OPTIMIZATION OF VELOCITY CHARACTERISTICS OF THE YURCHENKO VAULT

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Abstract

Various versions of the Yurchenko vault are contemporarily the most widely used vaults in women's gymnastics. Using a 3D kinematic analysis of the velocity characteristics, our aim was to investigate basic variants of the Yurchenko vault, their mutual relations in chosen phases and various influences on the technique of execution. 14 vaults performed by elite artistic gymnasts both from the Czech Republic and abroad were assessed, among which it was possible to observe an individual approach to handling the locomotor task displaying varying degrees of fluctuation in both the overall velocity of the COG - v_{abs}*, and its horizontal component* v_x *as well as vertical component* v_z*. Despite the variety, the obtained results were used to determine the optimal course of these velocity parameters, which serves as a precondition of the correct technical execution of the Yurchenko vault. Although our study deals only with the selected characteristics of the whole series of variables affecting the quality of the execution of the Yurchenko streched, we believe our new research findings may be used by coaches and their athletes in their training practice.*

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Keywords: *Biomechanics, Gymnastics, Vault, Optimization of Techniques.*

INTRODUCTION

The appeal of the Yurchenko vault topic lies in its rapid development over the last decade, unparalleled by any other gymnastic event and leading to the steep improvement of performance on this type of apparatus. To be able to perform the diagnostics of the technique execution and to improve athlete's motion performance, the motion analysis has to be performed.

We have chosen for the analysis the basic execution of the Yurchenko vault which is performed as early as the school-age category (at the age of 13-14 years) but whose mastery is critical for further development of the vault. Gymnasts should start learning this vault no later than at the age of 10 years. Although the vault only takes seconds to perform, it takes years to achieve its mastery. Wrong motion routines can stop the work even in the beginnings of practice, therefore, for trainers, it is important to have a good understanding of its mechanical principles influencing techniques. As with any other skill, the development of the Yurchenko vault may be divided into three stages, which may be trained simultaneously. These are a special physical preparation, special technical training and performance simulation. At the beginning, a gymnast should focus solely on the physical and technical training using specific exercises and their repetition. Only after sufficient technical preparation has been completed leading to a well-mastered practice of the Yurchenko vault, can the gymnast begin to perform the whole jump safely and effectively.

The Yurchenko vault can be devided in following seven phases (Čuk & Karacsony, 2004; Atikovič & Smajlovič, 2011): run, jump on springboard, springboard support phase, first flight phase, support on the table, second flight phase and landing.

The technical basis for each Yurchenko vault phase is as follows.

Each vault begins with a run phase, the aim of which is to obtain the maximum amount of kinetic energy, which is then converted to the corresponding vertical, horizontal and rotational velocity for the further course of the jump. The length of the run phase depends primarily on the individual personality of a gymnast and mastery of technique.

The main task of two next phases - jump on the springboard and springboard support phase is to maintain the horizontal velocity required for the next phase of the vault. With the Yurchenko vault the gymnast performs a round-off (a sideways somersault with landing on both feet) with landing on the springboard with their back to the vaulting table.

The first flight phase includes the execution of a back handspring with landing on hands on the vaulting table. The first flight phase will be mainly characterized by its duration. Its main task is to prepare the best possible conditions for both the touch and take-off from the vaulting table.

The touch and take-off phase from the vaulting table directs and extends a further movement of the centre of gravity (COG) upward and forward. Following the touch on the vaulting table the gymnast's body should make as a rapid movement as possible around the axis passing through the shoulder joints, with a simultaneous partial-movement around the axis passing through the touch spot, while the body's centre of gravity (BCG) rises. The prerequisite for the vaulting table contact phase is a correct and timely execution of the take-off prior to the gymnast performing a handstand.

The second flight phase is the longest and thus the most interesting phase of the vault. It includes another important action of the gymnast, namely one and a half somersault with landing on a landing mat. A gymnast pushes up from her hands off the vaulting table into a back layout. Following the push-up from the hands the COG is supposed to reach its highest point. Once the gymnast leaves the table, the potential of the technical execution of the back layout is given and cannot be changed.

Landing, through which the kinetic energy of the second flight phase is reduced, is the final part of each vault. Its quality depends mainly on the activities performed by the gymnast in the previous phases of the vault. The work of the arms is particularly important in this phase as the gymnast's arms, which are initially down, are raised in front of him or her thereby stopping the body rotation.

As is obvious, the technical basis of the motion is very complex. It is therefore kinematically possible to observe a number of relations between time, space and velocity characteristics. In this study, we focus on the velocity parameters of the Yurchenko vault.

In a number of studies, the authors state that the correct technical performance of the run phase is crucial for the successful execution of the entire vault. Arkaev and Suchilin (2004) reported that the last 5 m of the run phase prior to the landing on the springboard should not contain any significant increase or decrease in the velocity. This fact is, however, contradicted to some extent by Bradshaw (2004), who mentions a noticeable decrease in the horizontal velocity prior to the landing on the springboard. This is due to the required visual inspection and the preparation for the jump on the springboard. The ability to minimize the velocity loss while landing on the springboard may lead to a more successfully executed jump. Petković (2011) focused on the difference between the run start strategy of the best gymnasts, who slow down half way through the run start for a moment, and the average gymnasts who keep raising their velocity throughout the run phase. In their work, Bradshaw, Hume, Calton, & Aisbett (2009) also studied the acceleration rate in the run phase. They compared the velocity of different vaults performed by outstanding Australian gymnasts during their practice. Studies have shown that the slowest run phase velocity was measured with the very Yurchenko vault carried out by women. This is also stated by Farana & Vaverka (2011) in their article, where "the results of the study revealed that with the vaults of the Yurchenko type, the run phase velocity is lower than with the front handspring vault group and the round-off vault group. The lowest run speed velocity was achieved by the Yurchenko vault group, 7.35 ms^{-1} for men and 6.98 ms^{-1} for women". It must be, however, emphasized that it was the introduction of the new vaulting table which led to the increased need to maximize the velocity components in the run phase. Especially with the Yurchenko vault the landing onto the springboard phase is essential and very often critical for the execution of the vault. At this stage, the gymnast performing a round-off with landing on the spring board changes the direction of her body’s momentum. Hence, a great emphasis is placed on proper training of the technique to succesfully handle and execute this phase of the vault. For the fast execution of the round-off, it is therefore crucial to create sufficient momentum for the entire vault.

In their kinematic analysis Penitente, Merni, Fantozzi, & Perretta (2007) deal with the landing and the springboard take-off phase. The results show that the gymnasts are able to effectively use the springboard without decreasing the horizontal velocity while increasing the vertical velocity. The horizontal velocity while landing on the springboard reached the average value of 5.27 ms^{-1}. Similar values can also be seen in publications by other authors: 5.32 ms^{-1} (Nelson, Gross, & Street, 1985), 5.08 ms^{-1} (Ragheb & Fortney, 1988), 5.14 ms^{-1} (Kwon, Fortney, & Shin, 1990). The springboard take-off is a dynamic phase lasting for a very short time. In their work, Čuk & Karacsony (2004) deal with the take-off force and the springboard contact time for individual types of vaults. With the Yurchenko vault, the springboard contact time stood at 0.15 for women and 0.14 for men. It is important to note that the key variable for the moment of take-off from the springboard is the size of the horizontal speed.

The ideal conditions of the following first flight phase are characterized by the fastest possible performance of the back handspring onto the vaulting table. What is important is the correct body position throughout the first flight phase and especially prior to the landing on the vaulting table, thus ensuring a minimum speed loss.

The contact of the gymnast with the vaulting table is an important and most examined phase of the Yurchenko vault. The touch and take-off phase has been affected primarily by the change of the vaulting tools in 2001. Uzunov (2011) focused in his article on possible changes in the technique Yurchenko stretched execution, which can emerge resulting from the replacement for a new type of tool, and how these changes are reflected in biomechanical variables. Uzunov (2011) states in his other article that the vertical velocity of the COG upon completion of the take-off from the table is considered the most important variable. The optimal horizontal velocity of a gymnast upon leaving the table is 2.34 ms^{-1} and the vertical velocity is 2.27 ms^{-1}.

The quality of the second flight phase which largely contributes to the assessment of the actual vault is considered the most important. Following the take-off from the vaulting table the movement of the body during this phase shows an upward trend, which is dependent on the conditions created in the previous phases of the vault. Already Takei (1989) focused on the comparison of vaults performed at major international competitions, that received either high or low marks. The results showed that gymnasts that achieved higher horizontal and vertical velocity values upon touching the apparatus, achieved higher marks. "This resulted in a shorter duration of contact with the apparatus. Higher vertical and horizontal velocity affects the duration of the second flight phase and also the maximum height and distance when landing." Koh, Jennings, Elliott, & Lloid (2003) in their extensive research sought to identify changes in the technology needed to execute the optimal Yurchenko vault. The results showed that the best recorded attempt was not sufficient in comparison with the optimal execution of the Yurchenko vault. The vault failed to acquire sufficient length and height in the second flight phase due to the small vertical velocity when taking off from the table. Consequently, the gymnast in the second flight phase was slightly bent at the hips and due to this she would not receive too high a score.

Landing is one of the basic motion activities practised with all tools in artistic gymnastics and it also is the final phase of our analyzed vault. The correctly performed landing is important for the successful execution of the vault. This final stage requires great stabilization and the work of eccentric forces of great magnitude decreasing the body velocity in order to avoid injury to the lower extremities due to their large external load. Marinšek (2010) states that the forces measured during landing may be in the 3.9 to 14.4 BW (body weight) range.

As is shown by previous research, the best achieved velocity of the BCG at the end of the run phase is one of the key factors limiting the quality of the Yurchenko vault execution. The aim of this work is to extend the existing knowledge, especially in terms of velocity characteristics. The authors usually indicate maximum velocity achieved by gymnasts. We, however, aim not only to determine the maximum velocity values, but to focus on the velocity development in the course of the vault execution. We are interested in finding out what stages are characterized by the possible increase or decrease in the velocity of the BCG. We believe that a comprehensive overview of velocity changes during various stages can point to the facts important for the optimization of the techniques of the observed element.

METHODS

The research sample consisted of 14 artistic gymnasts of both Czech and foreign nationality. They are all contemporary national representatives in artistic gymnastics who participate in international and other high-profile competitions. The selected gymnasts fall within the age range of 18-25 years. The girls have been engaged in artistic gymnastics approximately since their 4 years of age, they have daily two-phase practices. In selection of the tested sample the emphasis was put on the high performance level and the absolute technical execution of the basic form of the Yurchenko vault. Following the consultation with coaches of the selected gymnasts, a 3D kinematic analysis of this vault was performed. The measurement sessions took place in the competition season during which we were able to record already stabilized level of the vault execution, i.e. a high performance level of the selected gymnasts. The data was collected during the two measurement sessions. One was held at the International Grand Prix competition in Brno, the other one during practice, nevertheless in the identical gym of the Sokol Brno I, which is the best gymnastics gym in the Czech Republic equipped with high-quality apparatuses. All of our tested persons (TP) were in a good shape and good health.

To carry out research, it was necessary to employ a quantitative method of motion analysis through which numerical values are generated, which refer to the magnitude of physical quantities. We therefore chose a 3D kinematic method to record the motion where two synchronized SIMI Motion high-frequency digital cameras with the frame rate of 100 Hz were used. Individual attempts were recorded from the moment of the hands touching the mat in a round-off after reaching the maximum height in the second flight phase of the performed vault. All these phases took place in the pre-calibrated space. The tested persons were provided with retroreflective markers which allowed easier evaluation of the video recording. The head as well as all the major joints - wrists, elbows, shoulders, hips, knees and ankles were marked. With each gymnast three attempts were filmed where the best one was chosen for the subsequent analysis based on the assessment of an international referee of artistic gymnastics. In the next step the data was processed using the SIMI Motion software produced by the German company SIMI Reality Motion Systeme GmbH. Due to suboptimal ligting conditions during field measurements in the gym, we decided to track data mainly manually.

From the recorded data, we assessed the selected temporal, spatial and velocity characteristics. For each of these variables basic statistical data was calculated. Given the non-normal data distribution (vertical velicities v_z of the BCG at the moment of landing on the springboard and take-off from the vaulting table) the Spearman correlation at the significance level of *p<0.05* was used for a closer statistical analysis of the relations between velocity parametres.

RESULTS

We have observed three phases of the Yurchenko vault: take-off on the springboard, the first flight phase and take-off on the vaulting table. For each phase, we evaluated the speed of the COG - v_{abs}, the horizontal velocity component v_x and also vertical velocity component v_z at the time of commencement and completion of each phase, as well as the size of their changes during the phases. Fig. 1 neatly shows the course of the overall velocity and its components for one of the attempts, which is closest to the average performance of the entire test set. The curves show the velocity changes from the moment of landing on the springboard to leaving the table; the first vertical line indicating the moment of leaving the springboard while the second one indicating the moment of landing on the vaulting table.

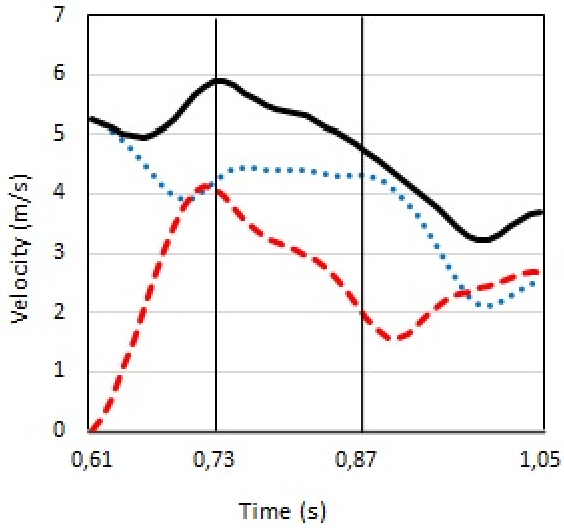

Figure 1. Graph shows the overall velocity curve v_{abs} - solid black curve, horizontal velocity components v_x - blue dotted curve and the vertical velocity components v_z - red dashed curve.

The take-off phase on the springboard:

At the moment of landing on the springboard gymnasts had the average velocity v_{abs} of 5.362 ± 0.204 ms^{-1}. At the end of this stage, during which a significant acceleration occurs, gymnasts reach their maximum velocity within the vault, i.e. 5.912 ± 0.299 ms^{-1} on average. The average velocity v_{abs} increase was 0.550 ± 0.238 ms^{-1} on average while the other phases displayed velocity losses of limited amounts only. It was detected that at the moment of landing on the springboard the average v_x value stood at 5.344 ± 0.203 ms^{-1} which is almost identical to the v_{abs} value. At the completion of the take-off phase the average v_x value is of 4.485 ± 0.424 ms^{-1} meaning there occurs a loss of v_x at the expense of v_z at this stage, as the gymnast is required to obtain a certain vertical velocity to be able to move her COG from the current height over to the vaulting table. This means that the horizontal velocity v_x fell on the springboard by 0.859 ± 0.364 ms^{-1}. The vertical component of the velocity v_z shows a negative value of - 0.133 ± 0.238 ms^{-1} at the moment of commencement of take-off on the springboard, which can be explained by the movement of the body in the second round-off phase, which smoothly converts to the landing on a flexible springboard plate. During the take-off there occurs a significant v_z increase of 3.935 ± 0.438 ms^{-1} on average. So gymnasts leave the springboard with a vertical speed of the COG of 3.803 ± 0.296 ms^{-1}.

The first flight phase:

During the first flight phase, i.e. from the moment of take-off completion from the springboard till the commencement of take-off on the vaulting table, all competitors were losing the overall v_{abs} velocity, by 1.116 ± 0.298 ms^{-1} on average. The velocity loss occurred even in the v_x component (- 0.231 ± 0.243 ms^{-1}) and the vertical velocity component v_z (- 1.621 ± 0.435 ms^{-1}).

The take-off phases on the vaulting table:

The competitors opened this phase with an average v_{abs} velocity of 4.796 ± 0.285 ms^{-1} and completed it with the lowest velocity recorded during the observed phases; with the average v_{abs} value of 3.721 ± 0.367 ms^{-1}. The decrease in the v_{abs} velocity in the gymnasts chosen for our observation therefore was of 1.074 ± 0.337 ms^{-1}. The horizontal velocity component v_x was also reduced from 4.255 ± 0.368 ms^{-1} at the moment of touching the vaulting table to 2.760 ± 0.320 ms^{-1} at the time of leaving it, i.e. by 1.495 ± 0.333 ms^{-1}. The vertical velocity component v_z, which contributes to the maximum height of the COG in the second flight phase, rose in accordance with our estimates, from the 2.182 ± 0.352 ms^{-1} value at the commencement of the take-off to the 2.449 ± 0.307 ms^{-1} value upon its completion. The increase amount was therefore of 0.267 ± 0.404 ms^{-1} on average.

The overall velocity characteristics:

We were interested in the amount of total loss for the individual velocity components. Regarding the overall velocity of the COG - v_{abs}, the average loss was that of 1.641 ± 0.253 ms^{-1} during the three observed phases, where the difference between the maximum and minimum velocity during the observed phases is equal to the average of 2.304 ± 0.439 ms^{-1}. With the v_x velocity, the total losses averaged 2.585 ± 0.246 ms^{-1}. In contrast, the v_z component increased by 2.581 ± 0.463 ms^{-1} on average.

DISCUSSION

Even at first glance, both the velocity of the COG and its components show differences among gymnasts. We were therefore interested to find out about the development of these velocity values during each of the monitored microphases, and their mutual influence during the selected stages of the Yurchenko vault. Table 1 shows the correlation coefficients of v_{abs}, v_x and v_z relations for all observed phases of the movement. The bold red numbers are commented in the text below.

Table 1
Spearman correlation coefficients of v_{abs}, v_x and v_z relations

Vault phases	var	Landing springboard			Take-off springboard			Landing table			Take-off table		
		v_{abs}	v_x	v_z	v_{abs}	v_x	v_z	v_{abs}	v_x	v_z	v_{abs}	v_x	v_z
Landing springboard	v_{abs}	1.00	**0.969**	-0.112	0.53	0.415	0.033	0.086	0.253	-0.04	**0.78**	**0.648**	**0.365**
	v_x		1.000	-0.077	0.442	0.455	-0.134	0.17	0.31	0.015	0.736	0.613	0.349
	v_z			1.000	-0.068	-0.015	-0.398	-0.319	-0.226	-0.052	-0.437	-0.266	-0.361
Take-off springboard	v_{abs}				1.000	**0.758**	0.231	0.248	0.547	-0.675	0.31	0.284	-0.108
	v_x					1.000	-0.336	0.477	0.754	-0.724	0.2	0.262	-0.262
	v_z						1.000	-0.152	-0.165	-0.614	0.24	0.077	0.389
Landing table	v_{abs}							1.000	**0.807**	-0.169	0.279	0.125	0.02
	v_x								1.000	-0.614	0.327	0.292	-0.046
	v_z									1.000	0.07	-0.092	0.383
Take-off table	v_{abs}										1.000	**0.824**	0.51
	v_x											1.000	0.026
	v_z												1.000

First, we are going to take a closer look at the velocity values at the moment of landing on the springboard and at the moment of take-off from the vaulting table in order to detect the relationship between the velocity characteristics of this crucial moment which determines the character of the second flight phase and the velocity obtained from a run phase. Due to the correlation coefficient r = 0.780, we were able to find out a strong connection between the v_{abs} velocity, at which the gymnast lands on the springboard, and the v_{abs} velocity which is in operation upon leaving the vaulting table. Given the fact that v_{abs} upon landing on the springboard is nearly equal to v_x, we may say that the horizontal velocity of the COG - v_x obtained during the run phase and the subsequent round-off is one of the decisive factors affecting the velocity of the COG at the moment of leaving the table. From the spatial-temporal structure of the observed vault it is clear that after leaving the table the gymnast must be able to fly far enough beyond the vaulting table but most importantly to be first able to rise to the height needed to obtain the time necessary for the execution of the given rotations of the body. From the kinematic characteristics of projectile motion it is clear that it is a v_z value which determines the second flight phase time as well as the height reached by the COG. We are therefore interested in the impact of the initial v_{abs} on the v_x and v_z values at the moment of leaving the table. The correlation coefficient r = 0.648 shows a closer relationship between the v_{abs} value when landing on the springboard and the v_x value upon taking off from the table, where the correlation coefficient is as low as r = 0.365. We therefore conclude that the initial velocity v_{abs} remains substantially unchanged in the horizontal axis. The height which the COG is able to reach in the second flight phase, is therefore not proportionally related to the velocity which the gymnast was able to obtain prior to landing on the springboard.

If we look at the velocity values at the moment of leaving the table, we are able to observe that on average the v_x exceeds v_z by of 0.31 ms^{-1}. Here, however, we need to admit that a greater conversion of v_x to v_z, i.e. a greater size of v_z in comparison with v_x was expected. However, when compared with the results of Uzunov (2011) the v_x (2.760 ms^{-1}) and v_z velocity values (2.449 ms^{-1}) achieved by our competitors at the end of the second take-off phase are above-average. According to Uzunov it is sufficient, if the horizontal velocity of the gymnast's COG is of 2.34 ms^{-1} and the vertical velocity reaches the value of 2.27 ms^{-1} upon leaving the table. Despite these optimal velocities according Uzunov (2011) where v_x exceeds v_z, in the separate assessment of these overall velocity components which was carried out for individual analyzed attempts we found out that upon leaving the table the v_z value was slightly higher than the v_x value in those gymnasts within the observed group who demonstrate above-average performance as assessed by international refererees. These vaults include the TP 2, TP 4, TP 8 or TP 12 attempts, where the v_z values range between 2.568 ms^{-1} and 2798 ms^{-1}. The reverse ratio of these two components in the average values of the test group is due to those poorer attempts where larger v_x than v_z was recorded. The examples include TP 13 and TP 14, where the v_z values reached were only of 1.854 ms^{-1} and 1.846 ms^{-1} respectively. On the basis of these results we would therefore argue that the correlation coefficient between the v_{abs} when landing on the springboard and the v_z upon taking-off from the table should, with the correct performance, be higher than the above-mentioned r = 0.365, namely due to the larger and proportional conversion of v_{abs} to v_z.

Let's look at how the individual velocity components of the COG change between the beginning and the end of the section of the Yurchenko vault chosen for observation, i.e. during its various phases. Table 2 shows the correlation coefficients of relations among v_{abs}, v_x and v_z changes for all observed phases of the movement. The bold red numbers are commented in the text below.

Table 2
Spearman correlation coefficiens - v_{abs}, v_x and v_z changes

Vault phases		Springboard			Flight 1			Vaulting table		
	variable	Δv_{abs}	Δv_x	Δv_z	Δv_{abs}	Δv_x	Δv_z	Δv_{abs}	Δv_x	Δv_z
Springboard	Δv_{abs}	1.000	0.746	0.148	-0.544	-0.386	-0.653	-0.425	-0.531	0.365
	Δv_x		1.000	**-0.507**	-0.214	-0.531	-0.223	-0.585	**-0.597**	0.249
	Δv_z			1.000	-0.34	-0.408	-0.054	-0.638	-0.548	-0.229
Flight 1	Δv_{abs}				1.000	**0.659**	**0.785**	-0.248	-0.02	-0.514
	Δv_x					1.000	0.177	-0.005	-0.02	-0.187
	Δv_z						1.000	-0.195	0.145	-0.692
Vaulting table	Δv_{abs}							1.000	**0.806**	0.368
	Δv_x								1.000	**-0.204**
	Δv_z									1.000

The results of our analysis point to the fact that for the successful execution of the Yurchenko vault both horizontal and vertical velocity components are essential. The horizontal velocity component v_x correlates in many phases with the total V_{abs} velocity of the COG. Similarity and some synchronization of changes in these two types of velocity is evident in the observed time interval of the vault, i.e. from the moment of landing on the springboard to the moment of leaving the vaulting table. This is evidenced also by the correlation coefficients between the v_{abs} and v_x values at the time of landing on the springboard (r = 0.969), upon the take-off from the springboard (r = 0.758), upon landing on the vaulting table (r = 0.807) and upon the take-off from the table (r = 0.824).

At the moment of landing on the springboard the horizontal velocity v_x of our test set averaged at 5.344 ± 0.203 ms^{-1}. The comparison of these results with those reported by other authors (Penitente, Merni, Fantozzi & Perretta, 2007, v_x = 5.27 ms^{-1}, Nelson, Gross & Street, 1985, v_x = 5.32 ms^{-1}, Ragheb & Fortny, 1988, v_x = 5.08 ms^{-1}, Kwon, Fortney & Shin, 1990, v_x = 5.14 ms^{-1}) shows that our gymnasts gave a superior performance in this respect. As stated by Petkovic (2011), achievement of the maximum velocity does not always set a perfect stage for the execution of further stages of the vault following the round-off. Sometimes lower velocity proves to be more efficient for the execution of a technically perfect vault. We lean towards this view too as we believe that the maximum velocity obtainable before having counterproductive effects depends on the technical expertise and functional capabilities of the given gymnast. This hypothesis is confirmed by the TP 13 vault, where the velocity was not handled well. On the springboard this gymnast's overall velocity v_{abs} increased by the above average 0.889 ms^{-1}, however, in the other phases, we observe in our test set the worst declines in both horizontal and vertical velocity values. For example, on the table the v_{abs} fell by 1.949 ms^{-1}, v_x decreased by 2.2 ms^{-1} and contrary to the expected growth the v_z dropped by 0.063 ms^{-1}. It is therefore necessary to speak about the optimal velocity rather than the maximum velocity, where the ideal condition is defined as that of the optimal velocity being equal to the maximum velocity.

The horizontal velocity during each phase is partially retained and partially transformed to the vertical velocity component of the BCG. The conversion of v_x to v_z may occur in the support stages, which in our case correspond to the first and second take-off phases. The values of the individual correlation coefficients reveal more precisely the relationships between these parameters during major or minor velocity changes. If we focus on the v_x variable, we can see that the higher the degree of v_x loss occurring on the springboard, the smaller the degree of v_x decrease occurring on the table, and vice versa (r = - 0.597). It is, however, not possible to claim the same regarding the vertical velocity component v_z (r = 0.212), which means that if there is an above-average v_z increase on the springboard, a proportionately smaller v_z increase on the table is not likely to follow. Let us, therefore, consider the relationship of these two variables separately on the springboard and on the table.

It is clear that in the first take-off phase the gymnast must obtain sufficient vertical velocity to be able to lift the COG from its current height over the vaulting table. This corresponds to the magnitude of the v_z change, which is at its largest during this phase of the entire vault. Let's now consider the relationship between changes in v_x and v_z on the springboard. The correlation coefficient r = - 0.507 expressing the relationship between the v_x change and v_z change on the springboard points to the fact that the decrease in the horizontal velocity is accompanied by the increase in the vertical velocity component. These two variables, however, are not as closely related as might be expected. We believe this is due to the fact that the issue in question is not a mere mechanical conversion of the v_x obtained in the run phase. An irreplaceable role is also played by the explosive power of the lower extremities, which to various degrees shows in the acceleration of the movement of the COG in the vertical axis. By comparing the magnitude of the v_x and v_z changes with the technical capability of individual gymnasts, we have come to a conclusion that the observed phenomenon is that of a very individual handling of the situation. As for the vertical velocity component, gymnasts demonstrating advanced techniques created within the test set an above-average v_z change, while other gymnasts created a below-average v_z change. However, concerning the horizontal velocity, unlike their weaker counterparts better gymnasts were able to maintain a higher v_x. This result corresponds with the findings of Penitente, Merni, Fantozzi and Perretta (2007), who stated that gymnasts should be able to effectively use the springboard without decreasing the horizontal velocity while increasing the vertical velocity. In the springboad phase it is therefore necessary to pay utmost attention to maintaining the horizontal velocity v_x accompanied by the optimal, not the maximum increase in the vertical velocity v_z.

In the first flight phase the COG rises for the gymnast to be able to reach the vaulting table with her hands. The decrease in the overall v_{abs} velocity in flight correlates primarily with the v_z (r = 0.785) decrease, to a lesser extent with the v_x (r = 0.659), mainly because the issue in question is that of a significant change in the height of the COG which is related to the conversion of the kinetic energy to the potential energy.

We believe that the following second take-off phase should be characteristized by the conversion of the horizontal velocity to the vertical velocity. We are able to observe here a considerable decrease in the overall velocity, correlating (r = 0.806) with the loss of horizontal velocity accompanied by an increase in the average vertical velocity of 0.267 ms^{-1}. The correlation coefficient (r = 0.204) between the change in the horizontal velocity v_x and the vertical velocity v_z during the second take-off phase on the table is even much lower than previously on the springboard. This indicates a highly individual execution, as regards the velocity transfer from the x-axis to the z-axis. As is evident from the magnitude of change in the v_z, its largest increase occurs in the springboard phase. In contrast, the increase in the v_z on the table is minimum, although the vaults of those gymnasts within the test set, who were able to perform an above-average conversion of v_x to v_z on the table, may be considered more technically advanced. This corresponds with their results at international events compared to the remaining gymnasts of the test set.

To better understand the velocity changes in the phase on the table, it is necessary to take into account not only the values at the beginning and end of the table phase, but also to consider the development of velocity curves during this phase. The TP 2, TP 5 and TP 8 (Fig. 2) graphs show the initial growth of the overall velocity v_{abs} on the table and its subsequent decline starting approximately half way through the contact time with the table. This v_{abs} development is based on the ability of the gymnasts to maintain the v_x constant as long as possible and to increase the v_z immediately after the contact with the table. If we compare these characteristics in less successful attempts, namely the TP 1, TP 3 and TP 13 vaults (Fig. 3), we are able to observe clear differences. These gymnasts are unable to preserve the magnitude of v_x even during the first moments of contact with the table. This velocity component tends to drop sharply very early on. Regarding v_z, gymnasts are unable to start accelerating from the moment of touching the table, their vertical velocity first significantly decreases and only then it begins to rise, however, not to such a degree as with gymnasts demonstrating advanced techniques.This development of v_x and v_z is manifested in the continuous decrease in the overall speed v_{abs} almost from the beginning of the second take-off phase.

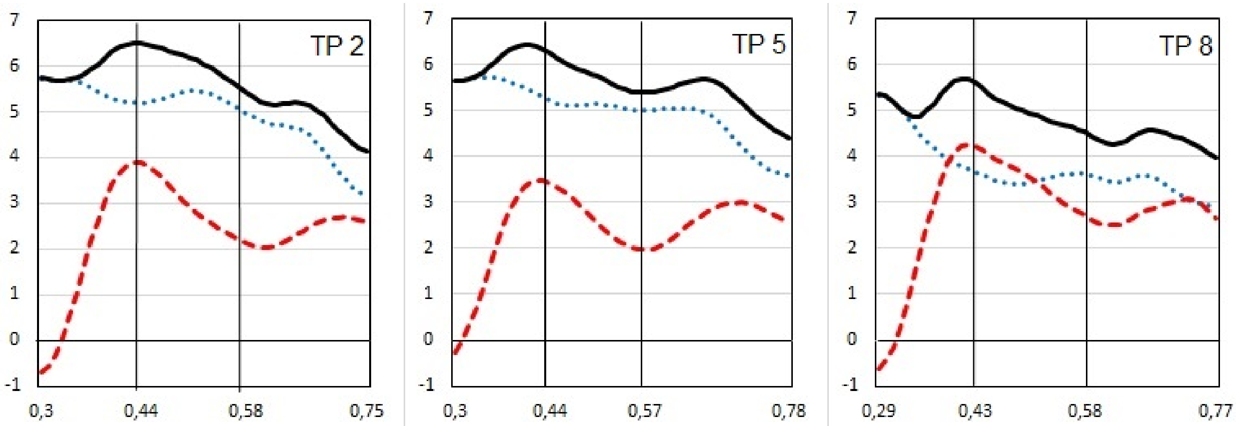

Figure 2. Curves showing velocity development in TP 2, TP 5 and TP 8, overall velocity v_{abs} - solid black curve, horizontal velocity component v_x - blue dotted curve and the vertical velocity component, v_z - red dashed curve.

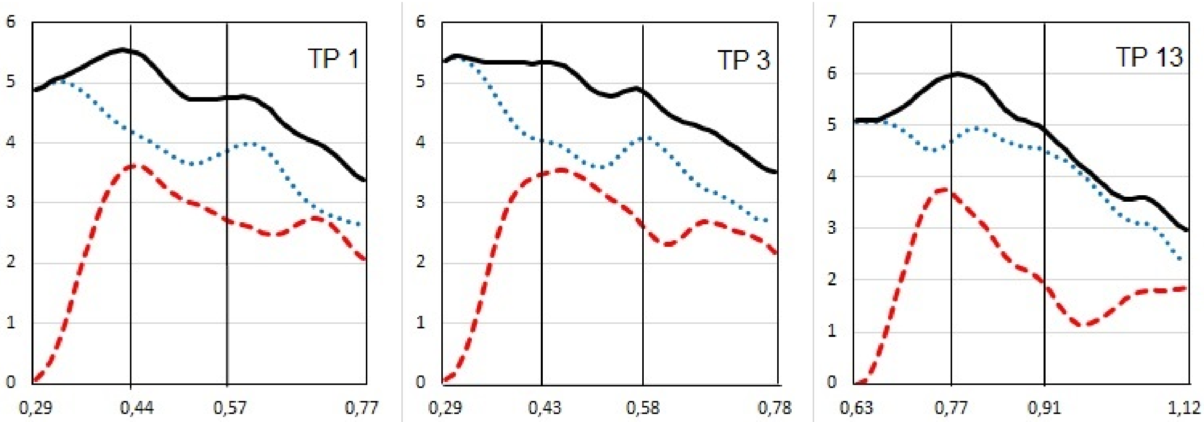

Figure 3. Curves showing velocity development in TP 1, TP 3, TP 13, overal velocity v_{abs} - solid black curve, horizontal velocity component v_x - blue dotted curve and the vertical velocity component v_z - red dashed curve.

The purpose of the take-off phases should be the minimization of the velocity loss. The graphs show gymnasts take a very individual approach to the work with the centre of body's velocity both on the springboard and on the table, as a result of which we are able to observe significant differences in the timing of acceleration and deceleration moments. The aim of the gymnast should therefore be landing on the springboard with the optimal speed in order to achieve a convenient starting position and subsequently to attempt to minimize velocity losses or even to increase velocity during a microphase on the springboard and the table. When comparing the velocity change in gymnasts that occurred between landing on the springboard and leaving the table, we note the smallest decline in TP 5 (1.251 ms^{-1}) and almost the same drop in TP 8 (1.267 ms^{-1}). The velocity curves showed in graphs for both of these gymnasts are characterized by rather discontinuous changes, something which we believe shows the dynamics of the execution associated with high explosive capabilities of the force. This is particularly obvious in the take-off phases both on the springboard and on the table, where both gymnasts display a tendency to acceleration at a certain moment. Frequent changes of the accelerated and decelarated movements are taking place here with a greater frequency, however, to a lesser extent than is the case with most of the test subjects. The reverse trend is observed, for example, with TP 3 and TP 13, where the continuity of velocity changes is apparent, but where a greater drop in velocity occurred between the beginning of landing on the springboard and the take-off from the table and where larger differences may be observed between the maximum and minimum recorded value of velocity.

CONCLUSION

In individual phases of the Yurchenko vault an individual approach to handling the locomotor task displaying varying degrees of velocity variations may be observed. First phase chosen for observation was the body work on the springboard. The velocity development for the individual gymnasts tested varied widely, although almost all of them demonstrated an acceleration in the phase of leaving the springboard, which signals the fulfilling of the take-off task and proper preparation for the first flight phase. In the first flight phase all tested persons were found to have lost velocity, although an overall duration of the flight played an important part in this microphase. Next is the support phase on the vaulting table, which we consider crucial to the performance and most significantly contributing to the entire vault assessment. Individual competitors show different levels of functional aptitudes. Through the analysis of these phases and as a result of comparing 14 different vaults performed by elite gymnasts, we were able to establish the basic criteria necessary for the successful execution of the Yurchenko vault such as obtaining optimal, if possible maximum, velocity in the first take-off phase, which the gymnast is able to use to her best advantage in order to execute a technically perfect vault. The other basic criteria include a minimum loss of horizontal velocity in the first flight phase and obtaining the optimal vertical velocity component in the take-off phase on the vaulting table. Our results were compared with those presented by other authors and a high degree of agreement between the two was detected, which shows a technical maturity of the research sample chosen for observation as well as provides us with the platfom to formulate valid conclusions for practice. Although it is vault, in our opinion, it is necessary to focus on work of upper extremities used in Yurchenko vault in two phases - round-off and the phase on the table, in comparison with most other types of vaults. Concerning work of upper extremities in the round-off, their dynamic take-off creates necessary conditions for optimal movement execution on the springboard. This phase should be, according to results, characterized by a minimal loss of horizontal velocity and the increase of vertical velocity which, in our opinion, is impossible without perfectly mastered round-off. Moreover, a fact worth mentioning is that the greatest velocity loss was found on the vaulting table. For this reason, we would recommend putting emphasis on the technical aspects of this phase execution and not neglecting fitness training focusing on the dynamic work of upper extremities again. Specifically, in round-off it is necessary to focus on powerful arms take-off and then to keep rebound to prevent lower limbs from falling down during jumping on the springboard. To strengthen the upper extremities dynamic work we recommend, for example, repeated take-offs in the handstand in different variations, also using trampolines. We want to use our research results as a basis for other measurements. Within the Yurchenko vault it would be appropriate to focus further studies on a more detailed analysis of the vertical and horizontal velocity components in each phase and their relation with angle characteristics. Futhermore, we are interested in kinematical changes in observed phases within the more complex forms of the Yurchenko vault. These measurements would provide relevant information for coaches on how to train this jump in beginners, as well as in jump improvement phase in advanced gymnasts.

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