ESTIMATION CORRELATION OF BIOMECHANICAL PARAMETERS AND VAULT START VALUE IN MEN'S ARTISTIC GYMNASTICS

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ABSTRACT
The gymnastics vault is a apparatus characterised by a complex and very short movement which can be divided into seven important phases. The aim of our research was to determine correlation between vault start value and run-up velocity, first flight phase, table support, second flight phase. In the correlations matrix criteria variables from the Code of Points FIG MAG (2017-2020) effected a statistically significant postive correlation with two variables: run-up velocity on springboad and second flight phase, but negative correlation with two variables first flight phase and table support. We can conclude that there are no differences in values in relation to the two cycle Code of Points.
Key Words: *Artistic Gymnastics, Vault, Correlations, Code of Points, Analysis*

INTRODUCTION

Fédération Internationale de Gymnastique (FIG) Code of Points (CoP) Mens Artistic Gymnastics (MAG) 2009-2012 and 2017-2020 arbitrary defines vault start value. Start value (Difficulty Value - DV) is determined by vault entry, number of saltos, direction of saltos, number of turns and position of the body during the flight. Each vault in the CoP can be divided into seven phases: (1) running, (2) jumping on springboard, (3) springboard support, (4) first flight phase, (5) table support, (6) second flight phase, and (7) landing (Čuk, & Karácsony, 2004; Ferkolj, 2010, Atiković, & Smajlović, 2011). Runway is the first phase and the most important one as all further phases depend on it (Čuk, Bricelj, Bučar, Turšič, & Atiković, 2007).

The aim of our research was to determine correlation between vault start value and run-up velocity, first flight phase, table support, second flight phase as the one of the most important factor of vault jumps (Čuk, & Karácsony, 2004; Usenik, 2006; Takei, 2007; Čuk et al., 2007; Naundorf, Brehmer, Knoll, Bronst & Wagner, 2008; Ferkolj, 2010; Atiković, & Smajlović, 2011; Atiković, 2012; Veličković, Petrović, & Petrović, 2011; Schwiezer, 2003; Frana, Uchytil, Zahradník, & Jandačka, 2015; Fujihara, 2016; Fernandes, Carrara, Serrão, Amadio, & Mochizuki, 2016; Fujihara, Yamamoto, & Fuchimoto, 2017; Schärer, Lehmann, Naundorf, Taube, & Hübner, 2019).

Authors Atiković, & Smajlović (2011) presetnt the overview of changes and correlations between the DV, shown that there have been no significant changes in the past years where correlations are rather high between the DV awarding rules that have been applied up to now. There is a big difference between a COP from 1964 to 2009 year where the correlations less than (r = 0.47) percent.

MATERIAL AND METHODS

The study of samples included (n = 55) of (n = 98) different gymnastics vaults as listed in the MAG CoP 2017-2020, ranging from 1.6 to 6.0 points. We analyzed all materials from large world men's competitions, accounting for 1/2 of all vaults. Some durations parameters: run-up velocity – maximum speed on springboard, first flight phase, second flight phase and duration of support on table phase determined as the average value from all vaults were calculated from elite gymnasts (n = 230) performing at the 2006 World Chapionship in Aarhus (Denmark). All jumps (n = 55) from five structural groups: I=24, II=19, III=7, IV=4, V=1, were recorded during the competition using cameras at 50 frames per second. Center of gravity of the body (BCG) velocity on springboad, duration of the fisrt fligt phase and second fligt phase and duration of support on table phase were obtained from our research (Čuk, & Karácsony, 2004; Čuk et al., 2007; Atiković, & Smajlović, 2011; Atiković, 2012). We took into consideration correlations and multiple correlations at the significance level of ($p < 0.05$).

RESULTS

First we calculated correlation between run-up velocity and start value (DV) Code of Points 2017 (Table 1) with all vaults included (n = 55). Value of correlation was (r = 0.72; p < 0.05) what means that runway velocity and start value share 53% variance, what is low. Second, we calculated correlation between run-up velocity and start value (DV) Code of Points 2009 with all vaults included (n=55). Value of correlation was (r = 0.72, p < 0.05) what means that runway velocity and start value share 53% variance, what is the same low results. We can conclude that there are no differences in values in relation to the two MAG valuting table Code of Points 2009 and 2017.

We also calculated correlation between second flight phase and start value (DV) Code of Points 2017 with all vaults included (n=55). Value of correlation was (r = 0.64, p < 0.05) what means that second flight phase and start value share 44% variance, what is low. Second, we calculated correlation between run-up velocity and start value (DV) Code of Points 2009 with all vaults included (n = 55). Value of correlation was (r = 0.65, p < 0.05) what means that second flight phase and start value share 42% variance, what is the same low results. We can conclude that there are no differences in values in relation to the two cycle Code of Points.

In (Table 2) are shown there are visible negative correlations between two variables MAG Code of Points 2017 and 2009 (DV) – first flight phase and MAG Code of Points 2017 and 2009 (DV) – table support.

Table 1. Data table containing all measured parameters of all (n = 55) valuts

Valut name	*MAG Code of Points 2017 VT (DV)*	*MAG Code of Points 2009 VT (DV)*	*Run-up velocity (m/s-^{1})*	*Fisrt flight phase (s)*	*Second flight phase (s)*	*Table support (s)*
Handspr. fwd.	1.60	3.00	6.95	.26	.70	.15
Handspr. fwd. w. 1/2 t.	1.80	3.40	7.10	.27	.71	.21
Handspr. fwd. w. 1/1 t.	2.00	3.80	7.50	.28	.85	.28
Handspr. fwd. w. 3/2 t.	2.20	4.20	7.60	.29	.74	.24
Handspr. fwd. w. 2/1 t.	2.40	4.60	8.00	.30	.75	.26
Handspr.fwd.a.salto fwd.t.	2.40	3.80	7.20	.24	.92	.16
Handspr.fwd.a.salto fwd.t.w.1/2 t.(or Cuervo t.)	2.80	4.20	7.50	.16	.96	.15
Handspr.fwd.a.salto fwd.t.w.1/1t.(Cu.t.w.1/2t.)	3.20	4.60	8.20	.17	.97	.12
Handspr.fwd.a.salto fwd.t.w.3/2t.(Cu.t.w.1/1t.) (Kroll)	4.00	5.00	8.60	.17	.98	.14
Handspr.fwd.a.salto fwd.p.	2.80	4.20	7.50	.28	.90	.16
Handspr.fwd.a.salto fwd.p. w.1/2 t. (Cuervo p.)	3.20	4.60	8.03	.22	.91	.16
Hdspr.fwd.a.salto fwd.p.w.1/1 t. (Cu.p.w.1/2t.)	3.60	5.00	8.56	.20	.98	.12
Hdspr.fwd. w.1/1t.a.salto fwd.p. (Rehm)	4.40	5.80	7.70	.08	1.00	.12
Hdspr.fwd. a.salto fwd.str.	3.60	5.00	7.95	.24	.88	.12
Hdspr.fwd. a.salto fwd.str.w.1/2t. (Cu.str.)	4.00	5.40	8.00	.16	.84	.24
Hdspr.fwd. a.salto fwd.str.w.1/1t. (Cu.str.1/2t.)	4.40	5.80	8.05	.17	.91	.19
Hdspr.fwd. a.salto fwd.str.w.3/2t. (Cu.str.1/1t.) (Lou Yun)	4.80	6.20	8.30	.17	.98	.14
Hdspr.fwd. a.salto fwd.str.w.2/1t. (Cu.str.3/2t.)	5.20	6.60	8.60	.16	.96	.16
Hdspr.fwd. a.salto fwd.str.w.5/2t. (Yeo 2)	5.60	7.00	8.90	.16	1.08	.12
Handspr.fwd.a.dbl.salto fwd.t. (Roche)	5.20	6.60	8.23	.18	1.09	.11
Roche w.1/2t. (Dragulescu)	5.60	7.00	10.50	.16	1.12	.12
Handspr.fwd.a.salto fwd.t.w.1/2 t.a.salto bwd.t. (Zimmerman)	5.60	7.00	10.50	.20	1.12	.12
Handspr.fwd.a.dbl.salto fwd.p. (Blanik)	5.60	7.00	10.00	.24	1.08	.08

Roche w.1/2t. (Dragulescu) piked	6.00	7.20	10.90	.14	1.15	.13
Handspr.sw.w.1/4t.	1.60	3.00	7.25	.15	.70	.09
Handspr.sw.w.3/4t.	1.80	3.40	7.43	.18	.73	.10
Handspr.sw.w.5/4t.	2.00	3.80	7.60	.20	.75	.12
Handspr.sw.w.1/4t.a. salto fwd.t.	2.40	3.80	7.65	.18	1.18	.10
Handspr.sw.w.1/4t.a. salto fwd.p.	2.80	4.20	7.90	.20	1.02	.11
Handspr.sw.w.1/4t.a. salto bwd.t. (Tsukahara)	2.20	3.80	7.00	.16	.98	.18
Tsukahara t.w.1/2 t.	2.40	4.20	7.20	.16	1.00	.16
Handspr.sw.w.1/4t.a.salto fwd.t.w.1/2 t. (Kasamatsu)	2.80	4.60	7.20	.14	.88	.22
Tsukahara t.w.2/1 t. (Barbieri)	4.00	5.40	7.60	.12	1.04	.22
Tsukahara p.	2.40	4.00	7.37	.14	.88	.16
Tsukahara str.	3.20	4.60	7.65	.14	.85	.26
Tsukahara str.w.1/2 t.	3.60	5.00	7.40	.12	.92	.24
Tsukahara str.w.1/1 t.	4.00	5.40	7.93	.14	.87	.24
Tsukahara str. w. 3/2 t. - Kasamatsu str. w. 1/2 t.	4.40	5.80	8.04	.13	.87	.23
Tsukahara str. w 2/1 t. (Akopian) - Kasamatsu str. w. 1/1 t.	4.80	6.20	8.13	.14	.96	.21
Kasamatsu str. w. 3/2 t. (Driggs)	5.20	6.60	8.50	.14	.98	.19
Kasamatsu str. w. 2/1 t. (Lopez)	5.60	7.00	8.87	.16	1.00	.16
Tsukahara w. salto bwd. t. (Yeo)	5.20	6.60	8.80	.12	1.00	.20
Tsukahara w. salto bwd. p. (Lu Yu Fu)	5.60	7.00	9.10	.16	1.04	.17
Melissanidis p.	5.60	7.00	8.74	.16	1.06	.14
Yurchenko str.	3.20	4.60	7.10	.16	.84	.20
Yurchenko str. w. 1/2 t.	3.60	5.00	7.23	.16	.88	.19
Yurchenko str. w. 1/1 t.	4.00	5.40	7.30	.16	.92	.18
Yurchenko str. w. 3/2 t.	4.40	5.80	7.37	.17	.93	.15
Yurchenko str. w. 2/1 t.	4.80	6.20	7.33	.18	.99	.13
Yurchenko str. w. 5/2 t. (Shewfelt)	5.20	6.60	7.44	.15	1.01	.13
RO a.1/2 t. a.hdspr. fwd. w. 1/2 t.	2.00	3.60	7.20	.16	.86	.14
RO a.1/2 t. a.hdspr. fwd. w. 1/1 t.	2.20	4.00	7.00	.17	.97	.13
RO a.1/2 t. a.hdspr. fwd. a. salto f. str. w. 1/2 t. (Hutcheon)	4.20	5.60	7.53	.16	.88	.12
RO a.1/2 t. a.hdspr. fwd. a. salto f. str. w. 5/2 t. (Li Xiao Peng)	5.80	7.20	8.23	.20	.96	.08
RO a.jp. bwd.w.1/1t.to back hdspr.a.salto bwd.str. (Scherbo)	3.80	5.00	8.22	.20	.84	.20

Table 2. Correlation between vault start value (DV) and run-up velocity, first flight phase, table support, second flight phase

Correlation between variables	*r*	r^2
MAG Code of Points 2017 VT (DV) – Run-up velocity (m/s-¹)	0.728	0.530
MAG Code of Points 2009 VT (DV) – Run-up velocity (m/s-¹)	0.726	0.528
MAG Code of Points 2017 VT (DV) – First flight phase (s)	-0.383	0.146
MAG Code of Points 2009 VT (DV) – First flight phase (s)	-0.347	-0.347
MAG Code of Points 2017 VT (DV) – Second flight phase (s)	0.670	0.449
MAG Code of Points 2009 VT (DV) – Second flight phase (s)	0.654	0.428
MAG Code of Points 2017 VT (DV) – Table support (s)	-0.194	0.037
MAG Code of Points 2009 VT (DV) – Table support (s)	-0.158	0.025
MAG CoP VT 2017 (DV) – MAG CoP VT 2009 (DV)	0.981	0.982

Figure 1. Comparison of the run-up velocities between the MAG CoP 2009 and 2017

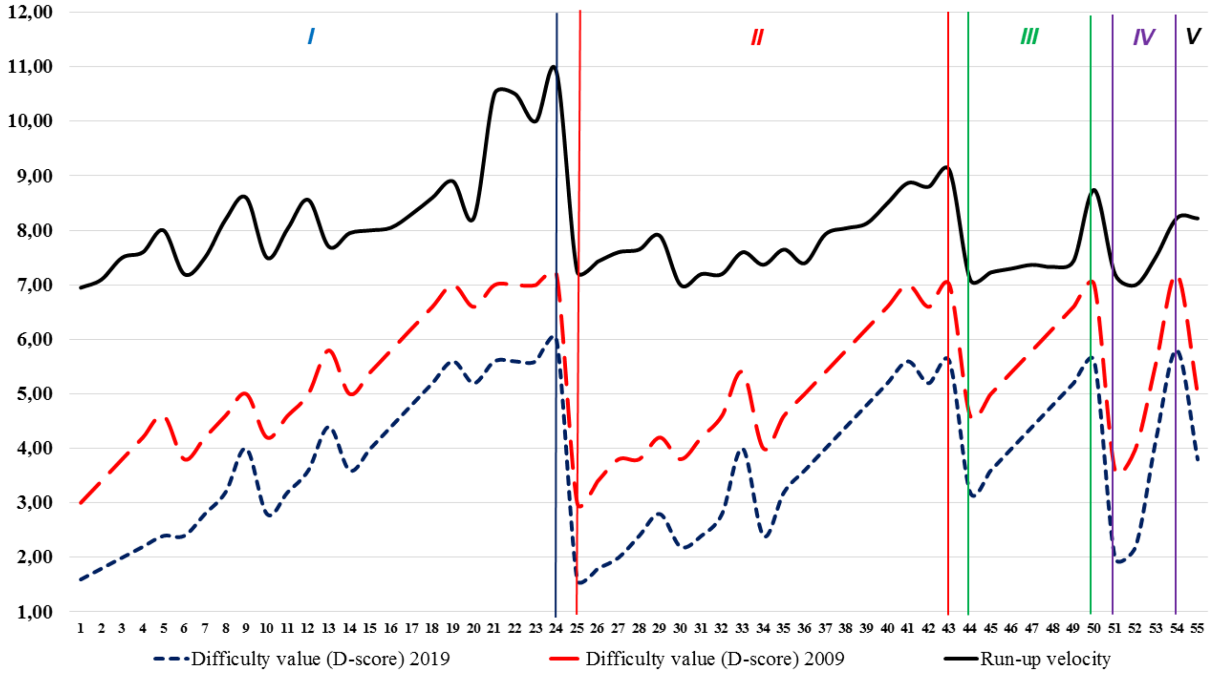
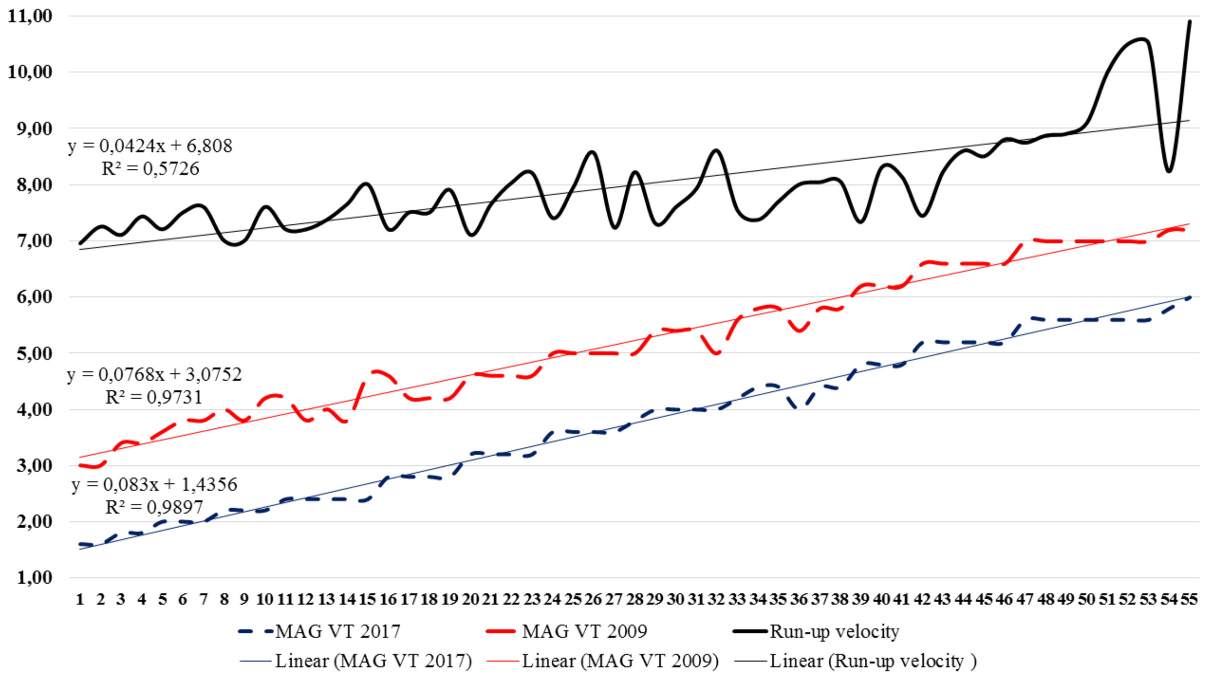


Figure 2. Linear comparison of the run-up velocities between the MAG CoP 2009 and 2017



DISCUSSION

The vault run is the basis of the energy production for vaulting. There are many studies reporting vault run-up velocity (Sands, & McNeal, 1995, Krug, et al., 1998; Sands, 2000; Čuk and Karácsony, 2004; Ferkolj, 2010, Naundorf et al., 2008, Veličković and Petković & Petković, 2011; Van der Eb et al. 2012, Frana et al,, 2015; Fujihara, 2016; Diener, & Aedo-Mućoz, 2019).

The author (Fujihara, 2016) has proved a significant review of previous research. Author emphasized Laveg seems to be reliable and valid in reporting a run-up velocity between 5–7 m from the edge of the vaulting table (Naundorf et al., 2008, Brehmer, & Naundorf, 2014). Naundorf et al. (2008) and Krug et al. (1998) both used a Laveg, but the data processing was different. While Krug et al. (1998) reported the maximal velocity, Naundorf et al. (2008)

computed the mean velocity of a 2 m range (5–7 m for forward take-off vaults and 8–10 m for backward take-off vaults), within which the maximal velocity was typically attained according to the authors. Based on the data of Van der Eb et al. (2012), Naundorf et al. (2008) and Krug et al. (1998), the worldclass gymnasts attained an average run-up velocity of approximately 8.2–8.4 m/s for forward take-offs, the implication is that most world-class gymnasts achieve a run-up velocity of over 8.0 m/s, and some faster gymnasts achieved a run-up velocity of over 8.5 m/s. Brehmer and Naundorf (2014) used the same method as Naundorf et al. (2008) with a focus on the high-difficulty vault (Lu Yu Fu, D-score = 6.0) performed by nine gymnasts. They reported that the mean velocity achieved by these gymnasts was 8.3 ±0.2 m/s. Veličković, Petković, & Petković (2011) recorded some run-up velocities of 9.95 ±0.74 m/s for several difficult vaults.

According to Čuk & Karácsony (2004) who analysed vaults in multiple international competitions, the suggested run-up velocity was 7.5–8.5 m/s for a moderate-level vault, 8.5–9.5 m/s for a high-level vault, and over 10.0 m/s for a highest-level vault involving double somersaults. By Čuk & Karacsony (2004) for most difficult vaults velocity can be even more than 10 m/s, what is a very fast runway. In the scientific project carried out on the occasion of the 1997 Gymnastics World Championships in Lausanne (Switzerland), new aspects of difficult vaults were analyzed. The study was concentrated on the progression of the running approach up to stepping onto the springboard and the progression of energy during take-off (Krug, 1997; Krug, Knoll, Köthe, & Zocher, 1998).

Diener, & Aedo-Muńoz (2019) present one systematic review of Yurchenko vault kinetic and kinematic indicators article was based on determining the most relevant kinematic indicators in the Yurchenko vault technique, using the mechanical purposes of each phase as linking elements. A systematic qualitative review was carried out with an initial search of (n = 67) scientific documents, of which (n = 27) were selected by matching the Yurchenko key words, kinetic, kinematic and artistic gymnastics and their respective combinations.

Atiković, & Smajlović (2011) their data also included (n = 64) vaults velocities of the mass centre on contact with the springboard. Previous studies by Atiković and Smaljović (2011) & Atiković (2012) was try to determine the relationship between biomechanical parameters of vault flights with respect to new models of initial vault difficulty values in men's artistic gymnastic. The sample of independent variables included twelve biomechanical parameters. After implementing the regression analysis, it could be established that the best model derived only the second flight phase with 95% of explained variance.

One of the objective way to determine start value of the vault is to use biomechanics characteristics of vault (Atiković, & Smajlović, 2011; Atiković, 2012, 2013). Some previous research showed that between time variables (even runway time) and start value of vault are not correlated. A big correlation between approach running velocity and performance score has been found (Van der Eb et al., 2012). The correlation coefficients between velocity at takeoff and final scores were (r = 0.60) for men and (r = 0.52) for women (Van der Eb et al., 2012). Farana, & Vaverka, (2012) present five out of 23 examined variables showed significant correlations with the scores. A significant correlation was found in the vertical height of the body center of mass during the take-off from the vaulting table (r = 0.86), in the maximum height of the body center of mass in the second flight phase (r = 0.83), in the change of the horizontal velocity during the phase of the take-off from the vaulting table (r = –0.69), in the horizontal component of the velocity during the spring from the vaulting table (r = 0.75) and in the duration of the second flight phase (r = 0.69). The phase of the take-off from the vaulting table is a crucial phase of the vault. Schärer, et al., 2019 they found out in females, run-up speed correlated significantly with the difficulty (D-) score and height of flight for all vaulting styles ($r \leq 0.80$). In males, run-up speed correlated significantly with the D-score, height and length of flight of Tsukahara ($r \leq 0.69$) and Yurchenko vaults only (r ≤ 0.65). Males reached 8–9% higher run-up speeds performing handspring and Tsukahara vaults than did females, but similar run-up speeds performing Yurchenko vaults. Elite females achieved higher run-up speeds than junior females performing Yurchenko vaults. Elite males displayed higher run-up speeds than junior males performing handspring and Tsukahara vaults.

CONCLUSIONS

Within every new cycle of Code of Points in Men's Artistic Gymnastics rules slightly improved, as start value share with run-up velocity and second flight phase. However, improvement is not on an expected level, where by our opinion this percentage should be limited toward 100%, with knowledge that runway velocity determines all other vault parameters. Interesting to see that the run-up velocity seems to have stabilized between 1997 and 2010. The results of this study can be used for coaches team competition, all around, individual events, as well as the creators next CoP for the next Olympic cycle.

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