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Research article

Does the Impact Force Depend on Arm Position and Run-up Speed during Forward Handspring on the Vault in Elite Gymnasts? A Pilot Study

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Abstract: (1) Background: This pilot study's aim was to examine the relationship between impact force, arm position and run-up speed, as well as to test new methods of measuring direct impact force on the vault while performing a forward handspring. (2) Methods: Data were collected from three elite, male artistic gymnasts (age 28.7±3.6 years, body weight 66.7±4.4kg; body height 169.7±3.2cm; experience 22±5.1 years), who performed two trials of the forward handspring. A high-speed camera, photocells and force plate were used to obtain and analyze the mechanical characteristics of the vault. Impact force (N), arm angle (degrees) and run-up speed (m/s) parameters underwent normality testing via the Shapiro-Wilks test, and bivariate correlations were used to explore relationships between them ($p<0.05$). (3) Results: Determined correlations between impact force and arm angle ($r=0.02$; $p=0.97$) and between arm angle and run-up speed ($r=-0.45$; $p=0.37$) have revealed non-significant relationship. Likewise, similar result was observed between impact force and run-up speed ($r=0.44$; $p=0.38$). (4) Conclusion: Non-significant correlations were observed, and new set-up (force plate-vault) for measuring maximal vertical impact force encountered in gymnastics vaulting showed consistent values with each vault performance, enabling researchers to measure the precise load magnitude..

Keywords: artistic gymnastics; technique; force, angle; speed; handspring

1. Introduction

One of the most appealing apparatuses used in both male and female artistic gymnasts is the vault. The most crucial phases of this apparatus are the flight from the springboard to the support on the vault, as well as the flight phase from pushing off the vault. To successfully perform this, the gymnast must achieve an appropriate running speed within a distance not greater than 25 meters from the vault [1,2]. Furthermore, each vault may involve one or more rotations around the body's two axes, or none at all [3]. The number of rotations varies with flight height, more specifically with executing a proficient take-off that converts translational energy into an optimal combination of translational and rotational energy [1].

Proper analysis for performing vault elements in artistic gymnastics is fundamental for the performance development of a gymnast. Different types of vaults have received a lot of research attention such as handspring, Yurchenko, Tsukahara, Kasamatsu, etc. [4,5].

The forward handspring is a standard fundamental skill widely employed by coaches to enhance performance. In that regard, high-speed cameras and various force plates enable accurate kinematic and kinetic parameters measurement while testing a gymnast [6]. In recent years, there was an increased interest in run-up speed and springboard mechanics which were critical in determining the energy transfer and propulsion achieved during the approach to the vault [7]. Likewise, contact mechanics, pre-flight or post-flight and landing characteristics included the analysis of forces exerted during the execution of a vault, joint angles, and overall stability, and contributed to a comprehensive understanding of the entire vaulting process [4,8,9].

The role of biomechanics research in artistic gymnastics has been extensively studied [10], and exhibits consistent growth, warranting scientific attention, as revealed by a bibliometric review [11]. Several studies have investigated kinematic measures [7,12-17] and a few studies used "gold standard" equipment for the direct force measurement [7,14,18], which is consistent with the suggestion that gymnastics research should adopt, at a minimum, a multidisciplinary perspective and strive for an interdisciplinary paradigm [19].

Existing biomechanical literature may provide some general insights into the mechanics of gymnastic movements, including the forward handspring, and may describe the forces involved in these actions [20]. Lehmann and associates [21] calculated the forces acting during the take-off position in forward handspring, and emphasized the need for the horizontal forces to be observed. However, the specific relationship between arm position, run-up speed, and impact force during the forward handspring on the vault in elite gymnasts is not well-understood, and to the best of the authors' knowledge, remains unexplored. It is unclear whether variations in these aforementioned factors significantly affect the forces experienced by gymnasts during this maneuver. This underscores the novelty and significance of the current study in addressing the particular aspect of vault biomechanics.

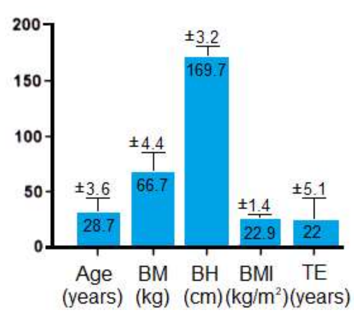
Therefore, in this pilot study we aimed to examine the relationship between impact force, arm position, and run-up speed, as well as to test new methods of measuring direct impact force on the vault, while performing forward handspring.

2. Materials and Methods

2.1 Participants Sample

The sample of participants consisted of three elite, male artistic gymnasts (Graph 1). In regard to the participants' recruitment criteria for current study, we have included senior, elite and injury-free gymnasts. Athletes signed an informed consent document prior to testing. Crossectional study was approved by the Gymnastics Federation of Serbia (approval No. 11-485/23) in accordance with the Declaration of Helsinki.

Graph 1. Participants sample descriptives (N=3).



Legend: -mean; -standard deviation; BM-body mass; BH-body height; BMI-Body Mass Index; TE-training experience;

2.2 Procedures

The procedures were performed in the well-equipped gymnastics hall, in the evening time when gymnasts usually train. Before test realization, the gymnasts had a warm-up that included a general (basic head, core and extremities movements) and a specific part (low intensity excercises) which lasted approximately 20-30 minutes. Then, gymnasts performed two handsprings (both jump values were taken for statistical analysis) with a two-minute pause in between.

2.3 Measurements

A high-speed video camera (Casio FX, 300 fps, 512x384 pixel) was positioned five meters on the side, with a calibration frame of 1×1m. The camera was placed sagittally to the trajectory of the gymnast's run-up, allowing it to capture the movement. At the moment of impact between the gymnast and the apparatus, the gymnast was in the "center of the camera lens". The vault (Janssen-Fritsen) was placed over the force plate (Kistler, Quatro jump, type 9290DD), had its legs firmly pressed against the plate and was absolutely safe and stable to obtain vertical components of impact force (Figure 1). The force plate was calibrated by body mass before the measurement started and after each gymnast performed one handspring. For obtaining arm angle (the angle between the extended arm and the surface of contact with the gymnastics apparatus, Figure 2), Kinovea (Kinovea–0.8.25 Copyright© 2006-2016–Joan Charmant) software was used (Figure 2). The software's validity and reliability were presented elsewhere [22]. Measurement, Analysis and Reporting Software (MARS) program was used for measurement protocol, where sample data were set at 10Hz (Figure 3).

Photoelectric cells (Witty System, Microgate, Bolzano, Italy) placed at 5, 10, and 20 meter distances from the starting line were used. The validity and reliability of speed measurement using this equipment were presented elsewhere [23]. Each photocell was placed at hip height (approximately), so that gymnasts run through with only one section of the body [24]. Likewise, all gymnasts' run-up start was from the same starting point and gymnasts started running on a pre-defined mark.

The vault height was also adjusted to 135cm, which is already pre-defined by the FIG rules [1,2]. The vaulting table with a "tongue" shape, has its upper surface slightly inclined, about five degrees [20].

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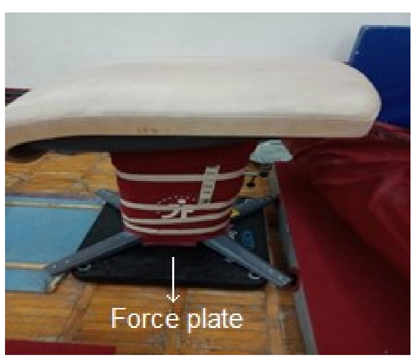

Figure 1. Set up of vault on the force plate.

Figure 2. Measurement of arm angle (the angle between the axis of the extended forearm and the axis of the hand placed to the contact surface of the vaulting table) at the impact.

We decided not to normalize the timing of the vault sequence because it was not necessary to address the research question. We used instead force data based on time only and focused on analyzing the force data within the specific context of the handspring phase to gain insights into the biomechanics of the vault (Figure 3).

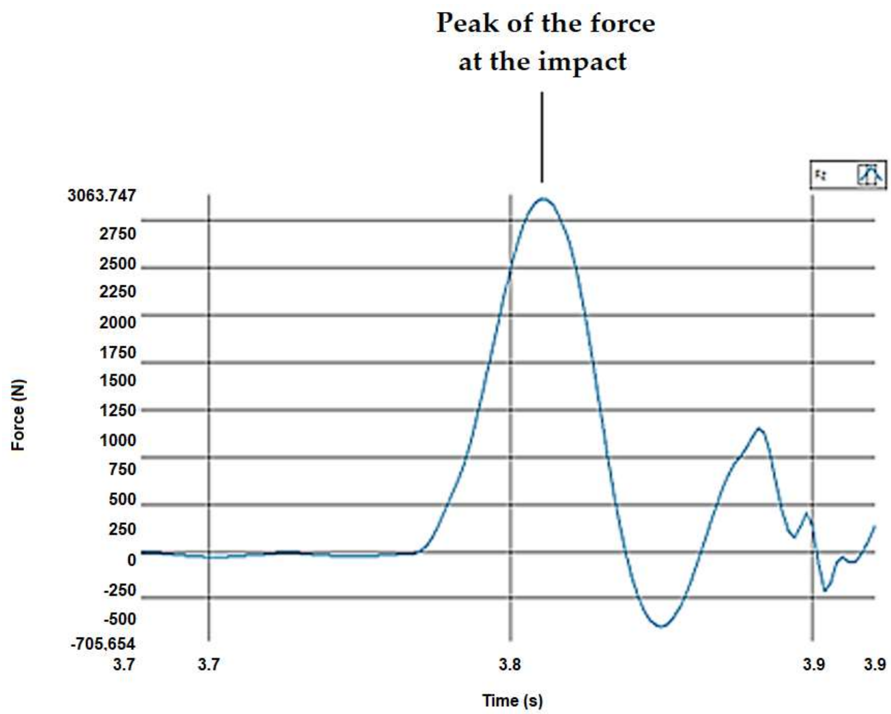

Figure 3. Time-force curve of the impact (MARS program)

2.4 Statistical Analysis

All variables were tested for the assumption of normality according to the Shapiro-Wilks test. Likewise, using bivariate correlations, the impact force parameters related to arm angle as well as run-up speed were examined [25]. The statistical package SPSS Statistics for Windows, version 24 (IBM Corp., Armonk, N.Y., USA) was used for statistical analysis. The correlation significance was set at the level of 0.05.

3. Results

Table 1 demonstrates descriptive statistics for vertical impact force (F) in Newtons, arm position (Arm_angle) in degrees, and run-up speed (V_run-up) in meters per seconds. Means and standard deviation (SD) values are presented on a sample of six measurements (N), as total jump attempts.

Table 1. Descriptive statistics of vault mechanics parameters.

	N	Mean	SD
F (N)	6	3379.33	471.05
Arm_angle (deg)	6	57.67	6.18
V_run-up (m/s)	6	6.22	0.37

Table 2. Bivariate correlation of vault mechanics characteristics.

		F (N)	Arm_angle (deg)	V_run-up (m/s)
F (N)	Pearson Correlation	1	0.02	0.44
	Sig. (2-tailed)		0.97	0.38
Arm_angle (deg)	Pearson Correlation	0.02	1	-0.45
	Sig. (2-tailed)	0.97		0.37
V_run-up (m/s)	Pearson Correlation	0.44	-0.45	1
	Sig. (2-tailed)	0.38	0.37	

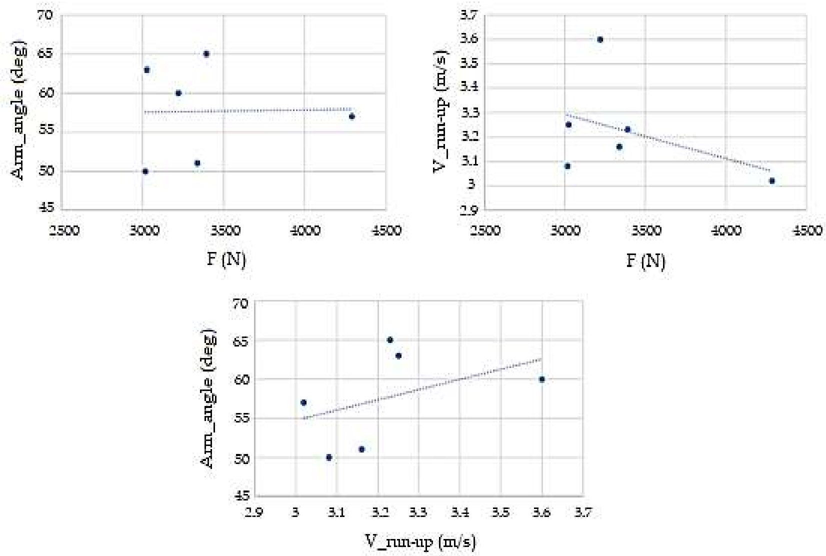

Figure 4. Scatterplots of vault mechanics characteristics.

The correlation between impact force, arm position and run-up speed are presented in Table 2 and Figure 4. Based on the provided correlations and associated p-values, the study did not find statistically significant relationships between vertical impact force, arm position, and run-up speed during the forward handspring. While there are some correlations, they are low (between F and Arm_angle) or low to fair (between Arm_angle and V_run-up and between F and V_run-up). Hence, they do not meet the threshold for statistical significance. Therefore, the study's results suggest that these variables may not have strong or linear relationships in the context of this gymnastics performance.

4. Discussion

This pilot study was designed to investigate the relationship between impact force, arm position and run-up speed, during the forward handspring vault performed by elite male gymnasts, as well as to test the new method of measuring direct impact force on the vault while performing handspring. Although the main study findings showed that there are no significant correlations between the abovementioned parameters, a possible new set-up (force plate–-vault) for measuring maximal vertical impact force has shown consistent values with each jump performance.

The gymnast initiates the vault by taking off from the springboard, making contact with the vault in a forward-entry position [26]. The impulse of forces in the case of the handspring can be understood through Newton's second law, which states that the force acting on an object is equal to the rate of change of its momentum. The force exerted by the gymnast on the vaulting table results in a rapid change in the gymnast's momentum, leading to the vaulting action. The efficacy of reactive strength relies on neuro-muscular elements, and the capacity of the tendo-muscular system to store and expel energy in the stretch-shortening cycle [27].

The substantial horizontal speed and kinetic energy during take-off from the board are identified as critical mechanical variables influencing the successful execution of the vault, next to a short duration, minimal vertical displacement of the body's centre of gravity, and a small somersaulting angular distance during preflight [16]. The horizontal energy obtained during the run-up is transformed into angular and vertical kinetic energy during take-off from the springboard and vaulting table to permit an optimum second-flight phase [9]. Since the amount of rotation achieved is determined by the moments of inertia [13,18], flight length, and starting angular momentum, high kinetic energy before take-off and push-off from the vaulting board and table is required for high-difficulty vaults.

The relationship between maximal vertical force and run-up speed was also analyzed, and a non-significant ($p>0.05$) correlation was obtained between the mentioned variables. However, the strength of correlation ($r=0.44$) shows that the possible reason for the non-significant correlation was the small sample size. Furthermore, a similar study [28] has also identified the importance of run-up speed, stating that elite gymnasts must attain a run-up speed of over 8.5m/s. Since this study was gathering information at competitions, where gymnasts have been performing competition jumps, there is a disagreement with our obtained results. Namely, our study was conducted in a training hall, in non-competitive conditions, and gymnasts were performing forward handspring only. Therefore, future studies should involve more participants, as well as examine the differences in competitive-noncompetitive conditions. Furthermore, Penitente and associates [29] have presented a maximum load of vertical impact force lower than in our study (1059.7 N vs. 3379.33 N). On the other hand, the results obtained in our study are in accordance with previous research conducted by Knoll and associates [30], who have presented approximately five bodyweight loads during impact on the vault. These results were expected, because of the gender differences (female vs. male). In practice, this maximal force can only be realized if the gymnast pre-activates the limb muscles before the actual impact shock [31,32]. Hence, following the fact that lower and upper extremities strength are important factors for successful vault performance [33], we can say that maximal vertical force and run-up speed can be achieved only with well-prepared lower and upper extremities strength.

Vertical speed in vaulting is directly related to the gymnast’s ability to use both the horizontal energy created during the run-up and the springboard, and elastic qualities of the vault to develop vertical momentum [34]. This means that the gymnasts must push off the vault with adequate angular momentum in order to perform the desired jump [8]. We analyzed the arm angle (the angle between the axis of the extended forearm and the axis of the hand placed to the contact surface of the gymnastics apparatus), as one of the significant factors in forward handspring vault. Since we have identified non-significant correlation ($r=0.02$; $p=0.97$) between impact force and arm angle, this suggests that participants had a similar handspring technique. In addition, this could be expected since these senior competitors have many years of competition experience [35]. But since authors haven’t identified studies that examined the relationship between impact force and arm angle, further ones are needed. Replication of the study by other researchers could be beneficial to validate the findings and ensure their reliability.

5. Study's Limitations

The study involved only three elite artistic gymnasts, which may not be representative of the various gymnast’s population. A larger and more diverse sample could provide a more comprehensive understanding of the relationships studied. In that regard, further studies will have to explore mechanical characteristics, to involve more participants in the study, as well as to explore more competitive-non-competitive conditions. The findings of the study may not be generalizable to gymnasts at different skill levels or age groups, which means that the focus on elite gymnasts may not apply to gymnasts with varying levels of experience. Likewise, each participant performed only two trials of the forward handspring, which also means that longer or more extensive data collection could provide a more robust dataset.

6. Conclusions

The present study aimed to analyze the correlation between impact force, arm angle, and run-up speed of elite gymnasts while performing the forward handspring vault. Non-significant correlations were observed, and new set-up (force plate-vault) for measuring maximal vertical impact force encountered in gymnastics vaulting showed consistent values with each vault performance, and enabled researchers to measure the precise load magnitude. The data provide preliminary evidence suggesting that similar techniques are applied when performing the vault handspring among elite gymnasts.

Author Contributions: "Conceptualization, P.V.; D.S.; M.P.; D.Đ.; and S.B.; methodology, P.V.; D.S.; M.P.; D.Đ.; S.B.; M.K.; B.M.; N.A.; B.B.; and V.S.; software, P.V.; D.S.; M.P.; D.Đ.; S.B.; N.A.; and V.S.; validation, P.V.; D.S.; M.P.; D.Đ.; S.B.; M.K.; B.M.; B.B.; and V.S.; formal analysis, P.V.; D.S.; M.P.; D.Đ.; and S.B.; investigation, P.V.; D.S.; M.P.; D.Đ.; and S.B.; resources, P.V.; D.S.; M.P.; and D.Đ.; data curation, P.V.; D.S.; M.P.; D.Đ.; S.B.; M.K.; B.M.; N.A.; V.S.; B.B.; and writing—original draft preparation, P.V.; D.S.; M.P.; D.Đ.; S.B.; M.K.; B.M.; V.S.; B.B.; and N.A.; writing—review and editing, P.V.; D.S.; M.P.; D.Đ.; S.B.; M.K.; B.M.; V.S.; B.B.; and N.A.; visualization, P.V.; M.K.; B.M.; N.A.; V.S.; and B.B.; supervision, P.V.; D.S.; M.P.; D.Đ.; S.B.; M.K.; B.M.; V.S.; B.B.; and N.A.; project administration, P.V.; D.S.; M.P.; D.Đ.; and S.B.; funding acquisition, P.V.; M.P.; and D.Đ.;. All authors have read and agreed to the published version of the manuscript."

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