COMPARISON OF THE KEY KINEMATIC PARAMETERS OF DIFFICULT HANDPSRING AND TSUKAHARA VAULTS PERFORMED BY ELITE MALE GYMNASTS

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The current study compared the key kinematic parameters of two difficult groups of vaults performed by elite male gymnasts. Five top-level male gymnasts (n=5) who participated in the 2010 World Cup competition performed Handspring and Tsukahara vault groups graded 6.2 points. For the 3D spatial movement analysis, we used two digital camcorders with a frame rate of 50 Hz. The data was digitized by the SIMI MOTION software. Temporal, spatial, velocity and angular variables were measured in critical phases of a vault. To establish the differences between the means, the effect size (ES) was calculated. Although both vaults have the same initial evaluation, the Handspring group requires highest peak, longer horizontal displacement of CoG and longer duration of the second flight phase and can be, in terms of performance, considered difficult.

KEY WORDS: sports biomechanics, kinematic analysis, gymnastics, technique, effect size.

INTRODUCTION: One of the aims of the gymnastics research is to find an optimal way of the motion action to achieve the best performance and to understand the already existing techniques (Prassas, Kwon & Sands, 2006). Sport biomechanics can improve the sport technique, training and minimize injuries (McGinnis, 2005). A vault is the only apparatus involving a single movement and, for this reason, it is the most researched and best understood apparatus (Prassas et al., 2006). A vaulting performance takes a short time and it is influenced by and affects the quantity of mechanical variables. After the 2000 Olympic Games, the vaulting apparatus was changed. The traditional horse was replaced by a new vaulting table. The vaulting table was introduced with the aim to improve safety without substantively changing the event (Irwin & Kerwin, 2009). On the other hand, this change has produced more difficult vaults (Rand, 2003). For example, the increase in the post-flight time provides gymnasts with the ability to complete more complex acrobatic movements in the air, increasing the degree of difficulty and the potential for a high score (Bradshaw, Hume, Calton & Aisbett, 2010). There are five main types of vaults according to the entry and table contact characteristics: Direct vaults, Vaults with full turns in pre-flight, Handspring vaults, Tsukahara and Kasamatsu vaults, Yurchenko vaults (Federation Internationale de Gymnastique, 2009). The Handspring, Tsukahara and Kasamatsu vaults are the most common vaults performed by elite male gymnasts in competitions and examined by researchers (e.g. Dillman, Cheetham & Smith, 1985; Takei & Kim, 1990; Takei, Dunn & Blucker, 2003; Takei, 2007). Currently, comprehensive biomechanical data related to the vaults performed on the new table (post 2000 Olympics) is not yet available (Bradshaw et al., 2010). In this study we have focused on the execution of both specific vaults of the Handspring (Cuervo straight with 1/1 twist - Lou Yun) and Tsukahara groups (Tsukahara straight with 2/1 twist - Akopian) which have an identical initial point evaluation of 6.2 (FIG, 2009). The question is whether the execution of vaults corresponds, from the point of view of kinematics parameters, to the difficulty score (D-score), i.e. the specific value assigned to every vault in the Code of Points. The aim of our study was to compare the key kinematic parameters of the difficult Handspring and Tsukahara vault groups performed by elite male gymnasts during the World Cup competition.

METHODS: All procedures used in this study complied with the guidelines of the University of Ostrava Ethics Committee.

Thirteen top-level male gymnasts, who participated in the 2010 Grand Prix Ostrava in the Czech Republic, were involved. All gymnasts performed Handspring (HSP) and Tsukahara (TSK) vault groups graded 6.2 points (FIG, 2009). From this group, we chose five gymnasts that received the highest score from the judges. The final score for vaults was 15.075 ±0.187 points. This group was aged 21.40 ±1.88 years, height 167.80 ±4.71 cm, and mass 64.60 ±4.50 kg. For the 3D spatial movement analysis, two digital camcorders (Panasonic NV-MX500EG, Japan) with a frame rate of 50 Hz were used. The shutter speed was set to 1/500 s. The angle between the optical axes of the cameras was near to 90°. The calibration pole was defined with a calibration bar and was defined by a virtual cube of 7x4x3 m (Figure 1). The data was digitized by the SIMI MOTION (SIMI Reality Motion Systems, Germany) software. In each frame, the gymnast's head centre and hand, wrist, elbow, shoulder, hip, knee, ankle, and toe on both sides of his body were digitized**.** A 14-segment model of the human body was created based on 17 body points. For the location of the center of gravity (*CoG*), the Gubitz model (Gubitz, 1978) was used. For each vault, approximately 75 frames were digitized. These included every frame from five frames prior to the board touchdown to five after the mat touchdown. The raw data was smoothed using a low pass filter with the cut-off frequency of 8 Hz (Bartlett, 2007). Temporal, spatial, velocity and angular variables were measured in critical phases of a vault. Reconstruction accuracy for known points was 0.016 m. Reliability based on repeat digitisation of a selected trial were <4.5 % for all measured parameters. The mean and standard deviations (*M±SD*) were calculated for each variable. To establish the differences between the means, the effect size (*ES*) was calculated and interpreted as <0.2 trivial, 0.2 - 0.6 small, 0.6 - 1.2 moderate, 1.2 - 2.0 large, 2.0 - 4.0 very large and > 4.0 perfect (Hopkins, 2002).

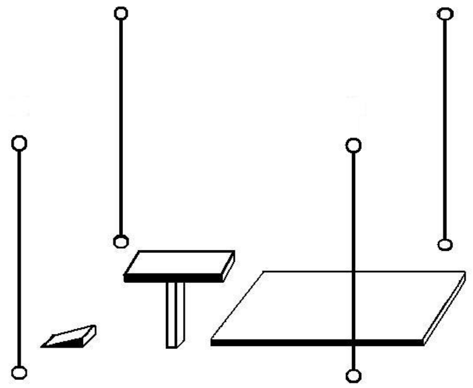

Figure 1: Calibration volume and vaulting apparatus

RESULTS AND DISCUSSION: The results of this study have shown that these two skills differ in some kinematic parameters and are summarized in Table 1 and Table 2.

Table 1
Descriptive statistics (*M ±SD*) and effect size (*ES*) for temporal and spatial variables in the Handspring (HSP) and Tsukahara (TSK) vault groups

Variable	M ±SD (HSP)	M ±SD (TSK)	ES	ES
Time (s)				
On board	0.09 ±0.02	0.10 ±0.02	0.5	Small
First flight	0.15 ±0.02	0.10 ±0.02	**2.5**	**Very large**
On table	0.15 ±0.03	0.25 ±0.02	**3.9**	**Very large**
Second flight	1.00 ±0.09	0.92 ±0.03	**1.2**	**Large**
Horizontal displacement of CoG (m)				
First flight	1.06 ±0.26	0.69 ±0.29	**1.3**	**Large**
Second flight	4.55 ±0.37	3.82 ±0.19	**2.5**	**Very large**
Official distance of second flight	2.88 ±0.22	2.67 ±0.26	0.9	Moderate
Height of CoG at critical instants (m)				
Board take-off	1.20 ±0.10	1.21 ±0.08	0.1	Trivial
Table touchdown	1.77 ±0.05	1.57 ±0.16	**1.7**	**Large**
Table take-off	2.24 ±0.05	2.31 ±0.06	**1.3**	**Large**
Peak of second flight	2.95 ±0.25	2.71 ±0.10	**1.3**	**Large**
Mat touchdown	0.90 ±0.14	0.97 ±0.06	0.6	Moderate

There were no differences in the duration on the board support (Table 1). Cuk and Karacsony (2004) state that the duration of the first flight phase and the table support phase differs according to the group of vaults. In our study, the duration of the table support was longer for TSK vaults as the gymnast touches the table with his first hand as soon as possible; that is also the reason why the first flight phase is shorter. A brief contact time on the table is likely to translate the gymnast's approach and take-off velocity into a longer post-flight time and distance, allowing the gymnast more time to complete more complex acrobatic skills in the air (Bradshaw, 2004; Bradshaw et al., 2010). The values of the time parameters of the TSK vault group were similar to those presented by Bradshaw et al. (2010). However, there was a difference in the duration of the table support as against the previous study by Dillman et al. (1985): by 0.07 s in TSK vaults and by 0.03 s in HSP vaults. That means that gymnasts can execute a more explosive take-off from the vaulting table than from the old vaulting horse. In our study, a large effect size was found in the duration of the second flight phase (Table 1). The horizontal displacement of CoG during the first and second flight phase was greater in the HSP vault group. The fast touching of the vaulting table with the first hand in TSK vaults results in shorter displacement of CoG during the first flight phase. In HSP vault group, the contact and take-off is executed from the front part of the vaulting table, which results in greater horizontal displacement of CoG during the second flight phase. A large effect was determined in the height of CoG at the peak of the post-flight phase (Table 1). This indicated that the HSP vault group requires a larger amplitude of the second flight phase. As reported by Takei (1998), the large amplitude of the second flight phase is governed by the horizontal displacement of CoG, the peak height of the second flight phase and the duration of the second flight phase. Although TSK vaults in our study include more twists around the longitudinal axis in the second flight phase, they require lower amplitude. This is probably caused by the gymnasts initiating the twist around the longitudinal axis already on the table, using the twist technique known as the contract twist (Yeadon, 1993a). On the other hand, in case of HSP vaults, the twists around the longitudinal axis occur only after the take-off (aerial twist) and they are more challenging for the extent of the movement during the second flight phase (Yeadon, 1993b).

Table 2
Descriptive statistics (*M ±SD*) and effect size (*ES*) for velocity and angular variables in the Handspring (HSP) and Tsukahara (TSK) vault groups

Variable	M ±SD (HSP)	M ±SD (TSK)	ES	ES
Resultant velocity (m/s)				
Board take-off	6.01 ±0.45	6.01 ±0.48	0	Trivial
Table take-off	4.76 ±0.42	4.43 ±0.35	0.9	Moderate
Horizontal velocity (m/s)				
Board take-off	4.93 ±0.43	5.59 ±0.42	**1.6**	**Large**
Change on table	-1.47 ±0.14	-1.53 ±0.24	0.3	Small
Table take-off	3.12 ±0.22	3.49 ±0.41	1.1	Moderate
Vertical velocity (m/s)				
Board take-off	3.67 ±0.35	3.35 ±0.38	0.9	Moderate
Table touchdown	3.53 ±0.42	3.37 ±0.26	0.5	Small
Change on table	-0.41 ±0.19	-0.37 ±0.22	0.2	Small
Table take-off	3.17 ±0.54	3.01 ±0.24	0.4	Small
Angles during critical instants (°)				
Angle at touchdown the table	39.48 ±4.18	46.36 ±5.28	**1.4**	**Large**
Angle at take-off from the table	79.12 ±4.66	85.22 ±4.40	**1.3**	**Large**

As for the velocity parameters, a large effect size of the board take-off horizontal velocity was determined while TSK vaults showed higher horizontal velocity of CoG. However, there were no differences in the resultant velocity at the board take-off between both vault groups. No differences in the velocity parameters at the table contact and table take-off were found (Table 2). In spite of the differences in the duration of the table contact, it is obvious in both vault groups that it is necessary to reach a high horizontal and vertical velocity during the table take-off to successfully execute the vault. The horizontal and vertical velocity at the table take-off is decisive for the horizontal distance and height of the second flight phase, respectively. Irwin and Kerwin (2009) reported that one of the effects of the vaulting table, compared with the old vaulting table, is an increase in the vertical take-off velocity. A large effect size was found at the angle of the table touchdown table and angle at the take-off from the table (Table 2). In spite of this large effect size, the take-off from the vaulting table was completed before the handstand position was reached and did not exceed 90° in both groups of vaults. Li (1998) reported that when the take-off angle surpasses 90°, the second flight becomes short and low.

CONCLUSION: This study compared the key kinematic parameters of difficult HSP and TSK vaults performed by elite male gymnasts during a World Cup competition. The greatest differences between both groups of vaults were caused by the different technique of the first flight phase and thus the execution of the contact and take-off from the vaulting table. In both groups of vaults, the take-off from the table is executed with high vertical and horizontal velocity that ensures a sufficient height of the vault and landing distance from the vaulting table. Although both vaults have the same difficulty score, the HSP group requires larger amplitude of the second flight phase and can be, in terms of performance, considered difficult. In case of HSP vaults the gymnasts need more time in the second flight phase to initiate and complete the twists around the longitudinal axis. Understanding of the mechanical and technical differences between two groups of vaults can help coaches to develop a training strategy for effective learning of the vaults.

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