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The impact of biomechanical parameters on initial vault values following the fig rules in men's artistic gymnastics

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Original scientific paper

Abstract
The primary objective of this paper is to establish precisely how and which biomechanical parameters explain and define the initial vault value. The study sample includes 64 vaults as per the Code of Points of the International Gymnastics Federation (FIG). The sample of dependent variables includes all points ranging from 2 points to 7.2 points, while the sample of independent variables includes 12 biomechanical variables expressed in various measure units. All data were analysed using SPSS Statistics 17.0. With regression analysis we explained 92.4% of the difficulty vault value. Only three biomechanic variables were predictors: degrees of turns around transversal axis, degrees of turns around longitudinal axis and body's moment of inertia around transversal axis in the second flight phase. Factor analysis has resulted in isolating the following four factors: degrees of turns around transversal axis in the second flight phase, first flight phase, longitudinal body axis in the second flight phase, and the support on the table. The results of the research may serve as a starting point for launching an initiative for changing the FIG rules on awarding points in relation to the existing Code of Points (2009). This type of research has confirmed that, from a biomechanical point of view, initial vault values can be far more realistically determined by the expert panel of the men's FIG technical committee.

Key words: **Code of Points FIG, Valut, Artistic Gymnastics, Biomechanics**

Sažetak
Primarni cilj ovog rada je utvrditi koji biomehanički parametari objašnjavaju i definiraju početnu vrijednost skoka na preskoku. Uzorak varijabli uključuje 64 skoka iz Bodovnog pravilnika Međunarodne gimnastičke federacije (FIG, 2009). Uzorak zavisnih varijabli su sve ocjene u rasponu od 2 do 7.2 boda, dok uzorak nezavisnih varijabli uključuje dvanaest biomehaničkih varijabli izraženih u različitim mjernim jedinicama. Svi podaci su analizirani pomoću SPSS 17.0 za statistiku. Sa regresionom analizom je objašnjeno 92,4% težišne skoka na preskoku. Rezultati dobiveni u manifestnom prostoru definiraju samo tri varijable: alfa x i y osi u drugoj fazi leta i moment inercije JX u drugoj fazi leta. Faktorska analiza je rezultirala u grupisanju sljedeća četri faktora: faktor količine okreta oko čeone ose u drugoj fazi leta, faktor prve faze leta, faktor količine okreta oko uzdužne ose tijela i faktor upora na stolu. Rezultati istraživanja mogu poslužiti kao polazna osnova za pokretanje inicijative za promjenu FIG pravila o dodjeli bodova u odnosu na postojeći Bodovni pravilnik (FIG, 2009). Ovaj tip istraživanja potvrdio je, da sa biomehaničkog stajališta, početne ocjene mogu biti daleko realnije određene od strane muškog tehničkog komiteta FIG.

Ključne riječi: **Bodovni pravilnik FIG, preskok, sportska gimnastika, biomehanika**

Introduction

First ever uniform instructions on Code of Points (COP) in gymnastics under FIG – International Gymnastics Federation date back to 1949. The FIG technical committee improves and further develops the COP every four years. Many biomechanical researches have been conducted in the past by Soviet, German, American, Japan, English, Slovene and other researchers (e.g. Šlemin & Ukran, 1977; Gaverdovsky & Smolevsky, 1979; Brueggeman, 1994; Prassas, 1995; Krug, 1997; 1998; Takei, 1998; Čuk & Karácsony, 2004; Marinšek, 2010; Ferkolj, 2010, etc.) and knowledge of physical parameters of vaults are generally-known. However, rules have not always followed the ever-changing nature of vaults since 1949. More specifically, rules have been late when it comes to the definition of the vault difficulty level. With inclusion of the saltos in the second flight phase (fp), the vault difficulty becomes defined primarily by body position: tucked, piked and stretched, number of rotation around the transversal and longitudinal body axis (COP FIG, 1964; 1971; 1978; 1985; 1989; 1993; 1997; 2001; 2006; 2009). Difficulty value (DV) have changed on the basis of the total number of rotations performed around transversal and longitudinal axis. Usually COP rewarded each new vault with more DV, old vaults had to be awarded fewer DV although the vault remained the same. The overview of changes and correlations between the DV is one of the evidence shown in (Table 1) 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.

Table 1. Correlations between FIG Codes of Points (COP) from 1965 to 2009

Year of publication	2009-2006	2006-2006	2006-2001	2001-1997	1997-1993	1989-1985	1985-1978	1978-1971	1971-1965
R	1	0.986	0.99	0.93	0.89	0.87	0.875	0.946	0.976
R^2	1	0.972	0.99	0.87	0.79	0.76	0.766	0.894	0.952

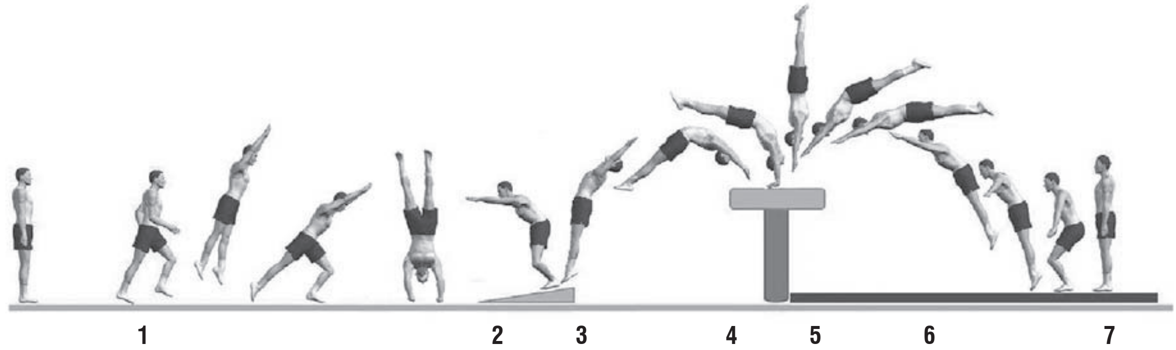

Figure 1. Vault phases: 1-run, 2-jump on springboard, 3-springboard support phase, 4-first flight phase, 5-support on the table, 6-second flight phase, 7-landing

Each vault in COP can be divided in the following seven phases (Figure 1) (Prassas, 2002; Čuk & Karácsony, 2004; Takei, 2007; Ferkolj, 2010) run, jump on springboard, springboard support phase, first flight phase, support on the table, second flight phase, and landing.

In (Table 2) we see that from 1964 to 2009 year, 96 vaults, increased the number of jumps on the vault. Analyzing (Table 3) we see that since 1997 year in the fifth group is the most vaults in comparison with other groups. Number of vaults by groups should be equal in the distribution of groups is not what this is

Table 2. Development of COP for assessing the number of elements in individual apparatus

Men's events	2009	2006	2005	2001	1997	1993	1989	1985	1978	1971	1964	Sum	Ave.
FX	137	130	132	136	116	134	123	103	98	109	75	1156	115.6
PH	113	118	112	115	182	230	202	82	131	113	57	1342	134.2
RI	142	145	141	126	148	145	122	97	116	115	83	1238	123.8
VT	115	114	114	105	109	86	61	48	45	32	19	733	73.3
PB	151	149	147	143	249	235	184	149	138	137	90	1621	162.1
HB	143	143	143	148	176	193	156	115	121	112	83	1390	139
Sum	801	799	789	773	980	1023	726	594	649	618	407	7358	735.8
Ave.	133.5	133.1	131.5	128.8	163.3	170.5	141.3	99	108.1	103	67.8		

Legend: floor exercise (FX), pommel horse (PH), rings (RI), vault (VT), parallel bars (PB) and horizontal bar (HB)

Table 3. Development of COP for assessing the number of elements in structural groups

Valut	2009	2006	2005	2001	1997	1993	1989	1985	1978	1971	1964	Sum	Ave.
I	7	7	7	7	7	12	8	9	19	16	14	113	18.8
II	6	6	6	6	28	7	2	4	1	0	0	66	11
III	32	31	31	27	29	22	22	19	20	15	4	252	22.9
IV	22	22	22	22	9	27	21	16	5	1	1	168	28
V	48	48	48	43	36	18	4	0	0	0	0	245	40.8
Sum	115	114	114	105	109	86	57	48	45	32	19		
Ave.	23	22.8	22.8	21	21.8	17.2	11.4	9.6	9	6.4	3.8		

Table 4. Development of COP for assessing the number of elements in difficulty elements

Valut	2009	2006	2005	2000	1997	1993	1989	1985	1978	1971	1964
1	A	A	A	A	A	A	A	A	A – 7.0	7	7.5
2	B	B	B	B	B	B	B	B	B – 8.0	7.5	8
3	C	C	C	C	C	C	C	C	C – 9.0	9	9
4	D	D	D	D	D	D	D	D	D – 9.4	9.3	9.5
5	E	E	E	E	E	E			E – 9.8	9.5	9.8
6	F	F	F						F – 9.4	9.6	10
7	G									10	
Sum	7	6	6	5	5	5	4	4	6	7	6

Table 5. Development of COP in terms of the range of points

Valut	2009	2006	2005	2001	1997	1993	1989	1985	1978	1971	1964
Range	2.0-7.2	2.0-7.2	4.5-7	7.5-10	7.5-10	8.6-9.8	8.7-9.6	9-9.6	7-9.8	7-10	7.5-10

now. The first unique instructions FIG for evaluation of gymnastic exercises were created in 1949. known as "*Code of Points*." for the assessment of the artistic gymnastics includes seven levels of degree of difficulty. Initial degree of severity represents the level A, and the next levels are B, C, D, E, F and G (FIG, 2009). The latest one is the greatest degree of severity. The main purpose and goal of the COP for evaluating is provision of more objective evaluation of exercises. In (Table 4) shows the development of difficulty vaults from cycle to cycle. It may be noted that since 1985 year with the release of each new COP increases in DV than the previous one. In (Table 5) notes that the range of ratings ranged from 0.60 points in 1985 to COP for the 5.20 points COP (FIG, 2009).

Methods

Sample of the examinees

The study sample included 64 vaults out of the possible 115 as listed in the COP (FIG, 2009), from which we managed to obtain data from the researches conducted so far. In collecting the data, we could not reach all vaults because some of them, for example, second group vaults have not been performed since last 20 years. Analysing all reading materials and video recordings from large world competitions, men's perform some 30 different vaults, accounting for quarter of all vaults. A total of 64 different vaults have been collected with 12 variables. The sample of dependent variables includes DV (COP) ranging from 2 to 7.2 points, while the sample of independent variables include biomechanical variables shown in (Table 6).

In the analysis, we selected the following variables: degrees of turns in x and y axis in the first and second flight phase (variable names: *alpha in the x and y axis – the first and the second flight phase* – shown on the basis of the COP (FIG, 2009) and defined by the quantity of rotations. The moment of inertia was calculated by cylindric model of Petrov & Gagin (1974), ($J=ml2/12$) for *the first and second flight phases and the moment of inertia in the x and y axis* (Table 7). Morphologic data of vault specialists were used for calculation of moment of inertia body height 167.35 cm and body weight 68.15 kg. Čuk & Karácsony (2004) with the g=9.81 m/s2 and the Dempster body model Winter (1979). Some time parameters: *vault run speeds – maximum run speed on springboard, first and second flight phase* determined as the average value from all vaults were calculated from elite gymnasts (N=230) performing at the 2006 World Championship (WC) in Aarhus – Denmark after analyzing video recordings from FIG (IRCOS-Instant Replay and Control System) as recorded at 50 frames per second.

Data procesing methods

Data were processed as follows: in analysing descriptive parameters of variables applied in vaults, Kolmogorov-Smirnov test to determine the normality of distribution of the results for further multivariate analysis, regressive analysis with vault difficutly values as criteria and selected biomechanical variables as predictors (according to the method enter). For the significance of the regression analysis F test was used. The regressive analysis will help us establish whether independent variable biomechanical parameters depend on the current initial value. Factor analysis helps us determine the latent structure of manifest variables applied. As vaults are continuous actions where vault phases build on one another, we therefore selected only independant variables (variable can not be a mathematical function of two or more known variable, as the variablility of such varibles do not bring any new variance). For that reason specifically, the analysis includes the trajectory, the moment of inertia and individual vault phase times. We will take into consideration correlations and multiple correlations at the significance level of ($p<0.05$).

Table 6. Descriptive characteristics for (N 64 = vaults)

Variables (N = 64 vaults)	Min.	Max.	Mean	Std. Dev.	Skew.	Kurt.	K-S test	Sig.
COP – FIG, 2009. (points)	2.00	7.20	5.021	.170	-.174	-.617	.758	.614
BCG velocity on springboard (m/s)	6.00	10.90	7.841	.117	1.240	2.300	1.018	.252
Time of first flight phase (s)	.08	.33	.193	.007	.910	-.207	1.637	.009
Time of second flight phase (s)	.70	1.20	.928	.014	.077	-.177	.679	.747
Time of support on the table (s)	.08	.28	.159	.006	.637	-.367	1.203	.111
Alpha in x axis second flight phase (°)	120	900	482.81	28.860	-.032	-.395	2.658	.000
Alpha in y axis second flight phase (°)	0	1170	348.44	38.496	.788	-.305	1.537	.018
Alpha in x axis first flight phase (°)	90	160	133.75	4.018	-.505	-1.659	2.968	.000
Alpha in y axis first flight phase (°)	0	360	45.00	8.504	2.048	6.155	2.842	.000
Moment of inertia Jx axis 1st flight phase ($kgms^2$)	1.145	1.978	1.745	.0280	-2.045	3.274	2.023	.001
Moment of inertia Jy axis 1st flight phase ($kgms^2$)	.000	.555	.192	.032	.701	-1.505	2.905	.000
Moment of inertia Jx axis 2nd flight phase ($kgms^2$)	.458	1.731	1.266	.071	-.466	-1.744	2.911	.000
Moment of inertia Jy axis 2nd flight phase ($kgms^2$)	.000	.127	.103	.006	-1.640	.711	3.543	.000

Legend: N – no. of performances; M – mean; Min, Max – lowest and highest value; SD – standard deviation; Skew., Kurt. – coefficients of skewness and kurtosis; K-S test – Kolmogorov Smirnov test normality of the distribution - significant at the 0.05 level.

Table 7. *Moments of inertia as calculated for various body positions in the first and second flight phases*

Calculated as per the model (J/g)	Body axis	Such, J. (2007.)	Petrov, V., J. Gagin (1974.)	Groups of vaults and body position in the flight phase
1.706	x	-	-	I – Direct vaults
1.978	x	-	-	II – Vaults with full turns in preflight
1.771	x	-	-	III – Front handspring and Yamashita style vaults
1.874	x	-	-	IV – Vaults with 1/4 turn in pre-flight
1.145	x	-	-	V – Round-off entry vaults
0.458	x	0.356	0.60	Tucked
0.738	x	0.662	0.50 – 0.70	Piked
1.731	x	-	1.70	Stretched
0.127	y	-	0.17	Shoulder width
0.555	y	-	-	Arch-like position in group IV vaults

Results and Discussion

In the (Table 8) predictor system of variables (R Sguare) explains 92% of the common variables with criteria, while the correlation of the entire predictor system of variables with criteria, the coefficient of multiple correlation amounts to 0.96 (RO). The analysis of impact of individual variables (Table 9) shows that the highest and statistically most important influence of the criteria variables are with the following variables: alpha x in the 2nd fp (Beta) .835, alpha y in the 2nd fp (Beta) .375, and the moment of inertia Jx in the 2nd fp (Beta) .373 which is deemed significance level of ($p<0.05$). Prediction has been found significant only with three variables, meaning that the present vault difficulties COP (FIG, 2009) is defined by these three variables of the 2nd fp. The regressive analysis clearly shows that the initial value prediction is very high. Degrees of turns around transversal and longitudinal axis, body position in the 2nd fp are the only predictors and the most significant predictors in the COP (FIG, 2009). It can be noted that the FIG technical committee only considered the 2nd fp starting with the table take-off onwards to just before landing. Hence the 5 different vaults to support on the apparatus have no significant predictions to initial jump difficulty level. While Pearson correlation between DV value and runway velocity is the highest in regression analysis all the variance of the velocity goes to other parameters, probably mostly to alpha x in 2nd flight phase (r=.748). Bruggemann (1987) and Kwon (1996) noted that the DV is often increased by adding more rotations of somersaults into it's basic form. Bruggemann (1987) reviewed the research literature on gymnastics valuting, based largely on his work on continous rotation vaults. He reported that the higher skilled gymnasts were better able to increase the linear and angular moment at horse take off than the lower skilled gymnasts. He concluded that approach velocity was of high significance to the overall preformance of vault. It would apper that the success of a vault could be attributed to a large extent to the preflight characteristics. However, Bruggemann (1994) noted that the purpose of 2nd fp is to alter the preflight phase. This is establishes by generating lift through a higher vertical velocity and maintaining sufficient momentum for the postflight since the main goal of the vault was to establish height and distance in the postflight phase, wich contains the actual difficulties of the vault.

Table 8. *The regressive analysis of the criteria variable COP (FIG, 2009)*

R	R Square	Adjusted R Square	Std. Err. of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
.961[a]	.924	.906	.418	.924	51.768	12	51	.000

Variables	Unstandardized Coefficients		Standardizd Coefficients	t	Sig.	95,0% Confidence Interval for B	
	B	Std. Error	Beta			Lower Bound	Upper Bound
(Constant)	-2.063	1.410		-1.463	.150	-4.894	.768
BCG velocity on springboard (m/s)	.219	.120	.151	1.832	.073	-.021	.459
Time of first flight phase (s)	.941	1.731	.043	.543	.589	-2.535	4.416
Time of second flight phase (s)	1.418	.886	.121	1.599	.116	-.362	3.197
Time of support on the table (s)	-.679	1.355	-.024	-.501	.619	-3.400	2.042
Alpha in x axis second flight phase (°)	.005	.001	.835	6.638	.000	.003	.006
Alpha in y axis second flight phase (°)	.002	.000	.375	7.308	.000	.001	.002
Alpha in x axis first flight phase (°)	-.003	.005	-.066	-.583	.562	-.012	.007
Alpha in y axis first flight phase (°)	.000	.001	.007	.128	.899	-.002	.002
Moment of inertia Jx axis 1st fp ($kgms^2$)	.300	.381	.049	.787	.435	-.465	1.065
Moment of inertia Jy axis 1st fp ($kgms^2$)	-1.116	.689	-.211	-1.621	.111	-2.498	.266
Moment of inertia Jx axis 2nd fp ($kgms^2$)	.888	.137	.373	6.489	.000	.613	1.163
Moment of inertia Jy axis 2nd fp (kgms2)	-.544	1.481	-.020	-.367	.715	-3.517	2.430

Table 9. The impact of individual variables on the criteria variable COP (FIG, 2009)

Factor analysis results have resulted in insolating four major components (Table 10) accounting for the overall variability (Cumulative %) with 72% common variables within the entire system (Table 10). Factor analysis has resulted in isolating four factors (Table 11), as follows: 1.) degrees of turns around transversal axis in the second flight phase (alpha x 2nd fp .951, duration 2nd fp .838, 2.) 1st flight phase Jy 1st fp .894, alpha x 1st fp -.823, Jx 1st fp. .725, alpha y 1st fp .717, 3.) longitudinal body axis in the second flight phase alpha y 2nd fp .859, Jy 2nd fp .848, 4.) the support on the table .807.

Table 10. The matrix of characteristic roots and explained parts of common variance

Com.	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Var.	Cum. %	Total	% of Var.	Cum. %	Total	% of Var.	Cum. %
1	3.168	26.400	26.400	3.168	26.400	26.400	3.016	25.134	25.134
2	2.813	23.439	49.838	2.813	23.439	49.838	2.685	22.372	47.506
3	1.607	13.395	63.233	1.607	13.395	63.233	1.714	14.285	61.791
4	1.098	9.151	72.384	1.098	9.151	72.384	1.271	10.593	72.384

Extraction Method: *Principal Component Analysis.*

Table 11. The structure matrix

Variables	Component			
	1	2	3	4
BCG velocity on springboard (m/s)	.796	-.095	.055	-.147
Time of first flight phase (sec.)	-.692	-.303	-.186	-.365
Time of second flight phase (sec.)	.838	.019	.063	-.299
Time of support on the table (sec.)	-.139	.154	.035	.807
Alpha in x axis second flight phase (°)	.951	-.021	-.211	.088
Alpha in y axis second flight phase (°)	.044	.067	.859	.138
Alpha in x axis first flight phase (°)	.023	-.828	-.084	-.121
Alpha in y axis first flight phase (°)	.027	.717	-.005	.096
Moment of inertia J in x axis 1.f.p. ($kgms^2$)	-.064	.725	.016	-.361
Moment of inertia J in y axis 1.f.p. ($kgms^2$)	.149	.894	.119	.207
Moment of inertia J in x axis 2.f.p. ($kgms^2$)	-.497	-.139	.384	.382
Moment of inertia J in y axis 2.f.p. ($kgms^2$)	-.037	.101	.848	-.073

Rotation Method: *Varimax with Kaiser Normalization*. Rotation converged in 5 iterations.

Conclusion

In determining the impact of biomechanical parameters of vault value in men's artistic gymnastics and it's initial values, we have attempted to identify and maximise the correlation between the present COP (FIG, 2009). The results obtained at this moment in the manifest space define only three variables of vault values as follows: alpha x in the second flight phase, alpha y in the second flight phase and the moment of inertia Jx in the second flight phase. Research conducted so far has not considered structural groups of vaults and the very phase leading to the apparatus which is represented by various moments of inertia. Further research requires consideration of all parameters that have been used by other authors, including Brüggemann (1987, 1994), Kwon (1996), Takei (1998), Prassas, S. (2002), Ferkolj and Čuk (2010), in order to determine within the latent space whether only 8% of the variance refers to the: run time/velocity, support on the table and some other parameters. Factor analysis has resulted in isolating the following four factors: degrees of turns around transversal axis in the second flight phase, first flight phase, longitudinal body axis in the second flight phase, and the support on the table. The results of the research may serve as a starting point for launching an initiative for changing the FIG rules on awarding points in relation to the existing COP (2009). It would be good to make 3D kinematic analysis for every vault, but for this type of research, we mention in the subject and in the problem, the individual jumps are difficult to collect because they are not being performed for many years. Only ¼ of the total number of vaults from COP (FIG, 2009) are being performed on competitions.

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Acknowledgments

This work is supported by the New Technologies in Sport „NTS", University of Sarajevo (Bosnia and Herzegovina), Faculty of Sport and Physical Education, University of Ljubljana (Slovenia), Faculty of Sport - Department of Gymnastics, Olimpic Committee of Bosnia and Herzegovina, Cantonal Ministry of Science, Culture and Sport in Tuzla

Submitted: April, 15. 2011.
Accepted: May, 28, 2011.
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