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LA MECÁNICA DEL DOBLE SALTO MORTAL ATRÁS EN LA SALIDA DE PARALELAS ASIMÉTRICAS

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RESUMEN

Este artículo muestra un estudio biomecánico cinematográfico de la salida de doble mortal atrás agrupado en paralelas asimétricas por cuatro gimnastas durante el campeonato mundial celebrado en Sttugart en 1989. Los resultados muestran el instante del despegue, para todos los gimnastas; los instantes posteriores (unos 62 milisegundos de media) y el instante en el que el centro de masas (CM) alcanza su máxima velocidad de componente vertical (max. Vy). En los últimos 62 ms previos al despegue, mientras el CM recorría los últimos 14º de rotación sobre la banda superior, se observó una reducción de un 5% en la velocidad vertical del CM. A pesar de ello, durante ese corto período de tiempo el gimnasta obtenía, gracias al impulso de reacción vertical de la banda, un gran incremento de 0.15 m en la máxima altura obtenida por el CM durante la fase de vuelo. Esto incrementa el importante rol que desempeñan las acciones ejecutadas en los instantes inmediatamente previos al despegue. Si el despegue hubiese ocurrido 62 ms antes, en el instante en que se obtiene la máxima Vy, el momento angular de los gimnastas podría haber sido superior, permitiendo una velocidad de rotación más elevada. Sin embargo, el ángulo de barrido en la fase aérea podría haber sido mayor y el tiempo de vuelo levemente menor (-1%).
PALABRAS CLAVE: Biomecánica, gimnasia, entrenamiento

ABSTRACT

Four double tucked back salto dismounts from the uneven parallel bars performed during the World Championships held in Stuttgart in 1989 have been studied by means of cinematographic biomechanical analysis. The results show that the instant of release, for all gymnasts, followed (by 62 ms, on average), the instant when the center of mass (CM) reached its maximum vertical velocity (máx. Vy). In the last 62 ms before release, while the CM was sweeping the last 14º rotation about the upper bar, a decrease by about 5% in the CM vertical velocity occurred. In spite of that, during that short period the gymnasts obtained, thanks to the vertical reaction impulse they elicited from the bar, as large an increase as 0.15 m in the peak height of the CM during flight. This highlights the important role of the actions performed in the instants immediately preceding release. If release had occurred 62 ms esarlier, in the instant of maximum Vy, the gymnasts' angular momentum would have been higher, allowing a faster rotation velocity. Yet, the angle swept in flight would have been larger, and the flight time slightly shorter (-1%).
KEY WORDS: Biomechanics, Gymnastics, Training

Gymnastics coaches are often forced to teach their gymnasts exercises, about which poor information is available, mostly limited to the video-recording of one of the rare performances of that exercise during high level competitions. In such circumstances coaches can but show the recorded performance models, and suggest a qualitative explanation based on their experience and intuition. Gymnasts must build their own motor program on the basis of the observed model and the advice or the coach.

To sum it up, new exercises are taught and learnt in a condition of extreme meagreness of specific information. Typically the needed scientific data that would allow coaches to better programme and structure the teaching action, are not reported in the specific literature.

The literature in the field of sports biomechanics does not include studies about the double back salto dismounts at the uneven bars. The purpose of this study is to provide the coaches, through the biomechanical analysis of four double salto dismounts at the uneven bars performed during the Stuttgart World Championships in 1989, with all quantitative parameters allowing thorough comprehension of the mechanics of these exercises.

METHODS

The exercise subjected to analysis in this study (Fig. 1, 2, 3, 4, 5) is indicated in the Code of Points edited by the IFG (1993) as a B difficulty exercise, n. 8206, and described as follows: "from handstand on the upper bar, through downswing between the bars, to forward swing and double tucked backward salto" (see Fig. 1).

Six double salto dismounts at the uneven parallel bars executed by gymnasts participating in the Stuttgart World Championships in 1989 have been filmed. The four best performances where then selected and analyzed. All gymnasts landed in perfect static equilibrium, except for subject 4, who was obliged to take a little step to the side an slightly backward.

The exercise was filmed with a Beaulieu Super-8 motion picture camera at a rate of 24 frames per second (f/s). The optical axis was in line with the longitudinal axis of the upper bar. The scale of the projected frames was determined using a 2 m long rod, placed on a plane normal to the bars, mid-way between the two standards of the uneven bars. Eleven body landmarks were digitized for each frame. Quintic spline functions developed by Wood and Jennings (1979) and described in detail by Vaughan (1980) were utilized to smooth the landmark coordinates and calculate instantaneous velocity of landmarks. The same quintic spline functions were used to interpolate the landmark coordinates at time intervals of 1/48 seconds (twice the sampling intervals). This was needed to more precisely determine the instants of release, and maximum vertical velocity of the gymnasts' center of mass (CM).

An eight segment model was utilized, assuming that the shoulder landmark coincided with the trunk proximal landmark. The mean segment inertia parameters reported by Zatsiorsky et al. (1990) and adjusted by de Leva (1994) were used to calculate, for each segment, mass, CM position, CM linear velocity, and moment of

Figura 1

inertia about an axis parallel to the camera optical axis, and passing through the segment CM. The inertia parameters by Zatsiorsky et al. (1990), and adjusted by de

Leva (1994) were shown to match the mean parameters of track and field athletes and divers better than any other available set of mean parameters (de Leva, 1993).

The normalized moment of inertia of the body about its CM was obtained by expressing it as a percentage of the estimated maximum moment of inertia about the CM. The latter was defined as the body moment of inertia on the instant when the CM reached the bottom point of the swing. On that instant the body assumed the layout position, with the upper limbs completely abducted and pointing cranially, parallel to the longitudinal axis of the body.

The method used for calculating the angular momentum was described by Hay et al. (1977). The angular momentum of the body about the salto axis (passing through the CM) was normalized by dividing it by the estimated maximum moment of inertia of the body about the salto axis.

The normalized values of the angular momentum are believed to be more easily to understood than the absolute values because they are expressed in revolutions (saltos) per second (r/s), while absolute values are expresed in Kg x m2/s. Moreover, they are not influenced by the gymnast's mass and stature and allow comparisons between exercises performed by different gymnasts. The normalized angular momentum was defined as the angular velocity (r/s) the body would be subjected to in a given instant if it were free to rotate about its CM (as during airborne motion), and in the position of maximum moment of inertia, as described above. For instance, the normalized angular momentum in a given instant of the airborne phase of the dismounts was equalled the angular velocity the body would have if it had suddenly been subjected to squared out therefore rigidly assuming the position of maximum moment of inertia. In a given instant of the lead to swing, the normalized angular momentum hatched to the angular velocity that the body would have had if the bar had suddenly disappeared, and the gymnast had rigidly assumed the position of maximum moment of inertia.

The body orientation vector (BOV) was arbitrarily defined as the vextor pointing from the lower limb CM to the CM of the rest of the body (upper body). Its zero orientation was the positive y direction, with the upper body CM directly above the lower limb CM. The positive direction for angular displacements was defined as the direction of the swing (counterclockwise). The BOV is useful to indicate the orientation of the body in a given instant, although it is not a proper concept in angular kinematics. In fact, the angular velocity of the BOV in a given instant is not strictly related to the angular momentum of the body in the same instant, unless the body is maintaining a still attitude, and can be considered rigid (which is hardly ever the case). For example, if the body angular momentum is zero and the body is changing its attitude,the angular velocity of the BOV can be different from zero. This is impossible for a rigid body. In fact, the angular velocity of a rigid body is proportional to its angular momentum..

In order to evaluate the effects of a theoretical early release, the following formulas, based on the laws of projectile motion, were used to estimate the consequent peak CM height (hmax) during flight, and flight time (T):

hmax = h0 - Vy02 / (2g)

(1)

$$T = \frac{Vy + (Vy02 \quad + 2g\ x\ \ h)}{-g}$$

(2)

where h0 is the height of CM at the theoretical instant of release., Vy0 is the vertical velocity of the gymnast’s CM at the same instant, g is the gravity acceleration (-9.81 m/s2), and h is the difference between the CM height at landing and h0.

All selected parameters were computed by means of a computer program devised by P. de Leva at the Laboratory of Biomechanics of the I.S.E.F. of Rome.

RESULTS

In the Figure 2, 3, 4, and 5 the trajectories of the centers of mass (Cms) and the positions assumed by the gymnasts at the key instants of the exercises are shown. Before release position, the position where the CM reaches its maximum vertical velocity (Vy) during the lead to upswing was also shown.

Figura 3

Figura 2

Figura 4

Figura 5

Table 1 contains a summary of the basic parameters selected to describe the exercise kinematics.

Table 1 A summary of selected data

	Subj.1	Subj.2	Subj.3	Subj.4	Mean	S.D.
Stature	.30 m	1.45 m	1.52 m	1.47 m	1.44 m	0.08 m
Flight time (ms)	979 ms	958 ms	979 ms	917 ms	958 ms	26 ms
Heigth of CM, relative to the bar:						
at max Vy of CM	-0.38 m	-0.36 m	-0.50 m	-0.62 m	-0.46 m	0.10 m
at release	-0.24 m	-0.22 m	-0.28 m	-0.32 m	-0.26 m	0.04 m
peak during flight	0.29 m	0.29 m	0.32 m	0.13 m	0.26 m	0.07 m
at landing	-1.55 m	-1.52 m	-1.47 m	-1.54 m	-1.52 m	0.03 m
Horizontal (Vx) and vertical (Vy) velocities:						
Vx at 180º (CM below bar)	4.4 m/s	4.8 m/s	4.5 m/s	4.7 m/s	4.6 m/s	0.2 m/s
Vx at max. Vy of CM	1.9 m/s	0.7 m/s	1.1 m/s	2.0 m/s	1.4 m/s	0.5 m/s
Vx release	1.6 m/s	0.7 m/s	0.8 m/s	1.2 m/s	1.1 m/s	0.4 m/s
Vy at 180º (CM below bar)	0.5 m/s	0.6 m/s	0.5 m/s	-0.4 m/s	0.3 m/s	0.4 m/s
max. Vy of CM	3.3 m/s	3.4 m/s	3.5 m/s	3.0 m/s	3.3 m/s	0.2 m/s
Vy release	3.2 m/s	3.2 m/s	3.4 m/s	2.8 m/s	3.2 m/s	0.2 m/s
Angular position of the CM bar*:						
at max. Vy of CM	242º	246º	237º	231º	239º	6º
at release	253º	255º	251º	251º	252º	2º
Angular position of body orientation vector (BOV), and its rotation during flight:**						
position at release	115º	113º	106º	101º	109º	6º
position at landing	716º	694º	705º	692º	702º	10º
angle swept during flight	601º	581º	599º	591º	593º	8º
Normalized angular momentum about CM*:**						
at 180º (CM below bar)	1.21 r/s	0.78 r/s	0.89 r/s	0.84 r/s	0.93 r/s	0.17 r/s
at max. Vy of CM	0.87 r/s	0.75 r/s	0.66 r/s	0.85 r/s	0.78 r/s	0.08 r/s
airborne phase	0.73 r/s	0.70 r/s	0.66 r/s	0.64 r/s	0.68 r/s	0.04 r/s
Normalized moment of inertia about the CM (% of max. moment of inertia):						
at release	69%	73%	61%	84%	72%	8%
minimum during flight	26%	25%	22%	21%	24%	2%

(*) The origin is vertical above the bar; positive direction=counterclockwise.

(**) The origin is vertical, when the CM is approximately at the lower point of swing; positive direction=counterclockwise.

(***) Saltos per second if the body had assumed the position of maximum moment of ineria, as at the bottom point of the swing.

The means of the parameters relative to (a) the instant when the CM reaches its maximum Vy, and (b) the instant of release, are reported in Table 2. The differences between the respective parameters (a- b) are reported in Table 2 as well. Note that the release occurred, on average, 62 ms (S.D.=26 ms) after instant of maximum Vy of the CM, and that the CM swept about 14º about the upper bar between the instant of maximum Vy and the instant of release.

Table 2

Comparison between mean parameters: (a) at the instant of maximum CM vertical velocity during upswing, and (b) at release. Release occurred, on average, 62 ms after the instant of maximum CM vertical velocity. Standard deviations are indicated within parentheses.

	at maz Vy of CM (a)	**release (b)**	**Difference (a -b)**
Heigth of CM, relative to thebar	-0.46 m	-0.26 m	-0.20 m
	(0.10 m)	(0.04 m)	(0.07 m)
Horizontal velocity of CM	1.4 m/s	1.1 m/s	0.4 m/s
	(0.5 m/s)	*(0.4 m/s)*	*(0.3 m/s)*
Vertical velocity of CM	3.3 m/s	3.2 m/s	0.2 m/s
	(0.2 m/s)	(0.2 m/s)	(0.1 m/s)
Position of CM relative tobar*	239º	252º	-14º
	(6º)	(2º)	(4º)
Normalized angular momentum	0.78 r/s	0.69 r/s	0.09 r/s
about CM***	(0.08 r/s)	(0.07 r/s)	(0.05 r/s)

(*) The origin is vertical above the bar; positive direction=counterclockwise.

(**) Saltos per second if the body had assumed the position of maximum moment of inertia, as at the bottom point of the swing (seee methods).

In the first column of Table 3 the theoretical values calculated by means of formulas (1) and those (2), based on the laws of projectile motions, are shown. The estimates concern flight time and the peak height of the CM during flight, in the theoretical hypothesis that the gymnasts released the bar on the instant when the CM reaches its maximum Vy. The same parameters have been calculated, with formulas (1) and (2), also for the actual dismounts, in which the release occurred on average 62 ms after the instant of maximum Vy. The data concerning the actual dismounts are reported in the respective column of Table 3, and approximately match, with precision, the means of flight time and peak CM height reported in Table 1. The means were computed with a simpler and more reliable method, respectively on the basis of the amount of frames between release and landing, and the positions of the gymnasts' body in the frames where their CM reached the highest point during the airborne phase. In Table 1 a mean flight time of 959 ms, and a mean peak CM height equal to 0.26 m are reported, while the relevant values in Table 3 are 921 ms, and 0.24 m. The close relationship between the values in Tables 1 (column ?Means"), and 3 (column ?Actual dismounts") indirectly confirms the reliability of the respective calculation methods.

Table 3

Estimated mean flight time and mean peak height of CM during flight, relative to the bar, both (a) for theoretical dismounts with release at the instant of maximum CM vertical velocity (Vy) during upswing, and (b) for the actual dismounts executed by the gymnasts. The values are obtained by applying the basic laws of projectile motion. Standard deviations are indicated within parentheses.

(1)

	Theoretical release atmax. Vy (a)	**Actual dismounts (b)**	**Difference (a - b)**
Flight time	910 ms	921 ms	-11 ms
	(42 ms)	(35 ms)	(13 ms)
Peak CM heigth during flight	0.10 m	0.24 m	-0.15 m
	(0.15 m)	(0.09 m)	(0.07 m)

The line graphs in Figures 6a.6b.6c and 6d show the average curves, during the upswing phase preceding the dismounts, and until the instant of release, the height (h) of the body CM among the upper bar, the horizontal (Vx) and vertical (Vy) velocities of the CM, and the normalized angular momentum of the gymnasts' body to their CM. Notice that in all graphs, except the one showing the horizontal velocity curve, the peak values (highest point of the curve) are the theoretically optimal ones. However it is evident that, on the basis of the graphs, the optimal values do not always coincide with the instant of release, as easily ascertainable for the vertical CM velocity and the angular momentum of the body. On the other hand, the horizontal velocity must be very low at release; hence, the optimal value (lowest point of the curve) coincides with the instant of release.

Figura 6a

Figura 6b

Figura 6c

Figura 6d

DISCUSSION

The gymnasts need to complete about two complete revolutions (saltos) during the flight. To this purpose both mean rotation velocity and flight time must be high. It is clear that a condition of reciprocal dependence exists between the two factors: the longer the flight time, the lower the mean rotation velocity needed to complete the dismount, and vice versa. In fact, it is even possible to state that rotation velocity and flight time are inversely proportional, all remaining conditions being the same. Flight time and rotation velocity are the two main parameters in all salto exercises.

All gymnasts released the upper bar with the body orientation vector (BOV, the arrow indicated in Figures 2, 3, 4, and 5 for each body position, joining the CMs of the lower and upper parts of the body, and passing through the body CM) already tilted backward (109º on average, to the vertical, approximately attained at the bottom of the swing). Moreover, all gymnasts are not yet vertical at landing (mean BOV angle=702º). As a result, the total angle swept during flight does not accomplish two complete revolutions (720º), but amounts to 593º (S.D.=8º) on average, that is about 1+2/3 of a revolution. It is evident that the gymnasts who release the bar in a more tilted backward position, and land in a more tilted forward position reduce the amplitude of the rotation during flight, and vice versa. However, the tilt of either release and landing cannot be varied freely, to the purpose of reducing the amplitude of the rotation during flight. On the contrary, optimal angles of tilt exist, which the gymnast must rigorously stick to, to obtain the right trajectory at release, the right flight time, the right rotation velocity, and equilibrium at landing. The angular position of the CM at release seems to be particularly critical. In fact, for all gymnasts the angle to the upper bar was included in the limited range between 251º and 255º (mean=252º, S.D.=2º). The tilt angles (angular position) of the BOV at release and landing vary within a larger range (respectively, S.D.=6º and 10º). However, all gymnasts selected the optimal landing angle for their own specific conditions, because all of them landed in a perfectly still standing position, except for subject 4, who was slightly out of balance.

Since the amplitude of the angle swept during flight is comparatively steady for all gymnasts, according to the above rationale, the two main variables that allow the gymnasts to complete the needed rotation are (a) the rotation velocity, and (b) the flight time.

Factors determining the rotation velocity

The rotation velocity of the body during flight depends, essentially, on two different factors: (a1) the angular momentum of the gymnast's body with respect to her CM, and (a2) her moment of inertia with respect to the CM. For the sake of simplicity, the most likely negligible effects that the segment motions may have on the rotation velocity due to action-reaction phenomena were not considered in this study. The angular momentum is acquired (and then partially lost) by the gymnast's body as an effect of the reaction force exerted by the upper bar on the hands of the gymnasts, and remains therefore constant during the flight phase, when the force from the bar is not present. During flight, no external force may influence the body except for weight force, that does not affect the angular momentum because it is applied to its CM (friction forces exerted by the air also exist, but are negligible). The rotation velocity of a body during flight is not only caused by its angular momentum, but also by its moment of inertia. The moment of inertia is a quantity merely depending on the distances of the particles of mass that make up the body from a transverse axis passing through the body CM (the axis about which the gymnasts rotate during saltos). Hence, the moment of inertia changes with the attitude of the gymnast, i.e. depending on the position of the single body segments to one another. A gymnast holding the layout position has a larger moment of inertia than a piking gymnast; in turn, the latter has a larger moment of inertia with respect to a tucked gymnast. It is well known that the minimum moment of inertia for the rotations about the transverse axis (saltos) is obtained with the ?splittucked" position, a tucked position with abducted thighs. To sum it up, the moment of inertia of the gymnast about the salto rotational axis changes depending on the degree of tucking-untucking, or picking-unpiking (flexion-extension) of the body. As you can see in Table 2, the moment of inertia at release was equal, on average, to 72% (about 3/4) of the maximum possible moment of inertia (occurring during a layout position with arms completely abducted upward, and parallel to the logitudinal axis of the body), and became equal to 24% (circa 1/4) of the maximum moment of inertia on the instant of maximum tuck (body flexion) during flight. This simply means that at release the rotation velocity was approximately equal to 4/3 (inverse of ¾) of the velocity that the body would have had if it had assumed a layout position, arms upward. In the instant of maximum tuck, the rotation velocity was obviously much faster, amounting to 4 times (inverse of 1/4) the body velocity in the stretched layout position, arms upward. This velocity is evidenced by the values of normalized angular momentum, and on average amounts to 0.68 revolutions (saltos) per second (r/s), with a standard deviation of only 0.04 r/s (about 14º per second).

Therefore, the angular momentum cannot vary after release, while the moment of inertia can. It follows that, if a gymnast releases the bar with insufficient angular momentum, she will not be able to correct her mistake during flight. On the contrary, if the angular momentum is sufficiently high, the right velocity of rotation is obtained and finely modulated or adjusted by varying the degree of body flexion (selecting the proper intermediate positions between layout and maximum tuck), thus changing the moment of inertia of the body. Since, as we explained above, the lower the moment of inertia, the faster the rotation velocity, a gymnast with poor (yet sufficient) angular momentum will need to tuck as much as possible, in some cases assuming the ?split-tuck” attitude, and maintain the tucked position as long as possible. The angular velocity will be thus increased, and maintained high for a sufficiently long period of time.

Factors determining the flight time

The flight time essentially depends on: (1) height of CM at release (mean=0.26 m below the bar, S.D.=0.04 m), (2) vertical velocity (Vy) of the CM at release (mean=3.2 m/s, S.D.=0.2 m/s), and (3) height of CM at landing (mean=1.52 m below the bar, S.D.=0.03 m).

The flight time increases as the CM height at release and/or the Vy of CM increase, and as the landing CM height decreases. It is interesting to notice that, if the gymnasts had released at the instant of maximum Vy of the CM (on average, 62 ms before the actual release), they would not have obtained a longer flight time. On the contrary, the flight time would have been shorter by 11 ms, according to the estimates reported in Table 3, essentially due to the lower CM height at release (-0.02 m, Table 2).

Selection of the instant of release

It is important to highlight that several among the above listed factors, determining flight time and rotation velocity during flight, depend on the instant of release (angular momentum, height and Vy of CM). As shown in the graphs in Figure 6, the angular momentum of the body has its largest value when the CM passes vertically below the upper bar (angular position of CM=180º relative to the bar), i.e. right on the instant when the CM reached its lowest position, and its Vy was approximately zero!.

The gymnasts had to let the CM further rotate about the bar before obtainig sufficient height and Vy of the CM itself. Unfortunately, however, as the CM moved higher, continuing its rotational trajectory about the upper bar, the angular momentum decreased. On the other hand, at the same time the Vy became larger and larger, although only up to a certain limit.

In fact, shortly before release (on average, 62 ms before), the Vy started decreasing again, under the action of the weight force (see Fig. 6). The release occurred after the CM had swept about the bar a mean angle of 252º starting from handstand, 18º before the CM could reach the level of the upper bar. In turn, the maximum Vy of the CM was reached about 14º before release .

The data suggest that the gymnasts selected the instant of release in such a way as to obtain a remarkable lift, to the detriment of their angular momentum. In fact, by delaying the release by 62 ms after the maximum Vy was reached, the recoil from the bar yielded additional upward lift causing an increase in the peak CM height amounting to 0.15 m, and a decrease in the backward angular momentum of the body amounting to 0.09 r/s, to total about 32 degrees per second. The loss of angular momentum during the last 62 ms before release may be seen as a disadvantage, however accepted by the gymnast with the aim to obtain an increased lift.

It should be considered that an early release would have indeed limited the loss of angular momentum, but would have caused a series of disadvantages, among which a slightly shorter flight time (in spite of the larger Vy of the CM at release), a larger horizontal velocity, and a less tilted back release position. Hence, in that case, a larger rotation of the body during flight would have been required out of the gymnasts.

The decrease in angular momentum during the period preceding release must not be necessarily seen as a negative phenomenon. An excessive angular momentum may also cause an excessive rotational velocity, and this makes the perception of body position during flight, and the selection of the right instant for starting the untucking action preceding landing harder. Apart from subjective perception, a higher rotational velocity, together with a larger horizontal velocity, also increase the difficulty of maintaining a still upright position immediately after landing.

CONCLUSIONS

The importance of the actions immediately preceding the release was highlighted by the fact that in the last 62 ms before release, while the CM swept its last 14º of rotation about the upper bar, the vertical reaction forces from the bar were large enough to increase the peak CM height during flight by 0.15 m. In fact, it was found that if the gymnasts had released the bar 62 ms earlier, the peak CM height would have been 0.15 m lower. Of course, the larger CM lift is a factor that is positively judged by the referees, during competitions.

The results of the study permit to better identify the factors determining the optimal release angle. If the release had been anticipated, the CM would have been lower at the peak of its airborne parabola, even though the body would have had a higher angular momentum, and consequently could have rotated faster. Moreover, the horizontal velocity would have been higher, affecting balance at landing.

On the contrary, if the release had been postponed, the peak of the airborne trajectory of the CM would have been higher, and the angular momentum smaller, causing a slow rotation velocity. A delayed release would have also been risky, as the horizontal velocity, continually decreasing, as the body rotates about the bar, might even have changed its direction, causing the gymnasts to hit the bar during the fall.

It is not clear if an early release would permit, thanks to the larger angular momentum, and notwithstanding the slightly reduced flight time, a significantly larger rotation during flight. In this case, it might be possible, with a particularly fast preparatory swing, to perform a triple salto. The need for completing three saltos instead of two could reverse the rank of release factors: the angular momentum could thus gain priority with respect to the CM lift, making an early release (with a lower peak CM height but with the advantage of a larger angular momentum) advisable. This hypothesis will be possibly tested in further studies, by means of computer simulation, even though it is not easy to understand to which extent the vestibular and visual apparati of the gymnasts can withstand the faster rotation velocity, allowing the gymnasts to maintain the correct perception of the body orientation during flight.

REFRENCES

DE LEVA, P. (1993). Validity and accuracy of four methods for locating the center of mass of young male and female athletes. *International Society of Biomechanics XIVth Congress* - *Abstracts*, Vol. I, 318-319.

DE LEVA, P. (1994). *Adjustments to the Zatsiorsky et al.'s (1990) mean segment inertia parameters*. (Not yet published).

MANONI, A. (1987). *Biomeccanica e divisione strutturale della ginnastica artistica*. Rome, ITALY: Società Stampa Sportiva.

VAUGHAN, C. L. (1980). *An optimization approach to closed loop problems in biomechanics*. Doctoral dissertation, University of Iowa.

WOOD, G. A., JENNINGS, L. S. (1979). On the use of spline functions for data smoothing. *Journal of Biomechanics, 12,* 477-479.

ZATSIORSKY, V. M., SELUYANOV, V. N., CHUGUNOVA, L. G., (1990). Methods of determining mass- inertial characteristics of human body segments. In G.G. Chernyi, and S.A. Regirer (Eds.), Contemporary problems of Biomechanics, (pp. 272-291). Boca Raton, MA: CRC Press.