Land where you look? Functional relationships between gaze and movement behavior in a backward salto

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LAND WHERE YOU LOOK? – FUNCTIONAL RELATIONSHIPS BETWEEN GAZE AND MOVEMENT BEHAVIOUR IN A BACKWARD SALTO

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ABSTRACT: In most everyday actions the eyes look towards objects and locations they are engaged with in a specific task and this information is used to guide the corresponding action. The question is, however, whether this strategy also holds for skills incorporating a whole-body rotation in sport. Therefore, the goal of this study was to investigate relationships between gaze behaviour and movement behaviour in a complex gymnastics skill, namely the backward salto performed as a dismount on the uneven bars. Thirteen expert gymnasts were instructed to fixate a light spot on the landing mat during the downswing phase when performing a backward salto as dismount. The location of the light spot was varied systematically with regard to each gymnast's individual landing distance. Time-discrete kinematic parameters of the swing motion and the dismount were measured. It was expected that fixating the gaze towards different locations of the light spot on the landing mat would directly affect the landing location. We had, however, no specific predictions on the effects of manipulating gaze direction on the remaining kinematic parameters. The hip angle at the top of the backswing, the duration of the downswing phase, the hip angle prior to kick-through, and the landing distance varied clearly as a function of the location of the light spot. It is 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.

KEY WORDS: gymnastics, complex skill, whole-body rotation, visual spotting, movement kinematics

INTRODUCTION

In most everyday actions, eye movements and whole body movements or movements of the body segments are thought to be spatially and functionally related [25,28]. The eyes look towards task-relevant objects and locations and this information is used to guide the corresponding action [24]. This strategy can be found for a wide range of natural behaviours and (rather simple) everyday actions. For instance, in manual tasks the movement of the eyes usually leads the movements of the hands [1,7]. However, this general strategy may or may not hold for complex skills in sport, such as performing acrobatic manoeuvres incorporating flight phases and/or rotations about one or more body axes [14,40]. Therefore, the goal of this study was to investigate relationships between gaze behaviour and movement behaviour in a complex gymnastics skill, namely the backward salto performed as a dismount on the uneven bars.

In goal-directed movements, the selection of task-relevant objects and locations in the environment is determined by the goals of the moving person [13,26]. Fixations towards task-relevant objects and locations are thought to provide information for a particular action, and are thus used in an anticipatory manner [1,19]. Grasso and colleagues had for instance six participants walking around an obstacle, either in the light or with eyes closed. The authors measured participants' head orientation and eye movements [12]. It was found that during turning individuals made anticipatory eye and head movements to align with the intended walking trajectory (cf., [18]). Hollands and colleagues had seven participants walking along a 9-m pathway whilst their gaze behaviour and their head and body movements were measured. Participants maintained a straight walking trajectory or changed their walking direction by 30° or 60° at the midpoint of the pathway. The authors found that prior to changing the direction of walking, participants aligned their gaze with the end-point of the required travel path. Head and body reorientation accompanied this alignment. The results lead to the conclusion that eye movements are aligned with the movement goals [16]. However, there is no comprehensive empirical evidence concerning the relationship between gaze behaviour and movement goals in complex skills incorporating flight phases and rotations about one or more body axes.

It has been speculated that the information extracted from the visual system is primarily used to provide the athlete with information to control the landing of aerial movements [9,10,17,30,41]. Additionally, it is thought that this might result from a prospective type of control of body orientation during the flight phase [2,28]. In these studies, athletes were asked to perform complex skills in different vision conditions, such as reduced visual acuity or reduced peripheral vision. Athletes' performance was compared across different vision conditions. It was found that gymnasts were in general more stable at landing during vision conditions than in no-vision conditions. It was furthermore found that parameters such as moment of inertia during the flight phase were regulated in a prospective manner to best suit the actual mechanical conditions together with the intended landing situation.

Nevertheless, one may speculate that manipulating visual information pickup may or may not affect gaze behaviour and/or movement behaviour in complex skills, depending on the functional role of the manipulated information for skill execution [35]. It may just be the case that gymnasts fixate their gaze to relevant objects or locations in the environment, but do not actively pick up information from these objects or locations, such as structure, colour or form. Instead they may use this *anchoring of gaze* for spatial orientation [17,19, 27,40].

Taken together, it can be assumed that the direction of gaze to specific objects or locations in an anticipatory manner may be functional for the execution of complex skills in gymnastics. Following this, it was predicted that manipulating gaze behaviour should have a direct impact on the landing location of the backward salto. To examine this prediction, expert gymnasts were instructed to fixate a light spot on the floor during the downswing phase on the uneven bars when performing a backward salto as dismount. Landing location was measured as well as certain kinematic parameters of the backward saltos. It was expected that fixating the gaze towards different locations of the light spot on the landing mat would directly influence the landing location of the backward salto, which in turn should result from changes of the backward saltos' swing motion. We had, however, no specific predictions on the effect of manipulating gaze direction on the kinematic parameters of the swing motion but additionally sought to explore this effect.

MATERIALS AND METHODS

Participants. Thirteen female gymnasts were recruited to participate in this study. The gymnasts in the current study were active gymnasts with at least ten years of training and competition experience (age: 22 ± 2 years, body mass: 58 ± 6 kg, body height: 163 ± 4 cm). They were able to perform the backward salto as a dismount on the uneven bars since 10 ± 2 years on average. It was decided to recruit expert gymnasts and study the relationship between their gaze behaviour and movement behaviour in a natural setting in order to investigate the impact of the manipulation of visual spotting on movement performance [42]. All participants were informed about the general purpose and the procedures of the study and gave their written consent prior to the study. The gymnasts were, however, naive about the purpose of the light spot (see Procedure Section). They all had normal or corrected-to-normal vision. The study was carried out according to the ethical guidelines and with the approval of the local ethical committee.

Task and materials

Experimental task

The experimental task was a backward salto performed as a dismount on the uneven bars. The apparatus was arranged as it would be in an international competition. Landing mats (0.20 m high) were put in front, below and behind the apparatus. The bars were adjusted according to the international competition guidelines for female artistic gymnastics [11]. Figure 1 presents a stick-figure sequence of the experimental task. In order to perform an intended dismount the gymnast needs to achieve sufficient angular momentum towards the take-off from the upper bar. She further needs to obtain adequate height during the flight phase in order to have enough time in the air to complete the intended salto rotation. Finally, the flight curve of the dismount should guarantee a safe landing [4].

The downswing and upswing motion prior to release are characterized by a particular coordination of the hip and shoulder joints [32]. The athlete starts from a support position (0), leaning the trunk forward while bending the hip (1) in order to perform a backswing with the centre of gravity reaching its initial height prior to the downswing phase (2). The athlete exhibits a slightly flexed hip joint during the first part of the downswing (3). This is immediately followed by an extension of the hip joint and an extension of the shoulder joints during the downswing phase (4), preparing the so-called "kick-through", prior to the upswing phase. During the kick-through, the gymnast actively flexes her hip joints towards the release from the bar. The gymnast leaves the bar for the dismount at the end of the upswing phase (5). During the dismount, the gymnast reduces her moment of inertia, whilst achieving the tucked position (6). She remains tucked for a short fraction of time (minimum moment of inertia), and afterwards extends the body (7) prior to touchdown at the end of the dismount (8). The task ends with the landing phase during which the gymnast dissipates her kinetic energy in order to land in a stable and upright position [39].

Kinematic analysis

An optical movement analysis system was used to determine the kinematics of the experimental task on the basis of videotaped sequences of all performed dismounts. Gymnasts' performances were videotaped using a Casio Exilim EX-FH100 Camera (sampling rate: 120 Hz, temporal error: ± 0.00833 s, spatial resolution: 640 x 480 pixels). The camera was placed 15 m away from, parallel to the uneven bars, and orthogonal to the movement direction of the gymnast. Its optical axis was adjusted to the plumb line from the upper bar to the landing mat, ensuring that the complete skill (preparatory phase to landing) could be recorded. Reflective markers were attached to six body landmarks, corresponding to the following joints: 1. right

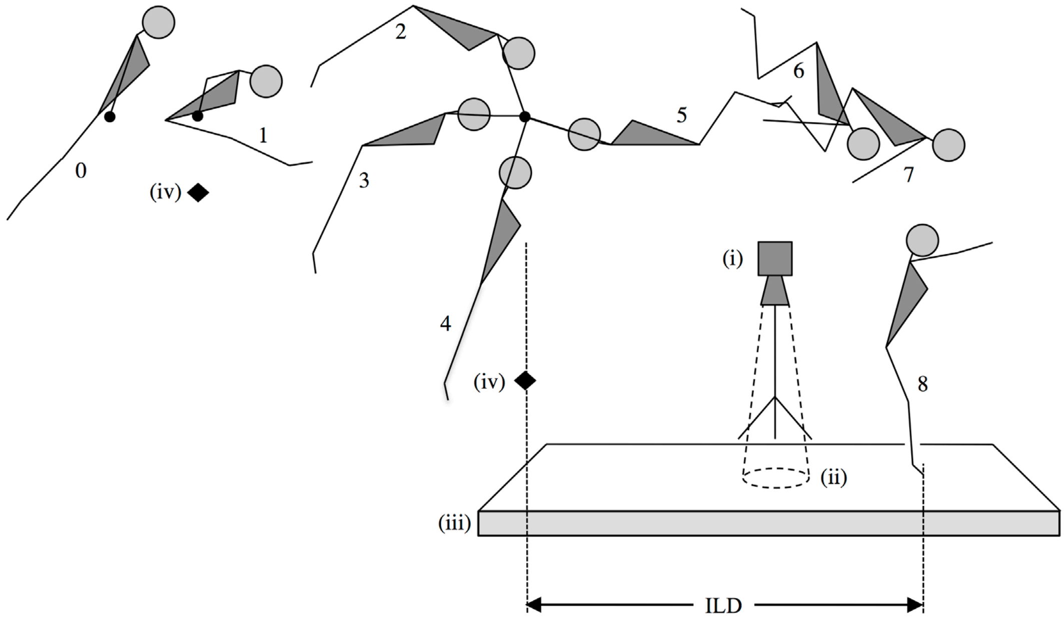

FIG. 1. SCHEMATIC STICK-FIGURE SEQUENCE OF THE EXPERIMENTAL TASK, WHICH CONSISTS OF THE FOLLOWING MOVEMENT PHASES: PREPARATORY PHASE (0 → 1), BACKSWING PHASE (1 → 2), DOWNSWING PHASE (2 → 4), UPSWING PHASE TO RELEASE (4 → 5), ACHIEVING TUCKED POSITION (5 → 6), REMAINING TUCKED (6 → 7), EXTENDING THE BODY (7 → 8), AND LANDING (8). THE SPOTLIGHT WAS ATTACHED TO A TRIPOD (I), AND PROJECTED AN OPAQUE WHITE LIGHT CIRCLE (II) ON THE LANDING MAT (III), PREDEFINING THE GAZE DIRECTION OF THE GYMNAST DURING THE DOWNSWING. TWO PHOTOELECTRIC SENSORS (IV) WERE PLACED BELOW THE BAR AND USED TO SWITCH THE SPOTLIGHT ON AND OFF (ILD = INDIVIDUAL LANDING DISTANCE). THE VALUES OF THE SEGMENT ANGLES REPRESENT THE VALUES FROM THE BASELINE CONDITION.

wrist, 2. right elbow, 3. right shoulder, 4. right hip, 5. right knee, and 6. right ankle. Two additional markers were attached to the right toe and to the right ear. The horizontal and vertical coordinates of these eight markers were tracked in a semi-automatic manner for each frame from the videotaped sequences using the movement analysis software WinAnalyze 3D [33]. A mean spatial error of ± .009 m was estimated from the recording process of the body landmarks. From the position data of the eight markers, kinematic parameters referring to a 7-segment model of the human body were calculated (cf., [20]). A digital filter (cut-off frequency = 6 Hz) for data smoothing was applied. Body-segment parameters were calculated on the basis of the individual anthropometric properties of each gymnast.

Time-discrete kinematic parameters for the experimental task were calculated. In collaboration with a biomechanist, a top-level gymnastics coach, and with regard to the movement phases of the experimental task, we chose 19 kinematic parameters of the task that represent the most relevant criteria from a biomechanical point of view [15,32]. The *timing* of the experimental task was defined by the relative durations of the particular movement phases of the swing motion and the dismount. The *swing motion* comprised the following phases: preparatory phase, backswing phase, downswing phase and upswing phase towards release. The *dismount* comprised the following phases: achieving the tucked position, remaining tucked, and extending the body. For these phases the relative durations were analyzed.

Changes in *body configuration* during the movement phases of the swing motion were expressed by the values of the shoulder angle, the hip angle, and the knee angle at the top of the backswing, prior to the kick-through movement, and during the release [5,15]. Changes in body configuration during the flight phase were expressed by the values of the moment of inertia about the transverse axis when tucked and during touchdown [14]. The flight phase itself was further characterized by analysing the height of flight, and the angular momentum about the transverse axis when airborne. The values of moment of inertia and angular momentum were normalized to a body mass of 55 kg and a body height of 1.60 m in order to allow for comparisons between all participants and between studies utilizing similar analyses (cf., [21,23]).

Finally, *landing performance* was characterized by analysing the absolute landing distance as well as the landing precision. The landing distance was measured as the orthogonal distance between the tiptoes during touchdown and the plumb line between the upper bar and the landing mat. The landing precision was calculated as variable error in foot positioning during touchdown [31].

Directing the gymnast's gaze

Gymnast's gaze direction was predefined by means of a portable spotlight (LED Lenser P7) operating at 200 lumen. The spotlight was attached to a tripod, which was placed about 1.50 m away from and orthogonal to the landing area of the gymnasts. The tripod was elevated to a height of 1.50 m. The spotlight was directed towards the landing mat. The spotlight was endued with a focus module, allowing it to project an opaque white light circle with a diameter ranging between 10 and 30 cm on the landing area (see Figure 1).

It was decided to choose a diameter of ± 15 cm of the light spot for two reasons. First, this value mirrored the average landing precision (variable error of foot positioning during touchdown) over all participating gymnasts (see Procedure Section). Second, a light spot projected on the landing mat with a diameter of ± 15 cm approximated the area that covered the average participant's central field of view (± 2°) during the top of the backswing. The activation and deactivation of the spotlight was coupled to the motion of the gymnast. Therefore, a photoelectric sensor was placed 0.50 m vertically below the upper bar. As soon as the legs of the gymnast wiped past the sensor during the initial flexion of the hip joints and prior to the backswing phase, the spotlight was activated. It was deactivated when the gymnast performed the swing motion, and her legs wiped past a second photoelectric sensor, which was placed 1.40 m vertically below the upper bar. When performing a salto in one of the experimental conditions, the gymnast was given the instruction to fixate her gaze to the light circle during the downswing phase of the experimental task. The gymnast was furthermore instructed to perform a rule-adequate landing at the end of the dismount and then stabilize her landing for at least three seconds. The location of the light spot was adjusted for each individual gymnast according to the Experimental Procedure.

Procedure

The experiment was conducted in four phases over two days: On the first phase (day 1) the gymnast arrived at the gymnasium and completed the informed consent form. The gymnast was informed about the general purpose and the procedure of the study except for the experimental manipulation of gaze direction in the third phase of the experiment. In particular, the gymnast was told that she was taking part in a study on the kinematics of the backward salto as a dismount from the uneven bars. Afterwards the gymnast's height and weight were measured and the gymnast was given an individual 15-minute warm-up period. After the warm-up period, the gymnast was allowed to perform four familiarization trials without the light spot, and another four trials with the light spot. There was no time pressure in this study and each participant was allowed to take breaks as requested.

On the second phase (day 1), and in order to create a baseline of landing locations of each participant, gymnasts were asked to perform five backward saltos performed as dismounts on the uneven bars after the familiarization trials. Performances were videotaped and landing distance as well as landing precision was measured. Individual average landing distance (ILD) and landing precision (variable error of foot positioning during touchdown) were calculated for each gymnast. The average landing precision over all participants was ± 15 cm. This value was used in the second phase of the experiment as a constant factor when manipulating the gymnast's gaze direction. The average landing distance was calculated to set up the experimental protocol for each gymnast in the second phase of the experiment.

In the third phase of the experiment (day 2) the gymnast arrived at the gym and was again given an individual 15-minute warm-up period together with another eight familiarization trials (4 without light spot and another 4 with light spot). Afterwards, the gymnast was asked to perform 5 backward saltos performed as dismounts on the uneven bars in 5 experimental conditions, for a total of 25 saltos. The experimental conditions delineated the location of the light spot in relation to the individual landing distance (ILD). In the first experimental condition, the centre of the light spot was placed at the gymnast's individual landing distance (ILD). In the second condition, the light spot was placed 0.30 m closer to the upper bar with regard to the ILD (ILD - 0.30 m). The third condition comprised a shortening of the light spot location of 0.15 m with regard of the ILD (ILD - 0.15 m). In the fourth experimental condition, the light spot was placed 0.15 m farther away from the ILD (ILD + 0.15 m), and in the fifth condition, the spot was placed 0.30 m farther away with regard to the ILD (ILD + 0.30 m). Prior to each trial, the gymnast was asked to prepare herself in an adjacent room (putting chalk on hands, resting, etc.). During that time, an instructed researcher placed the middle of the light spot according to one of the five conditions. The five conditions were presented to the participating gymnasts in a random order [10].

The fourth phase of the experiment took place after the 25 dismounts were completed. First, a manipulation check was conducted in which the gymnast was asked if she had perceived any experimental manipulation of the experiment. None of the gymnasts indicated that she had perceived an experimental manipulation of the light spot location. After the manipulation check, the gymnast was told the specific purposes of the study together with the experimental manipulation of the location of the light spot with regard to her individual landing distance. Each gymnast received 35 euros as a reward for participation.

Data analysis

A significance criterion of $\alpha = 5\%$ was defined for all results reported. First, and prior to testing the main hypothesis, gymnasts' individual landing distance in the ILD condition (with the light spot) was compared to their individual landing distance from the baseline condition (without the light spot) in order to assess whether changes in landing distance may have occurred just by having the light spot on the landing mat. A paired-samples *t*-test was performed indicating that there were no statistically significant differences in landing distance between the baseline condition and the ILD condition, $t(12) = 0.32$, $p = 0.75$. In a second step, separate univariate analyses of variance with repeated measures (ANOVAs) were conducted for each of the dependent variables, in order to investigate differences between the four experimental conditions [22,36]. Cohen's *f* was calculated as effect size for all significant *F*-values. Additionally, the achieved power was calculated for all significant *F*-values [8].

RESULTS

It was hypothesized that there is a functional relationship between the positioning of the light spot and the landing location. In particular it was expected that fixating the gaze towards different locations of the light spot on the landing mat would directly and linearly affect the landing location, which in turn should result from changes of the backward saltos' swing motion. However, we had no specific predictions on the effects of manipulating gaze direction during the downswing on the kinematic parameters of the swing motion but additionally sought to explore this effect.

Summaries of the kinematic parameters (means ± standard errors) are presented in Table 1. Manipulating the location of the light spot revealed a significant effect on downswing phase duration, $F(3, 36) = 8.935$, $p = 0.0001$, Cohen's $f = 0.86$, hip angle at top of backswing, $F(3, 36) = 3.437$, $p = 0.027$, Cohen's $f = 0.54$, hip angle prior to kick-through, $F(3, 36) = 4.075$, $p = 0.014$, Cohen's $f = 0.58$, and landing distance, $F(3, 36) = 5.411$, $p = 0.004$, Cohen's $f = 0.67$. The achieved power for all significant results was > 0.90. Manipulating the location of the light spot did not significantly affect the other variables.

In particular, the downswing phase duration was 0.04 s longer in the ILD – 0.30 m condition and on average 0.035 s shorter in the ILD + 0.15 m and the ILD + 0.30 m condition as compared to the baseline condition. Gymnasts exhibited on average a 3.6° larger hip angle at the top of the backswing in the ILD – 0.30 m and the ILD – 0.15 m conditions as compared to the ILD + 0.15 m condition as well as the ILD + 0.30 m condition. The hip angle prior to kick-through was about 2° larger in the ILD – 0.30 m condition, and on average 2.5° smaller in the ILD + 0.15 m and ILD + 0.30 m condition as compared to the baseline condition. Finally gymnasts exhibited on average a 5.5 cm shorter landing distance in the ILD – 0.30 m and the ILD – 0.15 m condition, and a 6.5 cm longer landing distance in the ILD + 0.15 m and ILD + 0.30 m condition as compared to the baseline condition.

DISCUSSION

The goal of this study was to investigate relationships between gaze behaviour and movement behaviour in a complex gymnastics skill, namely the backward salto performed as a dismount on the uneven bars. It was speculated that the direction of gaze to specific objects or locations during task performance in a proactive manner might be functional for the execution of the task. Therefore, it was predicted that functional relationships between gaze behaviour and movement kinematics exist, and thus a manipulation of gaze behaviour direction should have a direct impact on the kinematics of a complex skill.

Taking the results together, the following pattern of results emerged: The gymnasts exhibited larger hip angles at the top of the backswing

TABLE 1. PARTICIPANTS' KINEMATIC PARAMETERS (MEANS ± STANDARD ERRORS) OF THE DISMOUNTS IN THE FOUR EXPERIMENTAL CONDITIONS (ILD ± 0.30 M, ILD ± 0.15 M) AND THE BASELINE CONDITION (ILD), AS WELL AS STATISTICAL PARAMETERS OF THE SEPARATE ANOVAS (ILD = INDIVIDUAL LANDING DISTANCE)

	Baseline	Experimental Conditions					
Movement Phase Parameter	ILD Mean ± SE	ILD – 0.30 m Mean ± SE	ILD – 0.15 m Mean ± SE	ILD + 0.15 m Mean ± SE	ILD + 0.30 m Mean ± SE	F(3, 36)	p
Swing Motion							
Backswing Phase Duration [s]	0.34 ± 0.01	0.35 ± 0.01	0.33 ± 0.01	0.34 ± 0.01	0.33 ± 0.01	1.520	0.225
Hip Angle at Top of Backswing [°]	129.02 ± 6.46	131.68 ± 7.22	132.24 ± 6.82	128.55 ± 6.51	127.09 ± 6.89	3.437	0.027*)
Shoulder Angle at Top of Backswing [°]	125.86 ± 3.24	125.16 ± 4.14	124.89 ± 3.62	127.29 ± 3.66	125.50 ± 4.27	1.236	0.311
Downswing Phase Duration [s]	0.68 ± 0.02	0.72 ± 0.02	0.68 ± 0.02	0.66 ± 0.02	0.63 ± 0.02	8.935	0.0001*)
Hip Angle prior to Kick-Through [°]	180.19 ± 2.64	182.35 ± 2.06	180.94 ± 2.19	178.40 ± 2.66	176.98 ± 3.25	4.075	0.014*)
Shoulder Angle prior to Kick-Through [°]	179.25 ± 1.34	176.34 ± 1.39	178.21 ± 1.30	179.48 ± 1.36	179.20 ± 1.54	1.120	0.355
Upswing Phase Duration [s]	0.44 ± 0.01	0.45 ± 0.02	0.44 ± 0.02	0.44 ± 0.02	0.45 ± 0.02	1.220	0.316
Hip Angle during Release [°]	123.25 ± 5.45	123.46 ± 6.46	124.81 ± 7.06	125.08 ± 6.24	124.03 ± 5.74	0.271	0.845
Shoulder Angle during Release [°]	163.08 ± 2.32	163.86 ± 2.59	162.74 ± 2.59	162.56 ± 2.41	162.32 ± 2.13	0.850	0.475
Knee Angle during Release [°]	104.74 ± 10.01	105.81 ± 11.51	106.94 ± 11.87	105.79 ± 11.10	104.25 ± 10.94	0.463	0.709
Dismount							
Achieving the Tucked Position [s]	0.24 ± 0.02	0.25 ± 0.02	0.24 ± 0.02	0.24 ± 0.02	0.24 ± 0.02	1.716	0.181
Remaining Tucked [s]	0.08 ± 0.02	0.07 ± 0.02	0.08 ± 0.02	0.08 ± 0.02	0.08 ± 0.02	0.926	0.438
Extending the Body [s]	0.42 ± 0.02	0.42 ± 0.02	0.42 ± 0.02	0.42 ± 0.02	0.42 ± 0.02	0.804	0.499
Height of Flight [m]	0.31 ± 0.02	0.31 ± 0.02	0.31 ± 0.02	0.31 ± 0.02	0.31 ± 0.02	0.584	0.628
Moment of Inertia when Tucked [kg m^2]	12.67 ± 0.21	12.74 ± 0.21	12.75 ± 0.22	12.60 ± 0.25	12.61 ± 0.26	2.630	0.065
Moment of Inertia at Touch-Down [kg m^2]	17.13 ± 0.32	17.40 ± 0.36	17.26 ± 0.32	16.94 ± 0.54	17.38 ± 0.38	0.983	0.411
Angular Momentum [N m s]	96.77 ± 4.97	92.18 ± 3.17	96.89 ± 4.71	95.19 ± 4.86	97.30 ± 3.85	1.628	0.199
Landing Distance [m]	1.77 ± 0.04	1.70 ± 0.04	1.73 ± 0.04	1.82 ± 0.04	1.85 ± 0.04	5.411	0.004*)
Landing Precision [m]	0.15 ± 0.02	0.16 ± 0.02	0.15 ± 0.02	0.15 ±0.02	0.16 ± 0.02	0.094	0.962

Note: *) significant effect of Experimental Condition ($p < .05$)

in the ILD – 0.30 m and the ILD – 0.15 m conditions as compared to the baseline condition, the ILD + 0.15 m condition as well as the ILD + 0.30 m condition. The downswing phase duration was longer in the ILD – 0.30 m condition and shorter in the ILD + 0.15 m and the ILD + 0.30 m condition as compared to the baseline condition. The hip angle prior to kick-through was larger in the ILD – 0.30 m condition, and smaller in the ILD + 0.15 m and ILD + 0.30 m condition as compared to the baseline condition. Finally there was an almost linear dependency for landing distance, so that gymnasts exhibited the smallest landing distance in the ILD – 0.30 m condition and the largest landing distance in the ILD + 0.30 m condition. The duration of the backswing and the upswing phase as well as the duration of the dismount, the shoulder angle throughout the whole skill, the hip and knee angle at release, and the body posture during the flight phase remained uninfluenced by a manipulation of the light spot. Finally, gymnasts did not exhibit a different landing precision between the experimental conditions.

It can be shown from research on everyday actions that the eyes look towards objects and locations they are engaged with in a specific task and this information is used to guide the corresponding action [24]. This statement might also hold for more complex actions or skills such as the one we investigated in this study. The landing distance when performing the dismount varied clearly as a function of the location of the light spot. Therefore it can be stated that directing gaze towards the landing area is used in an anticipatory manner when performing dismounts on the uneven bars (cf., [26]). Anchoring the gaze on locations or objects in the environment that possess no significant information on structure, colour or form may primarily be used for spatial orientation [17].

When anchoring gaze, the fovea is directed towards a specific object [34]. When the gymnast's head moves in space, either intentionally for instance by extending or flexing the neck or as a consequence of the movement of the whole body, the eye position and velocity in the moving head may provide important information on spatial orientation only if the gaze is anchored [37]. The muscles of the eyeball are rich in muscle spindles and their discharge frequency is directly related to the position and velocity of the eye, and thus may provide information about spatial orientation [27]. This information is seen to be more reliable than information that is for instance provided by the semicircular canals, especially when the gymnast's head exhibits rather low angular velocities [6].

Reaching a particular landing location is a result of the flight phase itself, which in turn is a result of the take-off conditions when performing the dismount [3]. The mechanical conditions of the take-off are a result of the swing motion. Taken together, a prospective type of control seems to unfold during the downswing and upswing motion, which is directly related to the landing location, which in turn is driven by the gaze direction during the swing motion [29]. A prospective type of control was in general assumed in expert gymnasts when performing saltos, and gymnasts show a decrease in body orientation variability prior to touchdown [2]. Trained athletes usually organize their movement patterns in such a way that a few (often goal-related) parameters remain invariant whereas other parameters are regulated [43]. However, the invariant parameters may refer to different control levels and they may also differ depending on the task demands. A shorter downswing duration together with a different hip angle prior to the kick-through could result in a different upswing motion which in turn leads to differences in horizontal take-off velocity but not to differences in body segment angles. Differences in horizontal take-off velocity may directly lead to differences in landing distance [15].

We are aware of several limitations of our study and want to highlight two specific aspects. First, it was assumed that directing gaze towards the landing area is functional for the execution of a backward salto as a dismount from the uneven bars. The location of the light spot that was used to direct the gymnast's gaze was created from the individual landing location of each gymnast. It could however be possible that gymnasts potentially use different objects or locations in the environment when executing a backward salto as a dismount from the uneven bars, and that directing the gaze directly towards the landing area could be part of an adaptive gaze strategy. A subsequent study should, as a consequence, be conducted by directing gymnasts' gaze towards different objects and locations using light spots of different size, brightness, and even colour, in order to analyse the effect of this manipulation on kinematic parameters of the dismounts. Second, gymnasts' gaze behaviour was not measured in this experiment so one cannot be certain whether using the light spot did in fact direct gymnasts' gaze behaviour towards the location of the spot. A subsequent study should try to incorporate the measurement of gaze behaviour in its design in order to control for the intended effect of gaze behaviour instruction. To the best of our knowledge there is only marginal empirical evidence on gaze behaviour in gymnastics skills involving a whole-body rotation during the flight phase, so this could be a very fruitful way for future research [40].

There are, however, some practical consequences of our study so far. First, the knowledge about functional relationships between gaze behaviour and movement outcome as it is shown in this study could easily be incorporated in gymnastics training methodology for the uneven bars. Visual fixation of a specific point on the landing mat during a specific phase of a gymnastics skill results in a landing location influenced by this visual fixation. This seems to be of high practical relevance when aiming to integrate new and alternative training methods. A coach for example could advise a gymnast to intentionally direct his/her gaze on specific environmental cues, which seems to trigger regulative movement executions, with the outcome that a gymnast may change his landing location according to the visual fixation.

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