KINEMATIC AND KINETIC ANALYSIS OF COUNTER MOVEMENT JUMP VERSUS TWO DIFFERENT TYPES OF STANDING BACK SOMERSAULT

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Abstract

The aim of this study was to compare the take-off's kinetic and kinematic variables between three types of jumps from a standing position: counter movement jump with arm swing (CMJa), standing back somersault with landings on the spot (BSls) and standing back somersault with rear displacement at landing (BSld). Five elite level male gymnasts (age 23.17 ± 1.61 years; height 165.0 ± 5.4 cm; weight 56.80 ± 7.66 kg) took part in this investigation. A force plate and a 3D movement analysis system were synchronized and used for data collection. Statistical analysis via non-parametric Kruskal-Wallis test showed a significant difference between the take-off variables. The vertical component of force, peak power, impulse and displacement of the centre of mass were significantly different ($P<0.01$). Similarly, the horizontal component of force, maximum speed, peak power and displacement of the centre of mass were significantly different ($P<0.01$). However, vertical velocity remained relatively constant. In conclusion, the standing back somersaults performed on the spot's variables (without back displacement) were very similar to the ones analysed during counter movement jump with arm swing. The standing back somersault with landing on the spot allowed better force impulse. This was facilitated by a take-off closer to the centre of mass, unlike the standing back somersault with rear displacement in landing. Analysing kinetic and kinematic together, allowed the endorsement of linear regression equations enabling the prediction of some variables from others.

Keywords: *gymnastics, take-off, thrown off centre, reaction force.*

INTRODUCTION

Jumps take an important part of gymnastics men and women's daily routines. Gymnasts' ability to transmit their impulse from their feet to their upper bodies following rebounds is crucial, allowing acrobatic skills such somersaulting and twisting. Artistic gymnastics has seen amazing evolution throughout the last five decades (Jemni, Friemel, Sands & Mikesky, 2001). Exhibited strength, power, flexibility and spatial awareness via the incredible complicated aerial skills have contributed in shaping a new profile of the modern gymnast (Jemni, 2011; Jemni, Sands, Friemel, Cooke & Stone, 2006). This lately is nowadays able to perform triple tacked somersaults and even quadruple twists in one straight back. How could they do it? How important is to learn the “perfect” jumping technique? Are there any variables to analyse enabling coaches to dissociate the “good”, the “bad” and the “useful” jumps?

Vertical jumps are used in a plenty of sports. Their primary goal is usually to reach the greatest possible height (Psycharakis, 2012). Other goals could also include rotation in acrobatic somersaulting. Gymnasts’ jumping ability is often linked to successful performance (especially in floor routines and vault) and is sometimes considered as an overall indicator of gymnastics proficiency. Gymnastics’ performance is largely defined by the ability to successfully jump complex forward and backward rotating skills. Video analysis of world-class gymnastics competitions has shown gymnasts performing more backward rotation skills than forward ones (McNitt-Gray, 1992; Munkasy, McNitt-Gray, Michele & Welch, 1996; Harski, 2002; Sadowski, Boloban, Wiśniowski, Mastalerz, & Niźnikowski, 2005). This current study would put some more insight on the nature of the backward take-offs. Analysing the mechanics of ground reactions forces during different jumping cases could add significant understanding and tools for coaching. Reaction force passes through the centre of mass (COM) during vertical jump; meanwhile this force would be thrown off centre forward during a backward rotation. Performing somersaults from a standing position requires a production of significant amount of force and velocity during take-off phases. The transfer of force depends on the gymnast’s ability in backward rotating skills. Relatively large number of authors have analysed various executions of backward somersaults (Payne & Barker, 1976; Bruggemann, 1983; Lacouture, Junqua, Duboy, & Durand, 1989; Knoll, 1992; Newton, Turner, & Greenwood, 1992; Hong & Brüggemann, 1993; McNitt-Gray, Munkasy & Welch, 1994; Duboy, Junka, & Lacouture, 1994; Medved, Tonkovíc & Cifrek, 1995). Conversely, there is a paucity of literature that explores ground reaction forces during take-offs. Mc Nitt-Gray, Hester, Mathiyakom and Munkasy (2001) studied the mechanical demand during landing after three skills: the forward somersault, the backward somersault and the drop jump. Medved (2001) has studied ground reaction force during gymnasts’ take-off while performing two skills: backward somersault and straddle jump, both performed from a standing position. Lebeuf, Lacouture and Bessonnet (2003) analyzed the COM path during a successful and a failed backward somersault. Other studies have examined the vertical jump as in artistic gymnastics (Marina, Jemni & Rodríguez, 2012; Sands, 2011; Sands, Stone, McNeal, Jemni & Haff, 2006; Swartz, Decoster, Russell & Croce, 2005; Marina, Busquets, Padulles & Camps, 2005; Marina, 2002). Very recently, Marina, Jemni, Jimenez & Rodríguez (2012) have thoroughly investigated jumping abilities in significant number of gymnasts and compared them to a matching control group. They have came-up with a very important conclusion showing that studying jumping ability should take few variables into consideration. Flight time, contact time and power output are not enough to dissociate gymnasts; other variables such as Bosco expression and flight to contact times ratio should also be calculated for a more significant profiling purpose. For these reasons, the current study has not only analysed dynamic data acquired by a force plate but also kinematic data collected by synchronised cameras.

The purpose of this study was to compare the take-off’s kinetic and kinematic variables underpinning gymnasts’ ability to perform the counter movement jump with arms swing (CMJa), the standing back somersault with landing on the spot (BSls) and the standing back somersault with rear displacement in landing (BSld).

METHODS

Five elite level male gymnasts (age 23.17 ± 1.61 yrs; height 165.0 ± 5.4 cm; weight 56.80 ± 7.66 kg) took part in this study. The inclusion criteria were: to be ranked at international level with participation in world cups and/or championships; average training volume around 25 hours per week; healthy without any muscular, neurological or tendinitis injuries; able to perform back somersaults on the spot. After being informed on the procedures, methods, benefits and possible risks involved in the study, each subject reviewed and signed a consent form to participate in the study. The experimental protocol was performed in accordance with the Declaration of Helsinki for human experimentation and was approved by the university ethical committee.

The investigation's design contained a dual approach: kinematic and kinetic of three types of take-offs from a standing position. The direction of reaction forces was different between the three skills during the push-off phases (Figure 1):

- It passes through the centre of mass (COM) during the counter movement jump with arm swing (CMJa) (Figure 1a);
- It is thrown off centre forward but close to the COM during the standing back somersault with landings on the spot (BSls) (Figure 1b);
- It is very thrown off centre forward during the standing back somersault with rear displacement at landing (BSld) (Figure 1c).

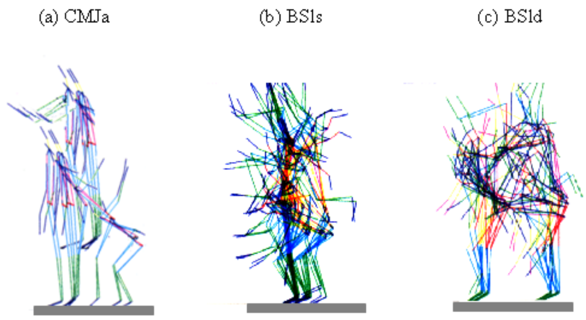

Figure 1. *Kinogrammes of three types of take-off from a standing position. (a) counter movement jump with arm swing; (b) standing back somersault with landings on the spot; (c) standing back somersault with rear displacement in landing.*

Kinetic data were acquired using a 60×40 cm Kistler force plate (Kistler Instruments, Switzerland. Ref. 9281C). Sampling frequency was 500 Hz, and the measuring range was set between 10 to 20 kN. Vertical (Fy) and horizontal (Fx) force variables, the COM displacement (dx; dy), velocity (vx; vy), peak power (Px; Py) and impulse (Ix; Iy) were analysed. Analysis was performed with a Bioware Performance Software 5.1.1 (Kistler Instruments, Switzerland).

Kinematic data were acquired using two high-speed cameras (NAC HSV-500C3; 250 Hz) in NTSC format with VCR C3D and SVHS tape. A motion analysis software (Movias, NAC Corp, Santa Rosa, CA) was used to process the data. 20 retro-reflective body markers were attached to the gymnasts' bodies allowing digitisation using a video based data analysis system (Movias for Windows 2.0.4). The body segments' centres of mass were computed using Matshui model (1983). Take-off angle (α_T), shoulder angle (α_S), hip angle (α_H) and knee joint angle (α_K) were analysed and compared at the different take-offs. Angular displacements of these respective joints (θ_S, θ_H and θ_K) and their angular velocities (ω_S, ω_H and ω_K) were calculated in the sagittal plane. Data acquisition and testing were carried out in a laboratory setting. All tests were performed within a 3-day period, starting at 4:00$_{PM}$ up to 6:00$_{PM}$ under the following environmental condition: average temperature 23°C (minimum 20, maximum 26°C). The force plate was synchronized with the two high-speed cameras. The first camera was placed in front of the subject and the second sideways, each at 5m from the centre of the force plate (figure 2). All participants wore only a short during testing to allow digitising. They were given ten-minute warm-up period including light jog, stretching and several jumps and somersaults with stable landing. Each gymnast performed each jump three times in separate days. The choice of jumps and/or somersaults was randomised using Latin Square randomisation protocol (Zar, 1984).

The execution of each skill was separated by a two-minute recovery period between repetitions. Two international judges marked each somersault by referring to the Code of Points FIG (2009). Only the best somersault was retained for analysis and comparison.

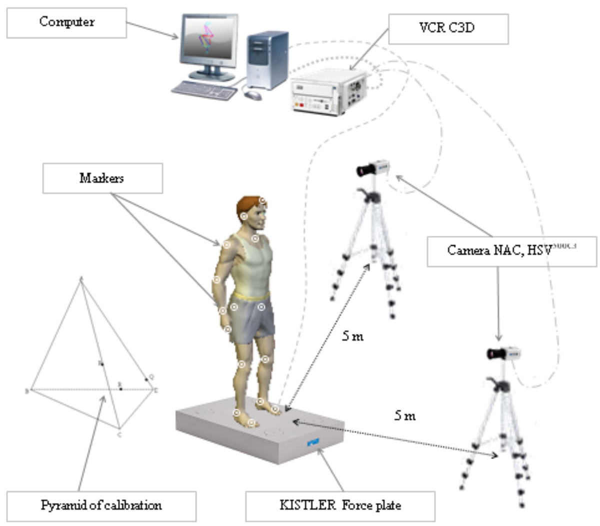

Figure 2. *Experimental setup.*

Data are reported as mean ± standard deviation (SD). The distributions' normalities, estimated by the Kolmogorov-Smirnov test, varied between variables. Therefore, we used the non-parametric Kruskal-Wallis test to compare all take-offs' variables, while the U test of Mann-Whitney was applied to pair-wise the somersaults and CMJ comparison. Spearman correlation analysis was performed to check any relations between the CMJ and the back somersaults. The results are considered significantly different when the probability is less than or equal to 0.05 ($P \leq 0.05$). Statistical analyses were performed using the software package SPSS version 13.0 (SPSS Inc., Chicago, IL, USA).

RESULTS

All kinetic data for the BSld have almost doubled in comparison to the tow other conditions. Significant statistical increases were noticed in all horizontal components: the horizontal force component (Fx) has increased by 63.36% during the BSld when compare to the CMJa and by 39.18% when compared to the BSls ($P<0.01$) (Table 1). Similar results were noticed for the horizontal velocity (vy): [+41.36% compared to CMJa ($P<0.05$), (+51.49% compared to BSls ($P<0.01$)], the horizontal peak power (Px): [+50.87% compared to CMJa ($P<0.01$) and +50.34% compared to BSls ($P<0.01$)] and the horizontal impulse (Ix): [+36.23% compared to CMJa ($P<0.05$) and +51.03% compared to BSls ($P<0.01$)] (Table 1).

The magnitude of change has ranged between 10% to 22% when it came to compare the vertical components. Force vertical component (Fy) has significantly increased by 10.04% during the CMJa in comparison to the BSld ($P<0.01$). Similarly, peak power's vertical component (Py) has significantly increased during the same take off compared to the tow other conditions: [by 19.031% compared to BSld ($P<0.01$) and by 11.81% compared to BSls ($P<0.05$)].

Looking at the absolute data, the CMJa and BSls showed the highest level of vertical force, followed by BSld (1808.89 ± 97.06 N; 1806.87 ± 78.08 N; 1625.55 ± 62.64 N respectively). Moreover the horizontal component of force was the highest during the BSld take-off (very thrown off centre). The BSld developed more force than the BSls and the CMJa (209.44 ± 4.80 N; 126.65 ± 22.14 N; 127.38 ± 7.97 N respectively) (Figure 3).

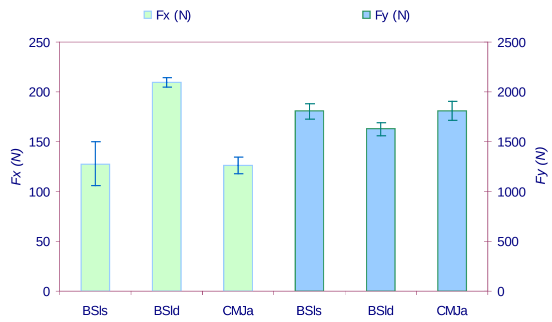

Figure 3. *Horizontal and vertical forces produced during the three take offs.*

Vertical axis' variables were different during the impulse of the three take-offs (214.91 ± 9.37 N/s; 194.72 ± 3.82 N/s; 176.31 ± 20.82 N/s respectively for CMJa, BSls and BSld). Moreover, the horizontal axis of the impulse was higher during the BSld compared to the BSls and to the CMJa (23.80 ± 3.84 N/s; 18.28 ± 2.68

N/s; 17.91 ± 6.09 N/s respectively) (Figure 4). Impulse's vertical component of (I_y) has significantly increased during the BSls compared to the other conditions: [by 21.89% compared to BSld (*P*<0.01) and by 10.37% compared to CMJa (*P*<0.05)].

Vertical velocity was almost the same between BSls, Bsld and CMJa (3.05 ± 0.04 m/s, 3.40 ± 0.40 m/s; 3.57 ± 0.37 m/s respectively); however, and as expected, the horizontal velocity was the highest during BSld, followed by the BSls and CMJa (0.41 ± 0.07 m/s; 0.29 ± 0.05 m/s; 0.20 ± 0.04 m/s respectively). This increase is indeed a basic condition allowing backward rotation, and is supported by the fact that power generated on the horizontal axis was greater during the BSld compared to BSls and CMJa (279.00 ± 60.34 W; 138.08 ± 35.00 W; 137.54 ± 27.62 W respectively). In contrast, the peak power produced on the vertical axis was more important during CMJa and BSls than during BSld (4774.12 ± 231.98 W; 4269.72 ± 245.65 W; 4010.94 ± 368.00 W respectively) (Figure 5).

Table 1. *Comparative statistics of the three take-offs.*

	Variables	*Kruskal Wallis Test*		*Mann-Whitney Test*					
				CMJa vs. BSls		CMJa vs. BSld		BSls vs. BSld	
		K²	Sig.	Z	Sig.	Z	Sig.	Z	Sig.
Kinetic	Fx (N)	9.517	0.009**	-0,522	0,602	-2,619	0,009**	-2,619	0,009**
	Fy (N)	9.380	0.009**	-0,104	0,917	-2,611	0,009**	-2,611	0,009**
	Vx (m/s)	11.060	0.004**	-2,193	0,028*	-2,402	0,016*	-2,611	0,009**
	Vy (m/s)	5.840	0.054	-2,402	0,016*	-1,358	0,175	-0,94	0,347
	dx (m)	9.500	0.009**	-0,522	0,602	-2,611	0,009**	-2,611	0,009**
	dy (m)	7.620	0.022*	-1,358	0,175	-1,567	0,117	-2,611	0,009**
	Px (W)	9.380	0.009**	-0,104	0,917	-2,611	0,009**	-2,611	0,009**
	Py (W)	8.340	0.015*	-2,193	0,028*	-2,611	0,009**	-0,731	0,465
	IFx (N/s)	10.640	0.005**	-2,402	0,016*	-1,984	0,047*	-2,611	0,009**
	IFy (N/s)	11.180	0.004**	-2,611	0,009**	-1,984	0,047*	-2,611	0,009**
Kinematic	α_T (°)	12.50	0.002**	-2,611	0,009**	-2,611	0,009**	-2,611	0,009**
	α_S (°)	8.960	0.011*	-2,402	0,016*	-2,611	0,009**	-0,731	0,465
	α_H (°)	2.060	0.357	-0,313	0,754	-1,567	0,117	-0,731	0,465
	α_K (°)	9.380	0.009**	-2,611	0,009**	-2,611	0,009**	-0,104	0,917
	θ_S (°)	6.720	0.035*	-0,731	0,465	-2,611	0,009**	-1,567	0,117
	θ_H (°)	12.500	0.002**	-2,611	0,009**	-2,611	0,009**	-2,611	0,009**
	θ_K (°)	1.820	0.403	-0,104	0,917	-1,358	0,175	-0,94	0,347
	ω_S (°/s)	7.580	0.023*	-0,731	0,465	-2,402	0,016*	-2,193	0,028*
	ω_H (°/s)	0.420	0.811	-0,522	0,602	-0,313	0,754	-0,522	0,602
	ω_K (°/s)	7.460	0.024*	-1,984	0,047*	-2,611	0,009**	-0,94	0,347

* Significant at *P* < 0.05; ** Significant at *P* < 0.01

Kinematic study has provided the following results: the take-off angle (α_T) relative to the vertical axis was significantly decreased in the BSld condition in comparison to the two other conditions (*P*<0.01): by 5.01% and by 13.45% compared to BSls and to CMJa respectively. Similarly, the angle of shoulder joint at take-off (α_S) was also significantly decreased by 18.22% during the BSld compared to the CMJa (*P*<0.05). The angle of knee joint at take-off (α_K) was significantly decreased at almost a similar percentage during the same skill compared to CMJa (18.72%) (*P*<0.01) (Figure 6).

Furthermore, the angular displacement of the shoulder joint (θ_S) was significantly increased by 9.65% in the CMJa condition compared to BSld (P<0.01). More considerable change was noticed in the hip joint. Its angular displacement (θ_H) has significantly increased compared to the two other conditions (P<0.01): by 34.50% and by 14.70% compared to BSld and to BSls respectively.

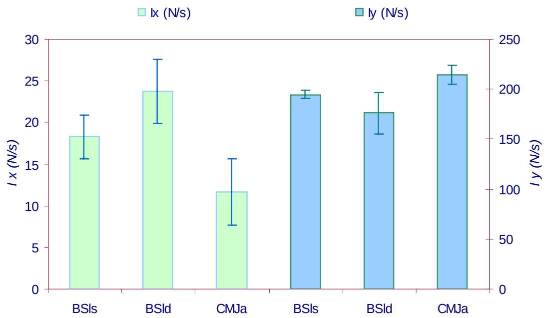

Figure 4. *Horizontal and vertical impulse generated during the three take-offs.*

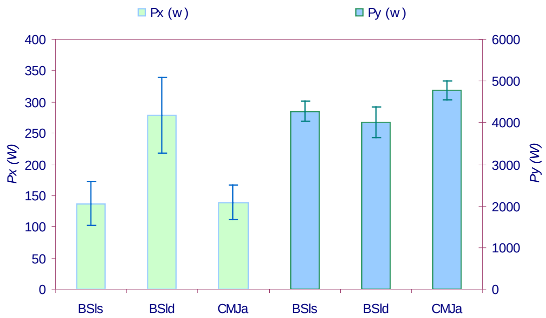

Figure 5. *Horizontal and vertical peak power generated during the three take-offs.*

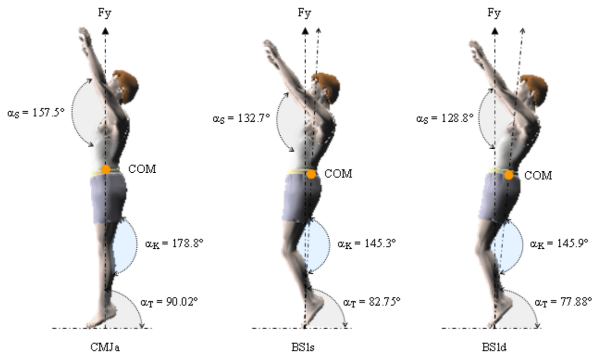

Figure 6. *Joint angles during the three take-offs.*

Angular displacement of the arms was larger during the CMJa compared to the BSld (157.51±6.77° and 128.81±7.63° respectively) and the flexion of the hip joint was also more important (55.48±2.05°; 47.32±2.36° and 36.33±2.65° respectively for CMJa, BSls and BSld). Angular velocity of the knee joint (ω_K) was likewise increased during the CMJa compared to the other situations by 27.95% v BSld (P<0.01) and by 19.70% v BSls (P<0.05). The angular velocity of the shoulder joint (ω_S) was itself, significantly increased in the BSld condition with respect to the two others (P<0.05): by as high as 65.53% compared to BSls and by 71.86% compared to CMJa (Figure 7).

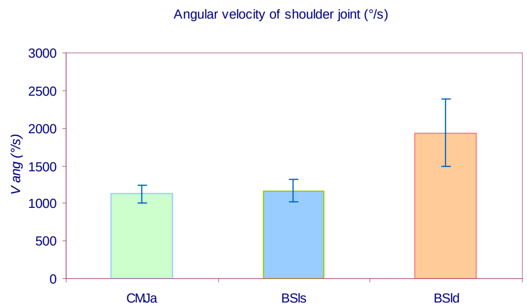

Figure 7. *Angular velocity of shoulder joint during the three take-offs.*

Lastly, the centre of mass's (COM) vertical velocity (vy) and the angular velocity of the knee joint (ω_K) did not vary during the different take-offs. In the same way, the hip joint's angle (α_H) at take-off and its angular displacement (θ_H) remained

Correlation analysis showed only one significant relation (P<0.05) across all data. It was between the BSls and CMJa and in particular between the vertical component of force (Fy) and displacement (dy) of the COM (r = -0.900 and r = 0.884 respectively) (Figure 8a and b).

Correlation between the kinematic and kinetic variables showed a significant relation at (P<0.05), between the take-off angle (α_T) and the horizontal displacement (dx) of the COM (r = -0.900). Similarly, there was a significant correlation at (P<0.05), between force's vertical component (Fy) and the angular displacement of the knee joint (θ_K) (r = -0.900). A highly significant correlation at (P<0.001) was also found between the vertical peak power (Py) and the angle of the hip joint (α_H) (r = 1.000).

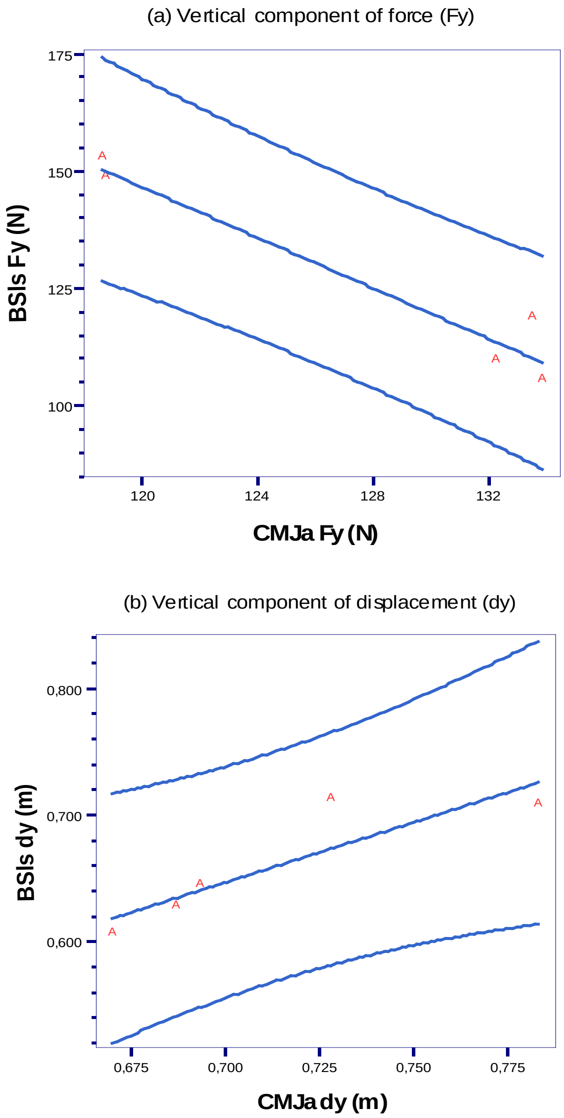

Figure 8. *Correlation between SBls and CMJa*

DISCUSSION

This study is focused on the variables that could affect the take-off phases by comparing them between three different jumps/skills. It is indeed well documented that different types of take-offs significantly affect the range of motion (ROM) of the lower limbs and therefore the entire height of the jump and the resultant power output (Marina, Jemni & Rodriguez 2012). In this study, the angle of the knee joints (θz) was significantly higher during the CMJa than during the BSls and the BSld. This variation of ROM during the take-offs could be explained by the direction of reaction force with respect to the COM. If the direction of the force is off COM this could lead to some "wasted effort" and therefore not enough height could be reached. Several studies confirmed that the optimal knee angle that produced the best vertical displacement in gymnasts was around 90° (Salles, Baltzopoulos and Rittweger 2011, Moran and Wallace 2007, Mathiyakom, McNitt-Gray and Wilcox 2006). In this current study, the five gymnasts have reached an average height of 0.71 ± 0.04m during the CMJa, whereas they only reached 0.65 ± 0.04m and 0.60 ± 0.03m during the BSLs and BSld respectively (Figure 9). Their horizontal displacement, however was expectedly the highest during the BSld, caused by a take-off very thrown off centre and allowing rotation, as described by Medved et al. 1995; Munkasy et al. 1996; Medved 2001; Leboeuf et al. 2003.

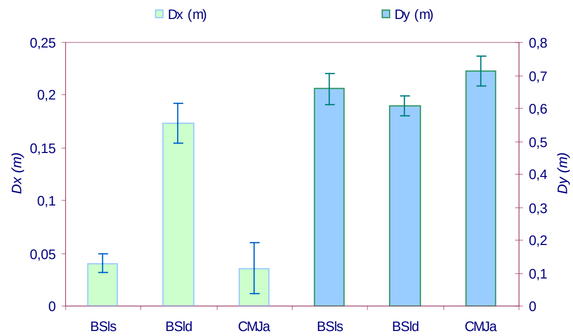

Figure 9. *Horizontal and vertical displacement of the COM reached during the three take-offs.*

Our investigation confirms, as previous studies, that CMJ allows more significant displacement. This was indeed shown by the knees' angle that was significantly more important during the CMJs' take-off compared to BSld and to BSls. Clansey and Lees (2010) suggested a strong relationship between the ROM of the knee and the hip joints during the vertical jump. This could explain the large knee amplitude during the CMJa in our study.

Table 2 highlights the main kinetic and kinematic findings of this study in comparison between the three take-offs. Comparison between the back somersaults showed that the BSld developed less force and impulse on the vertical axis compared to the BSls. However, there was a significant increase of the strength, maximum speed, impulse, peak power and displacement at the horizontal axis, as suggested by Medved (2001) and Leboeuf et al. (2003). Comparison between the BSld and CMJa showed, indeed, a very significant difference for all variables except for the vertical velocity of the COM that remained almost at the same level (Table 1). These results confirm similar investigation by Leboeuf et al. (2003), in which they showed that gymnast would miss the back somersault if he was inclined backwards during the take-off. Contrariwise, there was a great similarity between the CMJa and BSls in most variables, with the exception of the vertical impulse and peak power that were significantly lower, as also suggested by other authors (McKinley and Pedotti, 1992; Medved 2001; Mc Nitt-Gray 2001).

Table 2. *Variation of the main kinetic and kinematic variables at three take-offs.*

Variables		CMJa	BSls	BSld
Kinetic	Fx (N)	↘	↘	↗
	Fy (N)	↗	↗	↘
	Vx (m/s)	↘	↘	↗
	dx (m)	↘	↘	↗
	dy (m)	↗	↗	↘
	Px (W)	↘	↘	↗
	Py (W)	↗	↘	↘
	Ix (N/s)	↘	↘	↗
	Iy (N/s)	↗	↗	↘
Kinematic	α_T (°)	↗	↘	↘
	α_S (°)	↗	↘	↘
	α_H (°)	↗	↘	↘
	θ_S (°)	↗	↗	↘
	θ_H (°)	↗	↗	↘
	ω_S (°/s)	↘	↘	↗
	ω_K (°/s)	↗	↘	↘

** Where: (↗) is increase; (↘) is decrease.*

The increased horizontal force during the BSld was firstly caused by the take-off, which was thrown off centre, secondly by a surplus of horizontal displacement as suggested by (Mc Nitt-Gray, 2001; Medved 2001; Leboeuf et al. 2003). Leboeuf et al. (2003) mentioned that, if a back somersault is performed correctly, the pulse force would be around 200 N/s. These figures are indeed higher than the ones found in the current study as our gymnasts' force pulse ranged between 194.72 ± 3.82 N/s; 176.31 ± 20.82 N/s respectively for the BSls and BSld (Figure 4). This difference might be related to the fact that our gymnasts performed the somersaults on the spot whereas in Leboeuf et al. (2003)'s study, they performed it after a snap down.

Interestingly, the correlation analysis showed a significant relation between CMJa and BSls at the force's vertical component and the displacement of COM (R^2 = 0.94; R^2 = 0.78 respectively). Moreover, correlation analysis between kinetic and kinematic variables showed significant relations between the following: take-off angle (α_T) and horizontal displacement (dx) (R^2 = 0.89); vertical force component (Fy) and angular displacement of the knees joint (θ_K) (R^2 = 0.75); vertical peak power (Py) and the hips joint angle (α_H) (R^2 = 0.97). Thus, we could suggest a linear regression to predict the kinetic performance variables from the results of the kinematic study and vice versa. The regression equations would be:

Prediction of kinetic variables from kinematic data:

$d_{x\,(m)} = -2.26 + (-0.02 \times \alpha_{T\,(°)})$

$F_{y\,(N)} = 2429.88 + (-9.26 \times \theta_{K\,(°)})$

$P_{y\,(W)} = -185737.31 + (1061.23 \times \alpha_{H\,(°)})$

Prediction of kinematic variables from kinetic data:

$\alpha_{T\,(°)} = 91.48 + (-36.02 \times d_{x\,(m)})$

$\theta_{K\,(°)} = 219.35 + (-0.08 \times F_{y\,(N)})$

$\alpha_{H\,(°)} = 175.16 + (0.00 \times P_{y\,(W)})$

Where: (dx) is the horizontal displacement of the COM; (Fy) is the *vertical force component; (Py) is the vertical peak power; (α_T) is the take-off angle; (θ_K) is the angular displacement of the knee joint; (α_H) is the angle of hips joint.*

The above equations could indeed be considered as a “god saver” for those who can’t afford kinematic lab facilities. Some kinematic variables could indeed be predicted based on accurate kinetic data collection and vice versa.

CONCLUSION

The purpose of this study was to compare the take-off’s kinetic and kinematic variables between (CMJa), (BSls) and a (BSld). Kinematic analysis showed that gymnasts performed a more important flexion of the knees and an inclination of the trunk during the CMJa than during the two other standing back somersaults. This range of motion seems to allow for better vertical force, displacement and peak power. In addition, it allows a minimum loss of force and power on the horizontal axis.

The kinetic analysis showed great similarities between the BSls and the CMJa variables of strength, impulse, displacement and peak power on both the vertical and horizontal axis. As for the BSld, this take-off very thrown off centre forward, seemed to disfavour the gymnast from reaching a maximum elevation of the centre of mass during the standing back tucked somersault.

As expected, the take-off that passes through the COM, allowed better amplitude of movement than the take-offs thrown off centre forward. The CMJa and BSls showed the highest level of vertical displacement, force and peak power followed by BSld. This implies that, for a better performance of the standing back somersault, it is necessary that the impulse pass through the nearest point to the COM. Investigating kinetic and kinematic variables together, allowed the endorsement of linear regression equations enabling the prediction of some data from others. As practical implications, we recommend coaches to carefully monitor the position of gymnast's shoulders and to avoid a backwards inclination at the take-off during a standing back somersault.

REFERENCES

Brüggemann, G.P. (1983). Kinematics and Kinetics of the backward somersault take-off from the floor. In H. Matsui & K. Kobayashi Eds. *Biomechanics VIII-B*. Champaign, IL: Human Kinetics, pp. 793-800.

Duboy, J., Junka, A. & Lacouture, P. (1994). *Mécanique humaine: Eléments d’une analyse des gestes sportifs en deux dimensions*. Edition revue EP.S, pp. 69-74.

Fédération Internationale de Gymnastique, FIG. (2009). *Code de pointage, Gymnastique Artistique Masculine*. Comité Technique Masculine, F.I.G (Eds.), Suisse. http://www.fig-gymnastics.com

Harski, Z. (2002). Correlation between selected kinematic parameters and angular momentum in backward somersaults. *ISBS 2002*. Cilceres, Extremadura, Spain. pp.167-170.

Hong, Y., & Brüggemann, G.P. (1993). The mechanism of twisting somersault and its application on gymnastic practice. In: G.P, Brüggemann, & J.K, Ruehl, Eds. *Biomechanics in Gymnastics.* Cologne: Sport und Buch Strauss, pp. 357-366.

Jemni M, Sands W, Friemel F, Cooke C, Stone M. (2006). Effect of gymnastics training on aerobic and anaerobic components in elite and sub elite men gymnasts. *J. Strength Cond. Res.* 20(4), 899-907

Jemni, M. (2011). Physiology for gymnastics. In M. Jemni Eds: “*The Science of Gymnastics*”. Routledge, Francis and Taylor Grp (2011) pp: 1-53.

Jemni, M., Friemel, F., Sands, W., Mikesky, A. (2001). Evolution du profil physiologique des gymnastes Durant les 40 dernières années. (Evolution of gymnasts physiological profile during the last 40 years). *Can. J. Appl. Physiol*. 26(5), 442-456.

Knoll, K. (1992). The biomechanical chain of effect in flight elements of preparatory movements and implication for round-off and flick-flack technique. In: Proceedings of *the* 1st International Conference *"Biomechanics in Gymnastics"*. Cologne, Strauss, Germany, pp. 116-125.

Lacouture, P., Junqua, A., Duboy, J. & Durand, B. (1989). Dynamographic and cinematographic study of backward somersault. *Biology of Sport*, Volume: 6, Issue: Suppl. 3, pp. 207-213.

Leboeuf, F., Lacouture, P. & Bessonnet, G. (2003). Analyse dynamique d'un mouvement d'impulsion en gymnastique. In: Proceedings of *the* IXème Congrès de l'ACAPS, Valence.

Marina, M. (2002). Utilité et application du test de Bosco en gymnastique artistique. *Dossier EPS n° 57*. Éditions EPS.

Marina, M., Busquets, A., Padulles, J.M. & Camps, G. (2005). Cinématique du saut vertical en Gymnastique Artistique. In: M, Jemni and JF, Robin ed. *Proceeding of the 5th International Conference of the AFRAGA (Association Française de Recherche en Activités Gymniques et Acrobatiques)*, Hammamet, Tunisia, 11 - 13 April. AFRAGA Editions

Marina, M., Jemni, M. & Rodríguez, F. A. (2012). Comparison of the Squat Jumps and Counter-Movement Jumps with progressive added loads' performance between elite gymnasts and a matching control group. (Ahead of publication Nov 2012. J. Sport Med Phys Fitness).

Marina, M., Jemni, M. & Rodríguez, F.A., Jimenez, A. (2012). Plyometric jumping performances' comparison between elite male and female gymnasts and similar age groups. *J Strength Cond. Res*. 26(7),1879-1886.

Mathiyakom, W., McNitt-Gray, J.L. & Wilcox, R., 2006. Lower extremity control and dynamics during backward angular impulse generation in forward translating tasks. *Journal of Biomechanics*, 39 (06), 990-1000.

Matsui, S. (1983). *MOVIAS for Windows: Center of gravity of the human body in MOVIAS*. California, NAC Image Technology (Eds.), pp. 56-63.

Mc Nitt-Gray, J.L., 2001. Impulse generation during jumping and landing movements. In: Proceedings of the Biomechanics Symposia. University of San Francisco, pp. 95-99.

McKinley, P.A. & Pedotti, A. (1992). Motor Strategies in landing from a jump: the role of skill in task execution. *Exp. Brain Res*, 90:427-440.

McNitt-Gray, J.L. (1992). Biomechanical factors contributing to successful landings. *USGF Sports Science Publication*, 9, 19-25.

McNitt-Gray, J.L., Hester, D.M., Mathiyakom, W. & Munkasy, B.A. (2001). Mechanical demand and multi-joint control during landing depend on orientation of the body segments relative to the reaction force. *Journal of Biomechanics*, 34 (11), 1471-1782.

McNitt-Gray, J.L., Munkasy, B. & Welch, M. (1994). External reaction forces experienced by gymnasts during the take-off and landing of tumbling skills. *Technique*, (14) 9, 10-16.

Medved, V. (2001). *Measurement of human locomotion.*

Medved, V., Tonkovíc, S. & Cifrek, M. (1995). Simple neuro-mechanical measure of the locomotors skill: an example of backward somersault. *Medical progress through technology*, 21, (2), 77-84.

Moran, K.A. & Wallace, E.S. (2007). Eccentric loading and range of knee joint motion effects on performance enhancement in vertical jumping. *Human Movement Science*, 26, 824-840.

Munkasy, B.A., McNitt-Gray, J.L., Michele D. & Welch, M.D. (1996). Kinematics prior to contact in landings preceded by rotation. In: Proceedings of *the* 20th Annual Meeting of the American Society of Biomechanics. Atlanta, Georgia, USA.

Newton, J., Turner, R. I. & Greenwood, M. (1993). Biomechanical analysis of the triple back somersault. In G.P. Bruggemann and J. K. Ruhl Eds. *Conference Proceedings of the First International Conference on*

Biomechanics in Gymnastics, Cologne: Bundesinstitut fur Sportwissenschaft, pp. 259-269.

Payne, A.H. & Barker, P. (1976). Comparison of the take-off Forces in the Flic-Flac and the Back Somersault in Gymnastics. In P. V. Komi Eds. *Biomechanics V-B,* Baltimore: University Park Press, pp. 314-321.

Psycharakis, S.G. (2012). Dynamics of Vertical Jumps. *Edinburgh Napier University*, UK. Q4E Case Studies. http://www.quintic.com/education/case_studies/Vertical_Jumps.html

Sadowski, J., Boloban, V., Wiśniowski, W., Mastalerz, A. & Niźnikowski, T. (2005). Key components of acrobatic jump. *Biology of Sport*, Vol. 22, N°4.

Salles, A.S., Baltzopoulos, V. & Rittweger, J. (2011). Differential effects of countermovement magnitude and volitional effort on vertical jumping. *European Journal of Applied Physiology*, 111: 441-448.

Sands, W.A. (2011). Biomechanics for gymnastics. In: M. Jemni Eds. *The Science of Gymnastics*. Routledge, Francis and Taylor Grp (2011) pp: 55-104. ISBN: 978-0-415-54991-2.

Sands, W.A., Stone, M.H., McNeal, J.R., Jemni, M. & Haff, G.G. (2006). Estimation of power output from static and countermovement vertical jumps: Junior National Team Male Gymnasts. *American College of Sports Medicine, 53rd Annual Meeting*, Denver Colorado, USA.

Swartz, E.E., Decoster, L.C., Russell, P.J. & Croce, R.V. (2005). Effects of developmental stage and sex on lower extremity kinematics and vertical ground reaction forces during landing. *Journal of Athletic Training*, 40(1), 9-14.

Zar, J.H. (1984). The Latin Square Experimental Design – Multiway Factorial Analysis of Variance. In: *Biostatistical Analysis*. 2nd ed. Englewoods Cliff: Prentice – Hall, pp. 248.

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