



Maximal Power of the Lower Limbs of Youth Gymnasts and Biomechanical Indicators of the Forward Handspring Vault Versus the Sports Result

by

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The aim of the study was to define the relationship between maximal power of lower limbs, the biomechanics of the forward handspring vault and the score received during a gymnastics competition. The research involved 42 gymnasts aged 9-11 years competing in the Poland's Junior Championships. The study consisted of three stages: first - estimating the level of indicators of maximal power of lower limbs tested on a force plate during the countermovement jump; second - estimating the level of biomechanical indicators of the front handspring vault. For both mentioned groups of indicators and the score received by gymnasts during the vault, linear correlation analyses were made. The last stage consisted of conducting multiple regression analysis in order to predict the performance level of the front handspring vault. Results showed a positive correlation (0.401 , $p < 0.05$) of lower limbs' maximal power (1400 ± 502 W) with the judges' score for the front handstand vault (13.38 ± 1.02 points). However, the highest significant ($p < 0.001$) correlation with the judges' score was revealed in the angle of the hip joint in the second phase of the flight ($196.00 \pm 16.64^\circ$) and the contact time of hands with the vault surface (0.264 ± 0.118 s), where correlation coefficients were: -0.671 and -0.634 , respectively. In conclusion, the angles of the hip joint in the second phase of the flight and when the hands touched the vault surface proved to be the most important indicators for the received score.

Key words: countermovement jump, kinematic analysis, gymnastics, sports competition, coaching.

Introduction

In gymnastics, the vault is one of the apparatus of the men's all-around gymnastics competition. The vaults are based on a complex movement structure as well as on intense physical effort realised within a short period of time. Fast position changes at each phase of the movement pattern require the gymnast to have excellent timing, aerial awareness and proper coordination of each involved body part (Atiković and

Smajlović, 2011; Koperski et al., 2010; Takei et al., 2000). The vaulting gymnast needs their motor skills to be highly developed; at the same time, exercising vaults adds to such development. The vaulting movement pattern develops a gymnast's speed, agility, muscle power, the will to compete and courage (Arkaev and Suchilin, 2004). The vaults have been evolving with time, effectively changing their movement structure, from simple

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vaults over natural obstacles to forms strictly defined by the relevant norms (Zaporožanov et al., 2014). It is said that a gymnastic competition has been theoretically and practically developed by a number of coaches, competitors and scientists of various branches. New technologies have been implemented in order to change the construction of the vault (FIG, 2001), which, in effect, has improved the safety of competing gymnasts, as the size of the vaulting surface has been increased (Irwin and Kerwin, 2009). In consequence, vaults can become more difficult and spectacular. Each vault, regardless of its structure and level of complexity, includes such elements as: the run-up, hurdling onto a springboard, the first phase of the flight, the hands spring-off, the second phase of the flight and landing (Ferkolj, 2010; Kerwin et al., 1993). Currently, the most important element in the vaulting technique is the extension and elevation of the flight parabola and the centre of gravity in the second part of the vault, after the arm spring-off. Specialists pay significant attention to the run-up speed, the maximal force of the lower limbs, the angle of the take-off from the springboard and the orientation of anatomical segments and joint angles at hand contact with the vaulting table (Čuk et al., 2007; Heinen et al., 2011; King and Yeadon, 2005; Kochanowicz et al., 2009). When any of the above mentioned elements is performed improperly, it has a negative impact on the final score. What needs to be highlighted herein is the fact that not all details of the performed vault are noticeable for a human eye. Therefore, each vault element is analysed with regard to its kinematic value; moreover, the level of a gymnast's physical preparation is estimated, which allows improving the vault control and the process of teaching. Most of the scientific works focusing on the kinematic analysis of vaulting have not referred to the level of specific indicators of a gymnast's physical ability. Thus, the present research aimed at defining the relation between the maximal power of the lower limbs, biomechanics of the forward handspring vault and the score received during a gymnastics competition.

Material and Methods

Participants

The research involved 42 male gymnasts

aged 9 to 11 competing in the Poland's Junior Championships. The boys represented 6 independent sports clubs from various regions of Poland. All participating juniors started their training at the age of 6. The boys were 139.47 ± 7.9 cm tall and weighed 31.71 ± 4.86 kg, which proves their diversity. The BMI was 16.22 ± 1.49 . The study was conducted according to the Declaration of Helsinki and with assent from the Bioethical Committee of Ludwik Rydygier Collegium Medicum in Bydgoszcz of Nicolaus Copernicus University in Toruń. For each minor participating in the study, legal guardians gave their informed consent.

Procedures

Maximal force of the lower limbs was evaluated in a separate room during a general warm-up. The measurement was taken by means of the force plate (Quattro Jump Portable Force Plate System, Kistler Group, sampling rating = 500 Hz) where three countermovement jumps were performed interspersed with 1 min rest periods. During all jump phases the gymnast's hands were placed on the hips. The best result from all attempts was taken for further analysis. In order to describe the countermovement jumps performed by the gymnasts the following indicators were taken into consideration:

- Jump Height from Flight Time (cm)
- Relative Maximal Force (%BW)
- Maximal Power (W)
- Time to Maximal Force (s)

The kinematic part of the study was performed with a Basler camera asA2000-340kc with video recording frequency of 200 Hz. The camera was placed perpendicularly to the vault at a distance of 15 m from the vault. As the video was recorded during a sports competition, it was not possible for a gymnast to carry any markers. The biomechanical variables of the front handspring vault were developed in the Simi Reality Motion System GmbH (Germany) programme to define the angle and the line values as well as in the AS-1 programme to define the centre of gravity. The first program was used according to the manufacturer's instruction, with the exception that automatic tracking of coloured markers could not be used. Algorithms used in the second program and validation methods had been presented before (Aschenbrenner and Erdmann, 2002). In both programs, the relevant

points were marked on the kinematogram during the video analysis based on the kinematic joint axes. To minimize errors during the marker selection, analysis was made by one person with high anatomical and biomechanical knowledge and many years of experience in kinematic analyses. In both programs, image calibration was made by known dimensions of the vaulting table regarding the camera perspective. As the base for the scale, a distance in the long axis in the middle of the width of the apparatus was determined. It corresponded to the gymnasts' axis of movement in the sagittal plane. The analysis covered one of the two front handspring vaults performed during the competition; the vault which was awarded a better score by four competition judges was taken under consideration. The following vault parameters were analysed (Figure 1):

- $v1$ - the run-up speed, 5 m before the vault ($\text{m}\cdot\text{s}^{-1}$). The calculation was based on the movement of the centre of gravity of the whole body, 6 to 5 m before the vault.
- $d0$ - the spring distance before the vault (cm). It was defined as the distance measured between the axis of the ankle joint and the front edge of the vault upon the feet touching the springboard.
- $d1$ - the height of the first phase of the flight (cm). It was defined as the distance measured between the upper edge of the vault and the gymnast's centre of gravity, the moment his trunk (the line joining the axes of the glenohumeral and hip joints) was in a parallel position to the ground before the hand spring-off.
- $\alpha1$ - the angle at the hip joint in the first phase of the flight ($^{\circ}$). It was measured between the line joining the axes of the ankle and hip joints and the line joining the hip and glenohumeral joints, the moment the gymnast's trunk (the line joining the axes of the glenohumeral and hip joints) was in a parallel position to the ground.
- $\beta1$ - the upper limb absolute angle at hand contact with the vaulting table. It was measured between the line parallel to the upper surface of the vault and the line joining the axes of the wrist and glenohumeral joints, the moment the hands touched the vault surface for the first time.
- $\gamma1$ - the angle at the hip joint at hand contact with the vaulting table ($^{\circ}$). It was measured between the line joining the axes of the glenohumeral and hip joints and the line joining the axes of the hip and ankle joints, the moment the hands touched the vault surface for the first time.
- $t1$ - the time period when the hands touched the vault surface (s). The time was measured from the first touch of the vault surface until the hands take-off.
- $d2$ - the height of the second phase of the flight (cm). It was defined as the distance measured between the upper edge of the vault and the gymnast's centre of gravity, the moment the gymnast's trunk (the line joining the axes of the glenohumeral and hip joints) was in a parallel position to the ground after the hand spring-off.
- $d1-d2$ - the difference in height between the first and the second phase of the flight (cm).
- $\alpha2$ - the angle at the hip joint in the second phase of the flight ($^{\circ}$).
- $d3$ - the landing distance (cm). It was a distance measured between the ankle joint axis and the back edge of the vault, the moment the feet touched the ground.

The assessment of the front handspring vault was performed on the basis of FIG (2009) judging norms, modified by the Polish Gymnastics Federation. The score compiled the quality (up to 10 points max.) and the complexity of the jump (up to 5 points max.). The judges deducted points for technical mistakes during the first phase of the flight – a distorted vertical position while moving the trunk during the handstand; for technical mistakes during the second phase of the flight, insufficient height, lack of visible lift after the hand spring-off, insufficient trunk straightening before landing and lack of stability of landing. The complexity of the jumps was judged on the basis of the landing distance. The landing distance was measured from the point of placing the heels to the back edge of the vault. When landing less than 1 m behind the vault, the gymnast received 4.2 points; when landing 1 to 1.5 m – 4.6 points and over 1.5 m – 5.0 points. The given values were relevant, being the inner norms established by the Polish Gymnastics Federation in 2013.

Statistical analysis

First, the distribution of the dependent variable (a judges' score) and the researched independent variables was defined. The result was statistically non-significant in Shapiro-Wilk and Kolmogorov-Smirnov tests. Therefore, in order to define the relationship between the researched indicators, i.e., maximal power of the lower limbs, biomechanics of the front handspring vault and the score received, the Pearson's correlation coefficient r was applied. To define the most significant indicators predicting changes in the explained variable, the multiple regression analysis was applied by means of the backward stepwise method. In addition, the effect size of the developed equation was estimated (Cohen f^2 coefficient).

Results

The first stage of the research aimed at estimating the level of the indicators of maximal power of the lower limbs as well as their correlation to the score received for the front handspring vault (Table 1). The highest correlation coefficient was observed in the Maximal Power indicator ($r = 0.401$, $p < 0.05$), with the mean value of 1400.91 ± 502.74 W. The correlation of the Relative Maximal Force indicator was slightly lower and reached $r = 0.330$ with the mean value of 234.87 ± 34.34 %BW. The most significant correlation was found between Jump Height and Flight Time ($r = 0.324$, $\bar{x} = 0.26 \pm 0.04$ cm). An adverse correlation was observed between Time and Maximal Force; however, it was statistically irrelevant.

The second stage of the research aimed at estimating the level of biomechanical indicators of the front handspring vault as well as their correlation to the score received (Table 2). The judges' scores for the performed front handspring vault reached 13.38 ± 1.02 points. What proved to exert the highest impact on the judges' scores was the angle of the hip joint during the second phase of the flight ($r = -0.671$). The mean value of the mentioned indicator reached $196 \pm 16.64^\circ$. A significant correlation was also observed with the duration of hands' touching the vault surface ($r = -0.63$, $\bar{x} = 0.26 \pm 0.12$ s), in the flight height in the second phase of the flight with respect to the vault ($r = 0.602$, $\bar{x} = 41.74 \pm 15.79$ cm) and also in the landing distance ($r = 0.631$, $\bar{x} = 138.73 \pm 45.79$

cm). Other indicators proved to be of statistical significance with regard to the correlation to the final scores received i.e., the run-up speed ($r = 0.54$, $\bar{x} = 5.92 \pm 0.47$ s), the spring distance before the vault ($r = 0.441$, $\bar{x} = 96.64 \pm 22.78$ cm), the height in the first phase of the flight ($r = 0.468$, $\bar{x} = 43.15 \pm 10.89$ cm), the angle of the hip joint when hands touched the vault surface ($r = 0.554$, $\bar{x} = 164.33 \pm 23.08$) and the difference in height between the first and the second phase of the flight ($r = 0.410$, $\bar{x} = 1.38 \pm 11.34$ cm). The angle in the hip joint in the first phase of the flight as well as the upper limb absolute angle at hand contact with the vaulting table were not significantly related to the judges' scores.

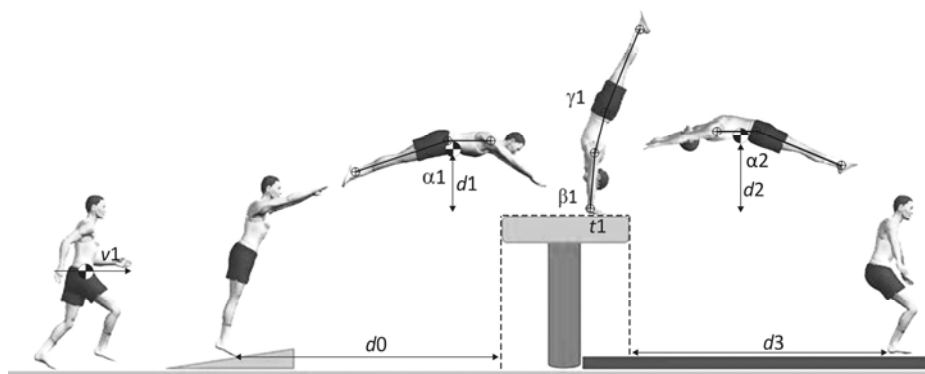
The last stage of the research consisted of conducting multiple regression analysis by means of backward stepwise regression in order to predict the performance level of the front handspring vault (Table 3). The judges' scores were the explained variable and the explanatory variables were: the value of the researched indicators of the lower limbs' maximal power, kinematic analysis and the selected indicators of physical abilities. The programme automatically incorporated these variables into the equation that mostly influenced the searched value, eliminating those that presented multicollinearity with other explanatory variables. The received model of the assessment considered only two kinematic variables, as they proved to be the most crucial ones for receiving a high score: the angle of the hip joint in the second phase of the flight ($p < 0.001$) and the angle of the hip joint when hands touched the vault surface ($p < 0.05$).

The multiple regression formula, equation (1), was developed to predict the potential score that a gymnast could receive for the front handspring vault.

$$\text{The score} = 17.79 - 0.032 \times \alpha_2 + 0.012 \times \gamma_1 \quad (1)$$

α_2 - the angle of the hip joint in the second phase of the flight [°]

γ_1 - the angle of the hip joint at hand contact with the vaulting table [°]

**Figure 1**

Characteristics of biomechanical variables of the front handspring vault prepared upon the Atiković scheme (2012), being modified. All markings are approximate

Table 1

Mean values of lower limb power indicators and their correlation to the score received

Lower limbs' maximal power indicators	\bar{x}	<i>r</i> value
Jump height from flight time (cm)	0.26 ± 0.04	0.324*
Relative maximal force (%BW)	234.87 ± 34.34	0.330*
Maximal power (W)	1400.91 ± 502.74	0.401*
Time to maximal force (s)	0.50 ± 0.27	-0.130

BW – body weight, * $p < 0.05$

Table 2

Mean values of biomechanical indicators and their correlation to the score received

Biomechanical indicators of front handspring vault	$\bar{x} \pm SD$	<i>r</i> value
<i>v</i> 1 - run-up speed, 5 m before the vault (m·s ⁻¹)	5.92 ± 0.47	0.541**
<i>d</i> 0 - spring distance before the vault (cm)	96.64 ± 22.78	0.441*
<i>d</i> 1 - height of the first phase of flight (cm)	43.15 ± 10.89	0.468*
α 1 - angle at the hip joint in the first phase of the flight (°)	155.55 ± 22.47	0.006
β 1 - upper limb absolute angle at hand contact with the vaulting table (°)	67.24 ± 9.64	0.096
γ 1 - angle at the hip joint at hand contact with vaulting table (°)	164.33 ± 23.08	0.544**
<i>t</i> - time period when the hands touched the vault surface (s)	0.264 ± 0.118	-0.634**
<i>d</i> 2 - height of the second phase of flight (cm)	41.74 ± 15.79	0.602**
<i>d</i> 1 - <i>d</i> 1 - difference in height between the 1 st and the 2 nd phase of flight (cm)	-1.38 ± 11.34	0.410*
α 2 - angle at the hip joint in the second phase of flight (°)	196.00 ± 16.64	-0.671**
<i>d</i> 3 - landing distance (cm)	138.73 ± 45.79	0.631**

* $p < 0.05$, ** $p < 0.001$

Table 3*Dependent variable regression results: the score for the handspring*

Effect	β	β Std. Error	Variable	Variable Std. Error	t (39)	p
Intercept			17.79	2.2	8.10	<0.0001
Hip angle during contact	0.28	0.13	0.012	0.01	2.14	0.0384
Hip angle in the II phase	-0.53	0.13	-0.032	0.01	-4.12	0.0002

Statistics of the regression: $r = 0.713$, $r^2 = 0.51$, $F(2,39) = 20.18$, $p < 0.0001$.

Std. Error of Estimation = 0.74, $f^2 = 0.351$

*Hip angle during contact: angle of the hip joint
at hand contact with the vaulting table;*

*Hip angle in the 2nd phase: angle of the hip joint
in the second phase of flight*

Discussion

Numerous authors have noted that the effectiveness of performed gymnastic exercises, including vaulting, depends not only on technical preparation, but also on the gymnasts' advanced level of psychomotor abilities and relevant physical abilities (Sawczyn and Zasada, 2007; Zaporozhanov et al., 2014; Ziemilska, 1985). Therefore, the conducted research aimed at defining the correlation between maximal power of the lower limbs of youth gymnasts, kinematic analysis of the front handspring vault and the sports result. The analysis of the correlation between the result obtained for the countermovement jump and the score obtained for the front handspring vault proved to be closely related with the indicator of maximal power of lower limbs. Similar relationships were analysed by Bradshaw and Le Rossignol (2004) in research on youth female gymnasts. Their research showed a higher correlation between the maximal power indicator and the front handspring vault result. However, one should take into account the fact that the research was conducted during training and involved subjects of a wider age span. When comparing this indicator in the studied girls to the same indicator in boys of the same age and with similar training experience, the boys' results were higher by about 536 W (Bencke et al., 2002). The difference can be also observed between 11-year-old gymnasts from Poland and their peers from England who did not practise any sports activities (Taylor et al., 2010). Considering such elements as body height and mass of the researched gymnasts who were on

average 6 cm shorter and 9 kg lighter than their English peers, it can be noted that their results in the countermovement jump were better by 200 W than the results obtained by the researched group in England. The research also proved that the most essential correlation to the judges' scores received for the front handspring vault was observed in the angle of the hip joint during the second phase of the flight, at the moment of touching the vault surface, in the height of the second phase of the flight with respect to the vault and in the landing distance. Similar results were obtained by Bradshaw and Le Rossignol (2004), Brehmer and Naundorf (2011), Čuk et al. (2007) and Veličković et al. (2011), despite the fact that these researchers examined male and female gymnasts of various ages. The obtained data significantly differ in some indicators with reference to the average values. For example, the mean run-up speed in German gymnasts was 7.3 m·s⁻¹ (Brehmer and Naundorf, 2011), which is 1.4 m·s⁻¹ better than in the Polish research group. However, the age difference of three years between both the examined groups needs to be mentioned herein. In research on professional senior competitors taking part in international competitions, the run-up speed measured a few metres before the vault was 8 – 8.5 m·s⁻¹ (Atiković and Smajlović, 2011; Brehmer and Naundorf, 2011). The time of the handsprung off the vault surface, though, was similar to the result obtained by Bradshaw et al. (2010), Irwin and Kerwin (2009), King and Yeadon (2005), Takei (1998) and Takei et al. (2000), being 0.11 - 0.20 s. When comparing the mean height of the second phase of

the flight of the young gymnasts to the finalists' results in Sydney 2000, the difference exceeding 1 m could be observed (Dancewicz et al., 2000). According to Takei (2007), in order to properly perform the handspring with $2\frac{1}{2}$ tucked forward somersaults along the transverse axis of the body, the gymnast needs to reach at least 130 cm of height at the peak point of the flight in its second phase; this value is then measured from the top surface of the vault to the gymnast's centre of gravity. The rest of the biomechanical variables described above such as the distance of the spring before the vault, the height of the first phase of the flight, the height difference between the first and the second phase of the flight, the angle of the hip joint at hand contact with the vaulting table and the angle of the hip joint during the second phase of the flight have not been referred to by other authors. Some previous research conducted by Kochanowicz et al. (2013) and Kochanowicz and Kochanowicz (2014) proved that jump effectiveness depended on one's somatic features, motor abilities and technical skills.

The present study is not only of cognitive significance, but also aims at improving the process of gymnastic training. The main methodological limitation of the research, due to

the restrictions of sports competition, was the lack of a possibility to use markers to indicate kinematic joint axes used in the analysis. To minimize errors associated with indicating the markers manually, all analyses were performed by one qualified person. The research, undoubtedly, needs to be extended and include gymnasts of various levels; moreover, correlations between maximal power of the lower limbs and biomechanical indicators in particular phases of the vault need to be researched.

Conclusions

The angle of the hip joint in the second phase of the flight and the angle of the hip joint at hand contact with the vaulting table proved to be the most important indicators for the score received. The indicator of maximal power of the lower limbs defined in the countermovement jump test can be helpful to assess physical abilities of young gymnasts preparing to train vaults. Moreover, clearly defined and simple biomechanical variables of the vault can be applied by coaches in a variety of multimedia means.

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