Topics: natural sciences
Keywords: artistic gymnastics, vault, run-up velocity, biomechanics, competition performance

The faster the better? Relationship between run-up velocity and the degree of difficulty (D-score) on vault in artistic gymnastics

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On vault in men's and women's artistic gymnastics a high run-up velocity is important for a successful execution of a difficult vault. During take-off from the springboard and vaulting table, the horizontal momentum is converted into angular and vertical momentum to facilitate an optimal second flight phase (Bruggemann, 2005; Prassas, Kwon, & Sands, 2006).

In competition, gymnasts can freely select a vault out of five different vault styles according to their skill level. Difficult vaults are assigned a high difficulty score (D-score) in the official competition rules (Code of Points) (FIG, 2013a, 2013b). The D-score is mainly influenced by the degrees of rotation around the transversal and longitudinal axes during the second flight phase. Since the final score is the sum of the D-score and the execution score, the probability of a good ranking in competition increases when a difficult vault is attempted.

Although the relationship between run-up velocity and the performance (D-score) is logical and has been assumed to exist for four decades (Brüggemann, 1979), the correlation between these factors has never been calculated with a large cohort of either junior or elite gymnasts.

Hence, the main purpose of our study was to calculate the relationship between run-up velocity and the D-score in a high level competition. The second and third aims were to show the differences between male and female athletes and between elite and junior gymnasts with regard to the run-up velocity and the D-score. To derive practical applications, the results will be used to explain the different requirements in run-up speed for the three most important vault styles Handspring (H) (forward rotating vaults), Tsukahara (T) (quarter to a half turn in the first flight phase) and Yurchenko (Y) (round-off in front of the springboard and backward handspring onto the table).

During the official competitions of the 31st European Championships in Men's and Women's Artistic Gymnastics in Bern 2016 maximal vault run-up velocity (vmax) was measured with a laser (LDM 301, Jenoptik, Rostock, D) for all male and female elite (M, F) and junior athletes (MJ, FJ) (M: n = 89; Age: 23.06 ± 3.68y; MJ: n = 123; Age: 16.86 ± 1.17y; F: n = 88; Age: 19.46 ± 3.44y; FJ: n = 106; Age: 14.52 ± 0.59y).

Descriptive statistics were run on all variables separately for the groups M, MJ, F and FJ and for the vaulting styles H, T and Y. Boxplots of vmax of the different vaults were constructed for each group to define the range of the optimal run-up velocity (lower to upper quartile) of each vault ($n \geq 3$). The relationship between run-up velocity and D-score was assessed by using Spearman's Rho. T-tests were used to determine differences between gender, age groups and vaulting styles. Significance level was set to $p < 0.05$.

In females, highly significant relationships were found between vmax and the D-score for all vaulting styles (F: r: 0.39 (Y) to 0.80 (H) and FJ: r: 0.48 (Y) to 0.65 (H)). The vmax of M and MJ correlated significantly with the D-score of T (M & MJ: r = 0.60) and Y (M: r = 0.65) but not with that of H (M: r = 0.14; MJ: r = 0.31) and Y in MJ (r = 0.27). Performing H and T, M and MJ reached significantly higher run-up velocities (M: + 9%; MJ: + 8%) than female gymnasts in the same category ($p < 0.05$). By contrast, the vmax of males and females performing Y were similar ($p = 0.20$). F and FJ athletes achieved similar vmax when performing H and T vaults

but F showed significantly higher vmax than FJ when performing Y. M athletes displayed higher vmax than MJ for H and T but not for Y.

The highest run-up speeds were observed in all groups performing H, whereas Y vaults were executed with the lowest vmax. For T vaults, the greatest difference in required run-up velocity between simple and very difficult vaults was found. T were the most common vaults in men's gymnastics but were only rarely performed by women. In contrast, Y vaults were performed most frequently by females but least by males.

The long-held assumption about a strong relationship between run-up velocity and the D-score on vault was completely confirmed in female gymnasts but was only partially true for males. Thus, it appears that it is more important for female athletes to run-up on vault with a speed that is close to their maximal sprint velocity than for male athletes.

The lack of correlations between vmax and D-score in males performing H is due to the generally high vmax required for all H vaults; even those assigned to a low D-score. Further, the different biomechanical requirements of H layout and double rotating vaults negatively influenced the relationships. Layout vaults require a high amount of horizontal velocity that is created during the run-up, but for double rotating vaults it is crucial to achieve a maximal vertical velocity (Knoll, 2004).

In men and women elite and junior athletes, the vmax and D-scores of T are highly correlated. Consequently, high run-up velocities are absolutely necessary when aiming to successfully perform a T vault with a high D-score. Furthermore, the quarter to a half turn in the first flight phase results in a successive hand contact on the vaulting table. Consequently, the push-off from the vaulting table is mainly performed with one arm, what makes it difficult for athletes with less upper body strength, to reach sufficient height of flight to perform a difficult vault. This might be the reason why females rarely perform T vaults.

The observed differences of vmax between M and MJ performing H or T can be attributed to better physical condition of M. In contrast, the run-up velocity is more or less similar between F and FJ athletes for H and T vaults. Consequently, it can be supposed that growth spurt and weight gain during puberty influences the strength-to-weight ratio (Claessens, Lefevre, Beunen, & Malina, 2006; Erceg, Delaš Kalinski, & Milić, 2014). Therefore, FJ athletes may have equal physical prerequisites for a good performance on vault than the more matured F gymnasts.

Due to the similar vmax of males and females performing Y, it might be assumed that women have to take higher risks when executing these technically very demanding vaults. Further, the higher vmax of F compared to FJ performing Y, leads to the assumption that the longer learning process enables the older athletes to acquire better technical skills. This in turn, allows the elite athletes to perform the preliminary elements with a higher velocity.

In conclusion it can be said that female athletes are the faster the better, but that males need to reach a certain minimum run-up speed to be able to perform the most difficult vaults. Moreover, the knowledge of the optimal run-up velocities for the different vaults (displayed by the boxplots of the vmax of each vault) is important for coaches and athletes when choosing an appropriate competition vault for each gymnast in consideration of individual's physical and technical abilities. Furthermore, it is helpful to assess the need to develop the physical qualities (strength, speed, sprint technique) in order to reach the required run-up velocity.

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