BIOMECHANICAL GUIDELINE VALUES TO SUPPORT GYMNASTS LEARNING OF HANDSPRING AND DOUBLE SALTO FORWARD TUCKED ON VAULT

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The vault handspring and double salto forward tucked was already studied biomechanically several times performed 20 or more years ago. However, this vault is still important today. Our aim is to check the validity of the published results under current apparatus conditions using 24 vaults from 24 gymnasts selected via the minimum execution-score (≥ 9.0) from high level competitions. For this purpose, 14 parameters are evaluated using a 2-dimensional analysis. Compared to published data the results show an increase of the velocity during the flight to the vaulting board. There is no notable change in the maximum height of the body center of mass in the post flight. Our new results are the basis for a comparison of one example national gymnast in an infographic, in which strengths and weaknesses are recognizable and should support the coach in his work.

KEYWORDS: Men’s artistic gymnastics, “Roche”, feedback, infographic.

INTRODUCTION: Using the 2023 World Championships (WCh) as an example, our own unpublished competition analyses show that jumps with a difficulty level of at least 5.2 points are required to safely reach the team final (defined by the average score of the teams ranked 5-7).
The vault group of handsprings is the second important in Men’s artistic gymnastics (Schärer, et al., 2019). Within this group the vault handspring and double salto forward tucked is the most performed. This special vault, named after the inventor Cuban gymnast Jorge Roche in 1980, is more than 40 years later still of great importance and has today a difficulty value of 5.2 (Figure 1, FIG, 2022). At WCh 2019 in Stuttgart 21 gymnasts performed the “Roche” and 11 gymnasts show further variants of this vault (with half turn, in piked position or in piked position with half turn).

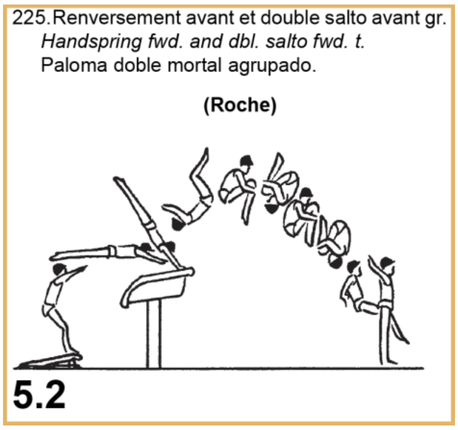

Figure 1: “Roche” Vault in the Code of points (FIG, 2022, 107)

Because of the importance of this vault several research groups published biomechanical data with different point of interests. Yang, & Li (2000) compared 5 international gymnasts from WCh 1999 with five Chinese gymnast. Takei, Dunn, & Blucker (2003), Takei, Dunn, & Blucker (2007) and Takei (2007) developed and evaluated a deterministic model to identify mechanical variables that govern linear and angular motions and their relationship to the judges’ scores. For this purpose they used different numbers of “Roche” vaults from the 2000 Olympic Games (OG). A short summery of the number of vaults and some biomechanical results are in table 1. If the studies have different groups, only the group with better performance (5 international gymnasts Yang, & Li, 2000; 16 high scoring vaults Takei, Dunn, & Blucker , 2003 and Takei, Dunn, & Blucker, 2007) and their results are shown in table 1.
All this research was done with vaults on the old apparatus vaulting “horse”. From 2001 on the International Gymnastics Federation changed the apparatus to the vaulting “table” (Čuk, & Ferkolj, 2008). After the change of the apparatus there is not so much research on the “Roche” vault. Čuk and Ferkolj (2008) get the possibility to compare “Roche” vaults on the “horse” from the 2000 World Cup (WC) in Ljubljana and vaults from the new “table” in 2002 WCh in

Debrecen. Ferkolj (2010) published data also based on the “Roche” from 2002 WCh. But during the last 20 years we could not found any publications on the “Roche” vault.

Table 1: Overview of selected biomechanical parameters (mean ± standard deviation) from published research on “Roche” vault.

Reference and apparatus (horse or table)	Year Event	N	vCM_{hor} to board [m/s]	t_{table} [s]	ω_{SS} [°/s]	Time of post flight [s]	height CM take off [m]	max height CM [m]
Yang, & Li (2000) - horse	1999 WCh	5	8.19 ± 0.03			1.04 ± 0.02		about 3.60
Takei (2007) - horse	2000 OG	23				1.01 ± 0.03	2.30 ± 0.05	3.01 ± 0.09
Takei, Dunn, & Blucker (2003); Takei, Dunn, & Blucker (2007)	2000 OG	16	8.12 ± 0.19	0.15 ± 0.02		1.02 ± 0.02	2.30 ± 0.05	3.05 ± 0.05
Čuk, & Ferkolj (2008) - horse	2000 WC	9	7.58 ± 0,23	0.16 ± 0.02	1075 ± 53	1.02 ± 0.03		
Čuk, & Ferkolj (2008); Ferkolj (2010) - table	2002 WCh	9	7.97 ± 0,28	0.16 ± 0.01	1105 ± 64	1.06 ± 0.02		3.13 ± 0.07

Learning to perform the “Roche” vault is also a good opportunity to contribute a relevant performance on vault for the national team. Biomechanical analyses can provide orientation for the learning process. However, first it is necessary to check whether the data from the publications presented are still applicable. Our aim is to support the learning process of the gymnasts. That’s why it is necessary to make this data usable for the gymnasts and their coaches.

METHODS: In training embedded scientists need a measuring and information system (MIS) on Vault which is a modular system for different approaches of biomechanical analysis (run up velocity, 2-dimansional- (2-d), 3-dimensional-kinematic analysis, force measurement [Knoll et al, 2014]) provide also an easy setup, sufficiently accurate analyses that can be carried out in a short time.

For the aim analysing “Roche” vaults, run-up velocity measuring with laser distance system (mean velocity 7 to 5 m in front of the table, Naundorf et al, 2008) and one video camera (Basler acA 1920–155 uc, USB 3.0, 100 fps, 1920x1200 px) was used.

To answer the first question, if previously published data are still valid, “Roche” vaults from (inter)national competitions (e.g. WCh 2019, EuropeanCh 2022, WC Cottbus 2021-2023, DTB-Pokal Stuttgart 2021-2023 and others) were selected. A minimum of execution (E) quality with an E-score ≥ 9.0 was chosen and 24 vaults from 24 gymnasts met the requirements. Because of this selection criteria no normal distribution is available (Figure 2). Due to this precondition in contrast to the publications explained above (Table 1 with mean and standard deviation) median (MD), interquartile range (IQR) and percentile ranks (PR) were used.

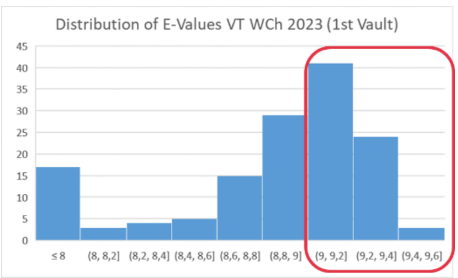

Figure 2: Distribution of E-scores on vault during WCh 2023 (red highlighted area E-score ≥ 9.0)

For 2-d-kinematric analyses vault specific positions were manually digitized with up to 13 body landmarks (head, 1-2 shoulder, 1-2 elbow, 1-2 wrist, 1-2 hip, 1-2 knee, 1-2 ankle – If left and right body landmarks are in a 2-d-plane on the same position only one is digitized). The specific positions (Pos) for “Roche” vaults are: Pos 1: last foot contact during run-up; Pos 2: landing on vaulting board (touch-down = TD); Pos 3: take-off (TO) from vaulting board; Pos 4: table touch-

down (TD); Pos 5: take-off (TO) from table; Pos 6: Begin of tucked somersault (ss) position; Pos 7: end of tucked ss position and Pos 8: Landing (first contact on the floor).
The position of the body's center of mass (CM) at all eight positions and selected angles (touch-down [Pos 2] and take-off [Pos 3] angle on/from board = ankle-CM to vertical; touch-down angle on table [Pos 4] = wrist-CM to horizontal; take-off angle from table [Pos 5] = wrist-CM to vertical) are calculated from the recorded body landmarks. Differences between the CM positions and their temporal distance result in mean CM velocities (e.g. from Pos 1 to Pos 2 vCM_{hor} to vaulting board [m/s]). The maximum (max) CM height in the post flight phase is determined (flight parabola) from the CM position during take-off from the table (Pos 5) and landing (Pos 8). Between begin of tucked ss position (Pos 6) and end of tucked ss position (Pos 7) the rotation of the hip angle bisector and their temporal distance result in mean angular velocities during tucked somersault (ω_{SS} [°/s]).

RESULTS: 24 "Roche" vaults from 24 gymnasts with E-score ≥ 9.0 were analysed. MD of the E-scores is 9.2 (IQR 0.25). Laser measured run-up velocity 7 to 5 m before the table was 8.35 m/s (0.4 m/s). 2d-analysis and calculations yielded the following results: mean horizontal velocity (vCM_{hor}) to vaulting board 8.3 m/s (0.42 m/s), vaulting board touch-down angle 21.5° (4.3°), vaulting board take-off angle 16° (5.3°), table touch-down angle 23° (6.3°) and CM height 1.43 m (0.08 m), table contact time (t_{table}) 0.26 s (0.02 s), table take-off angle 70° (6.8°), max CM height 2.90 m (0.21 m), CM displacement from take-off to max height 0.91 m (0.16 m), mean angular velocities during tucked somersault (ω_{SS}) 1030 °/s (33 °/s), CM height at end of tucked position 1.64 m (0.28 m) and at the landing 0.89 m (0.11 m) and last of all width of the post flight 3.22 m (0.34 m).
The PR for all parameters and individual data of one gymnast were plotted in a graphic (Figure 3) to highlight strength and weakness of the gymnast.

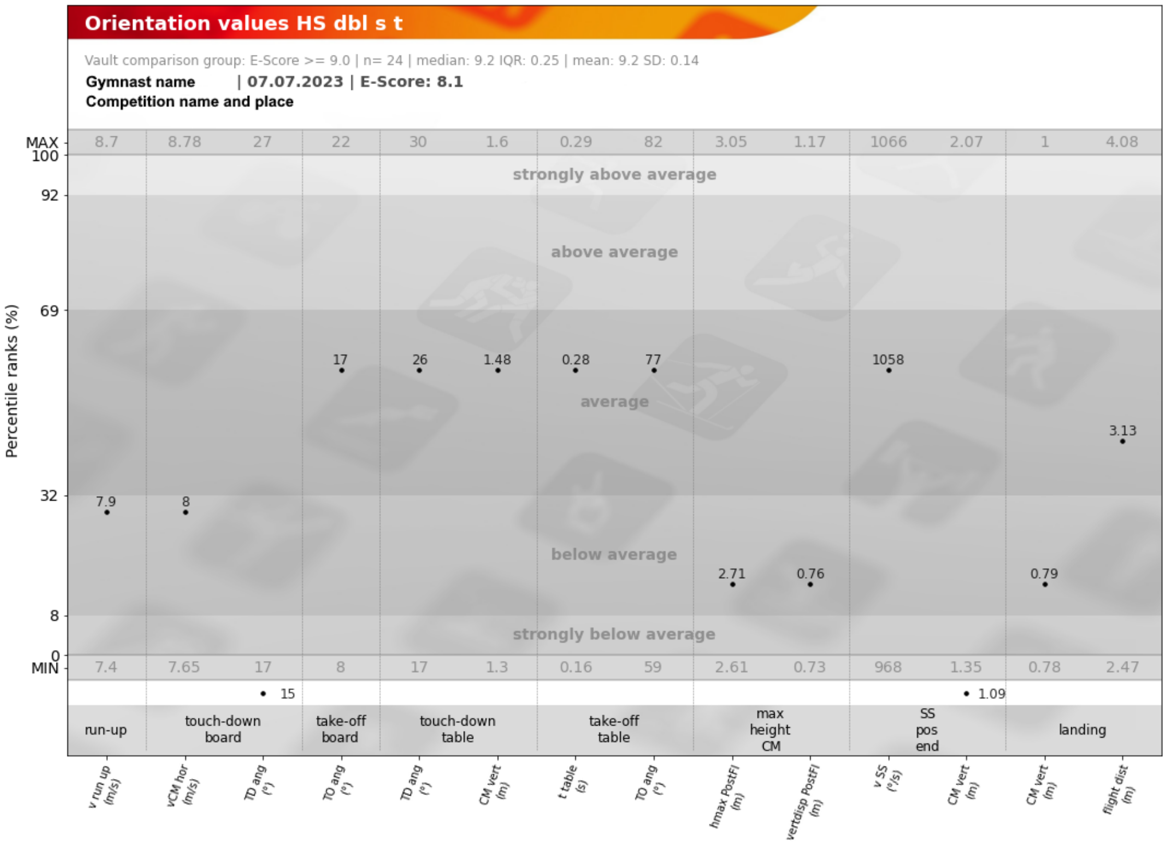

Figure 3: Biomechanical guideline values based on 24 high quality (E-score ≥ 9.0) for handspring and double salto forward tucked (HS dbl s t) and individual data of one national gymnast.

DISCUSSION: The comparison of the previously published results on biomechanical parameters for the “Roche” vault with the data currently obtained shows a higher horizontal velocity on the flight to the vaulting board. This may also be due to the increased run-up velocities with the introduction of the “table” (Naundorf, et al, 2008). With regard to the maximum CM height in the post flight phase, it should be noted that our data refer to the height above the 0.20 m mat. This puts the current value (MD 2.90 m + 0.20 m = 3.10 m) between the height of Takei (3.05 m; Takei, 2007; Takei, Dunn, & Blucker, 2003; Takei, Dunn, & Blucker, 2007) and Čuk and Ferkolj (2008) and Ferkolj (2010) with 3.13 m. The heights of 3.60 m published by Yang and Li (2000) are significantly higher than the other data and should therefore be questioned. With regard to the rotation speed, the data in the cited publications are hardly comparable. In Yang and Li (2000) the rotation speed in the “2nd turn” is given as 19.21 rad/s (1101 °/s). In the data presented here for the entire tucked ss phase, average angular velocity of 1030 °/s were calculated. For the results of the national gymnast in the learning process of the "Roche" vault shown as an example in Figure 3, below-average (PR 32 – 8) performance in the area of run-up velocity and mean horizontal velocity to vaulting board can be detected and the max post flight height is also currently low. The coach can therefore use the illustration to recognize the areas in which he should concentrate his training.

CONCLUSION: In the study presented here, the applicability of previously published biomechanical results for the "Roche" vault is examined. Differences and similarities were shown. In a second step, a possibility was presented, to show data of all 14 variables in an information graphic. Coaches can use it to detect strengths and weaknesses of their gymnasts.

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