Human Movement Science 95 (2024) 103211

Contents lists available at ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov

How spotting technique affects dizziness and postural stability after full-body rotations in dancers

Andrea Schärli [a,*], Heiko Hecht [b], Fred W. Mast [c], Ernst-Joachim Hossner [a]

[a] *Institute of Sport Science, University of Bern, Bern, Switzerland*
[b] *Institute of Psychology, Johannes Gutenberg University Mainz, Germany*
[c] *Institute of Psychology, University of Bern, Bern, Switzerland*

ARTICLE INFO

Keywords:
Balance
Dizziness
Motor control
Rotation
Spotting
Dance

ABSTRACT

Consecutive longitudinal axis rotations are very common in dance, ranging from head spins in break dance to pirouettes in ballet. They pose a rather formidable perceptuomotor challenge – and hence form an interesting window into human motor behaviour – yet they have been scarcely studied. In the present study, we investigated dancers' dizziness and postural stability after consecutive rotations. Rotations were performed actively or undergone passively, either with or without the use of a spotting technique in such an order that all 24 ordering options were offered at least once and not more than twice.

Thirty-four dancers trained in ballet and/or contemporary dance (aged 27.2 ± 5.1 years) with a mean dance experience of 14.2 ± 7.1 years actively performed 14 revolutions in *passé* or *coupé* positions with a short gesture leg "foot down" after each revolution. In addition, they were passively turned through 14 revolutions on a motor-driven rotating chair. Participants' centre-of-pressure (COP) displacement was measured on a force-plate before and after the rotations. Moreover, the dancers indicated their subjective feeling of dizziness on a scale from 0 to 20 directly after the rotations. Both the active and passive conditions were completed with and without the dancers spotting.

As expected, dizziness was worse after rotations without the adoption of the spotting technique, both in active and passive rotations. However, the pre-post difference in COP area after active rotations was unaffected by spotting, whereas in the passive condition, spotting diminished this difference. Our results thus suggest that adopting the spotting technique is a useful tool for dizziness reduction in dancers who have to perform multiple rotations. Moreover, spotting appears most beneficial for postural stability when it involves less postural control challenges, such as when seated on a chair and occurs in situations with limited somatosensory feedback (e.g., from the cutaneous receptors in the feet). However, the unexpected finding that spotting did not help postural stability after active rotations needs to be investigated further in future studies, for example with a detailed analysis of whole-body kinematics and eye-tracking.

1. Introduction

Everyday activities involve the continuous control of posture in upright stance and locomotion. During such activities, whole-body

* Corresponding author at: University of Bern, Bremgartenstrasse 145, 3012 Bern, Switzerland.
E-mail address: andrea.schaerli@unibe.ch (A. Schärli).

https://doi.org/10.1016/j.humov.2024.103211
Received 13 July 2023; Received in revised form 12 March 2024; Accepted 15 March 2024
Available online 6 April 2024

rotations are performed regularly, for example when changing direction during walking or turning around when standing. Such rotations (mainly) around the vertical axis can cause instability (Hase & Stein, 1999) and dizziness may occur in healthy humans as well as in patients (Kim et al., 2013).

In pathology, it has been shown that a dysfunction of the vestibular system can produce dizziness even without the induction of rotational movements (Sloane, Coeytaux, Beck, & Dallara, 2001) whilst in healthy humans, dizziness naturally occurs after consecutive rotational movements. However, it has been repeatedly shown that such post-rotatory vestibular responses, which can lead to a feeling of dizziness, can be reduced through regular exposure to rotational movements, for example in dancers (Dix & Hood, 1969; Nigmatullina, Hellyer, Nachev, Sharp, & Seemungal, 2015; Osterhammel, Terkildsen, & Zilstorff, 1968; Tschiassny, 1957) or in figure skaters (Alpini, Botta, Mattei, & Tornese, 2009; Collins, 1968; Tanguy, Quarck, Etard, Gauthier, & Denise, 2008a; Tanguy, Quarck, Etard, Gauthier, & Denise, 2008b). On the one hand, the reason for such a reduction of vestibular responses after rotations has been assigned to vestibular adaptation. As an example of such vestibular adaptation, Nigmatullina et al. (2015) postulate that the vestibular-ocular reflex is suppressed in dancers who are highly used to rotations. On the other hand, it has been shown that strategies of visual fixation during and after rotations can reduce vestibular responses, which are often quantified as slow phase velocity or time constant of the electro-ocular signal during horizontal eye nystagmus (Kim et al., 2013).

When investigating the phenomenon of postural instability and dizziness after rotational movements, it seems advisable to study populations that regularly perform such tasks. Several groups are confronted with consecutive rotations, the most established ones being dancers from different dance styles, figure skaters, gymnasts, freestyle skiers, or snowboarders. However, most of these athletes perform multiaxial rotations. Dancers and figure skaters, however, perform rotations around one axis, predominantly around the vertical axis when pirouetting in training and in competition.

When observing such consecutive rotations around the vertical axis in dancers, a typical eye-head coordination known as 'spotting' is frequently used. While rotating, a dancer's gaze is fixed to a single spot for as long as possible while the rest of the body turns. The head and eyes then rotate quickly, 'overtaking' the rest of the body, to then linger on another external spot for as long as possible, and so on. Spotting can be observed in dancers of different styles, but mainly in classical stage dances such as ballet, modern dance, and jazz dance. Interestingly, figure skaters and gymnasts for example do not adopt the spotting technique during their rotations around the vertical axis. In dance, it is widely accepted that the spotting technique helps to prevent dizziness, although scientific evidence thereof is scarce.

The effect of spotting on the occurrence of post-rotatory nystagmus in passive rotations on a rotating chair was investigated by Osterhammel et al. (1968) who showed significantly lower values for post-rotatory nystagmus in trials with spotting as compared to trials without spotting in ballet dancers. In line with this finding, a more recent study by Kim et al. (2013) found that fixating a spot during and after rotations on a rotating chair reduced both subjective perception of dizziness and objectively measured values of time constants of post-rotatory nystagmus in healthy adults. In addition, besides a decreased vestibular response in dancers after adopting the spotting technique, Osterhammel et al. (1968) found a significant difference in post-rotatory response between ballet dancers and controls. After turning on a rotating chair, dancers had lower mean values for slow-phase velocity of nystagmus than controls, which indicates a less pronounced nystagmus in dancers. Moreover, dancers did not report a feeling of dizziness after the rotations in that study independent of the occurrence of post-rotatory nystagmus.

Similarly, a study by Nigmatullina et al. (2015) showed that, as compared to controls, dancers reduced their slow-phase velocity of nystagmus and intensity of vertigo perception more quickly when being turned on a rotating chair. They further showed that the decrease in slow-phase velocity and intensity of vertigo was correlated in controls, but not in dancers, suggesting a loss of the normal association between vestibular-ocular reflex (VOR) and dizziness perception in dancers. This means that the measurement of the vestibular-ocular reflex might not be representative for the feeling of dizziness in the group of dancers. It could rather be that measuring postural stability by means of centre-of-pressure (COP) displacement might be a more appropriate functional measure for the extent to which multiple rotations affect performance.

Based on above findings, the reduced feeling of dizziness in dancers might not be due to spotting alone but might also result from vestibular adaptation. Therefore, the question why dancers adopt the spotting technique during their rotations is still an open one. Possible answers can be found in a three-round Delphi survey, in which dance experts (i.e., ballet teachers, professional ballet dancers, dance scientists) were asked for their opinions on the characteristics and uses of spotting in dance (Haber & Schärli, 2021). Although the survey found a low consensus among experts for reasons for spotting, the most prominent ones were dizziness reduction, balance improvement, orientation, and rhythm. However, no study so far has analysed the effect of spotting on these parameters experimentally.

Therefore, the aim of the present study is to investigate whether spotting influences self-perceived dizziness and postural stability after repeated full-body rotations around the vertical axis. In more detail, we explore the effect of spotting on postural stability and dizziness in dancers both after active (i.e., consecutive rotations around the vertical axis) and passive (i.e., on a motor-driven rotating chair) rotations. The active condition constitutes a highly functional mode of turning, whereas the passive condition without active motor involvement allows for a comparison with existing literature on consecutive rotations. Based on the current state of research (Kim et al., 2013; Osterhammel et al., 1968), we hypothesise that dancers' self-reported post-rotatory dizziness is less pronounced with spotting than without spotting. Moreover, given that visual fixation improves postural stability in simpler, non-rotatory balancing tasks (e.g., Schärli, Keller, Lorenzetti, Murer, & van de Langenberg, 2013), we expect lower COP-excursions and hence higher postural stability after rotations with spotting than without spotting.

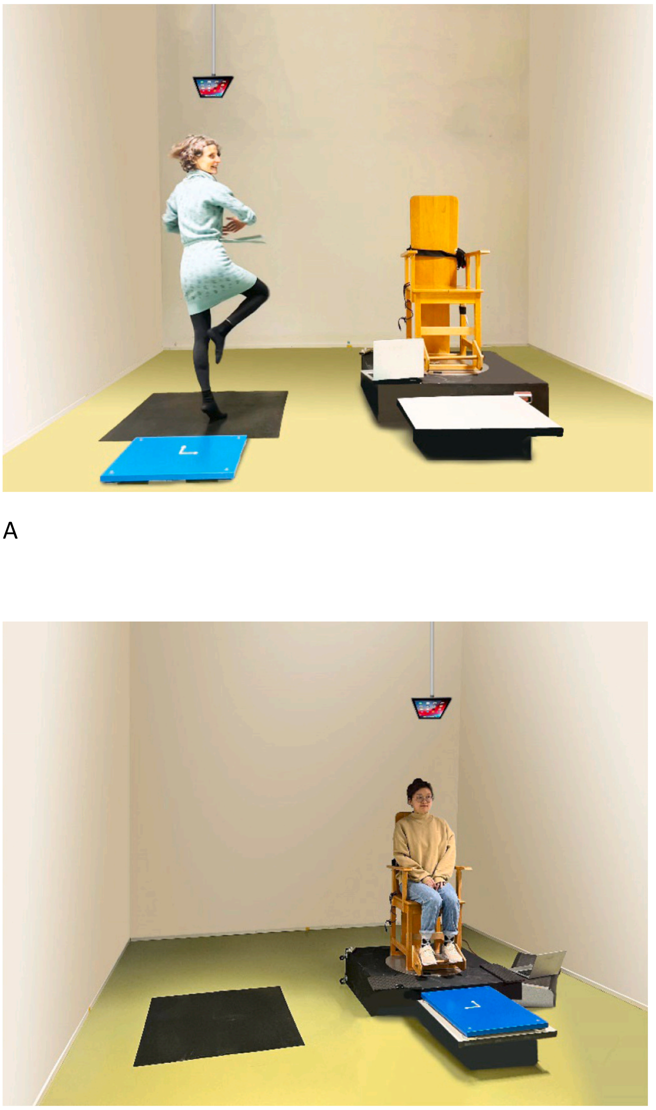
2. Methods

2.1. Participants

Thirty-four dancers (age: $M = 27.2 \pm 5.1$ years, 30 female- and 4 male-identified) trained in ballet and/or contemporary dance took part in this study. Sample size was chosen based on previous studies investigating dancers or controls on a rotating chair (i.e., Osterhammel et al., 1968: $n = 13$, Kim et al., 2013: $n = 18$, Nigmatullina et al., 2015: $n = 29$). Additionally, an a-priori sample size calculation was conducted with G*Power (version 3.1.9.7). We set our significance level at $\alpha \leq 0.05$, aimed for a statistical power of 80% (1 – beta = 0.80) and assumed a medium effect size of 0.5. The estimated sample size based on this calculation was $n = 35$. The dance experience of the participants ranged from 3.5 to 31.0 years ($M = 14.2 \pm 7.1$ years). Weekly training investment (including rehearsals) was on average 9.7 ± 11.0 h. The protocol was approved by the ethics committee of the local Faculty of Human Sciences and was carried out in accordance with the 1964 Declaration of Helsinki.

2.2. Apparatus

The participants were tested individually in a room equipped with both an area with a piece of dance flooring (measurement: 1.0 ×



A

B

Fig. 1. Experimental setup (A: active condition, B: passive condition).

1.0 m) for the active rotations and a motor-driven rotating chair for the passive rotations. The custom-built rotating chair could be started and stopped with a steering unit that, besides the velocity of rotation, also allowed for choosing the direction of rotation. On the steering unit maximal acceleration was achieved by turning a button to its end position. The acceleration and deceleration of the chair took about 3 s. After 2.25 rotations, the maximal speed of 270°/*sec* was achieved. Depending on the experimental condition, a 3D mobile force-plate (Kistler Type 9260AA, Kistler Group, Switzerland) was placed either in front of the piece of dance flooring or in front of the rotating chair at the same height as the turning platform (see Fig. 1). To control for compliance with the experimental conditions after the data collection, two iPads (iPad Air version 2, Apple Inc.) were mounted at the ceiling of the room in line with the rotational axis over the central area of the dance flooring and the rotating chair, respectively. The top-view videos of the rotations were a back-up for checking the experimental procedure in case of any ambiguity arising after data collection. Also, the videos were used to analyse the duration of spotting in the different conditions with the Kinovea software (version 0.9.5, 2009).

2.3. Procedure

Participants were informed about the aim and procedure of the study and subsequently gave their written informed consent for participation. Before starting the experiment, each participant conducted a short warm-up with a pulse raising activity as well as some *pliés* (i.e., knee bending) and *tendus* (i.e., extending the legs to the front, side and back) for mobilisation of the joints. Then, the participants tried out both rotation conditions (i.e., active and passive) with and without the adoption of spotting to get used to the experimental set-up. Subsequently, each participant was measured in the following four conditions, which were presented such that all 24 ordering options ($= 4 \times 3 \times 2 \times 1$) were given at least once and no ordering option more than twice:

- a 14 active rotations with spotting
- b 14 active rotations without spotting
- c 14 passive rotations with spotting
- d 14 passive rotations without spotting

The rotations were measured to the participants' preferred turning direction in both the active and passive conditions. The active rotations of conditions a and b were executed, according to the dancers' choice, either on one leg in *passé* (i.e., gesture leg foot touching the standing leg knee) or *coupé* (i.e., gesture leg foot touching the standing leg ankle) positions, in both cases with a short foot-down phase of the gesture leg at the end of each revolution. The position of the legs was either parallel or turned-out in the hip joint depending on the dancers' preference. The rotational velocity for the active rotations was chosen based on the maximum speed of the rotating chair, which was 270°/s. Thus, the active rotations were timed with a metronome to 45 bpm. This speed is close to a calm performance tempo of consecutive rotations in dance and can thus be seen as ecologically valid. It should be noted that Osterhammel et al. (1968) adopted the same velocity for the rotating chair in their study.

As in the active rotations, for the passive rotations in conditions c and d, participants were rotated to their preferred turning direction with a turning speed of 270°/s. The passive rotations were accelerated towards the maximal speed during the first revolution and decelerated during the last revolution to reach stillstand to the front. The rotations in the middle were performed with constant speed, which contrasts with the execution of the active rotations where a slowing down and speeding up phase in each revolution takes place. In the passive conditions, the participants sat on the rotating chair in a relaxed way without using the arm rest during turning. If a participant did not feel comfortable, the rotation of the chair could be stopped immediately. However, such an emergency stop was not necessary during our data collection.

Directly after the rotations in each condition, participants indicated a value for their perception of vertigo after-effect measured by self-assessment using a 0–20 scale (Kaufeld, Bourdeinik, Prinz, Mundt, & Hecht, 2022). Moreover, before, and directly after each condition (i.e., eight measurements), participants' postural stability was measured. To this end, participants were asked to stand on the mobile 3D force-plate quietly for 30 s with feet next to each other (i.e., big toes and heels touching) and hands on the waist. The force-plate measurement software included a sound with the phrase "step on" when the trial started, which ensured a similar timing of stepping on the force-plate after the rotations for all participants and conditions (i.e., approximately one second). Between conditions, participants were given 5-min breaks. If the dizziness value was not dropped to 0 during this period, the break was extended.

In conditions a and c, participants were asked to conduct spotting, which means that an imagined spot on the front wall was fixed for as long as possible during each revolution, and then immediately fixated again for each subsequent rotation. More precisely, this means that the body rotation started before the head rotation and the head stopped again facing the front before the torso arrived, which implies that head and torso were independently coordinated. Conversely, in conditions b and d, participants were instructed to refrain from spotting, which means that they rotated their head and eyes "en-bloc" with the torso. During the experiment, two investigators observed for compliance with the spotting technique (i.e., with spotting or without spotting). The conditions were repeated if a participant did not adopt a spotting pattern in the spotting condition or did adopt a spotting pattern in the condition without spotting. Only the latter occurred in our study in one participant, and the two investigators present ensured that all included trials had been correctly executed. Moreover, to validate these online-ratings, one researcher quantitatively double-checked participants' spotting behaviour for compliance with the instructions on the recorded iPad videos (frame rate: 120 Hz) after the experiment.

At the end of the individual sessions of 45–60 min duration, the participants were thanked and debriefed.

2.4. Data analysis

For the purpose of checking the spotting manipulation (i.e., with and without), video analyses were performed with the Kinovea software (version 0.9.5, 2009). To this end, spotting ratios for the conditions active with and without spotting and passive with and without spotting were calculated. The spotting ratio is the ratio between the mean duration of spotting and the mean duration of the rotations. Spotting occurs when the line through the centre of the head and the nose remains orthogonal to the front wall within $\pm 5^{\circ}$. The turn duration was calculated by counting the total number of frames for one rotation and dividing it by the frame rate (i.e., 120 Hz). The higher the ratio, the longer the portion of spotting to the front in relation to the turn duration. As a manipulation check, we conducted a paired samples *t*-test between the active condition with and without spotting. To check for a different spotting behaviour in the active vs. passive conditions, Δ spotting ratios were calculated for both the active and passive conditions (i.e., difference of spotting to the front in the spotting minus non-spotting conditions) and compared with a paired samples t-test.

As dependent measure for self-perceived dizziness the perception of vertigo after-effect was measured by self-assessment using a 0–20 scale (Kaufeld et al., 2022). As all participants started their rotations with a value of 0, the dizziness score represents the scale value after the rotations. The higher the value the dizzier the participants felt.

For calculating a dependent measure for postural stability, the ground reaction forces (i.e., Fx, Fy, and Fz) and moments (i.e., Mx, My, and Mz) were recorded with the 3D mobile force-plate at a sampling frequency of 1000 Hz. These force and moment time series were smoothed using a moving average with a 150 ms time window. Then, the centre of pressure (COP) pathways in medio-lateral and anterior-posterior directions were calculated using the following formula: $COPx = \frac{-(My - Fx^{*}az0)}{Fz}$, $COPy = \frac{(Mx - Fy^{*}az0)}{Fz}$, and centred on mean zero (az0: thickness parameter of the force plate). Subsequently, the COP 95% ellipse area during quiet stance on two legs was calculated over a duration of 20 s for both measurements before and after rotations in each condition as an indicative measure of postural stability (see Fig. 2). The calculation of the COP area started when the median of Fz reached 95% of its maximum value (i.e., indicating near full weight on the plate), which means that the participant stood almost quietly on the force-plate. Instabilities during the stepping-on movement were thus cut off. However, initial instability issues during quiet stance resulting from the rotations were still captured with this method. The last few seconds of the recording were not considered, to analyse exactly 20 s duration for all participants starting with full-weight bearing. It is widely accepted that larger COP areas stand for decreased postural stability (Winter, 1995). Finally, a Δ COP area was calculated as the dependent variable for postural stability by subtracting the COP area of the pre-rotation from the post-rotation measurements. Therefore, positive values stand for a larger COP area after the rotations as compared to before the rotations and thus indicate a decreased postural stability after the rotations.

Independent variables for inferential analyses were spotting (2 levels: spotting vs. no spotting) and rotation (2 levels: active vs. passive). Based on the central limit theorem, parametric tests were performed as the sample contained >30 participants. Thus, for both dizziness and postural stability, 2×2 repeated measures ANOVAs were performed. Moreover, Pearson correlation coefficients were calculated between the dizziness and postural stability values in each condition. Effect sizes were calculated as η_p^2 for the ANOVA and as Cohen's d for the paired samples *t*-test analyses, and Observed Power (OP) will be reported. Statistical significance was a priori set at $\alpha \leq 0.05$.

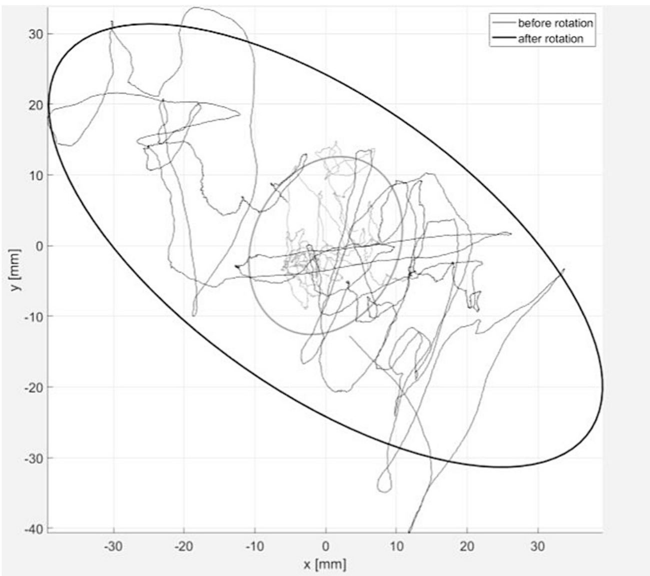


Fig. 2. Exemplary illustration of the 95% ellipse area of the COP time series during quiet stance in one participant in the active condition with spotting (gray line: before rotation, black line: after rotation).

3. Results

3.1. Spotting

For the additionally conducted posthoc manipulation check, some of the videos were not suitable for quantitative analysis as the participants moved out of the frame or the recording was faulty. Table 1 shows the resulting descriptive statistics for the spotting ratios in the active and passive conditions with and without spotting as well as differences between the values for the conditions with and without spotting (Δ spotting ratio). Higher spotting ratio values stand for a longer spotting duration towards the front.

For the passive condition without spotting, no spotting was present in all participants as they perfectly moved around continuously "en-bloc" on the chair, which rendered a statistical comparison between spotting and non-spotting impossible. However, in the active condition without spotting, a stabilisation to the front happened after each revolution due to the nature of the task with the touchdown of the gesture leg after each rotation. Notably, the stabilisation in the active condition without spotting was "en bloc", whereas in the active condition with spotting the head was also stabilised separately, while the body was rotating again. As expected, a statistically significant difference between the spotting ratio in the active conditions with and without spotting was revealed, $t(22) = 21.26$, $p < .001$, d = 4.43, whereas the difference between the Δ spotting ratios in the active and passive conditions failed to reach significance, $t(19) = -2.09$, $p = .05$, d = 0.47. Hence, the quantitative manipulation check confirmed the online ratings of the experimenters. Therefore, it can be assumed that the differences found in the dependent variables can partly be ascribed to differences in spotting behaviour.

3.2. Self-perceived dizziness

As depicted in Fig. 3, significant main effects for spotting (i.e., with and without), $F(1,33) = 8.37$, $p = .007$, $\eta_p^2 = 0.20$, OP = 0.80, as well as for rotation (i.e., active vs. passive), $F(1,33) = 44.77$, $p < .001$, $\eta_p^2 = 0.58$, OP = 1.00 were revealed, which indicates that after rotations without spotting and after passive rotations, a generally higher dizziness was perceived than after rotations with spotting and after active rotations, respectively. However, these effects are overlaid by a significant interaction, $F(1,33) = 5.13$, $p = .03$, $\eta_p^2 = 0.14$, OP = 0.60, which reflects the fact that dizziness reduction due to spotting was somewhat larger in the passive condition (−3.25) than in the active condition (−2.26; see Fig. 3).

3.3. Postural stability

Two participants showed extreme outliers in one condition each for postural stability after active rotations. After checking the protocol and videos it became clear that these participants did not comply with the given timing of stepping on the force-plate and were standing on the force-plate too early. Therefore, they were excluded from the postural stability analysis.

As illustrated in Fig. 4, whilst the main effect of spotting failed to reach significance, $F(1,31) = 3.07$, $p = .09$, $\eta_p^2 = 0.09$, OP = 0.40, a significant main effect for rotation indicates that in general a more pronounced decrease in postural stability was found after active as compared to passive rotations, $F(1,31) = 16.03$, $p < .001$, $\eta_p^2 = 0.34$, OP = 0.97. However, this main effect is overlaid by a significant interaction, $F(1,31) = 5.56$, $p = .03$, $\eta_p^2 = 0.15$, OP = 0.63. Whilst in the active rotations, instability after the rotations remained similar with and without spotting ($\Delta = .61$ cm^2), postural stability was less impaired after the passive rotations when spotting had been adopted, as compared to passive rotations without spotting ($\Delta = 6.32$ cm^2, see Fig. 4).

3.4. Correlations

As summarized in Table 2, whilst significant positive correlations were found between self-perceived dizziness and changes in postural stability after active rotations for both spotting conditions, no significant correlations were found after passive rotations.

4. Discussion

Our study aimed to investigate the effect of spotting on dizziness and postural stability in dancers after consecutive rotations around the vertical axis that were either actively performed or passively undergone. Postural stability was assessed with a force-plate

Table 1
Descriptive Statistics for the spotting ratio calculated as the ratio between the mean duration of spotting and the mean duration of turn for the conditions active with and without spotting and the condition passive with spotting.

	Active			Passive		
	N	M	SD	N	M	SD
With Spotting	23	0.680	0.069	25	0.650	0.067
Without Spotting	29	0.122	0.118	29	0	0
Δ Spotting Ratio	23	0.571	0.129	25	0.650	0.067

Moreover, the difference of spotting ratio was calculated for the active and passive conditions (i.e., active with minus active without spotting and passive with minus passive without spotting).

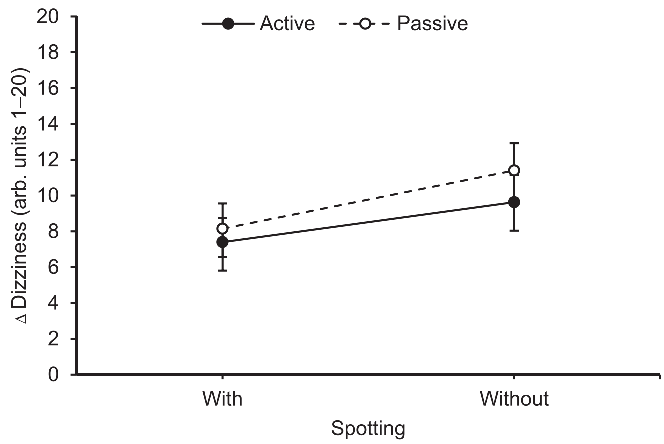


Fig. 3. Self-perceived dizziness (*M* and *SE*) as a function of spotting (with vs. without) and rotation (active vs. passive).

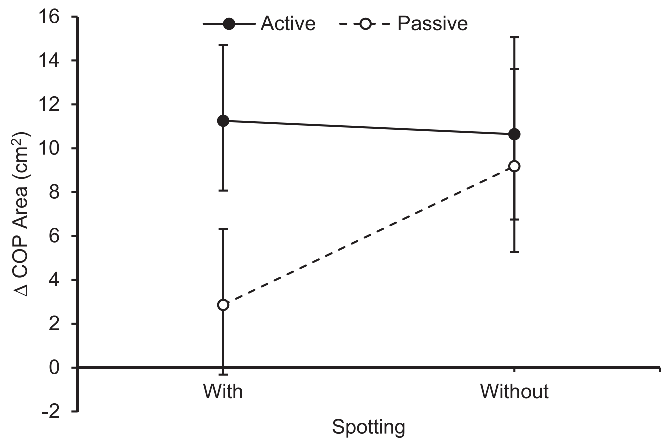


Fig. 4. Pre-post-rotation differences in postural stability (*M* and *SE*) as a function of spotting (with vs. without) and rotation (active vs. passive). Δ COP area stands for the difference in the 95% ellipse area before and after the rotations.

Table 2
Pearson correlation coefficients for self-perceived dizziness values and ΔCOP values for four combination of spotting (with vs. without) and rotation (active vs. passive).

Spotting		
With	Without	
Turning		
Active	$r(34) = 0.38, p = .03$	$r(34) = 0.35, p = .04$
Passive	$r(33) = 0.09, p = .64$	$r(33) = 0.17, p = .34$

and dizziness with a self-assessment scale. Dizziness was worse without rather than with spotting after passive as well as after active rotations, yet the last-mentioned difference was less pronounced when participants spotted. In contrast to dizziness, postural stability was less harmed by passive rather than active rotations but only if participants were applying spotting. Furthermore, dizziness and stability measures were only correlated for active but not for passive rotations, in both cases independently of spotting behaviour.

After separately discussing the results for dizziness and postural stability in the following paragraphs, we will discuss the aforementioned contrast between the dizziness and postural stability results and hence attempt to resolve their apparent contradiction.

4.1. Spotting reduces dizziness after active and passive rotations

To the best of our knowledge, this study is the first to investigate the effect of a high number of actively performed rotations with and without spotting on dizziness and postural stability in dancers. Interestingly, our study showed that participants were dizzier when passively rotated as compared to when they actively performed consecutive turns. In general, this suggests that if we are the actor of the rotations, we are better able to predict the sensory consequences, thus reducing the feeling of dizziness, an explanation that would be perfectly in line with current theories on sensorimotor control that emphasize the role of internal "forward modelling" of the consequences of one's own actions (e.g., Wolpert, Ghahramani, & Jordan, 1995). On a less computational but neural level, Angelaki and Cullen (2008) have shown in this context that neurons distinguish between self-induced and externally induced sensory inputs. These authors also describe that in self-induced movements, the vestibular response can be selectively suppressed, possibly by means of a more precise prediction of sensory consequences which might have also been the case in our active condition. On top of this, it should be noted that all our participants were experienced in actively turning around their vertical axis yet had never experienced being turned on a rotating chair. Consequently, weaker predictions of sensory consequences can be assumed for the last-mentioned condition, which possibly leads to a larger dizziness perception.

We should add a caveat regarding the generalizability from seated to standing posture. The postural challenge in the active conditions was larger than in the seated posture. Also, no somatosensory information from the feet were available when sitting on the chair as compared to rich sensory feedback from the ground contact when turning in the standing position. Thus, the comparison between the active and passive conditions is challenging and the respective difference should be interpreted with care. What would the data look like if we had let our subjects be rotated passively while standing? The advantage of spotting while passively rotated may look differently with this additional postural challenge in the passive condition. However, after piloting, we deemed it too dangerous to let participants stand on a rotating turntable. This could be considered in future experiments with precautions to catch participants with a harness or a similar device in case they might fall.

Besides the advantage of active over passive rotations, spotting generally helps to reduce self-perceived dizziness. For this effect, the study conducted by Dietrich et al. (2020) offers an interesting explanation as the authors showed that vestibular input is suppressed more in fast as compared to slow walking. Consequently, they argue that the more pronounced repetitive head movements in fast compared to slow walking allows for a more accurate prediction of sensory consequences and hence a smaller discrepancy between predicted and actual sensory feedback. Spotting during rotations involves more pronounced head movements as well and might thus similarly allow for more accurate predictions of sensory consequences and a greater correspondence between predicted and actual sensory feedback. Notably, this explanation would also provide a sound interpretation for the observed interaction effect, as a more pronounced dizziness reduction due to spotting should be expected for the passive condition with its, as compared to the active condition, decreased amount of self-produced sensory consequences. However, given the overall additive beneficial effect of actively turning and spotting, dizziness was lowest after actively turning with spotting. Again, these findings are compatible with an explanation in terms of an improved forward model: When turns are actively performed rather than statically undergone, predicted sensory consequences are not only based on active head movement, but on the active movement of the entire body, arguably rendering predictions more accurate.

4.2. Spotting hampers postural stability less after passive rotations

Besides dizziness, we deemed it important to assess an objective measure of stability. To this end, we obtained the 95% ellipse area of the COP path as an indicator for postural sway. For dancers, it is highly relevant to keep balanced after multiple rotations to continue with the next dance steps of the choreography. Hence, dancers must be able to cope with possible disturbances to their postural stability during and after rotations. Contrary to our predictions – and in contrast to what was found for dizziness – the participants showed lower postural stability after active rotations as compared to passive ones and spotting reduced the pre-post-rotation increase of postural sway only in the passive condition.

A possible explanation for the finding that spotting was more beneficial in passive than in active rotations relates to the role of proprioception, which is enhanced during active rotation. The muscular activity involved in the head rotations during spotting in the passive condition stands out, whereas it is merely another muscular aspect when already involved in actively turning the entire body (e.g., Nashner, 2009). Yet another reason why spotting was particularly helpful during passive rotation may lie in the non-linear and disproportionally high response of the vestibular afferences from the semicircular canals to jerk movement – as opposed to continuous steady rotation (e.g., Cullen, 2019). This sensitivity to jerk movements would explain why active rotations upset the vestibular system more than did passive ones, causing lower postural stability after active rotations. It might also explain why spotting was more effective in the passive case, when considering the impact of vestibular afference on the eye-movement system: During active rotation, eye-movements are triggered in multifold ways and may induce visual-vestibular conflict. In contrast, during passive rotation spotting could have suppressed the optokinetic nystagmus, which produced more severe visual-vestibular conflict when spotting was not allowed. Consequently, using the spotting technique on the chair might have been particularly efficient for VOR-suppression and a less harmed postural stability after the rotations. In all, our results suggest that spotting is beneficial to postural stability primarily in situations in which spotting itself does not impose a significant coordinative challenge or sensory feedback from the somatosensory system is rather limited.

Our video analysis revealed that the spotting instructions had been followed both in active and passive trials. Although the distinction between the spotting and non-spotting conditions seemed somewhat less pronounced in the active as compared to the passive situations, no significant difference of Δ spotting ratio in active and passive conditions emerged. The smaller decrease of postural stability after spotting in the passive as compared to the active condition can thus not be explained by the spotting duration, but much rather as pointed out above, with the different turning dynamics of the head and body on the chair and dance floor, respectively. It could thus be that the spotting coordination was more efficiently performed in the passive condition, where the head movement did not have to be coordinated with actively performed complex whole-body rotations in a stop and go manner. However, to conclusively interpret our findings in this direction, a motion capture study investigating the spotting quality and whole-body kinematics would have been needed.

4.3. Why does spotting cause different effects on dizziness and postural stability?

When comparing the result patterns obtained for dizziness and postural stability, we obtain an unexpected mismatch. Whilst dizziness was reduced through active rotations and spotting, postural stability was preserved by spotting only in the passive condition. This result was mirrored by our additionally conducted correlational analyses, in which dizziness and Δ COP area were positively correlated in the active conditions (i.e., with and without spotting) whilst no relevant correlations were found for the respective passive conditions. How could these unexpected findings be interpreted?

First, although considerably speculative, body sway after active rotations may be increased – despite a relatively low level of dizziness – by a possible post-rotatory lingering of whole-body movements after active (but not passive) turns, comparable to the lingering of eye movements known as post-rotatory nystagmus. Future research may test this plausible hypothesis by recording segment and head kinematics.

An alternative explanation of the larger body sway after active compared to passive rotations is the presence of muscle fatigue after active (but not passive) rotations. The continuous postural challenge with considerable muscle activation in the lower extremities and the torso during turning will lead to muscle fatigue after several revolutions, which consequently could lead to larger body sway after rotating actively as compared to rotating passively.

Another reason for the different result patterns could lie in the difficulty of the active rotation task. Even for highly trained dancers, consecutive rotations around the vertical axis are challenging. For each revolution, a new push-off is needed and the centre-of-mass (COM) must be transferred over the base of support (i.e., supporting leg forefoot) again and again. In this context, Lott (2019) showed that a larger base-of-support movement during the turning phase was positively correlated with a higher number of rotations successfully performed. Based on this finding, Lott (2019) advised dancers not to avoid such base-of-support (i.e., standing leg) movements as it is an effective postural adjustment strategy for multiple rotations. Thus, for multiple rotations performed actively, larger COM displacements seem to be functional for optimal performance – and this might apply for the COP displacements measured in the present study as well. Ultimately, this explanatory and rather speculative approach boils down to the insight that the COP 95% ellipse area determined in the present study does not reflect postural stability per se, but is rather composed of unwanted variance (i.e., in the task-irrelevant direction) and compensatory variance (i.e., in the task-relevant direction), and that variance is only actively controlled if it hampers task performance – as conceptualized in the uncontrolled manifold concept introduced by Scholz and Schöner (1999). Hence, when standing on the force-plate after active rotations, participants could have applied a strategy to exploit compensatory variance, which they had perceived as enhancing performance just before. Accordingly, larger COP 95% ellipse areas should be expected after the active rather than the passive rotations where no compensatory strategy is applicable. Overall, the – at least at first glance – poorer postural stability scores after active than after passive rotations might be attributed either to a 'postural nystagmus' that can be tolerated by experienced dancers, muscle fatigue after several rotations or to the application of a strategy of variance exploitation. In all three cases, however, dizziness would not play a causal role, so that the incongruent result patterns found in our study are explainable.

To recall, in the last paragraphs on the interpretation of our dizziness findings, the reduction of dizziness due to active rotations and spotting was traced back to an improved ability to predict one's own sensory consequences, while based on an internal forward-modelling approach, self-perceived dizziness was explained by discrepancies between predicted and actual sensory feedback. Combining this line of thought with the variance-exploitation approach presented before would predict higher dizziness scores for those participants who exploited variance more. Consequently, a positive correlation between dizziness and Δ COP area (i.e., postural instability) measures would be expected after active rotations, but not after passive ones where active exploitation of variance is impossible. Notably, this expectation exactly conforms to the correlation coefficients we have found in the present study.

4.4. Limitations

We would like to point out some limitations of our study. First, the nature of the active rotations did not allow for a completely standardised procedure, which means that we could not control for smaller timing differences in stepping on the force-plate within this condition. Sometimes dancers rotated away or towards the force-plate respectively and thus had different distances for stepping on the force-plate after the last revolution. Second, the active and passive turning conditions should be compared with caution as the turning dynamics and timings of finishing the rotations were different. In the passive condition, the participants were accelerated at the beginning of the rotations, then turned with constant angular speed and at the end they were decelerated over one rotation. In the active rotations, a short acceleration and deceleration phase happened at the beginning and end of each revolution. Moreover, participants might have needed somewhat more time to step on the force-plate in the passive condition, as they had to get up from the chair before stepping on the force-plate. In addition, the postural challenge differs considerably between the active and passive conditions because in the passive condition, no balance control is required during the rotations due to the seated position. Third, dancers generally perform their turns in training and performance with the adoption of the spotting technique. The active condition without spotting was thus more challenging for them to perform. However, with our quantitative manipulation check, we could ensure that we included only trials in the without-spotting condition in which the instructions had been sufficiently followed. Still, the whole-body coordination might have been somewhat compromised. Fourth, as we did not have EOG or eye tracking measures included in this experiment, we could not compare gaze stabilisation between the active and passive conditions quantitatively.

4.5. Conclusion

Despite the limitations we have outlined above, our study offers valuable new perspectives on the impact of spotting on dizziness and postural stability following multiple consecutive rotations in dancers. From a practical standpoint, it can be concluded that spotting appears to be an effective technique in mitigating dizziness after multiple rotations, regardless of the dancer's style. In the realm of motor-behaviour research, our study implies that when we are the ones performing the rotations (or adding head movements on top of passive rotations), our ability to anticipate the sensory outcomes is enhanced, leading to a decrease in subjective dizziness. This explanation aligns well with contemporary theories on sensorimotor control that emphasize the importance of internally simulating the expected consequences of our own action. In particular, the contrasting findings for active and passive rotations demonstrate that results obtained in passive rotation tasks may not necessarily generalise to the more common context of actively rotating. Future studies should thus focus on the effect of rotations on dizziness and postural stability in an improved ecological testing environment. Moreover, the reasons for the difference in active and passive rotations should be investigated in more detail. In particular, the differential adaptive control of head, neck, trunk, hips, and legs may have to be considered.

The differential effects of spotting on dizziness and postural stability underline the value of considering both factors simultaneously when investigating the effects of multiple rotations. Clearly, the revealed interactions need to be further deciphered in future research. In this context, we would find it particularly worthwhile to include further biomechanical measures (e.g., the topple angle using motion capture) or eye tracking (e.g., visual fixation) to further our understanding of the difference between active and passive rotations on spotting behaviour and balancing strategies. From these studies, we expect not only valuable insights for improving motor skills of dancers – or figure skaters or gymnasts –, but also for all individuals who are regularly at risk of losing balance in their daily activities. The effect of gaze behaviour strategies involving fixations such as spotting could be studied in these individuals as well.

CRediT authorship contribution statement

Andrea Schärli: Writing – review & editing, Writing – original draft, Software, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Heiko Hecht:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Fred W. Mast:** Writing – review & editing, Supervision, Conceptualization. **Ernst-Joachim Hossner:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Data availability

Data will be made available on request.

References

Alpini, D., Botta, M., Mattei, V., & Tornese, D. (2009). Figure ice skating induces vestibulo-ocular adaptation specific to required athletic skills. *Sport Sciences for Health, 5*(3), 129–134. https://doi.org/10.1007/s11332-009-0088-4

Angelaki, D. E., & Cullen, K. E. (2008). Vestibular system: The many facets of a multimodal sense. *Annual Review of Neuroscience, 31*, 125–150. https://doi.org/10.1146/annurev.neuro.31.060407.125555

Collins, W. E. (1968). Special effects of brief periods of visual fixation on nystagmus and sensations of turning. *Aerospace Medicine, 39*(3), 257–266.

Cullen, K. E. (2019). Vestibular processing during natural self-motion: Implications for perception and action. *Nature Reviews. Neuroscience, 20*(6), 346–363. https://doi.org/10.1038/s41583-019-0153-1

Dietrich, H., Heidger, F., Schniepp, R., MacNeilage, P. R., Glasauer, S., & Wuehr, M. (2020). Head motion predictability explains activity-dependent suppression of vestibular balance control. *Scientific Reports, 10*(1), 668. https://doi.org/10.1038/s41598-019-57400-z

Dix, M. R., & Hood, J. D. (1969). Observations upon the nervous mechanism of vestibular habituation. *Acta Oto-Laryngologica, 67*(2), 310–318. https://doi.org/10.3109/00016486909125456

Haber, C., & Schärli, A. (2021). Defining spotting in dance: A Delphi method study evaluating expert opinions. *Frontiers in Psychology, 12, Article 540396*, 19. https://doi.org/10.3389/fpsyg.2021.540396

Hase, K., & Stein, R. B. (1999). Turning strategies during human walking. *Journal of Neurophysiology, 81*(6), 2914–2922. https://doi.org/10.1152/jn.1999.81.6.2914

Kaufeld, M., Bourdeinik, J., Prinz, L. M., Mundt, M., & Hecht, H. (2022). Emotions are associated with the genesis of visually induced motion sickness in virtual reality. *Experimental Brain Research, 240*(10), 2757–2771. https://doi.org/10.1007/s00221-022-06454-z

Kim, K.-S., Kim, Y. H., Shin, S. H., Choi, J.-S., Lee, S., & Jang, T. Y. (2013). Post-rotatory visual fixation and Angluar velocity-specific vestibular habituation is useful in improving post-rotatory Vertigo. *The Journal of International Advanced Otology, 9*(2), 175–179.

Lott, M. B. (2019). Translating the base of support a mechanism for balance maintenance during rotations in dance. *Journal of Dance Medicine & Science: Official Publication of the International Association for Dance Medicine & Science, 23*(1), 17–25. https://doi.org/10.12678/1089-313X.23.1.17

Nashner, L. M. (2009). Balance and posture control. In R. S. Larry (Ed.), *Encyclopedia of neuroscience* (pp. 21–29). Academic Press.

Nigmatullina, Y., Hellyer, P. J., Nachev, P., Sharp, D. J., & Seemungal, B. M. (2015). The neuroanatomical correlates of training-related perceptuo-reflex uncoupling in dancers. *Cerebral Cortex (New York, N.Y.: 1991), 25*(2), 554–562. https://doi.org/10.1093/cercor/bht266

Osterhammel, P., Terkildsen, K., & Zilstorff, K. (1968). Vestibular habituation in ballet dancers. *Acta Oto-Laryncologica, 66*, 221–228.

Schärli, A. M., Keller, M., Lorenzetti, S., Murer, K., & van de Langenberg, R. (2013). Balancing on a slackline: 8-year-olds vs. Adults. *Frontiers in Psychology, 4*, 208. https://doi.org/10.3389/fpsyg.2013.00208

Scholz, J. P., & Schöner, G. (1999). The uncontrolled manifold concept: Identifying control variables for a functional task. *Experimental Brain Research, 126*, 289–306.

Sloane, P. D., Coeytaux, R. R., Beck, R. S., & Dallara, J. (2001). Dizziness: State of the science. *Annals of Internal Medicine, 134*(9 Pt 2), 823–832. https://doi.org/10.7326/0003-4819-134-9_part_2-200105011-00005

Tanguy, S. G., Quarck, G., Etard, O., Gauthier, A., & Denise, P. (2008b). Vestibulo-ocular reflex and motion sickness in figure skaters. *European Journal of Applied Physiology, 104*(6), 1031–1037. https://doi.org/10.1007/s00421-008-0859-7

Tanguy, S. G., Quarck, G. M., Etard, O. M., Gauthier, A. F., & Denise, P. (2008a). Are otolithic inputs interpreted better in figure skaters? *Neuroreport, 19*(5), 565–568. https://doi.org/10.1097/WNR.0b013e3282f9427e

Tschiassny, K. (1957). Perrotatory nystagmus in the ballet dancer, pigeon, and blind persons; its application as a test for differentiating organic from psychic blindness. *The Annals of Otology, Rhinology, and Laryngology, 66*(3), 641–648.

Winter, D. A. (1995). Human balance and posture control during standing and walking. *Gait & Posture, 3*(4), 193–214. https://doi.org/10.1016/0966-6362(96)82849-9

Wolpert, D. M., Ghahramani, Z., & Jordan, M. I. (1995). An internal model for sensorimotor integration. *Science (New York, N.Y.), 269*, 1880–1882. https://doi.org/10.1126/science.7569931