Gaze, head and eye movements during somersaults with full twists

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Abstract

Somersaults with or without twists are the most important elements in sports such as gymnastics or trampolining. Moreover, to perform elements with the highest possible difficulty gymnasts should show good form and execution during the flight phase. In order to ensure perfect body control and a safe landing, gaze behavior has been proven to be crucial for athletes to orientate in the air. As eye movement and head movement are closely coordinated, both must be examined while investigating gaze behavior. The aim of the current study is to analyze athletes' head motion and gaze behavior during somersaults with full twists. 15 skilled trampoline gymnasts performed back straight somersaults with a full twist (back full) on the trampoline. Eye movement and head movement were recorded using a portable eye-tracking device and a motion capture suit. The results indicate that gymnasts use the trampoline bed as a fixation point for orientation and control the back full, whereas the fixation onsets for athletes of a better performance class occur significantly later. A strong coordination between gymnasts' eye movement and head movement could be determined: stabilizing the gaze during the fixation period, the eyes move in combination with the head against the twisted somersault direction to counteract the whole body rotation. Although no significant differences could be found between the performance classes with regard to the maximum axial head rotations and maximum head extensions, there seems to be a trend that less skilled gymnasts need orientation as early as possible resulting in greater head rotation angles but a poorer execution.

Keywords: trampoline, somersault, twist, eye-tracking, gaze behavior, head motion.

1 Introduction

In gymnastic sports such as trampolining, athletes try to demonstrate several jumping elements with perfect form and execution. The difficulty of each element is defined in the "Code of points" by the *Fédération Internationale de Gymnastique* (FIG) based on the performed rotations around the transverse body axis and the longitudinal body axis (FIG, 2017). One of the most important twisting somersaults, which is often shown in competitions, is the back straight somersault with a full twist, also called a "back full". During a back full, gymnasts complete a 360° backwards rotation around the transverse axis in combination with a 360° rotation around the longitudinal axis in a straight body position. Several studies have examined how athletes are able to perform such difficult elements with twists introduced by producing tilt using asymmetrical movements of the arms, chest or hips (George, 2010; Yeadon, 1993) as well as fundamental biomechanical principles (Mikl & Rye, 2016; Prassas et al., 2006; Yeadon & Hiley, 2014).

In order to perform these jumping elements in a controlled manner and to be able to land safely after rotating several times around the body axes, gaze guidance is essential (Bardy & Laurent, 1998;

Lee et al., 1992; Sanders, 1995). Several exploratory studies have shown that the performance of straight leaps, and somersaults with or without twists, ending with a controlled landing, were performed better in conditions with vision than without vision (Davlin et al., 2001b; Heinen et al., 2012a; Luis & Tremblay, 2008). For example, Davlin et al. (2001b) used modified swimming goggles that restrict or fully prevent the amount of horizontal peripheral vision. Already in 1985, Rézette and Amblard examined gymnasts' execution of twists from stand to stand, backward somersaults, and back fulls on the trampoline under different visual conditions. Their results indicated that motion visual cues are generally very important for all types of jumps. Heinen and Veit (2019) found that picking up visual information is of high importance when gymnasts perform complex aerial skills. They asked athletes to do straight leaps under full vision, monocular vision, and occluded vision and examined flight duration as well as the gymnasts' horizontal displacement when landing on the trampoline bed. Davlin et al. (2001a) investigated gymnasts while they performed standing back tuck somersaults under different vision conditions and let gymnastic judges appraise the landing balance. Gymnasts gained the most stable landing scores when vision was available during the whole somersault. All authors contended that vision is necessary for receiving information in the flight phase to prepare for landing. However, all of these studies used the occlusion paradigm by obscuring relevant visual cues to analyze gymnasts' gaze behavior indirectly (Kredel et al., 2017). Mobile eye trackers with high frequencies should be used in order to record the eye movements of the athletes (Andersson et al., 2010; Mele & Federici, 2012).

For this reason, recent studies used mobile eye-tracking devices to analyze the gaze behavior of gymnasts during complex jumping elements (Heinen et al., 2012b; Natrup et al., 2020; Sato et al., 2015). By using portable eye-trackers, several authors ascertained that athletes use "spotting" behavior to orientate during rotations in the air and to prepare for landing (Davlin et al., 2004; Heinen et al., 2012c; Von Laßberg et al., 2014). Spotting is a method by which gymnasts or platform and springboard divers fixate specific visual cues while somersaulting with a high rotational speed to receive information for the orientation (Heinen, 2011; Huber, 2016). During somersaults, such spotting fixations need to be performed by complex coordination of eye and head movements in relation to the movement of the body. Raab et al. (2009) plotted the rotation of the eyes in the vertical direction in a back tuck and back straight somersault from take-off to landing. They detected that the eyes move upwards at the beginning of the somersault. As soon as the athlete can see the trampoline the eyes rotate continuously downwards to counteract the head movement and fixate the trampoline bed. Natrup et al. (2020) revealed similar results in their study by analyzing the gaze behavior of eleven trampoline gymnasts from two performance classes in a back tuck somersault with a time of flight of 1.3 seconds. Furthermore, they found that experienced and higher-level gymnasts do not seem to need the orientation point as early and only for a shorter time period as less skilled gymnasts, as can be concluded from the different onsets of fixation. They suggested that the athletes of the lower class might have an earlier onset of the fixation as their execution is less perfect regarding the increased head hyperextension and the need of orientation as early as possible (Natrup et al., 2020).

Nevertheless, these studies were limited as they did not capture the head movement in combination with the eye movement. Sidenmark and Gellersen (2019) stated that the gaze is "multimodal", thus it involves not only eye but also head and body movement. Hence, while investigating gaze behavior, head movement must be examined in addition to eye movement as they are closely coordinated (Fang et al., 2015; Fetter, 2007; Freedman, 2008; Von Laßberg, 2007). Some authors described that gymnasts decrease head velocities prior to landing in time to process optical flow information once visual feedback during the performance is possible (Davlin et al., 2004; Hondzinski & Darling, 2001; Marinšek, 2010). Furthermore, Hollands et al. (2004) let subjects perform a whole body turn around the longitudinal axis and captured the gaze, as well as the angular rotation of the eye, head, trunk, and foot. They characterized a clear sequence of body segment orientation with the eyes leading, followed closely by the head and observed a high degree of coordination between the eyes and head. Sato et al. (2017) analyzed gaze shift patterns during a jump with full twist in male gymnasts and plotted the gaze and the angle of rotation of eye, head, and trunk. Participants' eyes started to rotate in the same direction as their heads prior to take-off and immediately before and during landing, compensatory eye movements occurred. Using this pattern, gymnasts are able to stabilize their gaze on average about 110 milliseconds before landing and direct the gaze toward relevant locations to support landing preparation (Sato et al., 2017).

Based on this, the aim of the current study is to investigate head and eye movement and gaze behavior of 15 gymnasts during a back straight somersault with a full twist (back full) on a trampoline. The back full is one of the most important twisting elements in trampolining in which gymnasts have to perform and control simultaneously rotations around two body axes. Three hypotheses are indicated below. First, the present study investigates horizontal and vertical eye orientation synchronized with axial head rotation and head extension from take-off to landing. Similarities and differences between the subjects will be determined and additionally the coordination between eye movement and head movement will be scrutinized. Supposedly, the gymnasts' eye and head movements compensate the whole body backwards rotation in order to fixate a certain point in the trampoline bed and to receive orientation information as well as prepare for a good landing (Natrup et al., 2020; Raab et al., 2009). Furthermore, to stabilize the gaze a strong coordination between the eye movement and head movement when initiating and performing the twisting somersault is expected (Hollands et al., 2004; Sato et al., 2017; Von Laßberg et al., 2014). Secondly, the timing of maximum axial head angles, maximum head extension angles and the onsets of fixation in each back full will be captured. Gymnasts of a lower performance class are hypothesized to reveal both sooner onset times of their fixation and earlier timestamps of maximum head angles because they need orientation as early as possible (Natrup et al., 2020). Thirdly, in addition to the timestamps, the maximum absolute angle values of the axial head rotation and head extension will be evaluated. It is hypothesised that experienced and higher-level gymnasts will show smaller maximum angle values because the international rules demand a "good form and execution" in a twisting somersault, i.e. the head and spine should be in a straight line (FIG, 2017; Natrup et al., 2020).

2 Methods

2.1 Subjects

Active trampoline gymnasts (8 male, 7 female, age: 22 ± 5 years, body height: 170 ± 7 cm, and body mass: 63 ± 9 kg) volunteered as participants in the study. The gymnasts' training intensity was three to nine practices per week and all of them had performed the back full in several competitions. The subjects were divided into two performance classes according to the teams they belonged to. In performance class 2 (n=5), the athletes were part of national teams. The subjects of performance class 1 (n=10) competed in regional teams. During the measurements no corrective lenses were mounted to the eye-tracker, as none of the gymnasts wore glasses in training sessions. The study was approved by the local ethics committee of the Department of Sports Science and Psychology of the University of Muenster (# 2020-06-JN).

2.2 Experimental Setup

The gymnasts were asked to execute ten back fulls on a trampoline while wearing an eye-tracking device and a motion capture suit. The subjects were free to practise the back fulls with a twist direction to the left or to the right. To perform the elements with the correct jump height the athletes received an acoustic metronome which provided timing information. In order to prevent fatigue, subjects could have as many breaks as they needed between the somersaults. Furthermore, they had enough time to warm-up before the measurements started. Afterwards the time of flight was calculated using cameras (*HERO4*, GoPro, USA; Natrup et al., 2020).

2.3 Eye-Tracking Device & Motion Capture Suit

In this study, an eye-tracking device (*Tobii Pro Glasses 2*, Tobii AB, Sweden) with a sampling rate of 100 Hz was used. The front scene camera had a recording angle of 82° horizontal and 52° vertical. To prevent slipping of the glasses, the eye-tracker was attached to the head with an elastic strap and additionally fixed with an elastic band (Natrup et al., 2020). The recording unit was plugged into the motion capture suit.

The gymnasts' body movement and head movement were measured using a motion capture suit (*MVN Link*, Xsens Technologies B.V., Netherlands) with a sampling rate of 240 Hz. 15 motion trackers were placed at specific locations in the suit containing 3D linear accelerometers, 3D rate gyroscopes, and 3D magnetometers. All cables ran inside the suit and the system was connected wirelessly to the measuring computer, thus the athletes were not disturbed while jumping. All systems were synchronized using an external trigger.

2.4 Data Analysis

All somersaults with a time of flight between 1.3 s and 1.5 s were included in the analysis. 139 trials were edited from take-off (0%) to landing (100%). Due to differences up to 200 ms in the subjects' flight phases all timestamp values were evaluated as the percentage of the total time of flight.

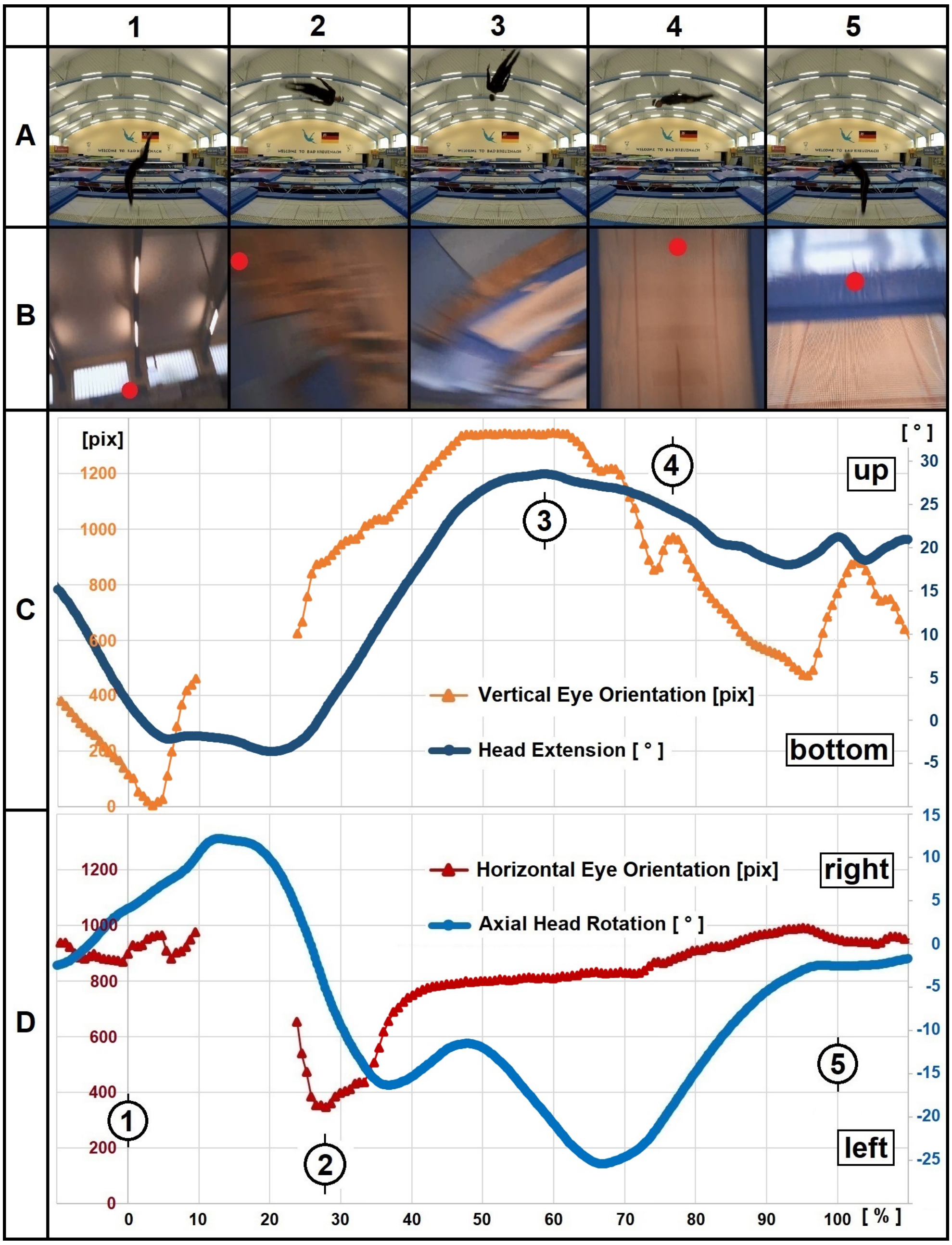

Figure 1: Example of gaze, eye and head movement during a back full (left-twist) of a class 2 gymnast who participated in the 2016 Summer Olympics in Rio de Janeiro. A: Five different phases of the element. 1: Take-off, 2: Max. eye direction to the left, 3: Max. head extension, 4: Start of fixation, 5: Landing. B: The gaze point in the front camera image is marked with a red dot. C: Vertical eye orientation in the front camera image (in camera pixels: orange curve, left y-axis) and head extension in angle (dark blue curve, right y-axis). D: Horizontal eye orientation (in pixels: red curve, left y-axis) and axial head rotation in angle (light blue curve, right y-axis) plotted for the flight period. A negative slope of the curve portrays a movement to the left. Between 10-24% the athlete closed his eyes so the eye orientation was not recorded. Between 38% and 71% the eye orientation is analyzed manually using the eyes' position in the head (see section 2.4; Natrup et al., 2020).

The eye-tracking data was processed using the program *Tobii Pro Lab* (Version 1.95). The horizontal and vertical eye orientation could be exported as x and y coordinates in the front camera movies. If the gaze direction was outside the front camera view angle, the eyes' position in the head had to be analyzed manually by using the eye movies (Fig. 1; Natrup et al., 2020). A fixation was defined provided the gaze was directed at a specific location for at least 100 ms (Heinen, 2011). The first timestamp when the gymnast focused at a specific point was determined as the start of fixation in percent of the time of flight. The timestamp can also be defined as the last local maximum of the vertical eye orientation before the fixation period, i.e. if a smooth continuous rotation of the eyes was recorded (Fig. 1, timestamp 4; Natrup et al., 2020).

The motion capture data was analyzed using the program *MVN Analyze* (Version 2020.0.0) using the scenario "Single Level". Axial head rotation angle (about Y axis) and head extension angle (about Z axis) were evaluated based on the joint angle between the first cervical spine segment and the head (Euler Sequence: ZXY; with Z: LeftEar to RightEar, Y: C1Head to TopOfHead, X: Perpendicular to Y and Z). The maximal axial head rotation and the maximal head extension (Fig. 1, timestamp 3) were defined as the maximum angle values from take-off to landing. For the statistical analysis, absolute values were used, as the gymnasts twisted to the left as well as to the right direction. Furthermore, the timestamps of the maximum head angle values were calculated in percent of the time of flight.

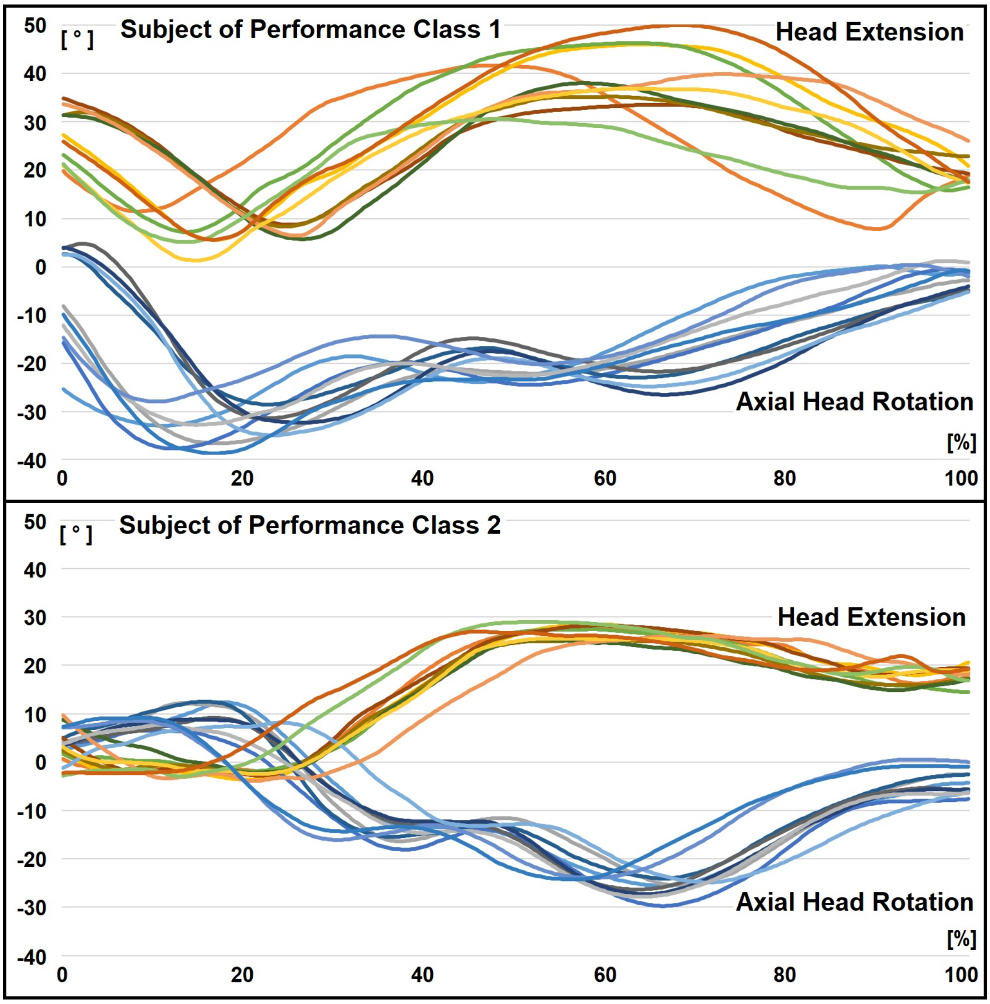

Figure 2: Head motion of two example gymnasts in each ten back fulls over the time of flight. Top: Subject of performance class 1. Bottom: Subject of performance class 2. Head extensions (light colors) and axial head rotations (dark colors) are plotted in angles. Both athletes had a twist direction to the left. The y-axes are defined from -40° to 50° in both graphs.

2.5 Statistical Analysis

The effect of the subject's performance class (`PerfClass`, a categorical independent variable with two levels: 1 = less experienced, 2 = more experienced) on five different responses (continuous dependent variables) was analyzed: fixation onset, timestamp of maximum axial head rotation, timestamp of maximum head extension, maximum axial head angle, and maximum head extension angle.

Each subject performed ten trials some of which had to be discarded (see section 2.4).

The analysis was performed by averaging over the trials of each subject, so that each subject obtained one value per response variable. As the subjects belonged to one of two groups, i.e. their performance class, and since the response variables in these performance classes were distributed with unequal variance, an unpaired Welch test per response variable was used. The Welch test is a generalization of the well-known Student's t-test used in case of unequal variances. Just as the t-test, though, the Welch test requires the distributions to be sufficiently normal, which was ensured by a preceding Shapiro-Wilk test.

Since five independent Welch tests were carried out, a subsequent statistical correction had to be performed to counteract a potential accumulation of Type-I errors. This statistical correction was done using the Bonferroni-Holm method (Holm, 1979). In case of a statistically significant difference, which was assumed whenever the corrected p-value fell below a global significance level of $\alpha = 0.05$, the effect strength was calculated using Cohen's d. These values were then interpreted according to Cohen's rule of thumb, so that values of d around 0.2, 0.5, and 0.8 were interpreted as small, medium, and large, respectively (Cohen, 1988). All statistical calculations and the generation of Fig. 3 was carried out using MATLAB version 9.8.0.1451342 (R2020a) Update 5 (The MathWorks Inc, Natick, Massachusetts), with the Welch test being performed using the command `ttest2` with the option `VarType` set to `unequal`.

3 Results

At first, the analysis of the patterns of gaze behavior is presented by a measurement example of a back full with a twisting direction to the left (Fig. 1 A and B). Synchronized pictures from the eye-trackers' front camera and a side camera are displayed in the upper part of the figure. In the front camera picture series, the gaze direction is identified with a red dot. At the beginning of the somersault, the gymnast focused on a specific area at the opposite wall, as can be seen in image 1. After take-off, the gaze pointed up to the ceiling. Between 10% and 24%, the athlete closed his eyes for a short period followed by a gaze movement to the left in the twist direction. After timestamp 3, the gaze was directed towards the trampoline until the gymnast had found the fixation point in the trampoline bed at around 77% (4). During the period of fixation, the gaze stayed at that specific area until shortly before landing, when the gaze moved up to the opposite wall again (5). All subjects fixated their gaze on specific locations in the trampoline bed in the second half of the back full, thus showing spotting. As soon as a stable gaze fixation point on the trampoline bed was found, the gaze remained pointing in that direction throughout the fixation period.

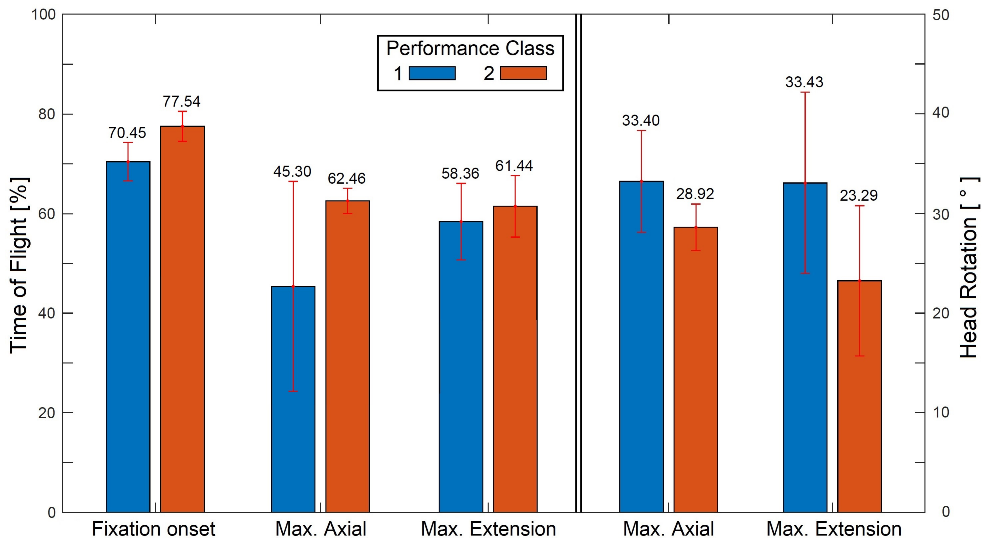

Figure 3: Mean values and standard deviations of the participants' individual mean values of five variables related to the performance class 1 (left, blue) and 2 (right, orange). X-axis from left to right: start of fixation, timestamp of maximum axial head rotation, timestamp of maximum head extension, maximum axial head rotation angle, maximum head extension angle. The first six bars refer to the left y-axis in percentages of the time of flight. The last four bars refer to the right y-axis in angles.

Next, the analysis will be turned to the coordination of head and eye movements that is used to produce stable gaze fixations. The vertical and horizontal eye orientation as well as the head extension and axial head rotation are plotted in Fig. 1 C and D. Before leaving the trampoline bed, the eyes and head oriented downwards, whereas the head turned slightly to the right without a horizontal eye movement. After take-off (timestamp 1), the eyes began to move up followed by an upwards movement of the head in the direction of the back somersault rotation. Simultaneously, the head moved to the left side in the direction of the twist rotation together with the eyes. After the eyes reached the maximum horizontal left position (2), they returned to the central orientation, while the head remained still turned to the left side. At timestamp 3, head and eye orientations both reached the maximum value, i.e. maximum head extension and maximum upwards rotation of the eyes. Thereafter, the head moved down, followed by a downwards rotation of the eyes and a right rotation of the head until the athlete found a stable gaze fixation point on the trampoline bed (4). With the beginning of the fixation period at around 77%, the eyes and head continuously and smoothly moved downwards until shortly before landing, when the eyes and the head moved up again such that the axial head rotation was around 0° (5).

The general eye and head movement patterns were similar in all gymnasts. In the first half of the somersaults, all athletes rotated their eyes and head towards the twist direction, independent of whether the subject performed a back full with a left or right twist. However, eight subjects closed their eyes for a short period after take-off and seven subjects had their eyes open throughout flight phase. When initiating the back fulls, all athletes rotated their eyes upwards and the head to the back (head extension) linked with a horizontal eye and head movement (axial head rotation) in the twist direction. As soon as the fixation on the trampoline bed was found, gymnasts' eyes rotated continuously and smoothly downwards, until landing or shortly before. Simultaneously, the gymnasts' heads moved downwards, compensating the backwards somersault rotation and a horizontal head movement occurred oppositely to the twist direction until the axial head rotation was around 0°.

In order to compare the two performance classes Fig. 2 shows the head movements of ten trials of two example athletes, respectively from class 1 and 2. Both gymnasts performed the back full twisting to the left. The maximum head extensions of the class 1 gymnast were between 30° and 50°, whereas the gymnast of performance class 2 showed values between 25° and 29°. With respect to the axial head rotation, the gymnast from class 1 yielded maximum absolute values between 28° and 38°. The subject of class 2 had maximum absolute angle values from 24° to 30°. On average, the class 1 athlete obtained higher absolute values than the class 2 athlete for head extension as well as for axial head rotation. Furthermore, the athlete of class 1 had higher deviations both in relation to the maximum angle values and to the timestamps of the maximum values.

Next, mean values (M) and standard deviations (SD) of the participants' individual mean values were evaluated regarding the start of fixation, timestamp of maximum axial head rotation, timestamp of maximum head extension, maximum axial head rotation angle, and maximum head extension angle. The results are shown in Fig. 3. The mean values of the performance class 1 are displayed with blue bars (left) and of the performance class 2 with orange bars (right). Gymnasts of class 1 revealed earlier fixation onsets with $70.5 \pm 3.6\%$ to $77.5 \pm 2.7\%$ (class 2). The performance classes 1 and 2 yielded average timestamps of maximum axial head rotation of $45.3 \pm 20.0\%$ and $62.5 \pm 2.3\%$, and timestamp of maximum head extension of $58.4 \pm 7.3\%$ and $61.4 \pm 5.5\%$, respectively. The subjects of performance class 1 resulted in greater axial head rotation angles ($M_1 = 33.4 \pm 4.8°$; $M_2 = 28.9 \pm 2.0°$) as well as greater head extension angles ($M_1 = 33.4 \pm 8.5°$; $M_2 = 23.3 \pm 6.6°$) compared to gymnasts of class 2.

Table 1: Results of the Welch test in comparison of the two performance classes refer to the onsets of fixation, the timestamp of maximum axial head rotation, the timestamp of maximum head extension, the maximum axial head rotation angle, and the maximum head extension angle. Statistically corrected p-values are notated as p_corr. Effect sizes in terms of Cohen's d are calculated for statistically significant effects.

Variable	**T**	**df**	**p**	**p_corr**	**d**	**Effect Size**
Time Fixation onset	-3.919	10.157	0.002	0.014	1.972	large
Time Max. Axial	-2.538	9.510	0.031	0.122		
Time Max. Extension	-0.836	9.933	0.423	0.423		
Max. Axial	2.373	12.974	0.034	0.122		
Max. Extension	2.327	9.727	0.043	0.101		

The statistically corrected p-values showed a significant effect of the performance class only for the onset of fixation (p_corr = 0.014). The corresponding effect size of d = 1.972 can, according to Cohen's rule of thumb, be considered as large. The other four dependent variables corrected p-values above 0.05 indicate that the effect of the performance class is not significant and hence cannot reasonably be attributed an effect strength (Tab. 1).

4 Discussion

The aim of the current study was to investigate the gaze, head and eye movements of 15 trampoline athletes in back straight somersaults with a full twist. The results confirm that gymnasts use the trampoline bed as a fixation point in order to orientate in the air (Davlin et al., 2004; Heinen, 2011; Heinen et al., 2012a), whereby the fixation onsets for the athletes of the better performance class occurred significantly later (Fig. 3; Natrup el al., 2020). The example of Fig. 1 illustrates a strong coordination between gymnasts' eye movement and head movement to stabilise the gaze during the fixation period (Hollands et al., 2004; Sato et al., 2017; Sidenmark & Gellersen, 2019). The class 1 athletes revealed both earlier maximum head rotation timestamps and greater head angles, regarding the axial head rotation and head extension (Fig. 3), though the statistical analysis did not result in any significant differences (Tab. 1).

During the take-off, the example athlete of class 2 focused on a point at the opposite wall. Although the body began to rotate to the back full direction, the athlete tried to stabilize the line of sight in the air as long as possible, thus an orientation is still possibly. After the athlete briefly closed his eyes between 10% and 24% of the time of flight, the gaze was quickly directed to the ceiling and to the twist direction. This behavior was the same for all gymnasts, regardless of whether their eyes were briefly closed or not. In this phase, the athletes did not focus on a certain point in the hall, but the gazes moved in the somersault direction in order that the trampoline bed appears in the field of vision as soon as possible. During the back full, the whole body performs a 360° backwards rotation and a 360° rotation around the longitudinal axis. Hence, to prepare for landing at the end of the somersault, trampoline gymnasts try to fixate a certain point in the foveal region to orientate themselves in the air (Fetter, 2007; Freedman, 2008; Heinen et al., 2012a). Throughout the fixation period, the gaze remains at a specific point in the trampoline bed so that the athletes are able to orientate and prepare for a good landing (Natrup et al., 2020).

Next, the coordination of head and eye movements that is used to produce stable gaze fixations will be discussed. At the beginning of the somersault, the eyes and the head moved downwards and to the right side to compensate the left back full rotation of the whole body and to keep the body tension straight as long as possible (George, 2010). With the initiation of the back full, the eyes leading and the head moved both to the left and upwards to the back full rotation (cf. Fig. 1). This period demonstrates that there is a connection between eye movements and head movements in order to quickly direct the gaze to the ceiling and to the twist direction (Sato et al., 2017; Von Laßberg et al., 2014). Similar to Raab et al. (2009) and Natrup et al. (2020), the gymnasts' eyes and head move together in the somersault direction in order to be able to orientate early. Although the mentioned studies did not investigate twisted elements but back tuck and straight somersaults, vertical eye movements appear to be similar, regardless of whether the gymnast perform somersaults with or without twists. In the second half of the somersault, when the trampoline bed appears in the gymnasts' view, the head extension has the maximum angle value. Subsequently, the head begins to move down, followed by a downwards eye rotation and an axial head movement against the twist direction to counteract the trunk rotation and to stable the gaze. As all subjects stabilized their gaze by moving the head in combination with the eyes opposite to the rotation of the body, the spotting hypothesis by Heinen (2011) is confirmed again in the present study.

Although these general patterns are similar for all subjects, the onsets of fixation as well as the timestamps of the maximum head rotations differed between the two performance classes. On average, performance class 1 gymnasts showed onset times of their fixation up to 98 ms earlier because they need orientation as early as possible (Fig. 3). This difference was significantly confirmed by the statistical analysis with a large effect size (Tab. 1). Hence, the hypothesis that less skilled athletes start sooner with the fixation in back fulls is confirmed. Moreover, it was hypothesized that class 1 gymnasts reveal sooner timestamps both for the maximum axial head rotation and the maximum head extension. Although a trend can be seen in Fig. 3, the statistical analysis resulted in no significant differences (Tab. 1). Thus the hypothesis can not be accepted. Natrup et al. (2020) proposed that less skilled gymnasts "may have an earlier onset of the fixation because their execution is less perfect and they need orientation as early as possible." In order to examine this statement, this study compared gymnasts' maximum head angles with the assumption that the maximum axial head rotations and the maximum head extensions are greater for less skilled athletes.

According to the "Code of points" (FIG, 2017), a trampoline routine should show "good form, execution, [...] to demonstrate perfect control of the body during the flight phase." This implies that the body, spine, and head should be in a straight line during a back full. The comparison of the two athletes in Fig. 2 shows that the less skilled gymnast revealed greater absolute values, with respect to the head extension and axial head rotation in all back fulls. Furthermore, the deviation of head movements between each back full was much smaller for the higher-level gymnast. Based on this, it can be assumed that the class 1 gymnast has less body control during the back full resulting in more adjustments in the air (Prassas et al., 2006; Raab et al., 2009). To ensure a safe landing of such a difficult element as the back full, less skilled gymnasts must incorporate these adjustments and therefore have to orientate themselves as early as possible. However, this leads to greater head angles and thus to poorer scores, which experienced gymnasts can avoid due to a better control of the element. They are able to fixate later to optimize the form and execution as they are more experienced and supposedly feel more confident about performing such difficult elements (George, 2010; Natrup et al., 2020). In Fig. 3 the mean maximum axial head angles and mean maximum head extension values between the two performance classes are compared. With values of 33.40° to 28.92° (axial) and 33.43° to 23.29° (extension), less skilled athletes yielded greater head rotation angles. However, none of these differences were significant (Tab. 1). Nevertheless, a trend can be seen that less skilled trampoline gymnasts have to produce greater head rotation angles in a back full, so that they can orientate earlier in order to ensure a safe landing even if it then results in a worse assessment of the back full.

In conclusion, during twisting elements such as the back full, trampoline gymnasts are able to fixate the gaze and receive information for the orientation in the air through a strong coordination of head and eye movements. After take-off, the gymnasts' head moves in combination with the eyes in the somersault direction and twist direction. As soon as the trampoline appears in the athletes field of vision, the eyes and head move contrary to the whole body rotation in order to stabilize the gaze and start to fixate a specific location in the trampoline bed. During the fixation period, the eyes and the head move continuously together until the back full is completed. However, subjects of a lower performance class have less control during the flight phase. To land safely, less skilled gymnasts need the orientation point as early as possible resulting in greater head rotation angles but a poor execution. Nevertheless, no significant differences could be determined between the two performance classes compared in this study with respect to the axial head rotations and the head extensions. In order to achieve a better division between the gymnasts' performances, twisting somersaults could be scored by judges in subsequent studies. Furthermore, to get a better knowledge of the gaze, head and eye movement strategies of athletes when rotating around body axes trampoline gymnasts could be compared to artistic gymnasts or springboard divers.

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6 Declarations of interest

None

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