REVISITING RUN-UP VELOCITY IN GYMNASTICS VAULTING

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The vault run-up velocity is important from a competitive aspect in gymnastics. Its importance is well understood by practitioners, and its measurement would seem to be simple. Relevant data are relatively abundant but disorganised in the literature. The purpose of this study was to delve into run-up velocity measurements in previous research and to interpret the data and the possible influences based on the methodologies of the studies. By organising a cluster of run-up velocity data as well as the methodologies of the previous studies, we have clarified what is known about run-up velocity and problems to be overcome for its practical use. This is one of the most essential steps to reaching ISBS's goal: to bridge the gap between researchers and practitioners.

KEY WORDS: approach velocity, vaulting table, speed, kinematics, coaching, review

INTRODUCTION: Our recent project has been to develop a training environment where objective data are measured and used in regular training of a subjectively-judged sport such as gymnastics. The first variable we selected for consideration was the vault run-up velocity for two reasons. First, it is clearly important from a competitive viewpoint. For both men's and women's artistic gymnastics, vaulting table is the only apparatus on which a performance is evaluated on just a single skill. In addition, no gymnast can vault without the momentum generated from the run up. There is even a report that the run-up velocities and the number of steps taken explained more than 90% of variance in the final scores on the vault (Sands & Cheetham, 1986). Second, the importance of run-up velocity is well understood by practitioners, and it seems to be simple to measure, providing a good chance to bridge the gap between theory and practice.
The data for run-up velocity for vaulting are abundantly available in the literature; however, they are not well organised. The velocities have been measured at different phases of the run-up motion, and the methods of measurements have been varied. The aspect of the run-up velocity most relevant to vaulting performance is the instant velocity just before the gymnast makes contact with the springboard. However, run-up velocity data in the literature has not been evaluated based on uniform criteria. Therefore, care must be taken when interpreting the results of previous research. In this study, run-up velocity data in previous research was organised and evaluated for possible influences related to each measurement method. Organising the available data and clarifying possibilities and limitations should be beneficial for interpreting the results for practice as well as for developing an optimal system for using run-up velocity data for daily training.
METHODS: The literature was searched to identify as many relevant studies as possible through following the databases: SPORTDiscus and PubMed were searched for international papers, and CiNii for domestic papers written in Japanese. Some papers were also found from the reference lists in other papers. Over 150 studies related to vaulting were reviewed, with closer attention paid to the papers that included the information about run-up velocity. The run-up velocity data in the literature were often compiled according to one of three types of vaults: Handspring-type, Tsukahara-type, and Yurchenko-type vaults (Figure 1). To take off backwards from a springboard, a Yurchenko-type vault requires preliminary motions called a round off between the run-up and the take-off. To execute a round off, the actual run-up distance is shorter than for vaults performed from a forward take-off.

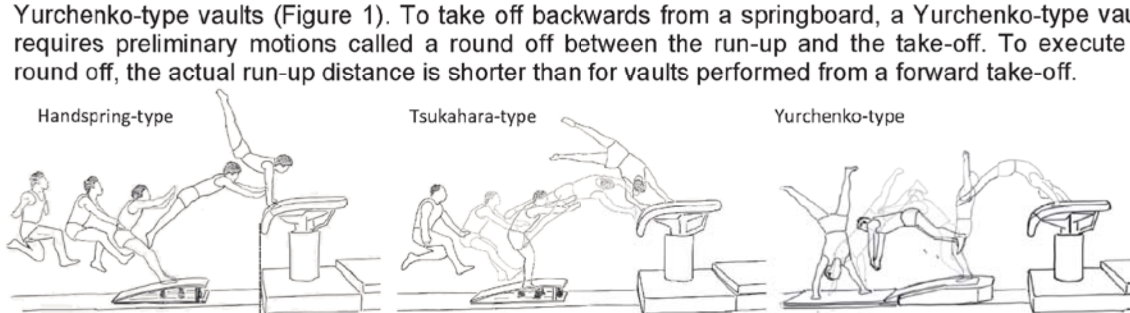

Figure 1: Take-off phases for handspring type (left), Tsukahara type (centre), and Yurchenko-type vaults (right). Note that a Yurchenko-type vault involves with a backward take-off.

RESULTS: Due to the space limitation, the present study focused only on the data available for male gymnasts. The run-up velocities have been measured in several major competitions using either a motion analysis or a laser Doppler device such as the Laveg (Jenoptik, Germany). (See Table 1). The mass-centre velocity derived from a motion analysis has commonly been presented as a run-up velocity, but the focused phase varied from each other. Takei (1990) reported take-off velocity from the last step onto the springboard, whereas Dillman, Cheetham & Smith (1985) reported the velocity from the vaulter's first actual contact with the springboard. Theoretically speaking, these two moments should have the same horizontal velocity as long as air resistance is negligible; however, it is possible for a smoothing process to alter data depending on a cut-off frequency due to a rapid change in frequency caused by the actual contact.

Naundorf et al. (2008) and Krug et al. (1998) both used a Laveg, but the data processing was different. While Krug et al. (1998) reported the maximal velocity, Naundorf et al. (2008) computed the mean velocity of a 2 m range (5–7 m for forward take-off vaults and 8–10 m for backward take-off vaults), within which the maximal velocity was typically attained according to the authors.

Based on the data of Van der Eb et al. (2012), Naundorf et al. (2008) and Krug et al. (1998), the world-class gymnasts attained an average run-up velocity of approximately 8.2–8.4 m/s for forward take-offs. Considering the standard deviations of 0.3–0.4 m/s, the implication is that most world-class gymnasts achieve a run-up velocity of over 8.0 m/s, and some faster gymnasts achieved a run-up velocity of over 8.5 m/s.

Brehmer and Naundorf (2014) used the same method as Naundorf et al. (2008) with a focus on the high-difficulty vault (Lu Yu Fu, D-score = 6.0) performed by nine gymnasts. They reported that the mean velocity achieved by these gymnasts was 8.3 ±0.2 m/s (Table 2). Note that in Table 2 Veličković, Petković & Petković (2011) recorded some run-up velocities of 9.95 ±0.74 m/s for several difficult vaults.

Table 1. Run-up velocities for forward and backward take-offs performed by male gymnasts. The abbreviation "n.a." indicates "not available," and "M.C." indicates "Mass centre." The significant digit for each data corresponds to that in the data source.

Type of Vault	Data Source	Number of Data (Vaults)	Run-up Velocity (m/s)				Measurement	Reference
			Mean	S.D.	Max.	Min.		
(Forward Take-off)								
Handspring Type	2010 World Championships	76	8.4	0.3	n.a.	n.a.	Motion Analysis (100 Hz) M.C. velocity	Van der Eb et al. (2012)
Handspring Type	2007 World Championships	62	8.39	0.28	9.00	7.59	Laveg (50 Hz) (5 - 7 m)	Naundorf et al. (2008)
Handspring Type	1997 World Championships	44	8.19	n.a.	8.90	n.a.	Laveg (50 Hz)	Krug et al.(1998)
Handspring Type	1987 Pan American Games	40	7.50	0.51	n.a.	n.a.	Motion Analysis (99.5 Hz) M.C. velocity	Takei (1990)
Handspring Type	1984 Olympics Event Finals	8	7.79	0.13	7.94	7.60	Motion Analysis (100 Hz) M.C. velocity	Dillman et al. (1985)
Tsukahara Types	2010 World Championships	212	8.2	0.4	n.a.	n.a.	Motion Analysis (100 Hz) M.C. velocity	Van der Eb et al. (2012)
Tsukahara Types	2007 World Championships	169	8.23	0.32	9.16	7.31	Laveg (50 Hz) (5 - 7 m)	Naundorf et al. (2008)
Tsukahara Types	1997 World Championships	47	7.86	n.a.	n.a.	n.a.	Laser System (Details unknown)	Krug et al. (1998)
Tsukahara Types	1984 Olympics Event Finals	8	7.71	0.16	7.92	7.39	Motion Analysis (100 Hz) M.C. velocity	Dillman et al. (1985)
(Backward Take-off)								
Yurchenko Types	2010 World Championships	52	7.7	0.3	n.a.	n.a.	Motion Analysis (100 Hz) M.C. velocity	Van der Eb et al. (2012)
Yurchenko Types	2007 World Championships	58	7.36	0.35	8.16	6.31	Laveg (50 Hz) (8 - 10 m)	Naundorf et al. (2008)
Yurchenko Types	1997 World Championships	26	7.35	n.a.	n.a.	n.a.	Laser System (Details unknown)	Krug et al. (1998)

Table 2. Run-up velocities for some specific vaults performed by male gymnasts. The abbreviation "n.a." indicates "not available." The significant digit for each data corresponds to that in the data source. The names of vaults are as per The Code of Points.

Specific Vault (Difficulty value)	Data Source	Number of Data (Vaults)	Run-up Velocity (m/s)				Measurement	Reference
			Mean	S.D.	Max.	Min.		
Lu Yu Fu (6.0)	2011 European Championships 2007 World Championships	9	8.3	0.2	8.6	8.2	Laveg (50 Hz) (5 - 7 m)	Brehmer & Naundorf (2014)
Yeo 2 (6.0) Dragulescu (6.0) Blanik (6.0) Lu Yu Fu (6.0)	2002 World Championships	4	9.95	0.74	n.a.	n.a.	Motion Analysis (50 Hz) Unknown point	Veličković, Petković & Petković (2011)
Kasamatsu str. (4.4) Kasamatsu str. with 1/2 tw. (4.8) Hdsp. fwd. & salto fwd. p. (3.2) Hdsp. fwd. & salto fwd. p. with 1/2 tw. (3.6)	2006 World Cup in Maribor	4	8.57	0.23	n.a.	n.a.	Opto-Track (1000 Hz)	Veličković, Petković & Petković (2011)

Figure 2 shows the relationship between run-up velocity and the difficulty value (D-score) for a particular vault based on the data presented by Atiković and Smajlović (2011). Their data also included very high velocities of the mass centre on contact with the springboard although the details of the motion analysis could not be found in the paper. According to Čuk and Karácsony (2004) who analysed vaults in multiple international competitions, the suggested run-up velocity was 7.5–8.5 m/s for a moderate-level vault, 8.5–9.5 m/s for a high-level vault, and over 10.0 m/s for a highest-level vault involving double somersaults.

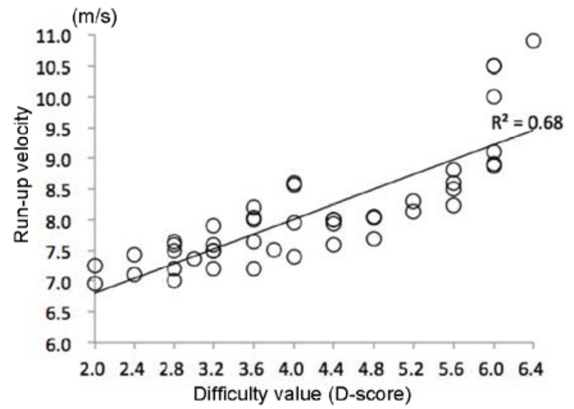

Figure 2: Relationship between run-up velocity and difficulty value of forward take-off vaults based on the data reported by Atiković and Smajlović (2011).

DISCUSSION: As seen in Figure 2, the correlation between run-up velocity and difficulty value is high, but how fast the run-up velocity should be to assure success is not as clear. It seems to be certain that a highly skilled gymnast reaches a run-up velocity of over 8.5 m/s. The data collected by Naundorf et al. using a Laveg seems to be reliable and valid in reporting a run-up velocity between 5–7 m from the edge of the vaulting table (Naundorf et al. 2008, Brehmer & Naundorf, 2014). However, the instant velocity just before the vaulter makes contact with the springboard would be of more importance. Typically, a gymnast jumps onto a springboard from approximately 4 m point, so the velocity data between 5–7 m does not actually correspond to the final velocity. According to Naundorf et al. (2008), the distance-velocity profile showed that the maximum velocity was observed within that range. It may be true, as reported in several studies, that a gymnast decelerates on the last step due to some factors related to the following take-off action. It may also be true that the velocity in the last step is underestimated because of some preparatory motions for a take-off. As shown in Figure 3, a gymnast largely flexes his hips during the last step. The displacement of the lower back, where a laser from a device hits, becomes smaller than the displacement of the mass centre, resulting in an underestimation of the velocity of the whole body. Interestingly, Veličković, Petković & Petković (2011) pointed out that top gymnasts increased their velocity in the last step more than the lower-level gymnasts. In their study, the top-level gymnasts showed 9.95 ±0.74 m/s in the last step and 8.58 ±0.18

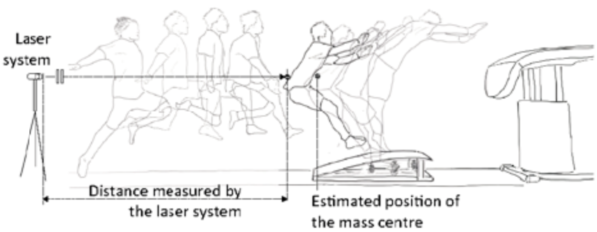

Figure 3: Hip flexion during the last step onto the springboard and the resulting difference between the position of the mass centre and the position of the lower back.

m/s in the second last step. On the other hand, the lower-level gymnasts were measured at 8.57 ±0.23 m/s in the last step and 8.00 ±0.43 m/s in the second last step. The velocity in the second last steps appears to correspond to the 5–7 m velocity data measured with a Laveg (Naundorf et al. 2008). Veličković, Petković & Petković (2011) used an Opto-track to measure the velocity for the lower-level gymnasts but did a motion analysis for the top-level gymnasts. Although the details are unknown, it seems that the motion analysis was used to derive the same kind of the data as was obtained by the Opto-track. In this case, the velocity of each step was computed based on the contact position of the feet of the athlete. Contrary to the use of a Laveg, a large flexion of the hips during the last step could result in a possible over-estimation of the whole-body velocity. Top sprinters in athletics achieve an average velocity of 9.5 m/s in 10–20 m and 10.5 m/s in 20–30 m (Hirokawa et al. 2010). The velocity of 10.5 m/s is equivalent to the average maximum velocity of top long jumpers, who take 40–50 m of a run-up. Taken together with the fact that an actual run-up distance is approximately 20 m for a vaulting table, more studies and careful investigations are required to determine the run-up velocity of top vaulters who reportedly achieve a run-up velocity of over 10 m/s. In particular, a final velocity during the last step should draw more attention.

Measuring such velocity data for daily training is more challenging than it may seem. To be useful feedback in practice, a reliable and valid way to collect data should be provided with a simple measurement system. Only with such a system, would a practitioner use it regularly. Although motion analysis might provide more valid data than other methods, it is too time-consuming to be used as a regular feedback system. The body motion during the last step makes it difficult for a laser Doppler system or photocells to estimate the instant velocity of the whole-body mass centre immediately prior to hitting the springboard. A novel system presented by Van der Eb et al. (2012) appears to be promising, but how practically it could be used on a training site is still unknown.

CONCLUSION: While we can be confident that high level gymnasts do attain a run-up velocity of over 8.5 m/s, more careful investigation is required to accurately verify that some can achieve velocities of over 10 m/s, and velocity profiles of the last step are also needed. An accurate method that has an enough reliability, validity, and simplicity to measure the final run-up velocity just before the athlete makes contact with the springboard is required to be developed. To be practically used, it is also important that the measurement should be automatically done with no marker and able to provide an immediate feedback to a gymnast and a coach.

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