in either jumps (see Tables 1 and 2)

These discrepancies may be caused by the type of jump used and the load increments. While in previous investigations squat jumps (SJ) or countermovement without arm action (CMJ with segmental limitation) have been used, for this research two maximum consecutive jumps with free segmental action have been used, which modifies the character of the displaced force when taking into account the segmental mass inertia.

But perhaps, the most significant factor that would justify these discrepancies would be the increase of mass for each condition. While in the exposed investigations, increases in loads are relatively high (5-20 Kg or 20% of the 1TRM), in this research the average increase was 3.5 kg (2.5% of the mass). We consider that the ($PP_{(PROPULSION)}$) can be a good indicator when jumps are compared at constant mass or using relatively high overload increases, while not sensitive enough when it comes to increase light loads, where the vertical velocity at takeoff may seem to be a more reliable indicator. Our data is consistent with contributions from Driss et al., (2001), by revealing that light loads have no effect on the $PP_{(PROPULSION)}$ in trained athletes.

Our data do not confirm the contributions by Widick and Fitts (1996) and Shoepe, et al., (2003), when they state that the muscle adaptation to heavy loads cause a displacement of $PP_{(PROPULSION)}$. Here, the time when the maximum power peak occurs during the propulsive phase was similar for both jumps and in all conditions ($\boldsymbol{t}_{(PP\text{-}PROPULSION)}$, see tables 1 and 2). Perhaps, the explanation for this discrepancy is also motivated by the reduced increases of load and the type of jump, especially when considering the relation between the time when maximum peak force occurs and segmental coordination during movement.

The comparative analysis between the two jumps shows that the propulsion time ($\boldsymbol{t}_{(PROPULSION)}$) is increased in the second jump for the four loading conditions, while the vertical take-off speed ($\boldsymbol{v}_{(Y)CM}$ *takeoff*) is reduced. Consequently, the peak power during the propulsive phase ($PP_{(PROPULSION)}$) was lower in the second jump for all load conditions (see Figure 2). These results could be explained by the braking impulse that must be undertaken to reverse the vertical velocity after falling from heights greater than 0.35 m, which coincides with the contributions of Bobbert, et al. (1987) and Peng (2011) when they point out that vertical jumps performed from drop height between 0.4 and 0.5 m, or higher, are not profitable on propulsive phase of the vertical jump.

CONCLUSIONS AND PRACTICAL

When light overloading are used in vertical jumps (2.5%, 5% and 7.5% of body mass), the vertical impulse ($\boldsymbol{IV}_{(PR0P+PRE\text{-}TAKEOFF)}$) and peak power ($\boldsymbol{PP}_{(PROPULSION)}$) do not vary. However, the CM takeoff speed ($\boldsymbol{v}_{(Y)CM}$ takeoff) is reduced to a similar percentage of the load increase rate. These results suggest the lack of sensitivity of the vertical impulse and the peak power as performance indicators of vertical jumps when light loads and free action of the segments (arm action) are used.

When overloads lower than 5% of body mass are used, the vertical impulse ($\boldsymbol{IV}_{(PR0P+PRE\text{-}TAKEOFF)}$) and runtime, in all its phases ($\boldsymbol{t}_{(COUNTERMOV\text{-}FINAL)}$, $\boldsymbol{t}_{(PROPULSION)}$ and $\boldsymbol{t}_{(PRE\text{-}TAKEOFF)}$), do not vary, while the final speed of the CM ($\boldsymbol{v}_{(Y)CM}$ takeoff) tends to be reduced in a similar proportion of the load increase.

According to these results, we would suggest that training with lower overload than 5% of body mass involves applying the same force and not modifying the timing of segmental involvement, while the intended objectives change by reducing the final speed of the CM. Thus, we believe that this training could be a neuromuscular stimulus for muscle action without affecting the coordination of complex explosive movements.

We need to be cautious with the use of overloads above 5% of body mass, where the time of the countermovement phase tends to increase, which implies increased takeoff time and consequently, a decrease in its effectiveness in dynamic activities such as running or jumping. We should also be cautious when generalizing these results to other populations different to those represented by the sample used in this research.

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