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

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Abstract

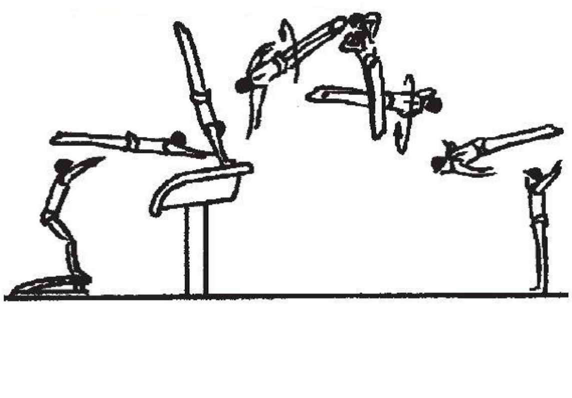
The aim of the study was to compare key kinematic parameters of two difficult groups of vaults performed by elite male gymnasts during a World Cup competition. The participants were twenty top-level male gymnasts who participated in the 2010 and 2011 World Cup competition in Czech Republic. The gymnasts performed Handspring and Tsukahara type vaults with a 5.2 level of difficulty. For the 3D movement analysis two digital camcorders with a frame rate of 50 Hz were used. The data was digitized by the SIMI MOTION software. To establish the differences between the means, the effect size (ES) was calculated. Results revealed significant technique differences. Although, both types of vaults are awarded the same initial points for difficulty, the Handspring group requires larger amplitude in the second flight phase and can be considered more difficult to perform.

***Keywords**: kinematic analysis, gymnastics, technique, effect size.*

INTRODUCTION

One of the aims of gymnastics research is to assist in the understanding of already existing techniques and in performance optimization (Farana & Vaverka, 2012; Prassas, Kwon, & Sands, 2006). The technical requirements and the difficulties of the single skills and routines in artistic gymnastics increased dramatically in the last thirty years (Brüggemann, 2005). Sport biomechanics can improve the sport technique, training and minimize injuries (McGinnis, 2005). The 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 is affects by 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 by the FIG with the aim to improve safety without substantively changing the event (Irwin & Kerwin, 2009). However, 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 (Federation Internationale de Gymnastique, 2013): Forward Handspring and Yamashita style vaults (Group I); Handspring with ¼ or ½ turn in in the 1st flight phase (Group II); Round-off entry vaults also ¼ turn with backward 2nd flight phase (Group III); Round-off entry vaults with ½ turn in the 1st flight phase and forward 2nd flight phase (Group IV); and Round-off entry vaults with ¾ or 1/1 turn in the 1st flight phase and forward 2nd flight phase (Group V). The Handspring, Tsukahara or Kasamatsu vaults (Group II) are the most common a popular vaults performed by elite male gymnasts in competitions and examined by researchers (e.g. Dillman, Cheetham & Smith, 1985; Takei & Kim, 1990; Kerwin, Harwood & Yeadon, 1993; Takei, Dunn & Blucker, 2003; Takei, 2007; Naundorf, Brehmer, Knoll, Bronst & Wagner, 2008). In the current study, we have focused on the execution of both specific vaults of the Handspring (HSP) group (Handspring forward and salto forward straight with 3/2 turns - Lou Yun, Figure 1A) and Tsukahara (TSK) group (Tsukahara straight with 2/1 turns – Akopian, Figure 1B) which have an identical initial point evaluation of 5.2 (FIG, 2013).



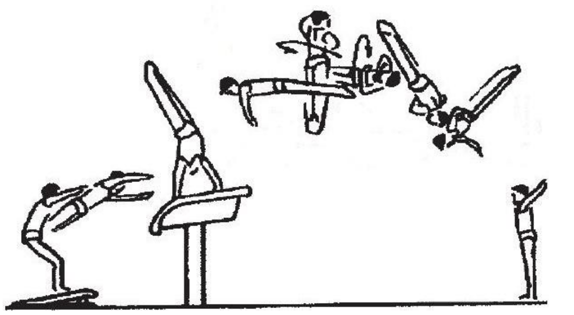


Figure 1. *(A) Handspring forward and salto forward straight with 3/2 turns - Lou Yun; (B) Tsukahara straight with 2/1 turns – Akopian (FIG, 2013).*

Cuk and Forbes (2010) concluded that the vault D-scores significantly differ from other apparatus and on the vault there was not enough discrimination among gymnast’s D-scores. Previous study by Atikovic and Smaljovic (2011) defined that degrees of turn around transversal axis, degrees of turns around longitudinal axis and body´s moment of inertia around transversal axis in the second flight phase were predictors of the vault difficulty value. 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 each vault in the Code of Points (FIG, 2013). Understanding mechanical and technical differences between two groups of vaults can help coaches develop a training strategy for effectively mastering the vaults. Moreover, the selection of a skill or technique may have a direct influence on the bio-physical demand placed on the performer (Farana, Jandacka & Irwin, 2013; Farana, Jandacka, Uchytil, Zahradnik & Irwin, in press). Especially on a vault with a high risk of injury, there is a need for effective and efficient skill development pathways to be identified that will not only optimize performance but also reduce the risk of injury (Irwin, Hanton & Kerwin, 2005).

The aim of this study was to compare key kinematic parameters of the difficult Handspring and Tsukahara vault groups performed by elite male gymnasts during a World Cup competition. The current study hypothesis was that the Tsukahara group vaults would need larger amplitude of the 2nd flight phase to complete more twists compared with the Handspring group vaults.

METHODS

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

Twenty top-level male gymnasts, who participated in the 2010 and 2011 World Cup competitions in the Czech Republic, were involved in this study. All gymnasts were members of the national teams of the participant countries. Both competitions took place in the competition period approximately two weeks before the World Championships in Rotterdam 2010 and Tokyo 2011, respectively. The age, height and weight of gymnasts were 22.69 ± 3.31 years, 166.92 ± 4.34 cm and 64.54 ± 3.67 kg. Gymnasts from this group performed ten HSP (vault no. 34; FIG, 2013; p. 99) and TSK (vault no. 29; FIG, 2013; p. 101) type vaults with 5.2 level of difficulty (FIG, 2013). From this group, we chose ten HSP and ten TSK vaults that received the highest score from the judges. The E-scores were 8.55 ± 0.35 points for HSP vaults and 8.90 ± 0.30 points for TSK vaults.

For the 3D 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° (Bartlett, 2007). The cameras were fixed on tripods located on the right side of the apparatus, 35 meters from the centre of the vault. Time synchronization of each pair of digitized data sets was achieved using the fields from each view which correspond to an event (i.g. feet contact with the springboard). The calibration pole was defined with a calibration bar and was defined by a virtual cube of 7x4x3 m (Figure 2).

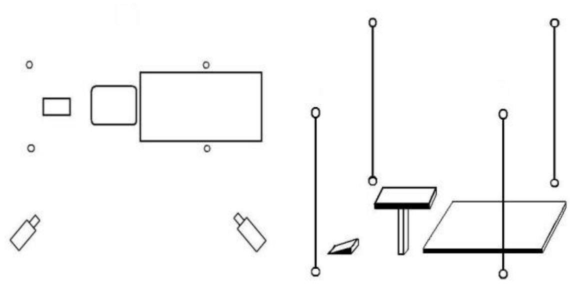


Figure 2. *Calibration volume and vaulting apparatus.*

The data was digitized utilizing the SIMI MOTION System (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. The data were manually digitized by an experienced researcher. For the location of the center of mass (CoM), 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 time of contact was defined as the time from the first frame when the gymnast contacted the board or table to the first frame when he lost contact with the board or table. The time of flight was defined as the time from the first frame when the gymnast lost contact with the board or table to the first frame when he contacted the table or landing mat (Takei et al., 2000; 2003). From these critical instants, the on-board, first flight, on-table and second flight phases were defined (Figure 3). First flight phase began when the gymnast lost contact with the board and ended just before contact with the table. Second flight phase began when the gymnast left the top surface of the table and continued until the end of the reconstructed data sequence. On-board contact phase and on-table contact phase started 0.02 s after the end of the corresponding flight phase and ended 0.02 s before the subsequent flight phase. For HSP vaults, on-table contact was performed with both hands simultaneously. For TSK vaults, on-table contact was performed with an alternating hand action. The heights of CoM of critical instants were measured from the floor (Takei, 2007). Official distance of second flight phase was measured from the end of vaulting table to gymnast landing mat contact point. Relative heights of CoM were determined as differences between height of CoM in board take off and table touchdown, table touchdown and table take off, and table to touchdown and mat touch down. For HSP vaults angles at table touchdown and table take off were defined as the angle between the left horizontal line and a line joining CoM with the contact point (both hands at table touchdown and table take off). For TSK vaults, angles were defined as the angle between the left horizontal line and the line connecting the CoM to middle point between the two hands (both hands at table touchdown and table take off).

The 3D DLT method was used for calculating 3D coordinates of the digitized body parts (Abdel-Aziz & Karara, 1971). The raw data was smoothed using a low pass filter with the cut-off frequency of 8 Hz (Bartlett, 2007).

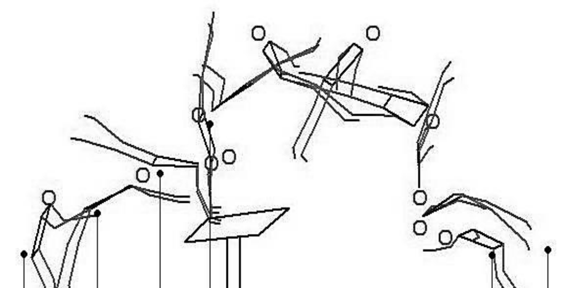


Figure 3. *Stick figure diagram with five phases of selected Handspring vault.*

The accuracy of reconstruction was determined by estimating the location of six known points distributed through the calibration volume. Reconstruction accuracy was 0.016 m within the 7 m field of view. A sample vault trial was digitized twice to evaluate digitizer reliability (Kerwin & Irwin, 2010). Reliability based on repeat digitization of a sample sequence were < 3 % for spatial parameters, < 4.5 % for velocity parameters and < 3 % for angular parameters. The temporal, spatial, velocity and angular variables in critical phases of vault were chosen on the basis of previous studies which had studied similar research questions (Dilmann et al., 1985; Takei & Kim, 1990; Takei, 1998, 2007; Takei et al., 2003; Bradshaw et al., 2010).

The mean and standard deviations (*M* ± *SD*) were calculated for each variable. To establish the differences between the means, the Cohen´s (1988) 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). The effect of > 1.2 was considered to be practically significant (Manning, Irwin, Gittoes & Kerwin, 2010).

RESULTS

No significant differences between the two groups in height and mass (*ES* < 0.2) were found. The results of the study are summarized in Tables 1 and 2. With regard to temporal results, a significant effect size was found in the duration of the first flight phase and a perfect effect size in the on table phase. A significant effect size was found in the duration of the second flight phase (Table 1). The spatial results showed a significant effect sizes in the height of CoM at the table touchdown, the relative height of board take-off to table touchdown and table touchdown to table take-off. A significant effect were observed in the horizontal displacement of CoM at the first flight phase, and the peak height of CoM during the second flight phase (Table 1). The velocity parameters showed a significant effect size in the horizontal velocity at board take-off and change in the vertical of velocity on the table (Table 2). With regards to angular variables, a significant effect size was found in the angle at table touchdown and in the angular velocity around the longitudinal axis during second flight phase (Table 2)

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

Variable	M ± SD (HSP)	M ± SD (TSK)	ES	Effect
Time (s)				
On board	0.10 ± 0.02	0.12 ± 0.02	1.00	moderate
First flight	0.16 ± 0.02	0.10 ± 0.02	**3.00**	**very large**
On table	0.16 ± 0.02	0.26 ± 0.02	**5.00**	**perfect**
Second flight	0.96 ± 0.06	0.88 ± 0.04	**1.57**	**large**
Horizontal displacement of CoM (m)				
First flight	0.80 ± 0.23	0.56 ± 0.21	**1.09**	moderate
Second flight	3.41 ± 0.24	3.03 ± 0.18	**1.31**	**large**
Official distance of second flight	2.66 ± 0.31	2.29 ± 0.19	0.66	**large**
Height of CoM at critical instants (m)				
Board take-off	1.24 ± 0.10	1.23 ± 0.07	0.12	trivial
Table touchdown	1.79 ± 0.11	1.55 ± 0.11	**2.18**	**very large**
Table take-off	2.28 ± 0.10	2.33 ± 0.06	0.60	moderate
Peak of second flight	2.85 ± 0.17	2.66 ± 0.12	**1.29**	**large**
Mat touchdown	0.89 ± 0.12	0.89 ± 0.09	0	trivial
Relative height of take-off (m)				
Board take-off to table touchdown	0.55 ± 0.09	0.32 ± 0.13	**2.06**	**very large**
Table touchdown to table take-off	0.49 ± 0.06	0.78 ± 0.12	**3.06**	**very large**
Table take-off to mat touchdown	-1.39 ± 0.11	-1.44 ± 0.10	0.48	small

M, mean; SD, standard deviation; ES, Cohen´s inter-vault effect size; Effect, verbal expression of the effect of size (Hopkins, 2002); s, seconds; m, meters

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	Effect
Resultant velocity (m/s)				
Board take-off	6.20 ± 0.36	6.10 ± 0.48	0.23	small
Table take-off	4.60 ± 0.48	4.33 ± 0.35	0.64	moderate
Horizontal velocity (m/s)				
Board take-off	5.00 ± 0.33	5.39 ± 0.42	1.03	moderate
Change on table	-1.45 ± 0.30	-1.95 ± 0.24	**1.83**	**large**
Table take-off	3.55 ± 0.30	3.44 ± 0.41	0.31	small
Vertical velocity (m/s)				
Board take-off	3.71 ± 0.27	3.35 ± 0.38	1.09	moderate
Table touchdown	3.36 ± 0.39	3.37 ± 0.26	0.03	trivial
Change on table	-0.35 ± 0.15	-0.60 ± 0.22	**1.32**	**large**
Table take-off	3.01 ± 0.24	2.77 ± 0.26	0.95	moderate
Angles during critical instants (°)				
Angle at table touchdown	38.10 ± 5.34	46.36 ± 5.28	**1.56**	**large**
Angle at table take-off	82.57 ± 6.29	85.22 ± 4.40	0.49	small
Angular velocity (°/s)				
Longitudinal axis second flight	584.97 ± 32.96	811.28 ± 38.04	**6.36**	**perfect**
Transversal axis second flight	585.00 ± 33.00	614.55 ± 30.26	0.93	moderate

M, mean; SD, standard deviation; ES, Cohen´s inter-vault effect size; Effect, verbal expression of the effect of size (Hopkins, 2002); m/s, meters per second; °, degrees; °/s, degrees per second

DISCUSSION

The aim of this study was to compare key kinematic parameters of the difficult Handspring and Tsukahara vault groups performed by elite male gymnasts during a World Cup competition.

There were moderate differences in the on the board support duration (Table 1). Bradshaw and Sparrow (2001) characterize an explosive take-off from the board by a short board contact time that resulted in an increased in post-flight time. In the current study values of board contact time were shorter to those that were reported by Takei et al. (2003) for difficult HSP vault (Roche vault) and Bradshaw et al. (2010) for TSK group (Tsukahara layout) performed by male gymnasts. A very large effect sizes were found in the duration of first flight phase and table contact (Table 1). Cuk and Karacsony (2004) states that the duration of the first flight phase and the table support phase differs according to the group of vaults. In the current study, the duration of the table support was significantly longer for TSK vaults as the gymnast touches the table with an alternating hand action (Table 1). 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 skills in the air (Bradshaw, 2004; Bradshaw et al., 2010). In the current study the duration of on-table phase contact were shorter than what was previously reported by Dillman et al. (1985). This indicated that the gymnasts in current study were able to execute a more explosive take-off from the vaulting table than from the old vaulting horse. One reason of on-board and on-table contact time differences may be due to an increase in run-up velocity. In a previous study reported by Naundorf et al. (2008) authors found an increase in run-up velocities from 1997 to 2007 for HSP and TSK group vaults. In the current study, a large effect size was found in the duration of the second flight phase (Table 1). The horizontal displacement of CoM during the first and second flight phase was greater in the HSP vault group. The rapid touching of the vaulting table with the first hand in TSK vaults results in shorter displacement of CoM during the first flight phase. The fact that TSH vaults are executed from the middle of the table and the HSP vaults from the front part, affects the horizontal displacement of CoM during the second flight phase, and the official distance of 2nd flight. The horizontal distances of the flight are affected by the horizontal velocity and time in the air. A large effect size was determined in the height of CoM at the peak of the post-flight phase (Table 1). This indicated that the HSP vault group requires larger amplitude of the second flight phase. Takei (1998) reported that the amplitude of the second flight phase is governed by the horizontal displacement of CoM, the peak height of CoM in the second flight phase and the duration of the second flight phase. The determinants of the CoM motion after take-off (from the spring board and from the vault table) are determined by the (relative) position of the CoM at that instant and its velocity. 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 the 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).

With regards to velocity parameters, a large effect size of the board take-off horizontal velocity was determined while the TSK vaults showed higher horizontal velocity of CoM. However, there were no significant differences between the two vault groups in the board take-off resultant velocity. At the same time, no differences in the velocity parameters at the table contact and moderate effect size in the table take-off were found (Table 2). In spite of the differences in the duration of the table contact, it is obvious that, in both vault groups, 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 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 the production of higher vertical take-off velocity. A large effect size was found at the angle of the table touchdown and angle at the take-off from the table (Table 2). The TSK vault group shows a greater angle at the table touchdown than the HSP vault group. 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. With regards to the number of twists during the second flight phase a nearly perfect effect size was observed in the angular velocity around longitudinal axis. However, both vaults showed similar angular velocity around the transversal axis. Thus, the HSP vaults have more problems for acquiring the necessary angular momentum around longitudinal axis and needs more time, and more height for completed all twists during second flight phase.

Although our study has brought some interesting findings in the field of kinematics of the examined group of vaults, to understand this issue better, it is necessary to work with a wider set of top-level gymnasts under the conditions of a real competition and to broaden the research to vaults from other vault groups (e.g. Yurchenko group). However, small sample sizes are a common feature when undertaking research at elite competition (Kerwin & Irwin, 2010; Manning et al., 2010).

CONCLUSIONS

In 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 both, sufficient height of the vault and sufficient horizontal distance from the table. Although both types of vaults are awarded the same initial points for difficulty, the HSP group requires larger amplitude in the second flight phase and can be considered more difficult to perform. In case of the HSP vaults the gymnasts need more time in the second flight phase to initiate and complete the twists around the longitudinal axis. With a higher level of understanding of the mechanical and technical differences in the different groups of vaults, coaches will have more knowledge at their disposal in order to select techniques effectively and therefore develop a more efficient coaching process and reduce the risk of injury.

REFERENCES

Adbel-Aziz, Y.I. & Karara, H.M. (1971). Direct linear transformation for comparator coordinates in to object space coordinates in close range photogrammetry. In *Proceeding of the ASP Symposium in Closerange Photogrammetry*. Urbana, IL: American Society of Photogrammetry.

Atikovic, A. & Smajlovic, N. (2011). Relation between vault difficulty values and biomechanical parameters in men´s artistic gymnastics. *Science of Gymnastics Journal*, 3, 3, 91-105.

Bartlett, R. (2007). *Introduction in to biomechanics: Analysing human movement patterns* (2nd ed). Abingdon, UK: Routledge, Taylor and Francis group.

Bradshaw, E. (2004). Target-directed running in gymnastics: a preliminary exploration of vaulting. *Sports Biomechanics*, 3, 1, 125-144.

Bradshaw, E., Hume, P., Calton, M. & Aisbett, B. (2010). Reliability and variability of day-to-day vault training measures in artistic gymnastics. *Sport Biomechanics*, 9, 2, 79-97.

Bradshaw, E. & Sparrow, W.A. (2001). The approach, vaulting performance, and judge´s score in women´s artictic gymnastics. In *International Society of Biomechanics in sport 2001: Scientific proceeding* (pp. 311-314). San Francisco: Univerzity of San Francisco.

Brüggemann, G.P. (2005). Biomechanical and biological limits in artistic gymnastics. In. Q. Wang (Ed.), *XXIII International Symposium of Biomechanics in sport* (pp. 15-24). Beijing: China Society of Sport Biomechanics.

Cohen, J. (1988). *Statistical power analysis for the behavioral science* (2nd ed.). New Jersey: Lawrence Erlbaum.

Cuk, I. & Forbes, W. (2010). How apparatus difficulty affect all around results in men´s artistic gymnastics. *Science of Gymnastics Journal*, *2*(3), 57-63.

Cuk, I. & Karacsony, I. (2004). *Vault: Methods, Ideas, Curiosities, History*. Ljubljana: ŠTD Sangvinčki.

Dillman, C.J., Cheetham, P.J. & Smith, S.L. (1985). A kinematic analysis of men's Olympic long horse vaulting. *International Journal of Sport Biomechanics, 1*, 96-110.

Farana, R., Jandacka, D. & Irwin, G. (2013). Influence of different hand positions on impact forces and elbow loading during the round off in gymnastics: a case study. *Science of Gymnastics Journal*, *5*(2), 5-14.

Farana, R., Jandacka, D., Uchytil, J., Zahradnik, D. & Irwin, G. (in press). Musculoskeletal loading during the round-off in female gymnastics: The effect of hand position. *Sports Biomechanics*.

Farana, R. & Vaverka, F. (2012). The effect biomechanical variables on the assessment of vaulting in top-level artistic female gymnasts in World cup competition. *Acta Universitas Palackianae Olomucensis. Gymnica*, *42*(2), 49-57.

Fédération Internationale de Gymnastique. (2013). *2013 – 2016 CODE OF POINTS Men's Artistic Gymnastics*. Lausanne: Fédération Internationale de Gymnastique.

Gubitz, H. (1978). *Zur analytischen Bestimmung der Lage des Koerperschwerpunktes*. International Symposium, Berlin: Germany.

Hopkins, W.G. (2002). *A scale of magnitudes for effect statistics*. In A New View of Statistics. Retrived from: www.sportsci.org/resource/stats/effectmag.html.

Irwin, G., Hanton, S., & Kerwin, D. (2005). The conceptual process of skill progression development in artistic gymnastics. *Journal of Sport Sciences*, *23*(10), 1089-1099.

Irwin, G. & Kerwin, D.G. (2009). The influence of the vaulting table on the handspring front somersault. *Sports Biomechanics, 8*(2), 114-128.

Kerwin, D., Harwood, M.J. & Yeadon, M.R. (1993). Hand placement techniques in long horse vaulting. *Journal of Sports Sciences, 11*(4), 329-35.

Kerwin, D.G. & Irwin, G. (2010). Musculoskeletal work preceding the outward and inward Tkachev on uneven bars in artistic gymnastics. *Sports Biomechanics, 9*(1), 16-28.

Li, S. (1998). Main technical analyse of the motion trajectory influencing the horse-vaulting movement. In *XVI International Symposium of Biomechanics in Sports*. Konstanz: Germany.

Manning, M.L., Irwin, G., Gittoes, M.J. & Kerwin, D.G. (2011). Influence of longswing technique on the kinematics and key release parameters of the straddle Tkachev on uneven bars. *Sports Biomechanics, 10*(3), 161-173.

McGinnis, P.M. (2005). *Biomechanics of sport and exercise* (2nd ed.). Champaign, IL: Human Kinetics.

Naundorf, F., Brehmer, S., Knoll, K., Bronst, A. & Wagner, R. (2008). Development of velocity for vault runs in artistic gymnastics for last decade. In Y.H. Kwon, J. Shim, J.K. Shim, and I.S. Shin (eds.), *XXVI International Symposium of Biomechanics in Sports*. Seoul: Korea.

Prassas, S., Kwon, Y.H. & Sands, W.A. (2006). Biomechanical research in artistic gymnastics: A rewiew. *Sports Biomechanics*, *5*(2), 261-291.

Rand, T. (2003). New vaulting table. *Technique*, 23, 1, 9-10.

Takei, Y. (1998). Three-dimensional analysis of handspring with full turn vault: Deterministic model, coaches' beliefs, and judges' scores. *Journal of Applied Biomechanics*, *14*, 190-210.

Takei, Y. (2007). The Roche vault performed by elite gymnasts: Somersaulting technique, Deterministic model, and Judge´s scores. *International Journal of Applied Biomechanics*, *23*, 1-11.

Takei, Y. & Kim, J. (1990). Techniques used in performing the handspring and salto forward tucked vault at the 1988 Olympic games. *International Journal of Sports Biomechanics*, *6*, 111-138.

Takei, Y., Blucker, E., Nohara, H., & Yamashita, N. (2000). The Hecht vault performed at the 1995 World Gymnastics Championships: Deterministic model and judges' scores. *Journal of Sports Sciences*, *18*, 849-863.

Takei, Y., Dunn, H. & Blucker, E. (2003). Techniques used in high-scoring and low-scoring 'Roche' vaults performed by elite male gymnasts. *Sports Biomechanics*, 2, 141-162.

Yeadon, M.R. (1993a). The biomechanics of twisting somersaults. Part II: Contact twist. *Journal of Sports Sciences*, *11*, 199-208.

Yeadon, M.R. (1993b). The biomechanics of twisting somersaults. Part III: Aerial twist. *Journal of Sports Sciences*, *11*, 209-218.

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