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The influence of a visual target point on the onset of visual regulation and kinematics on the approach run while performing the Tsukahara vault in artistic gymnastics

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ABSTRACT
Purpose. The study examined if a visual target for the hurdle take-off affects the onset of visual regulation and hurdle kinematics during the approach run in a vaulting event.
Methods. Ten high-level male artistic gymnasts (23.9 ± 4.2 years; body mass = 63.7 ± 6.4 kg; body height = 168.00 ± 0.11 cm) performed the Tsukahara vault using a visual target marking the last touchdown of the approach run and the commencement of the hurdle (tape condition) and under standard vaulting regulations (non-tape condition). Gymnast's trials were performed under training conditions, with five high-speed cameras (four stationary and one panning) used for the collection of the spatiotemporal characteristics of the approach run and hurdle.
Results. Although a faster onset of visual regulation was revealed in the tape condition, no statistically significant differences were found between the two conditions in the kinematic characteristics of athletes' run-ups. Furthermore, the profile of the average standard deviation for the contact positions of gymnasts' feet/soles differed in the two examined conditions.
Conclusions. The presence of a visual target positively affected the onset of visual regulation when high-level artistic gymnasts performed the Tsukahara vault.
Key words: perception, vault, artistic gymnastics, approach run, visual regulation

Introduction

With a duration of six [1] to 10 s [2], the vault is the most complicated and shortest discipline in artistic gymnastics (AG). The vault consists of seven phases, including the run-up, hurdle step, take-off, first flight phase, push-off, second flight phase, and landing [3]. Preparation for the execution of the vault takes place in the run-up phase, which is considered one of the predictive factors for success, with stride velocity being an important parameter for this prediction [4]. Successful execution of the run-up requires a precise approach to the springboard and subsequent complex movements to complete the vault [5–7]. The target constraints (springboard – vaulting table) and the actions implemented at the end of the run-up lead to differences in step patterns and control strategies, which are fine-tuned by the continuous feed of information from the sporting environment [8]. The sensory information available and a gymnast's capacity to process and adapt to the demands of the task and environment have a substantial impact on the planning and performance of the skill [8–10].

Gymnasts rely on a combination of perception and movement to adjust the length of the final steps when performing the vault, receiving continuous information from the springboard's position and the surrounding environment [7, 11, 12]. To make accurate and timely contact with the springboard, gymnasts must modify the length of the last four to five steps based on the observed deviation from the stereotypical model of movement pattern steps [13–17]. It is well established that the sources of information resulting from the perceived position of the springboard and the vaulting table are critical for regulating gait and the hurdle step phase to the springboard [18, 19]. When performing the vault,

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regulating step length with precision and stability when approaching the springboard is a fundamental and necessary function to rationally perform the subsequent take-off in accordance with the technical requirements of the performed vault [20]. According to Takei et al. [21], how the final approach and hurdle step are executed is an indicator of a successful take-off from the springboard.

Faster initiation of step regulation results from interactions between athletes and environmental conditions [22] and contributes to the onset of visual control during the run-up, increases take-off velocity, and positively impacts the second flight phase of the vault [23]. Achieving an optimal take-off from the springboard requires adequate synchronisation and support for the feet in the proper posture [5, 24]. This can lead to an optimal first flight phase, which is necessary for the efficient execution of the subsequent phases of the vault [20], as well as a higher vault performance rating [25].

When performing such complex motor tasks, most regulation often occurs in the final stages of the task when approaching a predetermined target [26, 27]. However, the view that the take-off is the primary task that "nests" at the end of the run-up risks obscuring the important fact that the main purpose of the run-up is to bring the gymnast quickly and accurately to the ideal point at the end of the run-up for the subsequent hurdle step to the springboard [28]. Furthermore, empirical studies on the improvement of vaulting provide evidence of a clear correlation between running velocity and precise foot placement on the springboard [29, 30]. Previous studies have shown that the presence of a visible target on the ground (the push point) and the location of the target (the springboard) in the environment are specific sources of information that influence visually driven behaviour in the regulation of running strides during the handspring vault [6, 8, 31].

We hypothesised that an additional visual stimulus would affect the kinematics of the hurdle step phase and the onset of visual regulation of vault performance. Therefore, the study aimed to investigate the potential impact of an additional visual stimulus on the initiation of visual conditioning and the temporal characteristics of the hurdle step phase in the Tsukahara vault.

Material and methods

Participants

Ten high-level male gymnasts (age = 23.9 ± 4.2 years; body mass = 63.7 ± 6.4 kg; height = 168.00 ± 0.11 cm), members of the Greek national team, participating in international competitions, volunteered to participate in the study.

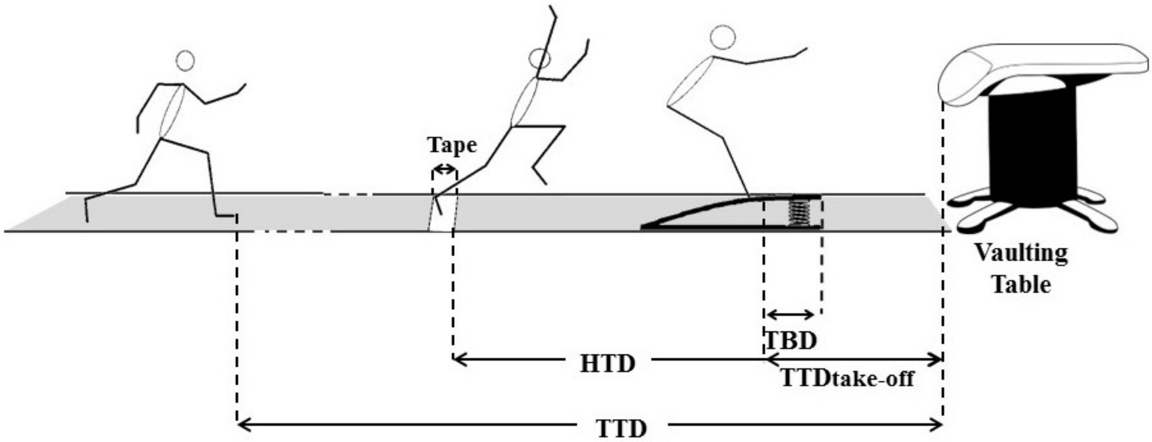
Experimental procedure

Before testing, all gymnasts performed three maximal effort Tsukahara vaults interspersed with three-minute rest periods to accurately determine (a) the length of their approach run, (b) the springboard-vaulting table distance (BTD), and (c) the distance between the last support phase of the approach run (take-off to hurdle step) and the vaulting table distance (HTD). The individual HTD was determined using the average value from three attempts (given that the distance between the three attempts did not exceed 0.10 m) and what the gymnast viewed as optimal for the specific vault.

Two days after the familiarisation procedure, the gymnasts returned to the gymnasium and were randomly assigned to two groups. Gymnasts in one group (n = 5) executed six Tsukahara vaults with a white tape (3M 1909 sticky cloth tape, 0.05 m deep by 1 m wide) laid on the runway (indicating the last touchdown of the approach run and the start of the hurdle step) at each gymnast's HTD (T condition). The tape size (0.05 m) was chosen to provide enough vision from a distance of 25 m while causing little hindrance to the proper execution of the Tsukahara vault [6]. The gymnasts were advised of the presence and purpose of the white tape before doing the six-vault battery. Gymnasts in the other group (n = 5) did six Tsukahara vaults using standard regulations (NT condition). After 72 hours of recovery, the gymnasts returned to the gymnasium and completed the six Tsukahara vaults under the condition (T or NT) that had yet to be executed. A total of 120 vault attempts were analysed.

Apparatus

The springboard and vaulting table used complied with the International Gymnastics Federation apparatus requirements [32]. For analysis purposes, custom black and white markers were placed at 1 m intervals along the longitudinal axis of the runway, parallel to its boundaries, to indicate each side of the 1 m wide and 25 m long runway. In addition, white stripes were placed around the springboard's four corners. The approach phase to the vaulting table was recorded with one panning and four stationary high-speed Exilim-Pro-EX-F1 video cameras (Casio Computer Co. Ltd, Shibuya, Japan) with a sampling rate of 300 fps (resolution: 512 × 384 pixels) [6].



TBD – distance from the toe to the leading edge of the springboard at the moment of landing on the springboard
TTD – toe-table distance at the moment of toe-off at each support phase of the approach run
HTD – self-selected distance between the last support phase of the approach run (take-off to hurdle step) and the vaulting table
The 0.05 m white tape was only present for the tape condition.

Figure 1. Diagrammatic representation of the experimental configuration

Kinematics of the approach run, hurdle step, and springboard

Kinematic analysis software (APAS v13.3.0.3; Ariel Dynamics Inc., CA, USA) was used to digitise the videos. Smoothing and accuracy of the two-dimensional reconstruction were done according to a previous study [6]. Toe-table distances (TTD) for each foot placement of each gymnast's approach run were measured using a five-point model that included the toe-off point during the support phase (contact) of the gymnast's foot on the ground, as well as the four markers that surrounded the foot at ground contact [16]. The horizontal distance between the toe and the line connecting the two nearest markers that had been digitised (toe-marker distance) was determined. The TTD was computed by adding the marker-table distance and the toe-marker distance. The length of a step was determined by subtracting the successive TTD and defined as the distance between two consecutive foot touchdowns (support phases). The hurdle step was defined as the horizontal distance between the foot contact (toe) at the last step of the run-up and the first foot contact (toe) on the springboard. The toe-board distance (TBD) was defined as the horizontal distance between the foot contact (toe) on the springboard and its front edge. The TTD at take-off from the board ($TTD_{take-off}$) was defined as the horizontal distance between the foot contact (toe) on the springboard and the vaulting table's front edge.

Time on the springboard (CT) was defined as the time elapsed (in seconds) between the first and last contact of the foot on the springboard. The accuracy of the kinematic analysis was determined by re-digitising 10% of the recorded vaults.

Onset of regulation

The onset of visual control was determined using inter-trial analysis at the last 11–12 steps of the run-up [6, 16, 33]. The standard deviation of the toe-table distance (TTD_{SD}) in each support of the foot on the running track across the six trials during a condition (T condition and NT condition) indicated the variability of foot placement. The onset of visual regulation was determined as the point (foot support phase) at which the maximum standard deviation of the TTD occurred, followed by a systematic decrease [26, 33]. The onset of visual regulation was assessed for each gymnast individually as well as for the group in each condition.

Statistical analysis

The mean and standard deviation of the dependent variables for each gymnast (across the six trials) and condition were determined using descriptive statistics. The distribution of the data was examined using the Kolmogorov-Smirnov test, and the normality of the data (skewness and kurtosis) was assessed. A paired samples *t*-test was used to assess differences in the analysed kinematic variables [34]. The level of significance was set at $p < 0.05$.

Results

Kinematics of the approach run and hurdle step

The gymnasts' approach runs ranged from 22 to 25 m and included 11 to 15 steps. Although the full approach was recorded, only the last 11 steps were exam-

Table 1. Step length of the participants for the last 11 steps of the approach

Variable	NT-condition (mean ± *SD*)	T-condition (mean ± *SD*)	All participants (mean ± *SD*)
Step length (cm)	156.73 ± 7.39	155.75 ± 5.43	156.24 ± 0.69

Table 2. Length of the last three steps of the approach and the hurdle step in tape and non-tape conditions

Condition	Hurdle step (mean ± *SD*)	Last step (mean ± *SD*)	Step 2 (mean ± *SD*)	Step 3 (mean ± *SD*)
NT	322.63 ± 30.13	168.08 ± 15.08	183.19 ± 14.05	168.79 ± 5.11
T	331.11 ± 21.85	164.01 ± 11.61	174.48 ± 14.73	169.97 ± 5.22

NT – non-tape condition, T – tape condition

ined for further analysis. Table 1 displays the mean step length for each gymnast in both conditions (NT – T) for the last 11 steps of the approach.

No statistically significant differences were found between conditions for the length of the hurdle step and the final three steps of the approach (Table 2).

No statistically significant differences ($p > 0.05$) were found between the NT and T conditions for CT and $TTD_{take-off}$ (Table 3).

Table 3. Time on springboard (CT), toe-board distance (TBD), and toe-table distance at take-off from the springboard ($TTD_{take-off}$) in each condition

Variable	NT (mean ± *SD*)	T (mean ± *SD*)
CT (s)	0.117 ± 0.005	0.116 ± 0.003
TBD (cm)	35.04 ± 7.84	30.56 ± 6.31
$TTD_{take-off}$ (cm)	119.46 ± 9.90	116.52 ± 8.57

NT – non-tape condition, T – tape condition

Onset of regulation

A systematic decrease in TTD_{SD} was observed at the fourth last step for the T condition and the third last step for the NT condition (Figure 2). Individual responses between gymnasts varied, with each one commencing visual regulation at distinct instances in each condition (Table 4).

Discussion

The study aimed to investigate the potential effects of a visual target point on Tsukahara vault kinematics and the onset of visual regulation during the run-up phase. The last two steps before the hurdle step had the same length as the gymnasts' corresponding steps in the handspring vault, with the penultimate step being

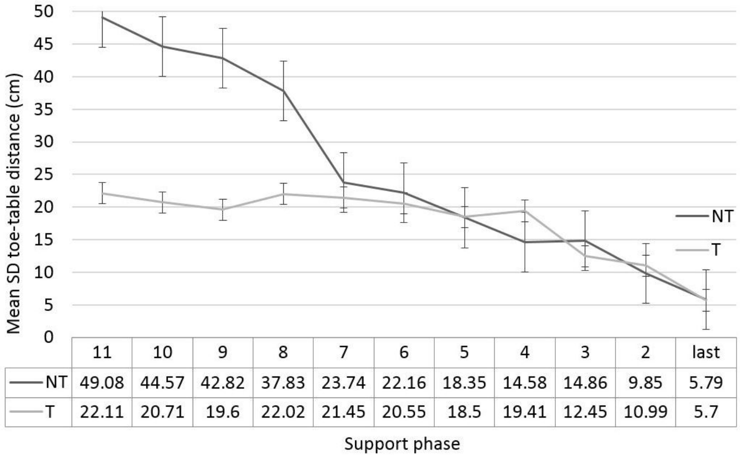


Figure 2. Mean values (cm) of the standard deviation (*SD*) of toe-table distance at each support phase for the non-tape (NT) and tape (T) conditions ($n = 10$)

Table 4. Length (m) and steps of the run-up and step where the onset of regulation occurred for each gymnast in both conditions

Gymnast	Run-up (m)	Steps (*n*)	Onset of regulation (step)	
			NT	T
1	24.85	13	0	2
2	25.00	15	2	2
3	24.25	14	4	3
4	24.60	15	5	6
5	24.80	15	3	4
6	22.80	14	4	5
7	25.00	15	2	2
8	24.20	14	2	3
9	24.80	13	0	2
10	22.80	14	1	5
Mean	24.31	14.2	2.3	3.4

NT – non-tape condition, T – tape condition longer and the last shorter, based on the results from both conditions (NT and T) [6]. The values for the penultimate and final steps, which were 183.19 cm and 168.08 cm for the NT condition and 174.48 and 164.01 cm for the T condition, respectively, were at approximately the same level as the corresponding values for the handspring vault (177 and 164 cm for the NT condition and 181 and 164 cm for the T condition). In addition, the penultimate step was often longer than the last step before the hurdle step to the springboard, which is consistent with long jumpers [15]. Under the conditions studied, the average hurdle step phase (towards the springboard) was 326 cm, with no discernible differences between the two values (306 and 310 cm for the NT and T conditions, respectively). These values are greater than the corresponding high-level athletes recorded during the handspring vault (306 and 310 cm for the NT condition and T condition, respectively) [6], but they are at the same level as Olympians (330 cm) and elite athletes [35].

The results show that the NT and T conditions were different in terms of the onset of visual regulation of the gymnasts, which occurred in the last three steps in the NT condition and the final four steps in the T condition. These results are consistent with research data from previous studies on the handspring vault in male [6] and female gymnasts [7] and also on the Yurchenko vault [5]. Furthermore, the results are consistent with those of Meeuwsen and Magill [24], who reported that visual regulation begins two steps before the hurdle step phase and occurs at an average distance of 7.83 meters during the handspring vault. This finding confirms recent theories about the vision used by gymnasts to control their approach in relation to the take-off point [27, 28].

The variation in visual regulation is due to how the first steps were performed, where an increase in standard deviations was observed at the beginning of the step (acceleration phase). Meanwhile, a systematic decrease was observed afterwards, indicating a more stable movement pattern as the gymnasts approached the final steps for the hurdle step phase. The run-up is divided into two phases, the acceleration phase and the visual correction phase, based on the recorded maximum standard deviation of foot contact positions. In addition, the heterogeneity of responses between athletes in terms of visual control regardless of performance level is consistent with the results of other studies [5, 16, 17, 26].

While the springboard acts as an informational constraint, the additional visual stimulus identifying a fixed point on the run-up that the gymnast must intercept accurately is perceived by peripheral vision and used as a remote attentional focus that, together with the informational constraint, forms a spatial parallel search that increases horizontal velocity during the final steps of the run-up [6]. The theoretical basis of this finding is the idea that gymnasts can perform the following skill with the best possible motor adjustment, associated with a faster run-up velocity when they directly perceive an environmental stimulus related to the vault, in this case, the additional visual stimulus. This finding is also supported by a previous study [5] that reported a correlation between the distance for the onset of visual fixation and the run-up velocity in the hurdle step phase. The results of the study demonstrate how gymnasts utilise their vision to regulate their steps in response to visual cues when the hurdle step phase (movement towards the springboard) begins. One advantage of using vision in the run-up phase, according to Bradshaw, is that it allows gymnasts to make minor adjustments for the cumulative inaccuracy of each foot placement throughout the run-up [5].

Conclusions

To summarise, the use of a visual stimulus (tape) to indicate the take-off position for the hurdle step phase appears to contribute to a faster (earlier) onset of visual regulation. Even though the study's results did not reveal any statistically significant differences between the two conditions when performing the Tsukahara vault, it is probable that the tape allows the gymnasts more time to process the information about the take-off point at the end of the run-up to perform the hurdle step. The length of the steps did not differ between the two conditions, especially the last three and the hurdle step to the springboard. Furthermore, no statistically significant differences were found in the spatial-temporal variables. Nevertheless, differences were observed between the gymnasts with regard to the step at which visual regulation began.

The results of the study cannot be generalised for all gymnasts in the vaulting event. Considering that perceptual ability differs between male and high-level female athletes, clarifying the gender factor on visual control in the vaulting phase of the gymnastic horse is required. In addition, a study should be conducted on collegiate athletes who have a lower level of physical ability, especially younger age groups with significantly lower training experience than elite athletes.

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Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the ethics committee of the Faculty of Physical Education and Sport Science, National and Kapodistrian University of Athens (approval No.: 1350/03-03-2022).

Informed consent

Informed consent has been obtained from all individuals included in this study.

Conflict of interest

The authors state no conflict of interest.

Disclosure statement

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