

Research article

Monocular and binocular vision in the performance of a complex skill

Thomas Heinen¹✉ and Pia M. Vinken²

¹German Sport University, Cologne, ²Leibniz University Hannover, Germany

Abstract

The goal of this study was to investigate the role of binocular and monocular vision in 16 gymnasts as they perform a handspring on vault. In particular we reasoned, if binocular visual information is eliminated while experts and apprentices perform a handspring on vault, and their performance level changes or is maintained, then such information must or must not be necessary for their best performance. If the elimination of binocular vision leads to differences in gaze behavior in either experts or apprentices, this would answer the question of an adaptive gaze behavior, and thus if this is a function of expertise level or not. Gaze behavior was measured using a portable and wireless eye-tracking system in combination with a movement-analysis system. Results revealed that gaze behavior differed between experts and apprentices in the binocular and monocular conditions. In particular, apprentices showed less fixations of longer duration in the monocular condition as compared to experts and the binocular condition. Apprentices showed longer blink duration than experts in both, the monocular and binocular conditions. Eliminating binocular vision led to a shorter repulsion phase and a longer second flight phase in apprentices. Experts exhibited no differences in phase durations between binocular and monocular conditions. Findings suggest, that experts may not rely on binocular vision when performing handsprings, and movement performance maybe influenced in apprentices when eliminating binocular vision. We conclude that knowledge about gaze-movement relationships may be beneficial for coaches when teaching the handspring on vault in gymnastics.

Key words: Experts-novice paradigm, gaze behavior, gymnastics.

Introduction

For those who watched the gymnastics competition at the Beijing 2008 Olympic Games you may still recall the fascinating moves of gold medalists Hong Un Jong and Leszek Blanik in their vaulting performances. Although the movements looked fluid and easy, they are in reality quite complex and the athlete has to meet temporal and spatial constraints to perform a controlled vault and land in a stabilized position. Visual information pickup has been characterized to be integral in complex skill performance in gymnastics (Hondzinski and Darling, 2001). However, it remains unclear how binocular vision contributes to the performance of complex skills in gymnastics. The purpose of this study was to establish whether or not binocular vision is critical for handspring performances on vault.

When a gymnast performs a handspring on vault, he or she has to achieve several movement aims (Arkaev and Suchilin, 2004; Brüggemann, 1994). The aim of the run-up is to achieve a sufficient level of kinetic energy,

which is then used and transferred in the subsequent phases. The hurdle prepares the take-off phase. During the take-off phase, the kinetic energy from the run-up is transferred into a whole body rotation about the transverse axis, and the gymnast has to generate an optimal vertical centre of mass velocity, which is then used in the first flight phase. In the repulsion phase, the horizontal and vertical velocities are altered and the angular momentum is reduced. The goal of the second flight phase is to achieve optimal height and sufficient rotation in order to land in an upright position. The kinetic energy is dissipated during the landing.

In order to achieve the aforementioned movement aims, gymnasts must control their actions by integrating perceptual information from the visual, vestibular, and somatosensory systems (Davlin et al., 2001a). Vision has been proposed to be the most influential system in controlling complex movements in gymnastics because it may inform the athlete about his or her current spatial orientation (Davlin et al., 2001a, 2001b, 2004; Hondzinski and Darling, 2001; Luis and Tremblay, 2008; Rézette and Amblard, 1985). It can furthermore be assumed, that the most important visual cue for spatial orientation is *binocular vision*, because it enables athletes to extract precise information about the locations of objects in three dimensions (Jackson et al., 1997). This function is needed to guide accurate interactions with the environment, such as take-offs, push-offs or landings, even when the environment is stationary.

Patla et al. (2002) studied for instance the role of binocular vision in six participants when walking along a pathway and stepping over an obstacle under three vision conditions: (1) binocular vision throughout the trial, (2) binocular vision at the beginning of the trial, and (3) monocular vision throughout the trial. It was found, that lead toe clearance was significantly higher in the monocular condition as compared to both binocular conditions. The authors concluded that binocular vision is crucial during the approach phase to extract accurate spatial information about environmental features, which are then integrated in the movement pattern.

Olivier et al. (1998) compared binocular and monocular vision in one-hand ball catching. Twenty participants were required to catch tennis balls, projected over a distance of 15 meters while wearing liquid-crystal visual occlusion goggles. It was found, that under binocular vision conditions, participants made more catches, less positional errors and less grasp errors as compared to monocular vision conditions. It was concluded, that binocular vision contributes to catching performance by reducing the spatial and temporal errors involved in intercepting a projected object.

It seems clear, that binocular visual information supports the performance of skills such as grasping (Coull et al., 2000), catching (Olivier et al., 1998) and locomotion (Patla et al., 2002), but it is unknown whether binocular vision is needed to be effective in the performance of a more complex skill, involving a whole body rotation, like the handspring on vault. There are, however, studies assessing the role of other visual informational sources in more complex skills, such as central or peripheral visual information. In these studies, athletes were asked to perform complex gymnastics skills such as single (Bardy and Laurent, 1998; Davlin et al., 2001a; 2001b; 2004; Lee et al., 1992; Luis and Tremblay, 2008), double (Hondzinski and Darling, 2001), or twisting somersaults (Rézette and Amblard, 1985) in different vision conditions, such as reduced visual acuity or reduced peripheral vision. Athletes' performance was in general compared across different vision conditions, such as restricted peripheral vision, restricted central vision or vision restricted to different phases of the skill.

The empirical results reveal that performance in complex skills is usually better when visual information is available. However, in most studies there were no, or only minor differences in motor performance between a full vision condition and conditions in which visual information pickup was manipulated (Davlin et al., 2001a; Hondzinski and Darling, 2001). Surprisingly, an even better motor performance was observed when visual information pickup was restricted to fewer visual samples (Luis and Tremblay, 2008). Nevertheless, taken together, there is no consistent evidence on how different visual informational sources are integrated in the performance of complex skills incorporating a whole body rotation. Therefore two intertwining assumptions should be taken into account.

On the one hand one may speculate that manipulating visual information pickup could lead to an adaptive gaze behavior, such that athletes are capable of producing an accurate and precise movement pattern that does not differ from their movement pattern under full vision (Raab et al., 2009). On the other hand, it may also be possible, that gaze behavior is not influenced by vision manipulations in complex skills since a specific eye movement strategy is thought to be associated with a specific motor skill, which is developed during skill acquisition (Land and Furneaux, 1997). Nevertheless, none of the aforementioned studies integrated the measurement of gaze behavior in their designs, one cannot be certain that a manipulation of visual information did or did not influence gaze behavior.

Furthermore, one may also speculate, that the manipulated visual information was either not needed or was of less importance in the performance of the aforementioned skills. Gymnastic skills are usually performed in a stationary environment, and there is no need to interact with other athletes or moving objects, as it would be in other sports such as soccer or basketball (Vickers, 2007). Therefore, it is questionable if gymnasts need for instance central vision when performing complex movements (Hondzinski and Darling, 2001). This, however, may also depend on gymnast's expertise level (Williams and Davids, 1998). Experts may rely to a lesser degree on visual information than apprentices, given the fact that athletes'

visual system adapts to training complex skills (von Laßberg et al., 2003; Schwarz, 1992). As mentioned before, binocular vision may play a significant role in guiding accurate interactions with the environment, such as take-offs, push-offs or landings, which are an integral part of handsprings on vault in gymnastics.

Given the current state of the art, we conclude, that it would at first be necessary to investigate the role of visual systems that are potentially more directly related to the task demands in complex skills in gymnastics (Bardy and Laurent, 1998). Second, this should be done in athletes on different expertise levels (Vickers, 2007). Third, one should measure athlete's gaze behavior to control if an adaptive gaze behavior may result from a vision manipulation, which in turn may lead to an accurate movement pattern that does not differ from a movement pattern performed under full vision (Raab et al., 2009).

To answer the question whether binocular vision is needed for gymnasts to perform their best, we reasoned the following: First, if binocular visual information is eliminated while subjects perform a handspring, and their performance level is maintained, then such information must not be necessary for their best performance. This would answer the question if binocular visual information were needed in the performance of a handspring on vault. Second, if the use of binocular vision is dependent on expertise level, then eliminating binocular vision should lead to performance changes in either experts or apprentices. Third, if the elimination of binocular vision leads to differences in gaze behavior in either experts or apprentices, this would answer the question of an adaptive gaze behavior due to vision manipulation, and thus if this is a function of expertise level or not.

Finally, we had three specific predictions on differences in movement performance and gaze behavior between experts and apprentices: First, experts should show a shorter hurdle phase, a shorter repulsion phase and a longer duration of the second flight phase, because these two parameters usually distinguish between "better" and "worse" handsprings on vault (Brüggemann, 1994). Second, experts should in general show fewer fixations of longer duration, as well as shorter overall blink duration when compared to apprentices (Williams and Davids, 1998) because this is often seen as a gaze behavior optimization strategy in experts.

Methods

Participants

A sample of sixteen participants was recruited to participate in this study. The apprentices in this study were eight students of sport science ($n = 4$ men and $n = 4$ women, age: 24 ± 2 years, body mass: 65 ± 5 kg) with gymnastics experience gained from successful participation in the basic and advanced gymnastics courses at the German Sport University Cologne. They had an average training experience of at least two years and were able to perform a handspring on vault without manual guidance. The experts in the current study were eight experienced gymnasts with at least seven years training experience ($n = 4$ men and $n = 4$ women, age: 23 ± 2 years, body mass: 63 ± 4 kg). It was decided to recruit experts and apprentices to

determine the influence of expertise-based differences on gaze and movement kinematics, and how athletes' gaze contributes to performance (Vickers, 2007).

All participants were informed about the purpose and the procedures of the study and gave their written consent prior to the experiment. They all had normal or corrected-to-normal vision and all participants were right-eye dominant (Porac and Coren, 1986). The study was carried out according to the ethical guidelines and the approval of the German Sport University Cologne.

Task and apparatus

Experimental task and analysis of handspring performance: The experimental task was a handspring on vault that had to be performed either with binocular vision or with monocular vision (see Figure 1).

Time-durations of the handspring's hurdle phase (1), take-off phase (2), first flight phase (3), repulsion phase (4) and second flight phase (5) were calculated from the videotaped performances of all participants. A high-speed video camera (Casio Exilim EX-FH100) operating at 120 Hz was placed orthogonal to the running track. Its optical axis was adjusted to the middle of the vaulting table in order to record the handspring performances. The videotaped sequences from the high-speed camera were used to measure the durations of the movement phases. We used three additional digital video cameras operating at 50 Hz to measure the orientation of the participant's head when performing the handspring. The first camera was placed 25 meters away and orthogonal to the running track with its optical axis adjusted to the middle of the vaulting table. The remaining two cameras were placed 45 degrees to the running track so that their optical axes comprised an angle of 90 degrees. This was necessary for integrating angular data of the eyeball into the kinematic data from the movement analysis system (see next section). We recorded the horizontal and vertical coordinates of four points (head landmarks) defining a model of the human head of all handspring performances. We started these analysis five frames prior to the onset of the hurdle phase and stopped it five frames after the touchdown of the feet on the landing mat during the land-

ing phase. All coordinates were recorded for each trial using the movement analysis software WINalyze 3D (Mikromak, 2008). A digital filter (cut off frequency = 6 Hz) for data smoothing was applied, and a mean temporal error of ± 0.02 seconds and a mean spatial error of ± 0.006 meters was calculated from the data.

Research has shown, that it is possible to differentiate between "better" and "worse" handspring performances on vault on the basis of phase durations. In particular, both, the hurdle and the repulsion phase show a shorter duration in better handspring performances. The second flight phase is characterized by a longer duration in better handspring performances (Brüggemann, 1994). From this it was hypothesized that experts should exhibit a shorter hurdle and a shorter repulsion phase and a longer second flight phase as compared to apprentices.

Eye movement recording system: We used a recently developed system to record eye movements (PS-Eye-2 System, Institute of Psychology, German Sport University Cologne; Raab et al., 2009). The system consists of a modified bicycle helmet with an attached wireless infrared miniature camera (approximate weight 250 g). The helmet was held in place with two chinstraps and another strap around the back of the head. While wearing the bicycle helmet, the participant was asked to wear safety glasses consisting of a polycarbonate pane and another soft strap. A miniature camera recorded images of the eyeball at a sampling rate of 50 Hz and was synchronized with the WINalyze 3D movement-analysis system (Mikromak, 2008). The eyeball was illuminated by two infrared diodes that created two reflection points on the cornea. The X- and Y-coordinates of both corneal reflection points, the centroid of the pupil, and another two reference points around the eyeball (tear sac and inner side of nasal bone) were digitized in a semi-automatic manner. From the coordinates of the reference points, camera movements that occur during complex movements were mathematically corrected. The rotation of the eyeball was calculated from the corneal reflection points and the centroid of the pupil.

Angular data of the eyeball was integrated into the kinematic data from the movement analysis system and the current gaze direction was then superimposed on the

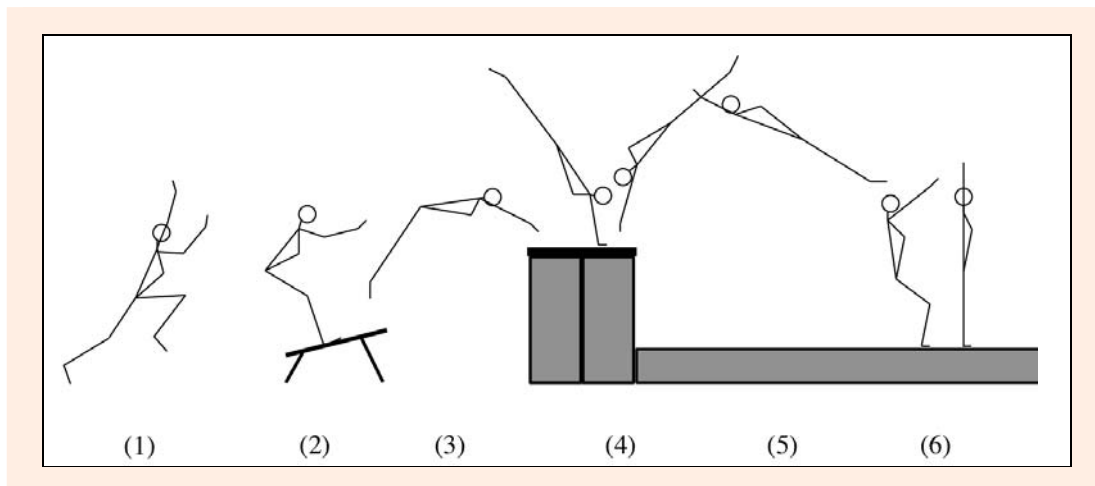


Figure 1. Stick-figure sequence and movement phases of the handspring on vault: (1) hurdle, (2) take-off phase, (3) first flight phase, (4) repulsion phase, (5) second flight phase, and (6) landing phase.

digital video sequences of the handsprings. The eye movement measurement error was ± 0.5 degrees between $+15$ and -15 degrees of the visual field in the horizontal and the vertical directions and ± 1.0 degree between $+15$ to $+30$ and -15 to -30 degrees of the visual field in the horizontal and the vertical directions.

In this study we divided gaze behavior into two categories: (1) when the gaze is directed at a specific spatial position for a minimum of 100 ms (fixation), and (2) when visual information is suppressed either by saccadic eye movements or when the eyeballs were covered due to eyelid closure (blinks). A fixation was operationally defined as any state in which the gaze remains stationary on one external point for five video frames (100 ms) or longer (Abernethy and Russell, 1987). During a handspring on vault this may occur especially when the eyes rotate to compensate for rotations of the head in order to hold the gaze fixated on one external point. Two independent and trained research assistants coded fixations and blinks frame by frame with the help of gaze profiles (cf., Vickers, 2007). Inter-rater reliability was calculated at $r = .92$ ($p < .05$). We calculated three parameters from the gaze behavior data: First, the number of fixations was directly determined from the gaze behavior protocols, indicating the absolute amount of fixations during handspring performance. Second, the fixation duration was also directly determined from the gaze behavior protocols. Finally, we calculated the overall blink duration as an indicator of visual information suppression.

Procedure

The experimental task was a handspring on vault that had to be performed either with binocular vision or with monocular vision (see Figure 1). The vaulting table was arranged according to the safety guidelines in gymnastics. Furthermore a professional coach was positioned on the side of the vaulting table to provide safety assistance if needed. Participants performed a run-up to the vaulting table and used a miniature trampoline as take-off surface. We decided to use the miniature trampoline as take-off surface to minimize vibrations of the eye-movement recording system, which may have occurred if we would have used a regular springboard. However, due to vibrations that occurred during the run-up and the landing, we excluded these two phases from further analysis. Each participant was allowed two familiarization trials under full vision without equipment, and another three trials under each condition with the eye-tracking helmet. There was no time pressure in this study and each participant was allowed to take breaks as requested.

After the familiarization trials, the participants were asked to perform the experimental task under the two conditions, the binocular and the monocular condition. In the binocular condition, the handsprings on vault were to be performed with no visual occlusion. In the monocular condition, participants dominant eye was occluded by an eye-patch (Coull et al., 2000). In both conditions, the participants were instructed to perform a rule-adequate landing at the end of the handspring and then stabilize their landing for at least three seconds. Each participant was asked to perform five handsprings in each

condition for a total of ten handsprings. Conditions were presented in a pseudo-random order, with the rule of not presenting a condition more than twice in a row.

Data analysis

Reliability for each kinematic variable (Cronbach's alpha) was between 0.87 and 0.96. No significant differences were found between trials. Therefore the average of all five trials in each condition was used for further data analysis. A significance criterion of $\alpha = 5\%$ was established for all results reported. We conducted separate 2 (Experimental Condition: binocular vs. monocular) \times 2 (Expertise: experts vs. apprentices) univariate analyses of variance (ANOVAs) for each of the dependent variables to explore differences between experts and apprentices and between binocular and monocular conditions, in movement performance as well as gaze variables (Knudson, 2009). To control for the inflation of Type I error we calculated Holm's correction to adjust the critical p -value (Lundbrook, 1998). Cohen's f was calculated as effect size for all reported F -values. Additionally, a post-hoc power analysis was conducted on all reported F -values.

Results

Handspring phase durations

Concerning the handspring phase durations it was hypothesized that experts show a shorter hurdle phase, a shorter repulsion phase and a longer duration of the second flight phase. We had no specific predictions on the effect of Experimental Condition on any of the phase durations of the handsprings. However, it was reasoned, first, that if binocular visual cues were eliminated while subjects performed a handspring on vault, and their performance level was maintained, then such information must not be necessary for their best performance. Second, if the use of binocular vision is dependent on expertise level, then an elimination of binocular vision should lead to performance changes in either experts or apprentices.

The ANOVAs revealed significant interaction effects of Experimental Condition \times Expertise for the duration of the hurdle, $F(1, 14) = 4.77$, $p < 0.05$, Cohen's $f = 0.58$, achieved power > 0.99 , duration of the repulsion phase, $F(1, 14) = 12.73$, $p < 0.01$, Cohen's $f = 0.95$, achieved power = 0.87, and the duration of the second flight phase, $F(1, 14) = 26.08$, $p < 0.01$, Cohen's $f = 1.37$, achieved power > 0.99 . However, after applying Holm's correction, the interaction effect for the duration of the hurdle became non significant. We found additional main effects of Expertise for the duration of the take-off phase, $F(1, 14) = 12.76$, $p < 0.01$, Cohen's $f = 0.95$, achieved power = 0.71, and the duration of the second flight phase, $F(1, 14) = 19.75$, $p < 0.01$, Cohen's $f = 1.19$, achieved power = 0.73. The main effect of Expertise for the duration of the repulsion phase, $F(1, 14) = 6.08$, $p < 0.05$, Cohen's $f = 0.66$, achieved power = 0.94, became non significant after applying Holm's correction. Furthermore, we found a significant main effect of Experimental Condition for the duration of the repulsion phase, $F(1, 14) = 7.28$, $p < 0.01$, Cohen's $f = 0.72$, achieved power = .82, and a main effect of Experimental Condition for the dura-

tion of the second flight phase, $F(1, 14) = 7.73$, $p < 0.01$, Cohen's $f = 0.74$, achieved power > 0.99 , that became non significant after applying Holm's correction.

Experts exhibited shorter contact times of the take-off phase as compared to apprentices. Participant's average duration of the repulsion phase was longer in the binocular condition as compared to the monocular condition. This effect was mainly driven by a longer duration of the repulsion phase of apprentices in the binocular condition and a similar duration of the repulsion phase of apprentices in the monocular condition as compared to experts. The second flight phase was in general shorter in apprentices. Surprisingly, apprentices exhibited up to 26% longer duration of the second flight phase in the monocular condition as compared to the binocular condition. Furthermore, experts showed a shorter duration of the take-off phase as compared to apprentices (Figure 2).

Gaze behavior

On the level of gaze behavior it was hypothesized that experts show fewer fixations of longer duration, as well as shorter blink duration when compared to apprentices. We had no specific predictions on the effect of Experimental Condition on any of the gaze behavior parameters. However, it was reasoned that if the elimination of binocular vision leads to differences in gaze behavior in either experts or apprentices, this would answer the question of an adaptive gaze behavior, and thus if this is dependent on expertise level or not.

The ANOVAs revealed significant interaction effects of Experimental Condition \times Expertise for amount of fixations, $F(1, 14) = 15.04$, $p < 0.01$, Cohen's $f = 1.04$, achieved power = 0.94, and fixation duration, $F(1, 14) = 12.21$, $p < 0.01$, Cohen's $f = 0.93$, achieved power = 0.91, We found additional main effects of Expertise for fixation duration, $F(1, 14) = 24.17$, $p < 0.01$, Cohen's $f = 1.34$, achieved power = 0.98, and blink duration, $F(1, 14) = 20.84$, $p < 0.01$, Cohen's $f = 1.22$, achieved power = 0.76, as well as a significant main effect of Experimental Condition for amount of fixations, $F(1, 14) = 18.24$, $p < 0.01$, Cohen's $f = 1.14$, achieved power = 0.95.

Participants exhibited fewer fixations in the mo-

nocular condition as compared to the binocular condition. This effect was mainly driven by differences in the amount of fixations in apprentices. Apprentices showed more fixations in the binocular condition as compared to the monocular condition. The fixation duration was in average longer in experts as compared to apprentices. However, apprentices showed similar fixation durations in the monocular condition as compared to the experts. Finally, the summed blink duration was longer in apprentices as compared to experts in both, the binocular and the monocular condition (Figure 3).

Discussion

The main goal of this study was to investigate the role of binocular vision in gymnasts as they perform a complex whole body movement, namely the handspring on vault. We approached this goal by asking experts and apprentices to perform handsprings on vault under binocular and monocular vision conditions. We expected differences in gaze behavior and movement performance between experts and apprentices. Additionally, we explored differences in movement performance and gaze behavior between monocular and binocular vision conditions.

Based on the results of our study it can be concluded, that experts as well as apprentices use visual information during the handspring on vault because they show fixations throughout the whole movement. Fixations to informational areas that are relevant for movement control when specific constraints are met could be part of a perceptual strategy to control handsprings on vault (Pelz and Canosa, 2001). Apprentices showed more fixations in the binocular condition as compared to the monocular condition. The fixation duration was in average longer in experts as compared to apprentices. However, apprentices showed similar fixation durations in the monocular condition as compared to the experts.

Fixation duration varies remarkably depending on the nature and difficulty of the task, as well as depending on the involved cognitive processes. In sport, relatively long fixation durations (> 800 ms) are found in complex viewing conditions whilst in familiar tasks or in practiced

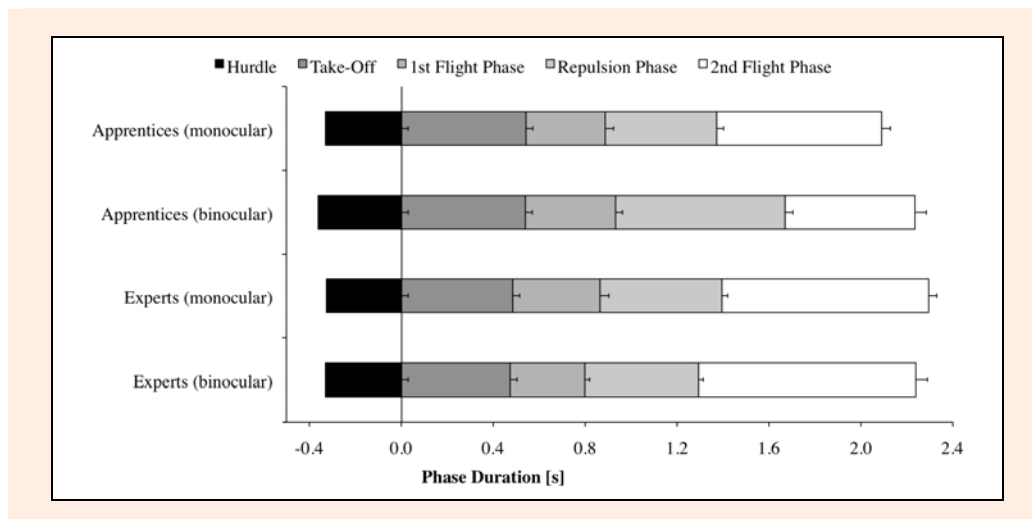


Figure 2. Experts' and apprentices' duration of movement phases of the handsprings on vault in the binocular and monocular condition (means \pm standard errors). The durations are scaled to the beginning of the take-off phase (0.0 seconds).

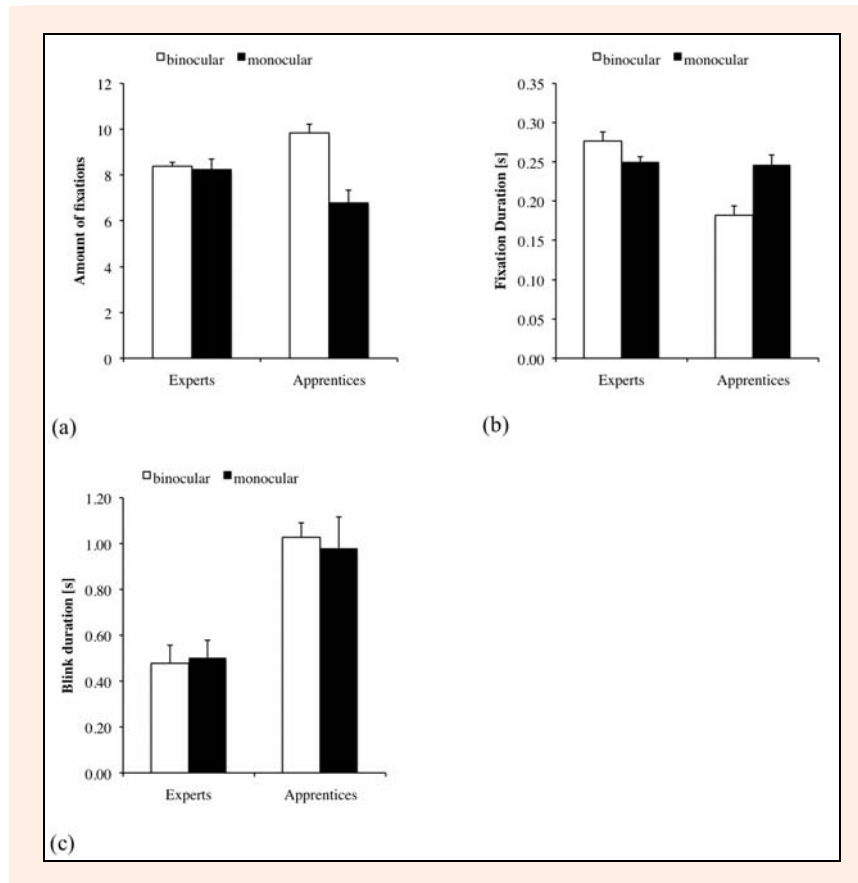


Figure 3. Amount of fixations (a), fixation duration (b), and summed blink duration (c) in experts and apprentices in the binocular and monocular condition (*means \pm standard errors*).

performers, durations about 200 ms are reported (Vickers, 2007; Williams et al., 1999). Shorter fixations may result if the arousal of the participant increases. Longer fixations may result if higher cognitive processes are involved during task execution. In general, fewer fixations with a longer duration in the same movement time could be an optimization strategy for visual information pickup (Vickers, 2007; Williams and Davids, 1998). An optimized visual information pickup could in turn lead to optimized movement planning and regulation (Land and Furneaux, 1997; Luis and Tremblay, 2008).

The summed blink duration was longer in apprentices as compared to experts, but it was not affected by eliminating binocular vision. During blinks the eyelid covers the eyeball so that visual information pickup is suppressed (Vickers, 2007). When the eyes are open, peripheral vision could provide information as to one's orientation in space even during head velocities that would prohibit the vestibulo-ocular reflex (cf., Roy and Tomlinson, 2004) from allowing the eyes to focus on stationary environmental cues (Bardy and Laurent, 1998; Davlin et al., 2001a; Hondzinski and Darling, 2001). If visual information pickup is suppressed during a blink, the athlete has to rely on other sources of sensory information to estimate current body orientation in space.

Movement performance was mainly influenced in apprentices when eliminating binocular vision. Apprentices' repulsion phase was shorter and their second flight phase was longer when compared to the binocular condition, and similar when compared to the phase durations of

the experts, leading to an optimization of handspring performance, which in turn may have resulted from a higher level of kinetic energy at the beginning of the handsprings (Brüggemann, 1994; Sands, 2011). Following the argumentation of Luis and Tremblay (2008), optimally selected vision withdrawal can lead to a significant improvement in performance. This may explain, why apprentices' but not experts performance was affected by eliminating binocular vision, because, the experienced performer quickly adapts his or her motor behavior to make optimal use of whatever sources of information the movement environment provides (Elliott and Lyons, 1998). It seems likely that eliminating binocular vision might improve performance parameters related to the repulsion phase (which enables the athlete to have enough flight time during the second flight phase), because velocity information is available more directly through vision (looming information) than through mechano-receptors or otoliths (Lee et al., 1992). One could speculate, that apprentices relied more on visual information such as monocular time-to-contact information leading to a better anticipation of the repulsion phase, which in turn might have optimized the second flight phase. This could explain why apprentices optimized their handspring performance in the monocular condition.

We are aware of some critical issues within the study that need to be taken into account and want to highlight three specific aspects. First, we manipulated binocular vision throughout the whole movement but did not manipulate binocular vision during specific movement

phases. It was assumed, that binocular vision is most important for spatial orientation, because it enables athletes to extract precise information about the locations of objects in three dimensions (Jackson et al., 1997). This function is needed to guide accurate interactions with the environment, such as take-offs, push-offs or landings, even when the environment is stationary. Therefore, subsequent studies should incorporate the manipulation of binocular vision or other visual cues during movement phases, which serve the function to interact with the environment. This could answer the question how information from different visual sources is weighted during distinct phases of complex movements (Vickers, 2007).

Second, we decided to compare apprentices and experts in order to determine the extent to which the athletes' gaze contributes to performance when eliminating binocular vision. We recruited a rather small sample of $N = 16$ participants ($n = 8$ apprentices and $n = 8$ experts). We acknowledge that this is a potential limitation with regard to the generalization of our results. However, a post-hoc power analysis on our results revealed that the average power for all significant results was above .80, which we assume as sufficient given the design of our study (Cohen, 1988).

Third, we concluded, that eliminating binocular vision might be part of an optimization strategy for apprentices. This may also be concluded from additional research, showing positive effects of directing learner's gaze in the acquisition of a handspring on vault (Heinen et al., 2011). However, we did not assess the influence of eliminating binocular vision in the learning process of a handspring on vault, but recruited apprentices with gymnastics experience gained from successful participation in the basic and advanced courses in gymnastics of the German Sport University Cologne. A subsequent study could comprise a learning experiment, analyzing the elimination of different visual informational sources, such as binocular vision, in the acquisition, retention and transfer of a handspring on vault. Assuming, that additional changes in perception and cognition might occur, it may also be wise to use specific methods in order to assess these changes (Magill, 2007).

We showed that athletes show fixations in the handspring on vault. Assuming that athletes can extract orientation information by fixating their gaze on distinct areas, the coach should encourage learners to intentionally use distinct fixations in the acquisition of a handspring on vault (Heinen et al., 2011), because additional empirical evidence from easy and complex tasks suggests that nearly all fixations are task-related and only a small fraction (about 5%) are irrelevant (Land et al., 1999). Furthermore, it could be fruitful to ask learners to perform complex skills such as a handspring on vault with reduced or even eliminated binocular vision if they are already able to perform the skill without additional external support, because in our study, movement performance was optimized in apprentices under the monocular condition.

Conclusion

Taken the results of our study together, we state that binocular vision may not be necessary for experts when per-

forming handsprings on vault. Experts may more strongly rely on other than visual information during handspring performance, which has yet to be analyzed. Apprentices however seem to be able to optimize both, gaze behavior and movement performance when binocular vision is eliminated. From this we conclude, that binocular vision may hamper performance in apprentices because they might need other visual information when trying to optimize handspring performance under binocular vision (Proteau, 1992). However, we state, that such a strategy should only be incorporated in the training process when learner's safety can be assured (e.g., by using manual guidance to give additional support). We conclude that knowledge about gaze-movement relationships may be beneficial for coaches when teaching the handspring on vault in gymnastics.

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References

- Abernethy, B. and Russell, D.G. (1987) The relationship between expertise and visual search strategy in a racquet sport. *Human Movement Science* **6**, 283-319.
- Arkaev, L.I. and Suchilin, N.G. (2004) How to create champions. The theory and methodology of training top-class gymnasts. Meyer & Meyer Sport, Oxford.
- Bardy, B.G. and Laurent, M. (1998) How is body orientation controlled during somersaulting? *Journal of Experimental Psychology: Human Perception and Performance* **24**(3), 963-977.
- Brüggemann, G.P. (1994) Biomechanics in gymnastics techniques. *Sport Science Review* **3**(2), 79-120.
- Cohen, J. (1988) *Statistical power analysis for the behavioral sciences*. 2nd edition. Lawrence Erlbaum, New York.
- Coull, J., Tremblay, L., Elliott, D., Weir, P.L. and Weeks, D.J. (2000) Monocular and binocular vision in the control of goal-directed movement. *Journal of Motor Behavior* **32**(4), 347-360.
- Davlin, C.D., Sands, W.A. and Shultz, B.B. (2001a) Peripheral vision and back tuck somersaults. *Perceptual and Motor Skills* **93**, 465-471.
- Davlin, C.D., Sands, W.A. and Shultz, B.B. (2001b) The role of vision in control of orientation in a back tuck somersault. *Motor Control* **5**, 337-346.
- Davlin, C.D., Sands, W.A. and Shultz, B.B. (2004) Do gymnasts "spot" during a back tuck somersault? *International Sports Journal* **8**(2), 72-79.
- Elliott, D. and Lyons, J. (1998) Optimizing the use of vision during motor skill acquisition. In: *Motor behavior and human skill: a multidisciplinary approach*. Ed: Piek, J. Champaign, Human Kinetics. 57-72.
- Heinen, T., Vinken, P. and Fink, H. (2011). Directing learner's gaze enhances skill acquisition in gymnastics. *Athletic Insight Journal*, **3**(2), 1-17.
- Hondzinski, J.M. and Darling, W.G. (2001) Aerial somersault performance under three visual conditions. *Motor Control* **5**, 281-300.
- Jackson, S.R., Jones, C.A., Newport, R. and Pritchard, C. (1997) A kinematic analysis of goal-directed prehension movements executed under binocular, monocular, and memory-guided viewing conditions. *Vision and Cognition* **4**, 113-142.
- Knudson, D. (2009) Significant and meaningful effects in sports biomechanics research. *Sports Biomechanics* **8**(1), 96-104.
- Lundbrook, J. (1998) Multiple comparison procedures updated. *Clinical and Experimental Pharmacology and Physiology* **25**, 1032-1037.
- Land, M.F. and Furneaux, S. (1997) The knowledge base of the oculomotor system. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences* **352**, 1231-1239.
- Land, M. F., Mennie, N. and Rusted, J. (1999) The roles of vision and eye movements in the control of activities of daily living. *Per-*

- ception **28**, 1311-1328.
- Lee, D.N., Young, D.S. and Rewt, D. (1992) How do somersaulters land on their feet? *Journal of Experimental Psychology: Human Perception and Performance* **18(4)**, 1195-1202.
- Luis, M. and Tremblay, L. (2008) Visual feedback use during a back tuck somersault: Evidence for optimal visual feedback utilization. *Motor Control* **12**, 210-218.
- Magill, R.A. (2007) *Motor learning and control. Concepts and applications*. 8th edition. McGraw-Hill, New York.
- Mikromak. (2008) WINalyze 3D (ver. 2.1.1). Berlin, Germany.
- Olivier, I., Weeks, D.J., Lyons, J., Ricker, K.L. and Elliott, D. (1998) Monocular and binocular vision in one-handed ball catching: Interocular integration. *Journal of Motor Behavior* **30**, 343-351.
- Patla, A.E., Niechwiej, E., Racco, V. and Goodale, M.A. (2002) Understanding the contribution of binocular vision to the control of adaptive locomotion. *Experimental Brain Research* **142**, 551-561.
- Pelz, J.B. and Canosa, R. (2001) Oculomotor behavior and perceptual strategies in complex tasks. *Vision Research* **41**, 3587-3596.
- Proteau, L. (1992) On the specificity of learning and the role of visual information for movement control. In: *Vision and Motor Control*. Eds: Proteau, L. and Elliott, D. Amsterdam: Elsevier. 67-103.
- Porac, D. and Coren, S. (1986) Sighting dominance and egocentric localization. *Vision Research* **26**, 1709-1713.
- Raab, M., de Oliveira, R.F. and Heinen, T. (2009) How do people perceive and generate options? In: *Progress in brain research: vol. 174. Mind and motion: the bidirectional link between thought and action*. Eds: Raab, M., Hekeren, H. and Johnson, J.G. Amsterdam: Elsevier. 49-59.
- Rézet, D. and Amblard, B. (1985) Orientation versus motion visual cues to control sensorimotor skills in some acrobatic leaps. *Human Movement Science* **4**, 297-306.
- Roy, F.D. and Tomlinson, R.D. (2004) Characterization of the vestibulo-ocular reflex evoked by high velocity movements. *The Laryngoscope* **114(7)**, 1190-1193.
- Sands, W. (2011) Linear kinematics applied to gymnastics. In: *The science of gymnastics*. Ed: Jemni, M. London: Routledge, 57-75.
- Schwarz, W. (1992) Do two eyes really see more than one? *Journal of Mathematical Psychology* **36**, 269-277.
- Vickers, J.N. (2007) *Perception, cognition and decision training: The quiet eye in action*. Human Kinetics, Champaign.
- von Laßberg, C., Mühlbauer, T. and Krug, J. (2003) Spatial orientation during fast body rotations in horizontal plane. In: *European workshop on movement science. Mechanics-Physiology-Psychology*. Eds: Schöllhorn, W.L., Bohn, C., Jäger, J.M., Schaper, H. and Alichmann, M. Cologne, Sport und Buch Strauß. 96.
- Williams, A.M., Davids, K. and Williams, J.G.P. (1999) *Visual perception and action in sport*. London, E.& F.N. Spon.
- Williams, A.M. and Davids, K. (1998) Visual search strategy, selective attention, and expertise in soccer. *Research Quarterly for Exercise and Sport* **69**, 111-128.

Key points

- Skills in gymnastics are quite complex and the athlete has to meet temporal and spatial constraints to perform these skills adequately. Visual information pickup is thought to be integral in complex skill performance. However, there is no compelling evidence on the role of binocular vision in complex skill performance.
- The study reveals, that apprentices optimize their gaze behavior and their movement behavior when binocular vision is eliminated, whereas experts gaze behavior and movement behavior is uninfluenced by eliminating binocular vision.
- We state, that binocular vision is not necessary for experts to perform to their best. However, eliminating binocular vision could be part of an optimization strategy for apprentices, which could in turn be transferred to new training programs.

AUTHORS BIOGRAPHY



Thomas HEINEN

Employment

Post-Doctoral Research Fellow at the German Sport University Cologne

Degrees

PhD, Diploma in Sport Sciences

Research interests

The role of vision in complex skills.

E-mail: t.heinen@dshs-koeln.de



Pia M. VINKEN

Employment

Scientific Coworker at the Leibniz University Hannover

Degrees

Diploma in Sport Sciences

Research interests

Sensorimotor integration in the perception of complex skills.

E-mail: pia.vinken@sportwiss.uni-hannover.de

✉ Thomas Heinen

German Sport University Cologne, Institute of Psychology, Am Sportpark Muengersdorf 6, 50933 Cologne, Germany