



## Registered reports

## Gaze behavior of trampoline gymnasts during a back tuck somersault



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## ABSTRACT

In trampolining, gymnasts perform a variety of rotational jumping elements and have to demonstrate perfect control of the body during the flying phase. The performance of a somersault should include an opening phase, i.e. the legs are fully extended pointing vertically at 180° called “kick-out”. As previous studies have shown, gaze behavior is essential for the controlling during the flight phase and to prepare for a perfect landing. Gymnasts supposedly use the trampoline bed as orientation and differences in gaze behavior can be expected, depending on how a somersault is performed. The present study investigates the gaze behavior of gymnasts during a back tuck somersault on the trampoline. Eleven experienced trampoline gymnasts performed back tuck somersaults with and without a kick-out while wearing a light weight portable eye-tracking device. All subjects fixated their gaze on a specific point at the trampoline bed and thus used visual information to prepare for landing. During the period of fixation, gymnasts' eyes moved continuously downwards to counteract the backwards head movement. The point of fixation differed between each somersault. Apparently, the fixation position depended on the gymnast's landing position in the bed. Performing a somersault with a kick-out allows gymnasts to orient themselves earlier and thus prepare sooner for landing. Unexpectedly, gymnasts of a higher performance class fixated the bed later compared to less experienced athletes. Supposedly, gymnasts of a better class can allow themselves to fixate later in order to optimize the form and execution of a somersault.

## 1. Introduction

In trampolining, gymnastics, springboard or platform diving athletes perform difficult somersault variations including several rotations around the body axes in the air. The *Fédération Internationale de Gymnastique* (FIG) defined in their “Code of points” that “a trampoline routine should be planned to demonstrate a variety of forward and backward twisting or non twisting elements [...]” (FIG, 2017). The single back tuck somersault is one of the most fundamental elements in trampolining. During the flight phase gymnasts complete a 360° backwards rotation around the transverse body axis. In the advanced training process, when the somersault is mastered safely, young athletes learn to perform an opening-phase, the so-called “kick-out” (FIG, 2017). Gymnasts perform the kick-out by stretching their legs towards the ceiling about halfway through the somersault to decelerate the angular velocity

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(Bardy & Warren, 1997; Yeadon & Mikulcic, 2000). In the second part of the somersault, gymnasts fly in a straight position until the element is completed by landing on the trampoline bed. The biomechanics of somersaults with and without twists have already been analyzed extensively (Blajer & Czaplicki, 2001; Prassas, Kwon, & Sands, 2006; Yeadon, 1993).

However, gymnasts' gaze behavior has not been studied sufficiently although it is important to orientate in the air and to control a perfect landing (Heinen, Velentzas, & Vinken, 2012a; Luis & Tremblay, 2008; Sato, Torii, Sasaki, & Heinen, 2017). Several authors argued that vision is crucial for receiving information in the flight phase to prepare for landing (Davlin, Sands, & Shultz, 2004; Heinen, Velentzas, & Vinken, 2012b; Lee, Young, & Rewt, 1992; Marinšek, 2010). Hence, in various studies the athletes' landing was measured or evaluated by judges in different visual conditions (Sands, 1991; Bardy & Laurent, 1998; Davlin, Sands, & Shultz, 2001b; Hondzinski & Darling, 2001; Rézette & Amblard, 1985). Davlin, Sands, and Shultz (2001a) asked ten female gymnasts to perform back tuck somersaults under four vision conditions: Full vision, no vision, vision only in the first half and vision in the second half of the somersault. They found that the landing balance was affected by the presence or absence of vision, i.e. the balance was less stable when gymnasts' vision was occluded compared to the condition with full vision. Luis and Tremblay (2008) used liquid crystal goggles to manipulate the gymnasts' vision and found that all visual conditions that allowed at least some vision resulted in significantly better landing scores than in the no-vision condition. Heinen, Jeraj, Vinken, and Velentzas (2012) used a variable light spot on the mat, which the gymnasts should fixate during a backward somersault on uneven bars and concluded that "fixating the gaze towards the landing mat serves the function to execute the skill in a way to land on a particular location." Therefore, it can be concluded that gymnasts use vision to assist landing performance and location.

Nevertheless, these studies were limited due to indirect methods used to measure visual information and eye movement (Davlin et al., 2001a; Kredel, Vater, Klostermann, & Hossner, 2017). In their review about research of the natural gaze behavior in sports Kredel et al. (2017) distinguished direct and indirect methods. Direct methods require the application of eye-tracking devices whereas indirect methods are based on the so-called occlusion paradigm that obstructs relevant visual cues. These indirect methods, however, have been repeatedly criticized as natural visual information pick-up is considerably restricted (Kredel et al., 2017). Due to the high angular velocities during somersaults, light-weighted mobile eye tracking devices with high sampling frequencies are needed to capture gymnasts' eye movements directly (Andersson, Nystr, & Holmqvist, 2010; Kredel et al., 2017). Therefore, Heinen, Velentzas, and Vinken (2012a) developed an eye-tracking prototype that allows to measure gaze behavior during complex skill performance. Their system consisted of a modified bicycle helmet and reaches a frequency of 50 Hz and weighs only 250 g.

With this device Heinen (2011) confirmed the "spotting" hypothesis and found that all participants in their study showed at least one fixation during the somersaults, thereby showing visual spotting. Davlin et al. (2004) defined "spotting as an intentional strategy in which gymnasts briefly decrease head velocities in an attempt to fix their gaze and use available visual information." Huber (2016) described spotting as a process of clearly seeing specific visual cues at specific times during rotations. Athletes attempt to fixate their gaze on specific locations like the bed in trampolining, the floor in gymnastics or the water surface in diving to enable the visual system to provide information on orientation needed in the performance of an aerial skill (Heinen, 2011; Huber, 2016; Neggers & Bekkering, 2000; Raab, de Oliveira, & Heinen, 2009). Heinen, Velentzas, and Vinken (2012b) analyzed the relationship between gaze behavior and movement kinematics when performing high bar dismounts using the eye tracking device connected with an optical movement-analysis system. They identified that gymnasts used fixations to serve specific movement goals and emphasized the importance of visual information in skills with rotations around the body axes. Furthermore, they revealed a correlation between fixation direction and landing position. Raab et al. (2009) used a telemetric eye-tracking system to capture the gaze behavior during a basketball jump shot, ball allocation in handball and trampoline somersaulting. They plotted the gaze direction in the vertical axis over the percentage of movement time in a back tuck and back straight somersault ascertaining that the eyes rotate upwards to fixate on the ceiling when taking-off from the trampoline. Afterwards, the eyes move upwards again to anticipate the trampoline bed in preparation for the landing. They concluded that trampoline gymnasts use their gaze on specific fixation points to pick up information about their rotation speed and positioning for adjustments in the air and to prepare the somersault landing (Raab et al., 2009). It is already known that the vestibulo-ocular reflex (VOR) helps to hold vision during head motion by moving the eyes contrary to the head to stabilize the retinal image (Fetter, 2007; Pulaski, Zee, & Robinson, 1981; Von Laßberg, 2007). Nevertheless, the VOR has been rarely analyzed in sports-specific tasks such as twisting or non-twisting somersaults (Heinen, Velentzas, & Vinken, 2012a).

Based on this, three hypotheses are described below, which will be investigated in the current study in order to get further knowledge of the gaze behavior of trampoline gymnasts during a back tuck somersault. First, this study examines the gaze direction from take-off to landing of eleven gymnasts to determine gaze similarities or differences, as well as to investigate the influence of the mechanisms of fixation stabilization in a backwards somersault. Supposedly, gymnasts will use the trampoline bed as orientation and fixate their gaze on fixed positions (Heinen, Velentzas, & Vinken, 2012a; Raab et al., 2009). Furthermore, the gymnasts' eyes compensate the head movement, to stabilize the retinal image in the somersault (Fetter, 2007). Secondly, the correlation between the landing position and the fixation point on the trampoline bed at each somersault will be calculated to analyze whether the center of mass' trajectory and thus the landing position has an influence on the fixation point. It is hypothesized that a correlation between the landing position and fixation exists insofar as the fixation points depend on the corresponding landing positions (Heinen, Jeraj, et al., 2012). Thirdly, the influence of the kick-out on gaze behavior in trampolining will be scrutinized regarding specifically the onset of the fixation to detect the benefits of performing a kick-out in a somersault. It is presumed that by decelerating their rotation speed with the kick-out, gymnasts will see the bed earlier and thus have more time to prepare for landing. It can be assumed that gymnasts of a higher performance class can orientate themselves sooner and thus start their fixation earlier (Heinen, 2011; Raab et al., 2009).

## 2. Methods

### 2.1. Subjects

Eleven healthy subjects (5 male, 6 female, age:  $23 \pm 3$  years, body mass:  $70 \pm 10$  kg, and body height:  $172 \pm 8$  cm) participated in the study after signing the informed consent form. They were active gymnasts with at least nine years of experience in trampolining and participation in national and international competitions. The subjects' training intensity was one to five exercises per week and all of them have practiced the back somersault for more than eight years. The subjects were divided into two performance classes defined by the highest competition ever participated in. The participants of performance class 1 ( $n = 7$ ) participated in German national competitions like the German Championship or German University Championship. The gymnasts of performance class 2 ( $n = 4$ ) participated in international competitions like the *World-Age-Group Competitions*. None of the gymnasts wore glasses during trampolining, thus all recordings were performed without corrective lenses mounted to the eye tracker. The study was approved by the local ethics committee of the Department of Sports Science and Psychology of the University of Muenster (# 2018–50-JN).

### 2.2. Experimental setup

The subjects were asked to perform single back tuck somersaults on a trampoline while wearing an eye-tracking device. A *Grand Master Exclusiv* trampoline (Eurotramp, Germany) with a  $4 \times 6$  bed was used. The gymnasts had to perform 20 back tuck somersaults overall, ten of which they performed with kick-out and ten without kick-out. The order of conditions was randomized. An acoustic metronome provided timing orientation in order to reach a time of flight of about 1.3 s. After reaching the correct jump height, participants were given a start signal allowing them to execute the somersault. If a somersault was not finished in a straight body position or the gymnast had to stop directly when landing, the trial was repeated directly. The somersaults were divided into four runs of five somersaults with a break in between to prevent physical fatigue. Before the first run gymnasts were given warm-up time as much as they needed.

All somersaults were recorded by two cameras (*HERO4*, GoPro, USA) with a sampling rate of 120 frames per second. One of the cameras was positioned central at the height of the trampoline bed so that the time stamps of leaving and reaching the trampoline bed could be recorded afterwards, to determine the gymnast's time of flight. The second camera was positioned central at a height of approximately three meters and was directed to the bed as well as the gymnasts. These recordings were used to determine the take-off and landing position in the trampoline bed.

### 2.3. Eye-tracking device

The eye-tracking device (*Tobii Pro Glasses 2*, Tobii AB, Sweden) consisted of a head unit (45 g) and a recording unit (312 g) connected by a thin cable. The head unit was composed of protective lenses, a front scene camera ( $1920 \times 1080$ ; 25 fps; recording angle:  $82^\circ$  horizontal,  $52^\circ$  vertical) and two more cameras for each eye, to record the eye movements with a sampling rate of 100 Hz. The head unit was attached to the head with an elastic strap and additionally fixated with an elastic band. The recording unit was fastened around the waist with a belt. The system was connected wirelessly to the measuring computer while the data was stored on an intern SD card. The eye-tracking device was synchronized with the two cameras using an LED trigger. After the systems had been started, the subject had to look at the LED, which was then triggered by a button manually.

### 2.4. Data analysis

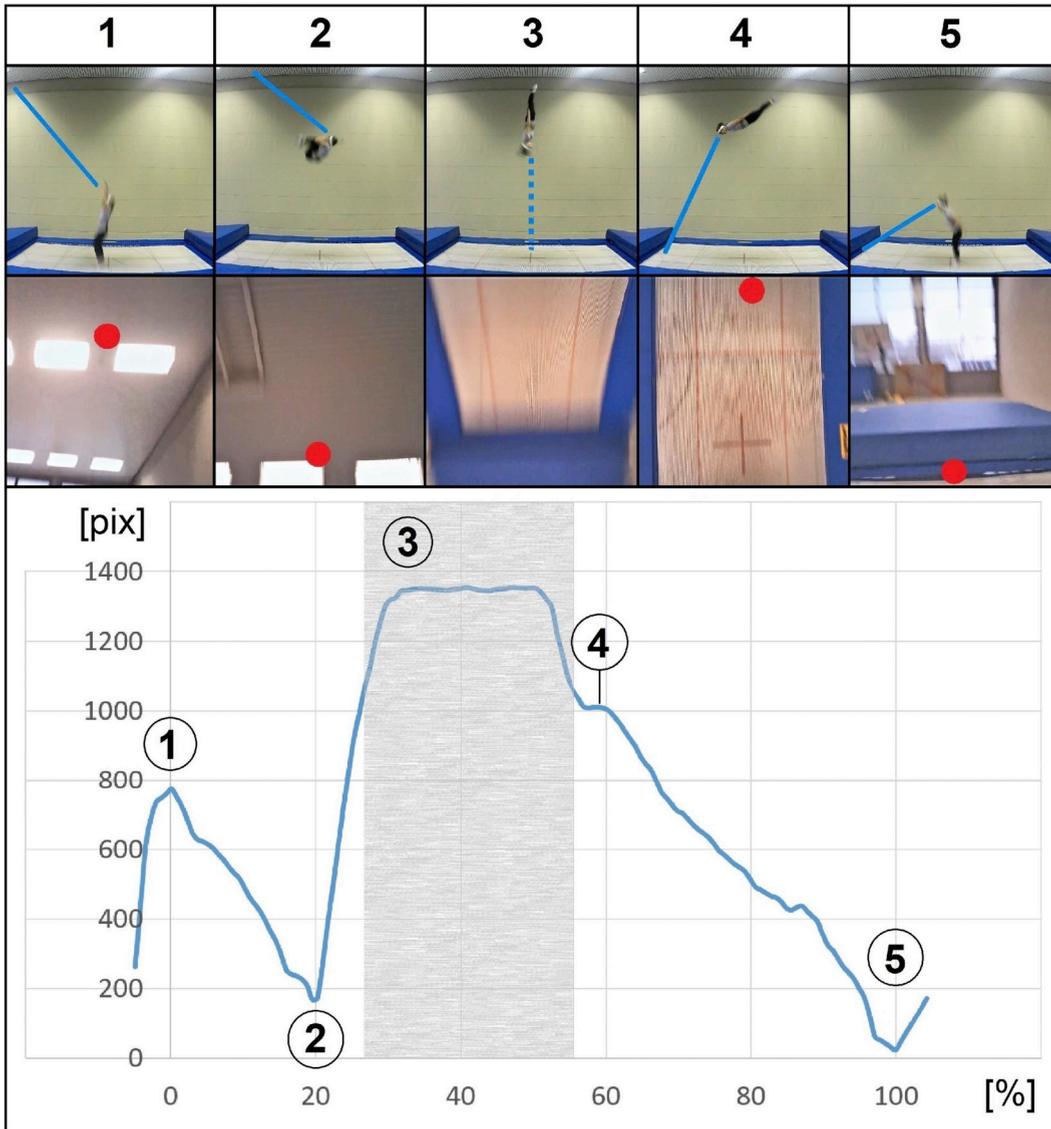
The eye-tracking data was processed using the program *Tobii Pro Lab*. Somersaults with a time of flight less than 1.2 s and more than 1.4 s were excluded from the analysis. 206 trials were edited from the take-off (0%) to the landing (100%). The eye movement in relation to the head movement can be exported as x and y coordinates in the front camera movies. If the gaze was outside the front camera view angle the eyes' position had to be interpolated manually by using the eye movies (Fig. 1, gray range). In this case, however, it is not possible to detect where the gymnast looked at, but only to capture the eyes' position in the head.

A fixation was defined if the gaze was directed at a specific position on the trampoline bed for at least 100 ms (Heinen, 2011). Based on a fixation period, the first time stamp was captured when the gymnast focused at that specific point. The time stamp can also be defined as the last local maximum in the graph before the fixation period (Fig. 1, timestamp 4). This time stamp was determined as the start of fixation in percent of the time of flight (Fig. 2, left first red point).

The trampoline bed was used as a one-dimensional coordinate system for measuring the distance between the landing and gaze position in each somersault with a kick-out. The bed has a total length of 4.12 m and the red cross in the middle of a trampoline bed was defined as the origin (Fig. 3). Using the front scene camera movies of the eye tracking device and the movies of the camera directed to the gymnast from the side, fixation and landing distances to the origin were evaluated in centimeters in relation to the overall length of 4.12 m.

### 2.5. Statistical analysis

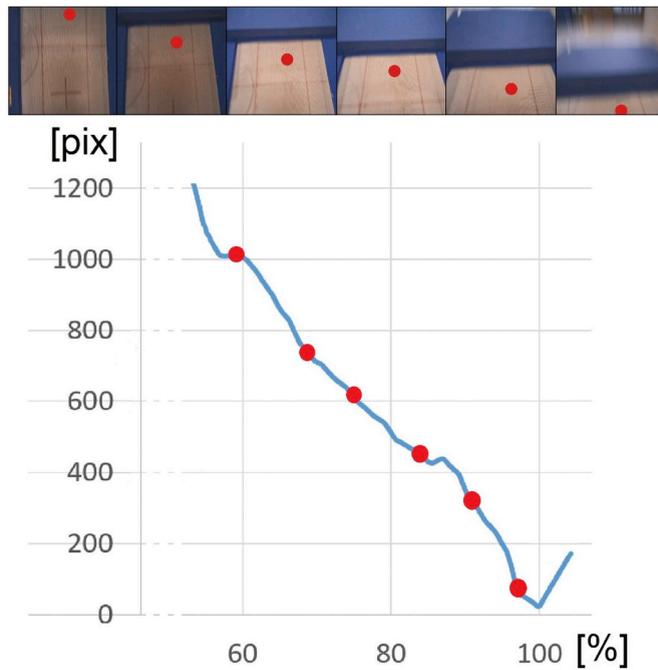
First, the position of the landing was compared to the position of fixation in each somersault with a kick-out. In order to determine the correlation between these two parameters, a type-2 regression was calculated in SPSS. Since there are multiple data points per



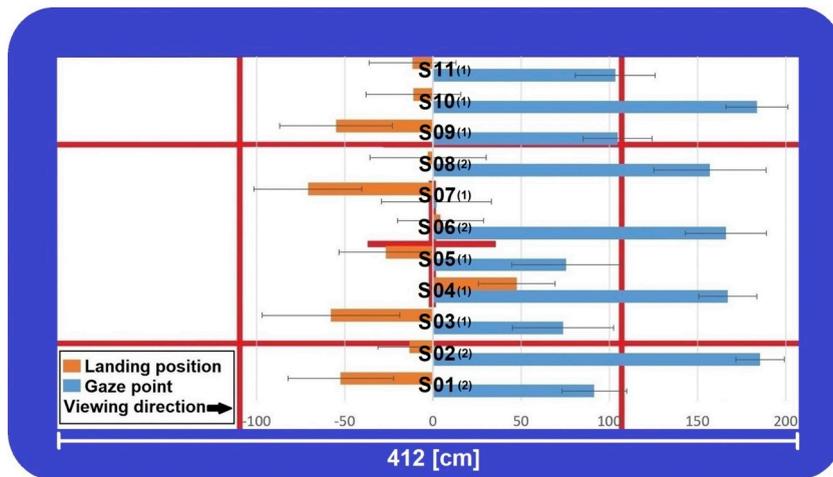
**Fig. 1.** Gaze behavior of a trampolining gymnast during a back tuck somersault. Top: Five different phases of the somersault. 1: Take-off, 2: Tuck position, 3: Kick-out, 4: Start of fixation, 5: Landing. The gaze point in the front camera is marked with a red dot. Bottom: Vertical gaze point in the front camera in pixel plotted over the time of flight. The five phases of the top picture series are represented in the graph by the respective numbers. The gymnast's gaze was outside the front camera between about 30% and 55%. Therefore, this area is grayed out and the line in the third frame is dashed because the gaze direction was interpolated using the eyes' position in the head (see section 2.4). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

participant, the factor “subject” was included in addition to the landing position, both as independent variables, and the factor “fixation point” was taken as the dependent variable. Furthermore, the interaction between the factors “landing position” and “subject” was included in the analysis to account for the variation in the effect of landing position on the position of fixation across participants. Based on Cohen's rule of thumb, values of  $r$  are interpreted as small, medium, and large, if they range around 0.1, 0.3, and 0.5 (Cohen, 1988).

Secondly, the effect of two factors on the onset of fixation was analyzed: the performance class (1, 2 = more experienced) and the somersaults with or without a kick-out (0 = without, 1 = with). Since this data structure requires a mixed model with one within-subject factor (kick-out) and one between-subject factor (performance class), a linear model (LM) analysis was performed instead of an ordinary ANOVA. The LM analysis using a likelihood ratio test was performed based on a  $\chi^2$ -statistics rather than on an F-statistics, so there are no F-values to report. Instead, the  $\chi^2$ -values and, additionally, the effect sizes in terms of Cramer's  $\phi$  (also known as Cramer's  $V$ ) were reported. The effect sizes were then interpreted according to Cohen's rule of thumb for 1 degree of freedom ( $df = 1$ , corresponding to two factor levels), so that values for  $\phi$  around 0.1, 0.3, and 0.5 were interpreted as small, medium, and large,



**Fig. 2.** Display detail of Fig. 1 in the range of 50% to 100%. Gaze behavior of a trampoline gymnast in the period of fixation. Top: Six subsequent phases within the period. The gaze point in the front camera is marked with a red dot. Bottom: Vertical gaze point in the front camera in pixels. The six phases of the top picture series are represented in the graph by red dots. The first time point corresponds to point 4 in Fig. 1. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)



**Fig. 3.** Illustration of landing positions and fixation points on the trampoline bed for the eleven subjects in all trials with a kick-out. The trampoline had a total length of 412 cm with the middle marked by a red cross and the quadrants marked by red lines. The viewing direction of the gymnasts was to the right side. The orange bars symbolize the mean values (M) and standard deviations (SD) of the gymnasts' landing positions. The blue bars indicate the M and SD of the fixation points in the trampoline bed. Subjects one to eleven are displayed on the y-axis while the numbers in parentheses define the classes. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

respectively (Cohen, 1988). In the model fit, random factors were included using an unstructured covariance structure.

The linear model was fitted using the statistical software R with the package 'lmerTest'. To obtain *p*-values for the main and interaction effects, a type-3 ANOVA-like analysis was performed on each fitted model using the command Anova from the 'car' package and the function lmer, according to the formula:

$$\text{FixOnset} \sim \text{PerfClass} + \text{KickOut} + \text{KickOut}:\text{PerfClass} + (1 \mid \text{Subject}) + (1 \mid \text{Subject}:\text{PerfClass}) \tag{1}$$

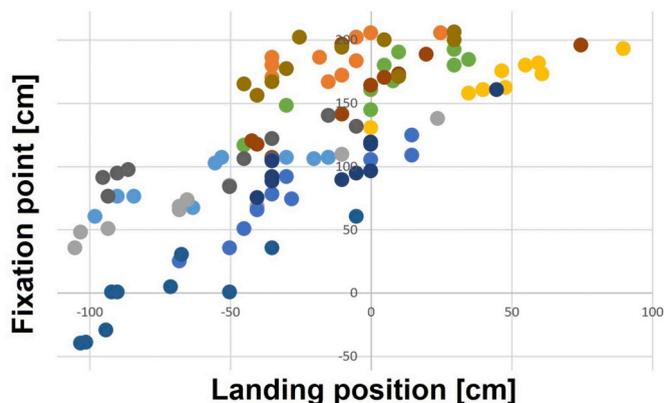


Fig. 4. Correlation between the gymnasts' landing positions (x-axis) and fixation points (y-axis) related to every somersault with a kick-out. Each colour presents one gymnast. The correlation coefficient over all 110 somersaults is approximately 0.75.

The FixOnset is the measured fixation onset, PerfClass is the subject's performance class, and KickOut is the variable whether or not the subject performed a kick-out during the somersault. The random factor Subject as well as the random interaction Subject:PerfClass were included. Beforehand, normal distribution was ensured using the Shapiro-Wilk test in SPSS Statistics. Furthermore, the collected data were tested for heteroscedasticity and they turned out to be not heteroscedastic.

Due to the number of multiple exploratory tests implemented in this study and to avoid type I errors, a Bonferroni-corrected alpha level of  $\alpha = 0.05/3$  was chosen, so p-values smaller than 0.017 indicate statistical significance.

### 3. Results

Gymnasts show fixations in each somersault by directing their gaze on a specific point on the trampoline bed over a period of at least 300 ms. As soon as the fixation is found, gymnasts keep their gaze on this point while the eyes move downwards (Fig. 1). The fixation point was always in front of the landing position. The average distance between the fixation point and the landing position is about 143 cm with a standard deviation of 40 cm (Fig. 3). A large correlation between the gymnasts' landing position and their fixation position was found ( $p < 0.0001$ ,  $r \approx 0.75$ ), while the factor "subject" did not have a significant influence ( $p > 0.82$ , Fig. 4). In the somersaults with a kick-out the onsets of fixation are significant earlier compared to the trials without a kick-out ( $p < 0.0001$ ). Gymnasts of performance class 2 start significantly later with their fixation in comparison to the subjects of class 1 ( $p < 0.001$ , Fig. 5).

Fig. 1 shows a measurement example of a back tuck somersault. In the upper part, there is a picture series of five phases during the somersault with synchronized pictures from the front camera and a camera that captured the whole gymnasts from the side. The gaze

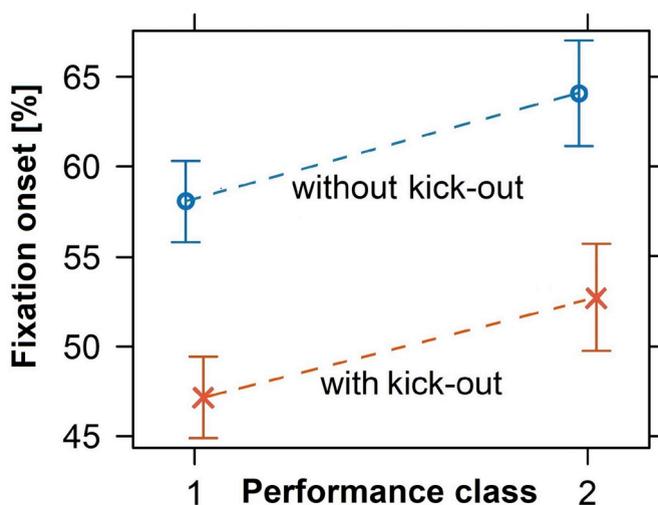


Fig. 5. Mean values and standard deviations of the start of fixation in all trials related to the conditions with and without a kick-out and the performance classes. X-axis: Performance classes, y-axis: Start of fixation in percent of the time of flight. Orange crosses present the somersaults with a kick-out, the blue circles present the trials without a kick-out. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

point in the front camera is marked with a red dot. In the lower part of the picture, the vertical gaze point is plotted over the time of flight. From the take-off (timestamp 1) until reaching the tuck position (2), the gymnast's eyes moved downwards. In this period, the gymnast focused a point at the ceiling. During the kick-out, the eyes moved far upwards until the trampoline bed appeared again in the athlete's field of view (3). Then the eyes rotated downwards until the subject had found the fixation point on the bed at about 60% of the somersault (4). With the beginning of the fixation period, the eyes continuously moved downwards till the gymnast landed on the trampoline bed (5). The gaze behavior of the subjects was always the same in the second half of the somersaults. Every participant started to fixate a point on the trampoline bed after the kick-out and kept that gaze direction until landing. However, the gymnasts' eye movements differed in the first half of the somersault. Three of the gymnasts closed their eyes immediately after the take-off and four subjects moved their eyes upwards rapidly as soon as they take-off until the bed appeared again in the gymnast's field of vision. Four of the gymnasts kept their eyes low at the beginning, as can be seen in Fig. 1.

In order to consider the fixation period more explicitly, Fig. 2 is a display detail from Fig. 1 in the range from 50% to 100%. In the upper part of Fig. 2, there is a new picture series based on the front camera in the gymnast's fixation period. With the beginning of the fixation at around 60%, the gymnast focused on a point in the trampoline bed (picture 1 from the left). In the following phases the gaze direction stayed at this specific point throughout the somersault, while the image of the camera and thus the field of view of the subject rotated upwards (pictures from left to right).

In this study, the positions of landings and positions of fixation points in the trampoline bed were measured in 110 somersaults with a kick-out. Mean values (M) and standard deviations (SD) of each gymnast's trial are shown in Fig. 3. Subject 2 and 10 landed almost exactly in the middle of the trampoline bed every time even though their fixation points were relatively far ahead ( $M_2 \approx 185$  cm,  $M_{10} \approx 183$  cm). Subject 7 often used the red cross in the bed as fixation point but had the rearmost landing positions with a mean of approximately  $-70$  cm. In Fig. 4, the individual fixation points and the corresponding landing positions of each somersault with a kick-out are displayed. The average distance between the gaze point and the landing was  $143 \pm 40$  cm (mean and standard deviation). With a correlation coefficient of  $r \approx 0.75$ , gymnasts' landing positions and fixation positions correlate with a large effect size. Furthermore, the landing position has a significant influence on the fixation point ( $p < 0.0001$ ). With a  $p$ -value of about 0.82 the factor "subject" revealed no significant influence on the fixation positions.

The influence of both the kick-out and the performance class on the percentage onset of fixation in the performed back tuck somersault turned out as follows (Fig. 5). With a kick-out, the performance classes 1 and 2 revealed average fixation onsets of  $47.1 \pm 3.9\%$  and  $52.9 \pm 4.1\%$ , respectively. Without kick-out, the fixation onsets occurred in both performance classes later, at  $58.1 \pm 4.9\%$  and  $64.1 \pm 4.1\%$ . The linear model analysis revealed significant differences in the main effects both between with and without a kick-out ( $p < 0.0001$ ,  $\chi^2 = 125.84$ ,  $\phi = 0.79$ ,  $df = 1$ ) and between the gymnasts fixation onsets of performance class 2 in comparison to the subjects of class 1 ( $p < 0.001$ ,  $\chi^2 = 13.05$ ,  $\phi = 0.26$ ,  $df = 1$ ). The effect sizes turned out to be large and medium.

#### 4. Discussion

The current study investigated the gaze behavior of eleven trampoline gymnasts in a back tuck somersault regarding the fixation points on the trampoline bed, the corresponding landing positions and the percentage onset times of fixations. Several authors examined the Spotting Hypothesis, which states that gymnasts show visual spotting by fixating a specific point and use this orientation to prepare for a better landing (Davlin et al., 2004; Heinen, 2011; Luis & Tremblay, 2008). This could be confirmed by this study as all gymnasts had a fixation period of at least 300 ms and thus showed visual spotting. By measuring the eye movements of all gymnasts it was shown that the gymnasts' eyes moved far up with the kick-out as they search the trampoline bed to use it as a fixation point.

When a gymnast establishes fixation on a spot on the bed, the eyes move downwards to counteract the rotational and translational head movement. This behavior is similar to the vestibulo-ocular reflex, which occurs during rotational head motion by moving the eyes contrary to the head (Fetter, 2007; Pulaski et al., 1981), and the optokinetic reflex, which move the eyes contrary to the translational visual flow pattern. Both reflexes stabilize the line of sight in space. Gymnasts try to fixate the same point on the trampoline bed in the flight time, but as the head rotates backwards the eyes have to move downwards in the head to stabilize the gaze. Fig. 2 confirms this behavior explicitly, as can be seen in the picture series that the gymnast's gaze was directed to the same point in the trampoline bed all the time, while the head rotated backwards. Raab et al. (2009) received same results and stated "by anchoring their gaze on fixed positions, gymnasts may be allowing themselves to pick up information about rotations that they can use for in-flight adjustments and to prepare the somersault landing." However, it seems that the gaze is not essential in the first half of the somersault during the tuck position, since the gymnasts did not show a consistent gaze behavior and some of them even closed their eyes for a short time.

Furthermore, it could be stated that gymnasts use the trampoline bed for their orientation in the air. Fig. 3 shows that almost all fixation points of the gymnasts were between the red cross in the middle and the front edge of the trampoline bed. Heinen, Valentzas, and Vinken (2012a) captured similar results in the first measurements with their eye-tracking prototype. Gymnasts of the current study did not always have the same fixation point in each somersault. The fixation points of subject 3, e.g. ranged from 35 cm to 137 cm. Apparently, the fixation point varies based on the gymnasts landing position. The average distance of 143 cm between the landing position and the fixation position seems to be crucial because the fixation point was closer to the central cross when gymnasts landed further away from the cross. This phenomenon is illustrated in Fig. 3 and is statistically confirmed by a correlation with a large effect size ( $r \approx 0.75$ ). As multiple data points per participant were present in the data, a type-2 regression was performed with the factor "subject" as an additional independent variable. The regression revealed no influence of the factor "subject" on the fixation

point, thus the correlation can be considered to be independent of the participants' identity. Since the landing is determined by the location and velocity of the center of mass at take-off (Yeadon, 1997), it is assumed that the gaze direction during fixation depends on the landing position in order to achieve the best possible orientation and landing balance.

Moreover, the influence of the kick-out on gymnasts' gaze behavior was examined in this study. Since a kick-out increases the moment of inertia and thus decreases the angular velocity it allows the gymnasts to better control the somersault (Prassas et al., 2006; Yeadon & Mikulcik, 1996). The results show that the gymnasts' start of fixation is significant earlier with a kick-out because they can see the trampoline bed earlier due to a faster rotation speed in the first part of the somersault. Moreover, the effect size is large. That is why gymnasts should demonstrate a kick-out during a backwards somersault. Accordingly, the kick-out has a positive influence on the back tuck somersault, as athletes can orient themselves up to 150 ms earlier to prepare a better landing (Fig. 5).

However, gymnasts of the better performance class 2 showed up to 78 ms later onset times of their fixation both with and without a kick-out. There was a medium effect size and a general trend is discernible in Fig. 5. This contradicts Heinen (2011) results to a certain extent since they claimed that experts showed longer fixation compared to novices. One possible explanation could be the time of flight. Heinen (2011) had ten experts and ten apprentices perform back tuck somersaults on the trampoline both from a standing position and with a time of flight of one second. In contrast, the gymnasts in this study have a flight time of  $1.3 \pm 0.1$  s. Hence, the subjects had more time to prepare the landing. It can be presumed that gymnasts of a better class only need a certain time of visual orientation to perform a good somersault and moreover, they have less variability and have smaller adjustments to make (Yeadon & Hiley, 2014).

Furthermore, gymnasts are required to show a good form and execution in a somersault, i.e. the head and spine should be in a straight line (FIG (Fédération Internationale de Gymnastique), 2017). A typical novice fault is a hyperextension of the head to the back at take-off, resulting in the gymnast seeing the trampoline bed earlier, but also producing a worse execution. On the other hand, experienced gymnasts are capable of moving the head at half of the somersault without losing their straight body configuration. The subjects of class 1 may have an earlier onset of the fixation because their execution is less perfect and they need orientation as early as possible. The gymnast in Fig. 1 is a subject of class 2 and started with the fixation at about 60% of the somersault. As can be seen in Fig. 1, the gymnast still had a stretched body position in the third picture while the head is only slightly in hyperextension. A fixation duration of about 500 ms appears to be early enough for experienced trampoline athletes to show a good performance. Nonetheless, the back tuck somersault is a basic element of little difficulty for skilled gymnasts. Therefore, it would be interesting to analyze gymnasts' gaze behavior in double somersaults or in single somersaults with twists in which the time for orientation and preparing for landing is not that long.

In conclusion, it can be stated that all subjects show fixations by focusing their gaze on a specific point in the trampoline bed and thus use spotting to prepare for landing. During the so called kick-out gymnasts' eyes move far up, as they search the trampoline bed for a fixation point. As soon as a fixation is found, the eyes move downwards to counteract the backwards head rotation to generate a stable gaze in the period of fixation. Nevertheless, the fixation point does not seem to be the same in all somersaults. Apparently, the fixation positions depend on the corresponding landing position in the bed, insofar as the distance between these two parameters is decisive. The kick-out has a positive influence on the back tuck somersault, as athletes can orient themselves earlier and thus better. Nevertheless, experienced and higher-level gymnasts do not seem to need the orientation point as early and not as long as less skilled gymnasts in a back tuck somersault. In further studies, these parameters could be investigated in more difficult trampoline elements such as double or twisted somersaults, or in other sports such as gymnastics or diving.

## Declaration of Competing Interest

None.

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