THE REGULATORY INFLUENCE OF THE VISUAL SYSTEM: AN EXPLORATORY STUDY IN GYMNASTICS VAULTING

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Abstract
Approach runs in order to maximize approach velocity are an inherent component in many sports. The goal of the study was to investigate the regulation of a complex motor task in gymnastics vaulting and the impact of the visual system within these processes. It was hypothesized that a visual perception-based strategy incorporating time-to-contact information derived from the variable tau is used to optimize the run-up in particular. Kinematic parameters of 10 gymnasts performing handsprings were examined. The analysis revealed that, on average, onset of visual control took place three steps prior to the hurdle. Linear regression showed that tau margin is dependent on the velocity of the approach run. The study supports the idea of a regulation of the run-up that is based on a visual strategy in which the influence of the vaulting table is crucial. The gymnasts were able to adapt the step length and duration respective to the movement velocity in order to facilitate an optimal transition of the run-up towards the take-off board and subsequent the vaulting table. In the process the influence of run-up velocity relating to the value of tau at the onset of visual control is of utmost importance.

Keywords: *handspring, visual control, run-up, kinematic analysis.*

INTRODUCTION

Goal-directed run-ups are an inherent component in many sports. Every run-up has its own characteristic structure depending on the goal and the requirements of the intended motor skill (Jemni, 2018). Approach runs in order to maximize approach velocity to successfully perform a complex motor skill are typical for gymnastics vaulting (Bradshaw, 2004). For a well-performed and highly scored vault, gymnasts need to optimize each aspect of the vault, including the approach run as well as body posture and movement during subsequent phases of the vault (Bradshaw, 2004; Heinen, Jeraj, Thoeren, & Vinken, 2011; Heinen, Vinken, Jeraj, & Velentzas, 2013; Velickovic, Petkovic, & Petkovic, 2011).

The relevant information allowing athletes to guide and regulate their segment movements can be perceived through different sensory system, whereby the visual system can be considered as the most important (Vickers, 2007). Results from Heinen et al. (2011; 2013) highlight for instance that the perceived position of the springboard and vaulting table are relevant information sources that guide gymnasts' movement regulation during the approach run. Furthermore, Bradshaw (2004) and Meeuwsen and Magill (1987) had experienced gymnasts perform different vaults. It was found that a visual regulation strategy is used to adapt the last few steps prior to the hurdle and that movement regulation at an early stage in conjunction with a fast approach run is likely to contribute to a well-performed and highly scored vault. Current empirical evidence thus clearly suggests that it is possible to regulate the approach run in order to perform a complex motor task, such as a handspring over the vaulting table in gymnastics. Nevertheless, the question still arises which role the visual system itself plays in the course of regulating the run-up prior to a complex motor skill in gymnastics vaulting.

There are several theoretical approaches that account for the process of movement regulation during whole-body movements. The theory of direct perception (Gibson, 1986) treats athletes as open biophysical systems, where a constant interaction between the environment and sportsperson can be seen as the key criterion to movement regulation (Raab, Oliveira & Heinen, 2009). In gymnastics vaulting, visually guided movement regulation is evidentially utilized to perform complex motor tasks (Bradshaw & Sparrow, 2001; Bradshaw, 2004; Heinen et al., 2011; Heinen et al., 2013; Lee, Lishman, & Thomson, 1982). Visual perception is an active process in which information of the surrounding environment is interpreted using light. This "optic array" (Gibson, 1986, p. 73) has a defined structure depending on the place of observation. Hence, the optic array is constantly changing while the gymnast is moving, whereby the invariants are unchanging, visually perceptible sources such as the vaulting table (Gibson, 1986). Thus, perceptual information is thought to guide motor tasks, without an immediate necessity of cognitive interpretation (Raab et al. 2009).

During the approach towards an obstacle the retinal image undergoes a dilation. The center of this "optical flow" (Gibson, 1986, p. 123) is considered to be an invariant used as a reference in goal-directed motor tasks (Magill, 1989; Gibson, 1986). In the individual reference frame consisting of the gymnast and the environment, only information obtained from the invariants and the changes in the optical flow field is relevant for visually based movement regulation (Araújo, Davids, & Hristovski, 2006; Gibson, 1986; Williams, Davids, & Williams, 1999). Based on Gibson's theory of direct perception, Lee (1976) as well as Lee and Kalmus (1980) argued that relevant information can be obtained directly from the optic flow field. Both the ecological stimulus and the body movement exhibit spatiotemporal components. Following the authors' argumentation, it can be stated that in the course of the run-up absolute variables such as velocity, size of the obstacle or other physical quantities are unlikely to be of importance for visually based regulation. Instead, body scaled visual information is thought to allocate the necessary information (Lee, 1998). The corresponding variable which incorporates the concept of how a target-directed action can be controlled based on the perception-action-relationship of the ecological approach was denoted as *tau* (τ) by Lee (1976). Tau is comprised of the spatiotemporal component and it specifies the time-to-contact (T_c), the time until a collision with an object would occur. Following Gibson's ideas, tau depicts a "formless invariant" (Lee, 1998, p. 225).

A constant flow of velocity vectors originating from the reflected ambient light is the basis for determining time-to-contact information. Consequently, it becomes apparent that information regarding distance can be obtained directly from the retinal image projected by the obstacle onto the gymnast (Tresilian, 1991; Williams et al., 1999). By the time tau reaches a threshold value the gymnast is able to anticipate the following path of motions, facilitating the initiation of the required adjustments to reach the intended movement goal. This threshold value was denominated as "tau margin" (Lee & Young, 1985, p. 3). It has been presented in detail that the time-to-contact can be determined by two different forms of tau.

On the one hand, there is "global tau" (Tresilian, 1991, p. 866), which is a variable that takes the entirety of the optical flow field into account. Global tau is defined as the ratio between the center of the optical flow field undergoing a dilation in relation to the distance of an obstacle r (respectively Z) and the sportsperson's velocity $\dot{r}$ (respectively $\dot{Z}$). On the other hand, there is "local tau" (Tresilian, 1991, p. 866), which can be determined as the ratio of two points on the surface of the obstacle undergoing a dilation. Based on the last-mentioned equation it is possible to determine how tau changes in the course of the sportsperson's movement.

Lee's theory, however, exhibits several points of criticism. It can be stated that the application spectrum is limited to movements with constant velocity and direct collision by the theory itself (Williams et al., 1999). Nevertheless, studies by Lee and Reddish (1981) and Lee et al. (1982) underline the possibility to control a motor task with non-constant velocity based on the time-to-contact information specified by tau. Wann and Tresilian expatiated upon the mathematical derivation and the deficiency of tau to specify the T_c information. Assuming direct collisions as the core requirement excludes both points of criticism mentioned in this study. For more detailed analysis see Tresilian (1990; 1991; 1994; 1999, 2005) and Wann (1996). Lee et al. (1982) analyzed the run-up of three international long jumpers in order to answer the question of how the acceleration in the "approach" and "zeroing in phase" (p. 455) towards the take-off board is regulated. It was found that during the last five steps the athletes were able to decrease the standard deviation to a maximum of 5 cm, which enabled them to hit the board with precision. Similar findings from Hay (1988), Berg, Wade und Greer (1994), Scott, Li and Davids (1997) supported the conclusion that the run-up can be advantageously regulated by utilizing visual information. In gymnastics vaulting the afore-cited studies of Meeuwsen und Magill (1987) and Bradshaw (2004) underline the advantage of regulating the run-up through a visually based regulation strategy. In both studies the obstacle was a vaulting horse, which has been replaced in 2001 by the vaulting table. In conclusion the studies provide empirical evidence for the theory of ecological perception which assumes that complex motor tasks are regulated with an individual body-scaled reference frame.

However, the utilization of tau can only be derived, which is why there is no consistent evidence that empirically substantiates the theory of movement regulation by means of the optical variable tau (see also Williams et al., 1999). Moreover, the influence of the vaulting table with its specific three-dimensional expansion as well as the rate of chance of tau and its derivation $\dot{\tau}$ has not been examined. Taking the empirical and theoretical groundwork into account it was predicted that gymnasts use a visual strategy to regulate their run-up prior to a vaulting skill through the time-to-contact information derived from Lee's variable tau. To examine this prediction, gymnasts with different levels of expertise were asked to perform a handspring on vault during which the kinematic parameters of the run-up were measured. It was expected that the standard deviation of the steps prior to the hurdle should reduce considerably in compliance with the findings of Bradshaw (2004), Meeuwsen and Magill (1987) as well as Velickovic et al. (2011).

METHODS

N = 10 participants took part in this study (n = 5 men and n = 5 women). Participants were between 22 and 30 years of age (mean ± SD: 26.9 ± 3.18 years). Being able to perform a handspring in compliance with the technical guidelines was the key criterion for the recruitment of the participants. In contrast to novices, a group with this level of expertise display a better overall performance regarding for example the use of cognitive strategies as well as their technical and physical preconditions (Chi, 2006). Therefore, the participating mid-range gymnasts can be considered as a group with more advanced skills and capabilities than novices, particularly regarding an enhanced ability to use the visual system efficiently when performing the experimental task. Prior to the study, all participants were informed about its purpose as well as the procedure and gave their written informed consent. The study was carried out in line with the guidelines of the local ethics committee.

The experimental task for the gymnasts was to perform handsprings on vault. Each participant was asked to perform three trials, leading to a total of 30 handsprings. The vaulting table was adjusted to a height of 1.25 m for women and 1.35 m for men. In compliance with the guidelines of the FIG the run-up had a maximum length of 25 m (Féderation Internationale de Gymnastique [FIG], 2017). The handspring can be subdivided into three functional phases, namely the preparation phase, the main phase, and the final phase (Magill, 1989). The preparation phase consists of the first step, a short and powerful sprint-run, the last step, as well as a hurdle movement (Arkaev & Suchilin, 2004; Bradshaw, Hume, Calton & Aisbett, 2009). The approach-run is a cyclic movement with the aim of achieving task-dependent velocity prior to the vaulting motion (Prassas, Kwon & Sands, 2006). At the end of the hurdle, the gymnast places his or her feet onto the springboard and slightly in front of the upper body. The joints of the ankles, knees and hips are flexed and fixated in order to prepare the takeoff and the first flight phase. The kinetic energy resulting from the run-up is used to optimize the subsequent main phase (Bradshaw, 2004; Schärer, Lehmann, Naundorf, Taube & Hübner, 2019).

The main phase of the handspring can be subdivided into five subphases: the takeoff, the first flight phase, the repulsion phase, the second flight phase and the landing phase. By pushing off the board the gymnast enters the first flight phase, moving the hands towards the vaulting table which initiates a rotation around the transversal axis of the body. With tension in the whole body, vertical and horizontal velocity are modified as a consequence of the repulsion, regulating the angular momentum of the handspring. The subsequent second flight phase with controlled angular momentum leads to the last and final phase of landing in an upright position (Farana & Vaverka, 2012; Hedbávný & Kalichová, 2015).

To determine the approach run and handspring kinematics, an optical movement analysis system was used. The handsprings were recorded using a USB 3.0 video camera type (Basler acA 1920-155) with a spatial resolution of 1920x1200 pixels and a sampling rate of 100 Hz (temporal error: ±0.01 s, spatial error: ±8 mm). The camera was placed orthogonally to the running track, springboard and vaulting table, capturing 13 m of the approach run as well as the backmost edge of the vaulting table. The adjustment was made in order to ensure comparability between the different lengths of the participants' run-ups. In this manner the approach run, last step and hurdle, takeoff, first flight phase, and the repulsion phase were recorded (Figure 1). Gymnasts were marked with white adhesive strips at the temple and the hip. The time-course of the velocity and acceleration of the marker as well as the coordinates of the feet were analyzed by adding the video data to the video analysis and modeling tool Tracker of the Open Source Physics project. Each video was analyzed consecutively in order to obtain the x- and y-coordinates of the aforementioned markers. The onset of visual strategy use for movement regulation was marked by a peak standard deviation of the footfall position. A subsequent systematically decreasing standard deviation was a distinctive feature (see also Bradshaw, 2004; Lee et al., 1982).

The study was conducted in three phases. In the first phase, the gymnast arrived at the gym and the aim and the procedure of the study were explained. After completing the informed consent form, the gymnast could warm up individually for 15 minutes. In order to familiarize and prepare the athlete's motor system in an optimal way for the experimental task, the gymnast was allowed to perform 3 handspring trials after the warm-up phase. Subsequently, adhesive strips were attached to the gymnast's temple and hip. In the second phase, the gymnast was asked to perform three handsprings. Between the trials, the gymnast was allowed to rest individually to guarantee each motor task was performed as precisely as possible. Each vault was videotaped as described above, including the run-up, takeoff, first flight phase and repulsion phase. In the third phase of this study, after having performed three handsprings, the gymnast was debriefed.

For this study, a significance criterion α = 0.05 was defined a priori. At the beginning, the distance to the vaulting table and the duration regarding the use of visual movement regulation were computed. Based on the collected data it was investigated whether there is a relation between the distance to the vaulting table or the time and the initiating use of a visual strategy utilizing linear regressions. Tau was computed with equation 1 and its values in the course of the gymnasts' movement were investigated:

$$\tau_Z^{(1)} = \frac{x}{\dot{x}} = -\frac{z}{\dot{z}} \quad \text{(equation 1)}$$

By differentiating equation 1 with respect to time (Bardy & Warren, 1997), it is possible to determine the change of tau $\dot{\tau}$ during the run-up. Moreover the possibility to control a motor task on its basis was examined:

$$\dot{\tau} + 1 = \frac{z\ddot{z}}{\dot{z}^2} \qquad \text{(equation 2)}$$

Equation 2 highlights that a value of $\dot{\tau} > 1$ during the approach implies acceleration, whereas values of $\dot{\tau} = 1$ imply movements with constant velocity and a $\dot{\tau}$ between 0.5 and 1 will lead to a controlled collision. The values of $\dot{\tau}$ were computed between each step.

RESULTS

First, the analysis showed that in four cases onset of visual control took place three steps prior to the hurdle, with an average distance of 7.05 m (SD = 0.74), an average velocity of 6.5 m/s (SD = 0.09), and an average duration of 0.83 s (SD = 0.06). From the standard deviation it can be derived that the start of visual control with reference to distance and duration is similar regardless of the total number of steps. The data of two gymnasts indicated visual strategy onset four steps prior to the hurdle leading consequently to different values for distance and duration, whereas the gymnasts' velocity accords with the afore-mentioned valuation. Linear regressions yielded a significant correlation neither between visual regulation onset and velocity (r = .15, p = .78) nor between distance to the vaulting table at the onset of visual regulation and velocity (r = .52, p = .29). The analysis of data of four participants added up to divergent findings which did not correspond to the hypothesized pattern.

Second, analysis revealed the onset of visually guided movement regulation, which started with the antepenultimate step to the hurdle exhibited a tau of 1.05 (SD = 0.07). The values of tau marking the onset of visual control, more specifically tau margin, showed little deviation. Analogous results followed from the data analysis of the gymnasts in whose cases the onset of visual control occurred four steps prior to the hurdle (M_{tau} = 1.36). In this case, tau margin exhibited a higher value due to the temporal and spatial differences respective to the beginning of visual regulation (see Table 1). In addition, the values of tau margin diverged very little as well (SD = 0.08). Linear regression revealed that tau margin was correlated with gymnasts' velocity of the approach run (r = .81, p = .048). Visual regulation of the run-up was initiated when tau reached an average value of 1.16. The tau-theory is based on the hypothesis of tau providing information about time-to-contact that is utilized for instance in movement regulation. It was shown that with a decreasing distance to the vaulting table and an increasing velocity up to the last step, the variable declined.

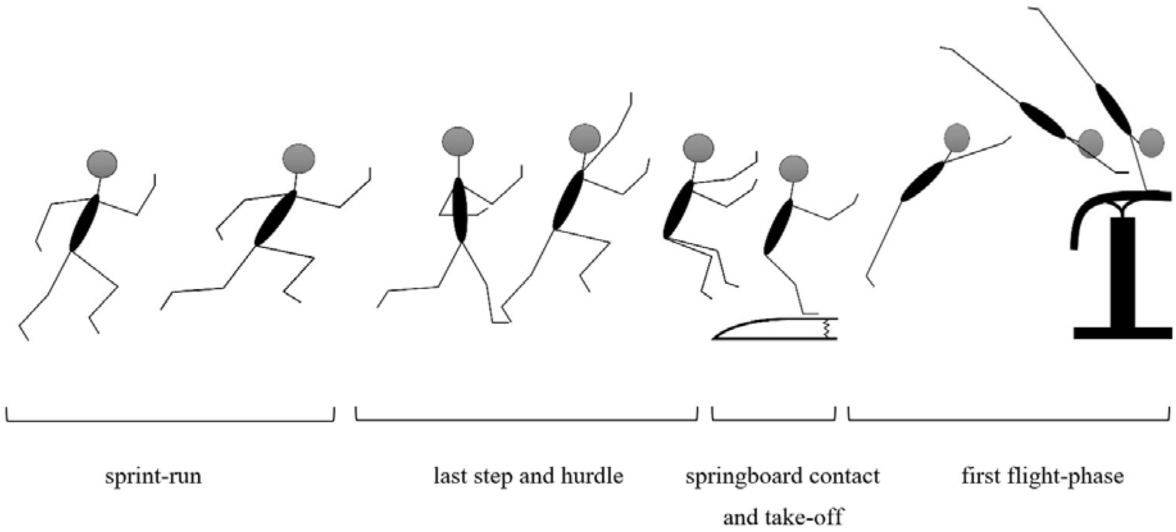

Figure 1. Stick-figure sequence of the video-taped phases of the motor task (handspring on vault).

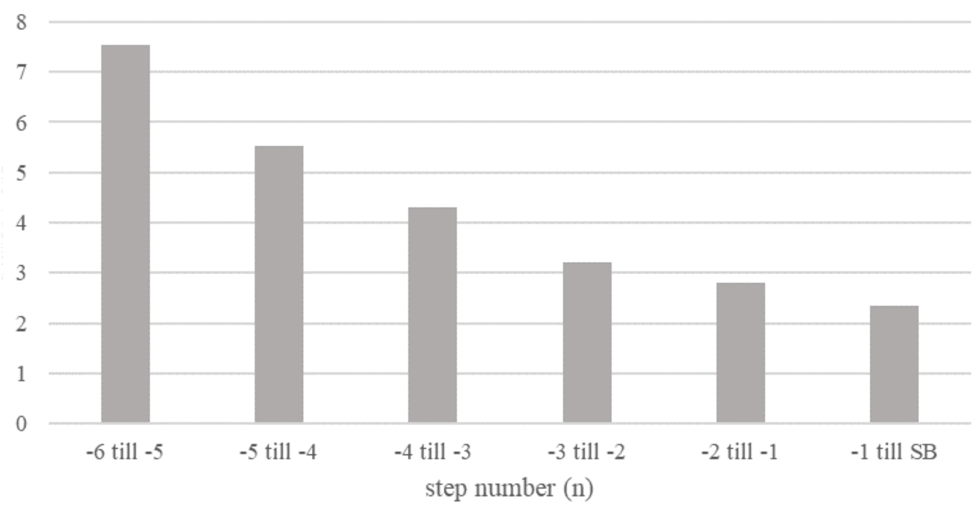

Figure 2. Mean values of $\dot{\tau}$ as well as its changes during the steps in the approach-runs, for participants with 6 recorded steps.

Table 1
Values of tau for visual regulation onset.

Participant	Step number (n)	Tau	
		M_x	s_x
3	-3	-1.00	0.02
4	-3	-1.02	0.02
6	-4	-1.43	0.01
8	-3	-1.16	0.02
9	-4	-1.28	0.10
10	-3	-1.00	0.02

Table 2
Values of $\dot{\tau}$ for the steps referring to participants with 6 recorded steps prior to the hurdle (Note: SB = contact with springboard).

Step	Participant				$\dot{\tau}$	
	2	4	8	9	M_x	s_x
-6 till -5	5.99	8.67	7.17	8.33	7.54	1.05
-5 till -4	4.55	5.98	5.71	5.92	5.54	0.58
-4 till -3	3.47	4.76	4.51	4.50	4.31	0.50
-3 till -2	2.91	3.25	3.19	3.54	3.22	0.22
-2 till -1	2.55	2.70	2.92	3.04	2.80	0.19
-1 till SB	2.35	2.03	2.64	2.34	2.34	0.22

Table 3
Values of $\dot{\tau}$ for visual control strategy onset.

Participant	Total number of steps	Visual strategy onset at step n	$\dot{\tau}$	
			M_X	s_x
3 and 10	7	-3	2.48	0.00
6 and 9	6 or 7	-4	4.45	0.05
4 and 8	6	-3	3.22	0.03

Third, tau's rate of change over time $\dot{\tau}$ is presented for each step in Table 2 and 3. The starting values are individually different due to different velocity and acceleration development. Analysis of the mean value of $\dot{\tau}$ for the gymnasts with 6 recorded steps until the hurdle revealed a systematic decrease of this informational variable with decreasing distance to the obstacle (see figure 2). Moreover, the standard deviation of the mean values of $\dot{\tau}$ exhibited a systematic diminution in the course of the run-up, which leads to a mean variation from the antepenultimate step until the hurdle and constant values regarding the change of tau over time (see Table 2). A similar development could be found for gymnasts with 7 recorded steps prior to the hurdle. Until step -1 the decrease occurs analogously, which also holds true for the standard deviations of the corresponding mean values. Accordingly, the mean value of $\dot{\tau}$ between step -2 and -1 exhibits a standard deviation of 0.26. Hence it can be stated that the mean values of the penultimate step in both groups represent the aggregate data of the corresponding step in an adequate fashion. In contrast, the computed values of $\dot{\tau}$ for the last step and hurdle in the second group do not correspond to the displayed pattern. In fact, a renewed increase of $\dot{\tau}$ is evident. One attempted explanation could be to assume the data of gymnasts 1 and 7 as anomalous. Both recorded run-ups do not accord with the pattern. Regarding participant 7, it could be hypothesize that the changing number of steps in the different attempts are the reason for the anomaly. In attempt 1, 6 steps could be recorded, in contrast to 7 steps in the following two attempts. In the case of athlete 1, the computed values of $\dot{\tau}$ for the last step are higher than the value of $\dot{\tau}$ for the first step, which is conspicuous, considering the other gymnasts' data record (see Table 3). For the moment of hitting the springboard, an average velocity of 5.67 m/s as well as a value of $\dot{\tau}$ = 2.28 (SD = 0.71) for the change of tau over time was computed for all gymnasts. Furthermore, it became apparent that the values of $\dot{\tau}$ for the onset of visually controlled motor execution differed marginally between the athletes (see table 4). It is important to note that the data analysis and interpretation is carried out by comparing the values of $\dot{\tau}$ referring to gymnasts with the same total number of recorded steps as well as the same step number at the beginning use of a visual control strategy. Perception-based movement regulation starting with the fourth from last step (*n* = - 4) yielded similar values for $\dot{\tau}$.

DISCUSSION

The goal of the study was to investigate the regulation of complex motor tasks involved in gymnastics vaulting and the impact of the visual system within these processes. It was hypothesized that a visual perception-based strategy that incorporates time-to-contact information derived from Lee's variable tau is used to optimize each aspect of the run-up. Therefore, it was speculated that the data analysis would provide evidence for the application of a visual strategy and that the standard deviation of the steps prior to the hurdle would thus reduce considerably. The study was able to produce proof for the regulation of the run-up prior to a gymnastics vault based on a visual strategy in which the influence of the vaulting table is crucial. It seems possible to guide target-directed movements by visually perceiving the time-to-contact information specified through the variable tau. When tau reached a threshold value ($\tau_{step\ -3}$ = 1.05; $\tau_{step\ -4}$ = 1.36), a considerable decrease of the standard deviation could be validated, starting with the third and fourth to last step, respectively. The differing results from four participants relative to the pattern of a decreasing standard deviation during the run-up indicate that the findings of the study should be verified through further research with a larger sample. It can be reasoned that this variation may emerge from the partial videotaped run-up. Tau's rate of change over time did also exhibit a systematic decrease resulting in a well-executed handspring, in which a value of $\dot{\tau}$ = 2.28 is considered to be advantageous.

Taking the results into consideration, the measured distance at the onset of visual control (7.06 m) is similar to the findings of Bradshaw and Sparrow (2001), who stated a distance of 4.91 m. The differences arise from the reference point of the measurement. Bradshaw and Sparrow measured the distance to the take-off board, whereas in this study the distance to the vaulting table was measured. Taking into account the length of the take-off board, as specified by the technical committee of the FIG (FIG, 2017), as well as the distance from the take-off board to the vaulting table, which was set individually by the gymnasts, led to similar results. Bradshaw (2004) was able to provide analogous results in gymnastics vaulting. Analyzing Yurchenko vaults, the author determined that 7.83 m of the run-up were regulated on the basis of visual perception. Disparities regarding run-up velocity and the following duration of the visual regulation strategy in this study result from the unique kinematic structure of Yurchenko vaults (Atiković & Smajlović, 2011; Naundorf, Brehmer, Knoll & Bronst, 2008).

Furthermore, the presented study provides evidence for the use of a visual strategy to regulate goal-directed movements, as Bradshaw (2004) was able to establish for other vaulting groups. In spite of increasing velocity, the gymnasts were able to adapt the steps' length and in order to facilitate an optimal transition of the run-up towards the take-off board and the vaulting table. In the process, the influence of run-up velocity relating to the value of tau at the onset of visual control is of utmost importance. This dependent relationship was established by Bradshaw and Sparrow (2001) in a previous study. An early onset of visually controlled movement leads to a longer and particularly more effectively controlled and adapted run-up. It was previously verified by Bradshaw (2004) that a longer duration of regulation based on visual perception leads to a vault that is performed better and scored higher. In consequence, the challenge for athletes and especially for coaches is to find a balance in the field of technical training between high run-up velocities and maximized duration of visual determined run-up regulation. Bradshaw (2004) summarized the advantages arising from the utilization of a visual strategy in a concise fashion. Alterations and varying foot placements in the course of the run-up were caused by intrinsic and extrinsic factors. Signs of fatigue, improved performance prerequisites or a lack in concentration due to inner restlessness are examples of intrinsic factors. In contrast, changes in the surrounding conditions such as different light or apparatus conditions at competitions as compared to the home gym, as well as the audience, represent extrinsic factors.

The irregularities regarding 5 of the participants could result from the limited recording zone. It is unproven that a systematic reduction of the standard deviation marking the onset of the visual regulation strategy could not occur earlier in the course of the run-up. Therefore, another study is required to investigate the pattern of the run-up beginning with the first step. The presented study showed that the onset of visual control is not influenced by the parameters time or distance to the vaulting table. Instead, a value of tau margin was established which influences the regulation of the run-up. In contrast to the findings of Bradshaw and Sparrow (2001), the results did not reveal two phases within the run-up. On the one hand, only a section of the vault run-up was recorded. The gymnast's velocity increases towards the vaulting table, whereby no acceleration phase can be separated. Hence the developing of tau's rate of change over time did not exhibit a minimum. On the other hand, the experimental task was of a different nature. Both studies incorporated the crossing of a take-off board. However, the vaulting table and the handspring are additional elements in the current study, which resulted in a modified experimental task. Based on their results, Bradshaw and Sparrow (2001, p. 425) ultimately came to a similar conclusion: "Target and obstacle characteristics were shown to constrain step length regulation for the whole approach, with the number of defining boundaries and other qualitative differences being the main circumstances underlying this". The hypothesis by Lee et al. (1992) that a value of $\dot{\tau} > 1$ corresponds to an accelerating movement was confirmed. An increasing velocity in conjunction with the approach towards the vaulting table was associated with a systematic reduction and adaption of $\dot{\tau}$ leading to an advantageously timed movement, whereby an optimized hurdle and first flight phase is ensured. Due to similar velocities and distances to the vaulting table at the onset of visual control, the values of $\dot{\tau}$ are comparable as well. Whether or not this applies to a wider range of performance level cannot be resolved sufficiently. In conclusion, the study could not definitively establish a regulation based solely upon tau. It is necessary to investigate the potential influence of other visual parameters such as the size of the obstacle, retinal velocity and others. Following the dynamic systems approach to action and perception that is based on the deliberations of Turvey (1990) and Kelso and Haken (1995), learning is associated with and notably requires the self-organization of a subject in order to stimulate learning and optimization processes. In the course of the acquisition and the retention of a technique, individual variations are always to be found. This is due to the fact that there is only a mean probability for an athlete to replicate the structure of a movement accurately. Following this argument, it becomes clear that it is necessary to support the athlete's ability to adapt to changing surrounding conditions. Taking this into account, Schöllhorn, Hegen and Davids (2012) argued in favor of a theory of differential learning, in which the form of teaching and the learning process can be adjusted individually in consideration of the personal abilities and needs of the athlete. These Processes and adjustments are undertaken in order to enable the athletes to perform a general technique. During a gymnastics competition the movements are graded based on criteria referring to a general technique and execution. In conclusion, this deductively guided inductive learning process can be an effective way to enhance gymnastics training. This can be derived from the results of the study that visual regulation is individually different. In addition, there are further practical consequences that can be drawn from the results of the study.

The visual regulation strategy to adapt and adjust the approach run depends on the height and width of the obstacle (Meeuwsen & Magill, 1987). Regarding the acquisition of the unique approach run in gymnastics vaulting, different parameters have to be variegated. First, the length of the run-up track should be changed constantly so the gymnasts are forced to adapt their movements to the new condition without reducing the quality of execution. Second, considering the gymnasts' age and abilities, the learning process of a handspring should begin with fewer steps and a reduced approach velocity. Consecutively, the variation of the length of the run-up is introduced so that the gymnasts are able to define their ideal run-up distance. Similar conclusions have been drawn by Bradshaw and Sparrow (2001) as well as Bradshaw (2004). Furthermore, the distance from the take-off board to the vaulting table can be modified (Heinen et al., 2011). The authors argue that a training which exposes the learner to different conditions by modifying the approach run or take-off board distance can convey different movement experiences and variable disposal referring to the general technique. This position corresponds to the findings in the current study. The use of a visual strategy could be improved by marking spots in the course of the run-up, for example at the take-off board or vaulting table (see for instance Heinen, Vinken, & Fink, 2011). The dimensions of the object that is to be vaulted or used for further movements is highly important for the regulation of the run-up (Bradshaw & Sparrow, 2001). Taking this into account, Bradshaw (2004) reasoned that the inclusion of different targets into training is a basic necessity. The results presented by the author indicate that a visually regulated run-up that begins at an early stage as well as a wide range of movement experiences and visual strategies contribute to a better vaulting performance in changing surrounding conditions. As previously described, the regulation is based upon the specific obstacle which is why it should be examined which effect such training methods have on the gymnasts' vaulting performance and abilities.

CONCLUSION

We conclude that the run-up in gymnastics vaulting is subject to a visual strategy with which athletes can adapt the approach run as well as the hurdle prior to a handspring on vault advantageously by using time-to-contact information specified by the variable tau. However, we add that future studies should explore whether these values of tau differ between novice and top-ranking gymnasts and whether differences can be found regarding other vaulting groups (e.g., Tsukahara vaults). Furthermore, it should be investigated whether there is a correlation or relationship of dependency between the values of τ and $\dot{\tau}$ and the score of the judges and the level of execution. Beyond that, there is a lack of empirical evidence for possible transfer effects on the onset and duration of visual regulation resulting from the use of different obstacles and colored markings. Relevant insights could provide opportunities of adjusting training programs in order to enhance the acquisition and retention of handspring and gymnastics vaulting performances in general.

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