Behaviour Research and Therapy 47 (2009) 345–352

Contents lists available at ScienceDirect

Behaviour Research and Therapy

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

The impact of visual flow stimulation on anxiety, dizziness, and body sway in individuals with and without fear of heights

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ARTICLE INFO

Article history:
Received 19 March 2008
Received in revised form
14 January 2009
Accepted 15 January 2009

Keywords:
Acrophobia
Dizziness
Balance system
Posturography etiology

ABSTRACT

Individuals with acrophobia experience anxiety and dizziness when exposed to heights. It may be that their balance system is disturbed and that they therefore have to rely more strongly on visual information.

We tested this hypothesis by exposing 20 individuals with high fear of heights and 20 healthy control participants to nine different visual flow stimuli through a head mounted display, thereby inducing a conflict between visual input and somatosensory information. Anxiety and dizziness were assessed repeatedly by means of self-reports, while resultant body sway was measured continuously with a force plate individuals stood on.

Individuals with fear of heights felt more anxious and dizzier, and also showed stronger body sway than healthy control participants.

Merely receiving visual balance information contradictory to somatosensory balance information is sufficient to induce anxiety, dizziness, and body sway in individuals with fear of heights. An underlying balance dysfunction may contribute to the development of height phobia.

Introduction

The symptoms of individuals suffering from acrophobia include cognitive, behavioral, and physiological patterns. When acrophobic patients are unable to completely avoid a height situation, they display comparably high levels of anticipatory anxiety, tend to overestimate the risk of falling, overrate the risk of getting seriously injured (Menzies & Clarke, 1995a) and report dizziness as a common symptom (Brandt, Arnold, Bles, & Kapteyn, 1980). Interestingly, dizziness is also a prominent feature in panic disorder and agoraphobia (e.g., Andor, Glöckner-Rist, Gerlach, & Rist, 2008). In contrast to patients with other specific phobias (such as spiders), individuals with acrophobia interpret ambiguous bodily sensations as threatening, and have an increased tendency to report physiological symptoms of anxiety such as dizziness and nausea, which is similar to patients with panic disorder (Davey, Menzies, & Gallardo, 1997). Hence, acrophobia might develop similarly to panic disorder with an emphasis on the role of attentional biases for bodily symptoms and misinterpretations of these symptoms (see Hofmann, Alpers, & Pauli, 2008).

Only 11% of acrophobic patients attribute the onset of their acrophobia to a traumatic experience (Menzies & Clarke, 1995b). Consequently, in the majority of cases, fear of heights may not be primarily mediated by direct conditioning. In support of this notion, in a prospective study, injury-causing falls before the age of nine and the development of acrophobia until the age of 11 or of 18 were not correlated (Poulton, Davies, Menzies, Langley, & Silva, 1998). These authors make a case for a non-associative etiology of acrophobia by explaining the development of fear of heights as the result of prepotency of height stimuli and insufficient unlearning of fear.

Prepotency may be rooted in height cues themselves or preconditions which are only indirectly related to heights. Jacob, Redfern, and Furman (1995) state that specific anxiety arousing bodily symptoms such as dizziness can be attributed to an underlying hypersensitivity of the balance system: in healthy individuals, maintenance of a stable bodily equilibrium is the result of correct integration of balance information provided by the proprioceptive, visual, and vestibular channel within the balance system (Maurer, Mergner, & Peterka, 2006; Peterka & Loughlin, 2004). If the vestibular system is impaired in its functioning, or if it is given less weight compared to the other channels, dizziness and feelings of imbalance may be experienced in situations in which the balance

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doi:10.1016/j.brat.2009.01.011

system retrieves conflicting or too little information from either the visual or the proprioceptive channels (Bronstein, 2002; Paulus, Straube, & Brandt, 1984; Redfern, Yardley, & Bronstein, 2001). Interestingly, Hsiao and coworkers have investigated the effects of vision on balance system functioning in healthy construction workers and found pronounced body sway in height conditions when standing on deformable surface (Simeonov & Hsiao, 2001) or sloped surface (Simeonov, Hsiao, Dotson, & Ammons, 2003). Most importantly, sway was reduced when individuals were able to perceive close visual references, suggesting a crucial role for visual information in proprioceptive ambiguous surroundings. For a review of factors that are related to the control of balance when working in elevated places, see Hsiao and Simeonov (2001).

Arguably, height situations, due to the lack of fixation points, contain visual information insufficient for maintaining bodily balance (Jacob et al., 1993). Thus, it has been suggested that development of acrophobia might be attributed, at least partly, to an inadequate balance system, which relies more on visual information in contrast to proprioceptive information and balance information provided by the vestibular organ (Redfern et al., 2001).

So far, the link between an inadequate balance system and acrophobia has not been studied directly. However, comorbidity between agoraphobia, panic disorder and balance disorders is common (Clark, Hirsch, Smith, Furman, & Jacob, 1994; Clark, Leslie, & Jacob, 1992; Eagger, Luxon, Davies, Coelho, & Ron, 1992; Furman & Jacob, 2001; Stein, Asmundson, Ireland, & Walker, 1994). Jacob et al. (1993) argued that agoraphobic situations such as movie theaters or walking down supermarket aisles could also be described as challenges to the balance system. The authors therefore introduced the term "space and motion discomfort" (SMD) to refer to sensations of dizziness and imbalance occurring in such situations. Furthermore, individuals with visual balance hypersensitivity, as it would be the case in vestibular disorders and as well is hypothesized to be present in various anxiety disorders, are expected to report higher levels of SMD. In accordance with their theory, Jacob et al. (1993) found high levels of SMD as assessed by questionnaire both in patients with vestibular balance disorders and panic disorder. Since they suggested that acrophobic symptoms are also the consequence of SMD, it seems necessary to examine whether acrophobic individuals have indeed higher levels of SMD compared to healthy individuals directly.

Redfern and Furman (1994) investigated the relationship between vestibular disorders and the impact of visual information on bodily equilibrium via static posturography and visual flow stimulation: patients with vestibular diseases tended to sway more and their body sway matches the oscillation frequency of visual stimuli, suggesting a crucial role of visual information in individuals with balance disorders. Furthermore, Jacob, Redfern, and Furman (1995) examined the impact of visual flow stimulation on body sway in individuals with panic disorder, agoraphobia, and generalized anxiety disorder. Notably, all of these groups also reported symptoms of SMD. Again, the authors found significant increases in the body sway frequency spectra which matched the oscillation frequency of the visual flow stimulation and also a greater magnitude of overall body sway. Hence, in individuals with various anxiety disorders, visual flow information makes it exceedingly difficult to maintain a stable bodily balance in quiet stance.

An underlying hypersensitivity of the balance system in the acquisition of acrophobia has been proposed by Pogany (1958). Furthermore, Hallam and Hinchcliffe (1991) found fear of heights as the most frequently named symptom in patients with vestibular dysfunctions. Conversely, individuals with acrophobia benefited from vestibular rehabilitation therapy regarding symptoms of dizziness and body sway (Whitney et al., 2005). In a pilot study, Nakahara, Takemori, and Tsuruoka (2000) investigated body sway in height situations of 0, 1, 2, and 11 m above ground level. In the first experiment, they found more body sway in acrophobic individuals compared to healthy participants in the 11 m height condition, which required the participants to stand on the edge of a roof. This effect emerged equally in two visual conditions, in which the participants were either blindfolded or had to look down to the street. When being led to the roof blindfolded (Exp. 2), acrophobic individuals showed a different pattern of body sway as compared to healthy participants: when the blindfold was removed, sway in healthy participants decreased but actually increased in acrophobic individuals, hence the results support the theory of a greater reliance on visual information for maintaining bodily balance. However, the sample consisted of only six acrophobic individuals. Furthermore, effects of height anxiety triggered by the investigation setting's height of 11 m and visual effects due to missing fixation points are both valid explanations for these findings. With other words, results from Nakahara et al. do not allow conclusively to disentangle the specific contribution of vestibular hypersensitivity and effects of height anxiety on body sway.

Alpers and Adolph (2008) investigated the relationship between fear and body sway in healthy individuals during explicit height exposure 16 m above the ground. Whereas body sway and trait fear of heights were not significantly correlated, anticipatory fear was the best predictor for body sway. The authors emphasize the role of cognitive characteristics since their study design did not directly test the association of vestibular functioning with trait fear of heights. However, Alpers and Adolph investigated a convenience sample resulting in restricted variance regarding trait fear of heights. Furthermore, for clarification of balance system processes, it is also necessary to investigate participants outside of feared, i.e., height related situations: body sway and reports of dizziness during exposure to height related situations may either be caused by physical anxiety reactions or by receiving misleading visual balance information due to the lack of fixation points or both. Thus, neither the results from Alpers and Adolph (2007) nor of Nakahara, Takemori, and Tsuruoka (2000) can disentangle effects of anxiety and the specific contribution of balance system functioning: if fear of heights is at least partially based on an overreliance on visual balance information, it is important to test whether individuals with fear of heights show increased body sway and dizziness solely due to reception of misleading visual balance information.

The current study tried to directly probe the functioning of the visual balance system and thus determined the reliance on visual information in individuals with fear of heights. We used similar visual flow stimuli as provided by Jacob, Redfern, and Furman (1995). Note that with only one exception, these stimuli are unlikely to evoke a height related anxiety reaction since they do not entail height related scenes or perspectives. However, self-reported anxiety may be a secondary result due to the experience of dizziness or in reaction to receiving misleading balance information. Consequently, our methodology allows us to examine the impact of misleading visual balance information on balance system functioning in individuals with fear of heights. We hypothesize that individuals with fear of heights have an underlying hypersensitivity in the visual channel of their balance system and therefore are more strongly influenced by visual flow information. Consequently, they should show greater levels of overall body sway during visual flow stimulation. Further should they also sway more in synchrony with the oscillation of visual flow stimulation.

Method

Participants

Participants were screened when registering at the University of Münster, where students had to wait for up to half an hour prior to their appointment. We asked 800 students to complete a series of questionnaires, including the fear of heights questionnaires. Five hundred and ninety eight students (74.7%) completed the survey after giving informed consent. Five months later, 40 participants were invited for further investigation based on their scores on the fear of heights questionnaire: 20 of them scored above the 80th percentile on the fear of heights questionnaire (see below). Twenty additional participants were selected randomly from the rest of the sample and served as the control group. At the outset of the experimental session, participants completed the fear of heights questionnaires again.

In order to control for possible gender effects, we included only women. Their mean age was 20.2 years (SD = 1.51) in the normal fear of heights group (NFH) and 20.5 years (SD = 1.82) in the high fear of heights group (HFH). Their mean body height was 1.71 m (SD = .07) in the NFH and 1.68 m (SD = .06) in the HFH group, respectively. The average body weight was 66.8 kg (SD = 10.5) for NFH and 68.9 kg (SD = 14.8) for HFH individuals. None of these differences reached significance, as investigated by ANOVA and summarized in Table 1.

To determine whether self-reported fear of heights was clinically relevant, we conducted the specific phobia section of the Structural Clinical Interview for DSM-IV (Wittchen, Wunderlich, Gruschwitz, & Zaudig, 1997). None of the NFH participants were given a diagnosis for acrophobia. In the HFH group, four members fulfilled all criteria of acrophobia. In addition, seven height fearful individuals fulfilled the criteria with the exception of "a significant impact of the fear on their lives".

Questionnaires

Fear of heights was assessed with the German version (Schubert, Friedmann, Böhme, & Kreß, 1998) of the Acrophobic Questionnaire (Baker, Cohen, & Saunders, 1973), which consists of two subscales: first, anxiety referring to height situations is investigated with the subscale "ACRO", which has a satisfying internal consistence in our sample at both times of measurement (Cronbach's $\alpha = .94$ and $\alpha = .97$). Second, avoidance of these situations is assessed with the "AVOI" subscale ($\alpha = .88$ and $\alpha = .92$). Test–retest-reliabilities were $r = .81$ (ACRO) and $r = .89$ (AVOI), indicating a high stability of fear of heights levels in our sample over 5 months. Therefore, the subsequently reported values of ACRO and AVOI are means derived from the two assessments. Baker, Cohen, and Saunders (1973) and Cohen (1977) reported that mean values for acrophobic outpatients declined from the range of 48–65 before treatment to 19–32 after completed treatment for ACRO and from 10–15 to 3–7 for AVOI.

Table 1
Characteristics of the normal fear of heights (NFH) and the high fear of heights (HFH) samples.

	NFH	HFH	F (df$_1$, df$_2$)	Cohen's d
	Mean (SD)	Mean (SD)		
Age	20.2 (1.5)	20.5 (1.8)	.2 (1, 38)	.18
Body height (cm)	171.5 (7.1)	167.8 (6.3)	3.0 (1, 38)	.61
Body weight (kg)	66.8 (10.5)	68.9 (14.8)	.3 (1, 38)	.16
ACRO	12.6 (8.5)	53.5 (14.8)	115.5 (1, 38)**	3.40
AVOI	12.6 (1.4)	24.3 (4.1)	145.0 (1, 38)**	3.82
SMD-I	2.0 (1.8)	5.4 (2.8)	19.5(1, 37)**	1.44
BDI-V	22.6 (13.9)	23.4 (16.4)	<.1 (1, 38)	.06
ASI	14.8 (5.0)	23.4 (8.5)	14.5 (1, 37)**	1.22
BSQ	41.4 (7.9)	47.3 (11.2)	3.8 (1, 38)	.61
MI (alone)	1.5 (.5)	2.0 (.7)	6.3 (1, 36)*	.81
MI (accompanied)	1.1 (.1)	1.4 (.3)	15.0 (1, 36)**	1.23

Note. Abbreviations are used for Acrophobic Questionnaire subscales (ACRO and AVOI), Situational Characteristics Questionnaire subscales (SMD-I), simplified Beck Depression Inventory (BDI-V), Anxiety Sensitivity Index (ASI), Body Sensations Questionnaire (BSQ), Mobility Inventory subscales (MI alone and accompanied). $^*p < .05$, $^{**}p < .01$.

According to these clinical data, the mean values for our HFH group (ACRO: 53.5, SD = 14.8 and AVOI: 24.3, SD = 4.1) indicate clinical relevance of the acrophobic symptoms, while our NFH group showed normal values (ACRO: 12.6, SD = 8.5 and AVOI: 12.6, SD = 1.4).

To examine whether acrophobic participants indeed display space and motion discomfort, we used the German translation of the Situational Characteristics Questionnaire (Jacob & Lilienfeld, 1991). This instrument asks for discomfort occurring from absence or paucity of visual information for orientation in space and contains three scales, SMD-I, Ag-I, and SMD-II. Since the SMD-I scale has been shown to best differentiate anxious and healthy participants, we restricted our analysis to this subscale (Jacob, Furman, Durrant, & Turner, 1996). Each of the 20 items of the SMD-I consists of two subitems; on the one hand there is a space- or motion-phobic elicitor, on the other hand a non-space- and non-motion-phobic alternative. This paired format was utilized to control for the fact that many of the given situations elicit anxiety or panic in phobic patients and thus would not be specific to patients with an additional comorbid vestibular dysfunction. Item scores are computed as differences between space- or motion-phobic elicitor and its alternative.

In addition, we used the German version of the Patient Health Questionnaire (Lowe et al., 2001) to screen for possible diagnoses of panic disorder. None of the participants in the NFH group indicated a possible diagnosis of panic disorder. Regarding the HFH group, one subject fulfilled screening criteria for panic disorder.

We assessed the level of anxiety related cognitions regarding bodily symptoms with the Body Sensations Questionnaire (Chambless, Caputo, Bright, & Gallagher, 1984; German version: Ehlers, Margraf, & Chambless, 2001). Furthermore, the pattern of avoidance was examined by the Mobility Inventory (Chambless, Caputo, Jasin, Gracely, & Williams, 1985; German version: Ehlers et al., 2001), which consists of two subscales investigating avoidance behavior in a given situation either alone (MI alone) or accompanied (MI accompanied). We used the Anxiety Sensitivity Index (German version: Alpers & Pauli, 2001; Reiss, Peterson, Gursky, & Mcnally, 1986) to assess the beliefs about possible consequences concerning symptoms of fear and anxiety. In order to examine the degree of depression, we used the simplified Beck Depression Inventory (Schmitt, 2000). Means of both groups indicate normal levels of depression. A summary of sample characteristics regarding various questionnaires can be examined in Table 1.

Data recording and processing

The investigation of body sway was conducted with a custom-made force plate, which measured the center of pressure (CoP) through two strain sensors (Graphtec, RS Components GmbH, Germany). The plate was calibrated to measure CoP displacement up to 19 cm in both anterior–posterior and medio–lateral direction. Output from the two force plate channels was recorded with the Vitaport II system (Temec Instruments, The Netherlands) at a sampling rate of 512 Hz. Prior to the experiment, we calibrated sway data in order to normalize for body weight and to reduce the impact of measurement artifacts (for more specific information, compare Alpers & Adolph, 2007). We operationalized body sway by analyzing two common indicators, which are sway path and sway frequency. First, we assessed the sway path in order to examine the mean velocity (cm/s) of CoP (Baratto, Morasso, Re, & Spada, 2002; Jacono, Casadio, Morasso, & Sanguineti, 2004), which was done by an established algorithm programmed in Matlab (Jacono, Spada, & Re, 2005). In the CoP velocity measure, both anterior–posterior and lateral sway was included. We therefore obtained CoP displacement measures for each participant which are standardized with reference to the duration of the particular measurement unit.

Second, the anterior–posterior component of body sway was analyzed by the fast Fourier transform using Welch's method. Prior to frequency analysis, data were re-sampled at 4 Hz. Body sway frequency was estimated as the spectral power between 0.2 and 0.4 Hz in order to match the oscillation of the visual flow stimulation.

Visual flow stimuli

While standing on the platform, participants were exposed to the visual stimulation binocularly through a head mounted display (Sony PLM-S 700 E). The exposure included a *pre-flow baseline,* followed by a *visual flow phase* and a *post-flow baseline*. Both pre-flow baseline (BL1) and the post-flow baseline (BL2) consisted of a blank black screen. Visual stimulation was provided by an openGL-based program written by one of the authors (FK) (cf. Table 2 and Fig. 1).

During the flow phase, each of the following stimuli was shown: (1) horizontally oscillating checkerboard (HC); (2) vertically oscillating checkerboard (VC); (3) sinusoidally translating towards a checkerboard (SinC); (4) sinusoidally translating through a tunnel (SinT); (5) pitching into a tunnel (PitT); (6) rotating into a shaft (RotS); and (7) sinusoidally cloud of dots (SinD). The stimuli oscillated at a frequency of 0.3 Hz either horizontally (HC), vertically (VC), or apparently backwards and forwards (actually, expansion-contradiction, SinC, SinT, SinD). In PitT, the tunnel stimulus was bending back and forth and therefore giving participants the impression of tilting into the tunnel. In RotS, the shaft stimulus rotated up and down which leads to an impression of looking up and down a shaft. Oscillation frequency was 0.3 Hz throughout.

Each stimulus, including the pre- and post-flow stimuli, was presented for 30 s. Stimulus images used in the various visual conditions can be seen in Fig. 1.

Table 2
Characteristics of the visual stimulus conditions.

Condition	Abbreviation	Description
A. Pre-flow		
1. Baseline 1	(BL1)	Blank black screen
B. Visual flow		
2. Horizontal checkerboard	(HorC)	A checkerboard pattern moving back and forth sideways
3. Vertical checkerboard	(VerC)	A checkerboard pattern moving up and down
4. Sinusoidal checkerboard	(SinC)	Subject seems to translate sinusoidally towards and away from a checkerboard
5. Sinusoidal tunnel	(SinT)	Subject seems to translate sinusoidally back and forth into a tunnel
6. Pitching tunnel	(PitT)	Subject seems to pitch back and forth into a tunnel
7. Rotating shaft	(RotS)	Subject looks down and up into a lift shaft
8. Sinusoidal cloud of dots	(SinD)	Subject seems to translate sinusoidally back and forth into a cloud of small dots
C. Post-flow		
9. Baseline 2	(BL2)	Blank black screen

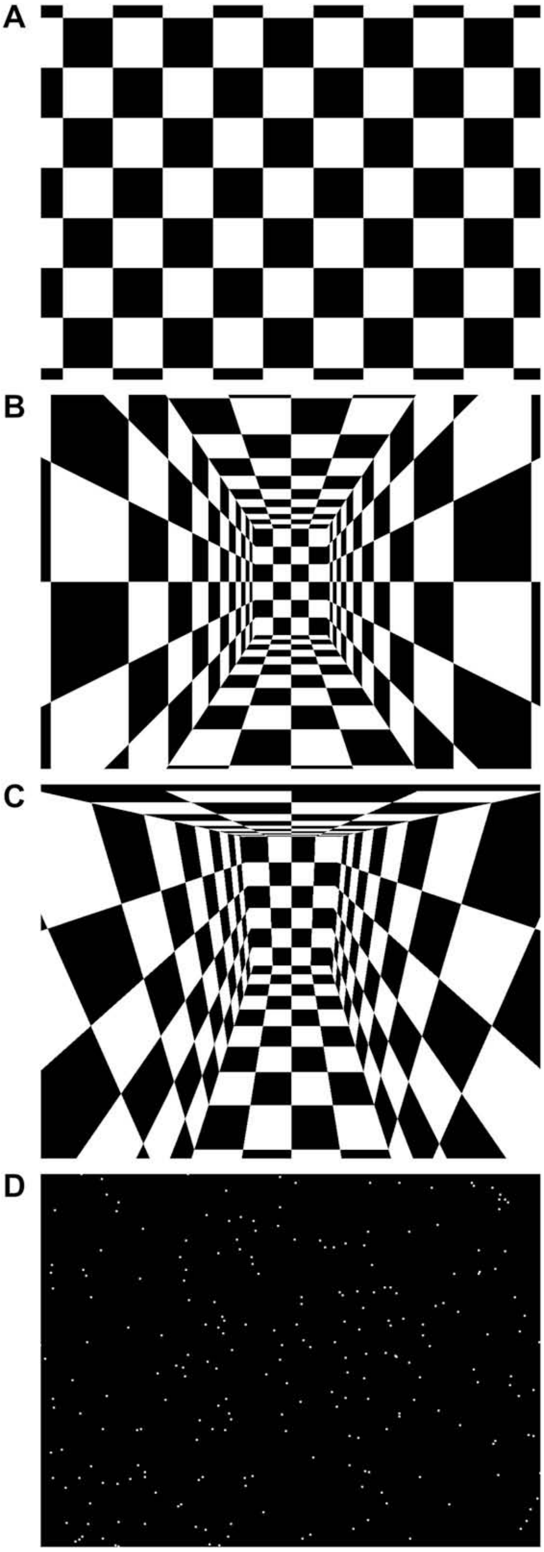

Fig. 1. Still images of visual flow stimuli used in (A) horizontal checkerboard (HC), vertical checkerboard (VC), and sinusoidal checkerboard (SinC); (B) in sinusoidal tunnel (SinT) and pitching tunnel (PitT); (C) in rotating shaft (RotS); and (D) in sinusoidal cloud of dots (SinD).

Procedure

Participants completed all questionnaires during student enrollment. Five month later, we first assessed the severity and the clinical relevance of each participant's fear of heights with the specific phobia section of German version of the Structured Clinical Interview for DSM IV (SKID-I, Wittchen, Wunderlich, Gruschwitz, & Zaudig, 1997). Following the interview, participants had to complete the Acrophobic Questionnaire a second time in order to explore the stability of fear of heights and to ensure each participant's correct group assignment. Furthermore, we assessed body height and measured body weight. We subsequently asked participants to stand on the force platform and to put on the head mounted display. The visual stimuli were run in the sequence listed in Table 2. After each stimulus presentation, participants rated their current anxiety (0 = not at all anxious, 9 = extremely anxious) and dizziness (0 = not at all dizzy, 9 = extremely dizzy). The investigation took place in a room on the ground floor.

Statistical analysis

We conducted a MANOVA and two ANCOVAs to examine the effects of fear of heights and of visual stimulus condition on self-reported anxiety and dizziness, velocity of CoP and the power in the 0.3 Hz frequency band. "Fear of heights" was the between subjects factor with the two categories NFH and HFH. "Visual stimulus condition" was a within-subject factor.

As covariates in the analysis of CoP, first, we used the mean of the pre- and post-flow condition CoP velocity in order to control for individual differences unrelated to visual stimulation. Second, we included body height as covariate because of the apparent positive association between body height and the level of CoP.

Similarly, as a covariate in the analysis of power in the 0.3 Hz frequency band, we included the mean power in the 0.3 Hz frequency band assigned to pre- and post-flow condition. Since frequency data are ipsative, there was no need to use body height as a covariate in this analysis.

As an estimator of effect size, we reported partial eta squared (η_p^2). This term is a variance based effect size which describes the ratio of explained variance to the particular error variance used in the belonging F ratio in addition to the variance explained.

Results

Self-reported fear and dizziness

Using MANOVA with Wilk's criterion, we found a significant effect of fear of heights ($F = 7.23$, $p < .01$; $\eta_p^2 = .28$) and visual stimulus condition ($F = 3.17$, $p < .01$, $\eta_p^2 = .69$). The interaction of visual stimulus condition and fear of heights reached only a marginally significant level in the multivariate analysis ($F = 1.94$, $p = .07$, $\eta_p^2 = .58$).

The follow-up ANOVA with self-reports of anxiety as dependent variable revealed a main effect for fear of heights ($F = 14.84$, $p < .01$, $\eta_p^2 = .28$), visual stimulus condition ($F = 14.06$, $p < .01$, $\eta_p^2 = .27$), and a significant interaction of fear of heights and visual stimulus condition ($F = 11.92$, $p < .01$, $\eta_p^2 = .24$). Planned comparisons showed significant group differences in all stimulus conditions except for BL1 and BL2, which are depicted in Fig. 2 and described in detail in Table 3.

The follow-up ANOVA with self-reports of dizziness as dependent variable revealed a main effect for fear of heights ($F = 7.10$, $p = .01$, $\eta_p^2 = .18$), visual stimulus condition ($F = 21.11$, $p < .01$, $\eta_p^2 = .38$), and a significant interaction of fear of heights and visual stimulus condition $F = 3.97$, $p < .01$, $\eta_p^2 = .09$). Planned comparisons revealed significant differences between groups in all stimulus conditions except for BL1, HorC and BL2. Group means are depicted in Fig. 2. For a detailed summary, see Table 3.

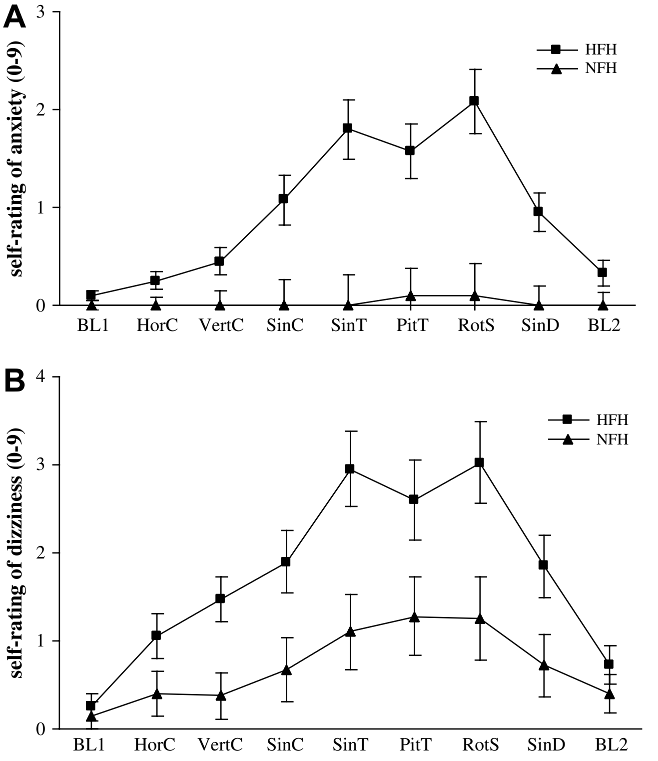

Fig. 2. (A) Self-ratings of anxiety during visual stimulation. (B) Self-ratings of dizziness during visual stimulation. Note: abbreviations are used for visual stimulus conditions baseline 1 and 2 (BL1 and BL2), horizontal checkerboard (HorC), vertical checkerboard (VerC), sinusoidal checkerboard (SinC), sinusoidal tunnel (SinT), pitching tunnel (PitT), rotating shaft (RotS), sinusoidal cloud of dots (SinD). Abbreviations are used for the group categories high fear of heights (HFH) and normal fear of heights (NFH). Bars indicate standard errors.

CoP velocity

An ANCOVA indicated a multivariate effect using Wilk's criterion for the visual stimulus condition during the visual flow phase on CoP velocity ($F = 2.72$, $p = .03$, $\eta_p^2 = .35$). Subsequent investigation of within-subjects main effects did not confirm this ($F = 1.90$,

Table 3
Planned comparisons for self-ratings of anxiety and dizziness between groups.

		HFH	NFH	F (df$_1$, df$_2$)	Cohen's d
		Mean (SD)	Mean (SD)		
BL1	Anxiety	.1 (.3)	.0 (.0)	2.1 (1, 38)	.65
	Dizziness	.3 (.7)	.2 (.7)	.2 (1, 38)	.20
HorC	Anxiety	.3 (.6)	.0 (.0)	4.1 (1, 38)*	.91
	Dizziness	1.1 (1.3)	.4 (.9)	3.4 (1, 38)	.82
VerC	Anxiety	.5 (.9)	.0 (.0)	5.2 (1, 38)*	1.01
	Dizziness	1.5 (1.5)	.4 (.7)	9.0 (1, 38)**	1.34
SinC	Anxiety	1.1 (1.6)	.0 (.0)	8.8 (1, 38)**	1.32
	Dizziness	1.9 (2.0)	.7 (1.1)	5.7 (1, 38)*	1.07
SinT	Anxiety	1.8 (1.9)	.0 (.0)	17.3 (1, 38)**	1.86
	Dizziness	3.0 (2.2)	1.1 (1.6)	9.4 (1, 38)**	1.37
PitT	Anxiety	1.6 (1.7)	.1 (.3)	14.2 (1, 38)**	1.68
	Dizziness	2.6 (2.0)	1.3 (2.0)	4.4 (1, 38)**	.94
RotS	Anxiety	2.1 (2.1)	.1 (.3)	18.1 (1, 38)**	1.90
	Dizziness	3.0 (2.4)	1.3 (1.7)	7.2 (1, 38)**	1.20
SinD	Anxiety	1.0 (1.2)	.0 (.0)	11.9 (1, 38)**	1.54
	Dizziness	1.9 (1.8)	.7 (1.4)	4.8 (1, 38)*	1.00
BL2	Anxiety	.3 (.8)	.0 (.0)	3.3 (1, 38)	.81
	Dizziness	.7 (1.2)	.4 (.8)	1.1 (1, 38)	.46

Note: abbreviations are used for baseline 1 and 2 (BL1 and BL2), horizontal checkerboard (HorC), vertical checkerboard (VerC), sinusoidal checkerboard (SinC), sinusoidal tunnel (SinT), pitching tunnel (PitT), rotating shaft (RotS), sinusoidal cloud of dots (SinD). *$p < .05$, **$p < .01$.

$p = .08$, $\eta_p^2 = .05$) but disclosed a significant interaction of fear of heights and visual stimulus condition ($F = 2.40$, $p = .03$, $\eta_p^2 = .06$). Planned comparisons revealed significant differences between groups in SinT ($F = 5.81$, $p = .02$, Cohen's $d = 0.56$) and SinD ($F = 5.77$, $p = .02$, Cohen's $d = 0.49$). In both group differences, HFH members showed more CoP velocity in comparison to NFH participants. When investigating the type of stimuli which oscillated vertically, which are all stimulus conditions except for baseline conditions and horizontal movements, HFH participants showed greater CoP velocity in comparison to NFH group ($F = 4.10$, $p = .05$, Cohen's $d = 0.36$) for combined means of the vertically oscillating stimuli VerC, SinC, SinT, PitT, RotS and SinD. Means for groups and stimulus conditions are depicted in Fig. 3.

Power spectra of body sway

Regarding power in the 0.3 Hz frequency band, visual stimulus condition did not reach significance with respect to multivariate effects using Wilk's criterion ($F = 1.31$, $p = .28$, $\eta_p^2 = .20$) as investigated by ANCOVA with the mean of the two baseline conditions as a covariate. Neither the within-subjects main effect for visual stimulus condition ($F = 1.12$, $p = .35$, $\eta_p^2 = .03$) nor the interaction with fear of heights ($F = 0.89$, $p = .50$, $\eta_p^2 = .02$) yielded a significant effect.

Discussion

Acrophobics often experience dizziness, arguably induced by lack of visual balance cues in height situations. We directly tested the functioning of the visual balance system in individuals with high fear of heights compared to individuals with normal fear of heights by examining the impact of visual flow stimuli on body sway, anxiety, and dizziness. We expected individuals with high fear of heights: (1) to report more anxiety and dizziness during visual flow stimulation; (2) to show greater body sway during visual flow stimulation; and (3) to sway more in synchrony with the oscillating visual stimuli.

Levels of self-reported dizziness were higher in participants with fear of height, especially during the vertical flow conditions. They showed greater CoP velocity and therefore a greater amount of body sway in the anterior–posterior direction during vertically oscillating stimulation. Contrary to our hypothesis, they did not show greater body sway patterns in synchrony with the oscillation frequency of the visual flow stimuli compared to controls. Finally, they reported more anxiety during visual flow stimulation. In line with participants being explicitly tested in a situation not related to height (at ground level), the highest mean value of anxiety in HFH participants was only 2.1 (the scale ranges from 0 to 9).

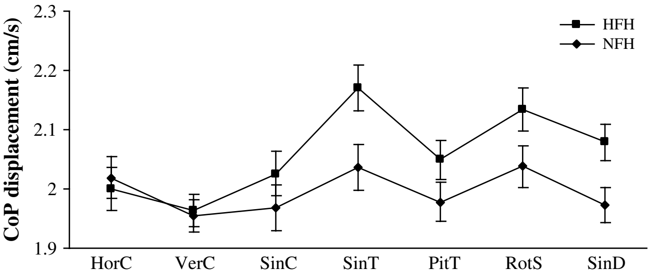

Fig. 3. Center of pressure velocity in (cm/s) during visual stimulation. Note: abbreviations are used for visual stimulus conditions horizontal checkerboard (HorC), vertical checkerboard (VerC), sinusoidal checkerboard (SinC), sinusoidal tunnel (SinT), pitching tunnel (PitT), rotating shaft (RotS), sinusoidal cloud of dots (SinD). Abbreviations are used for the group categories high fear of heights (HFH) and normal fear of heights (NFH). Bars indicate standard errors.

Nonetheless, it could be argued that those visual stimuli we presented that included a strong 3D effect may have served as conditioned stimuli to evoke a height related fear response in persons with fear of heights, which might have led to a greater amount of anxiety, dizziness, and body sway not because of receiving misleading balance information but rather due to actual, albeit small, height related anxiety reactions. However, we consider this an unlikely explanation: when inspecting the still images of the stimulus types B and C in Fig. 1, at first sight, both may appear to be related to visual cues of height scenes. However, the three-dimensional animations our participants viewed differ substantially from each other. The movement pattern of stimulus type B (used in SinT and PitT) creates the impression that the viewer looks into a (horizontal) tunnel whereas stimulus type C (used in RotS) creates the impression that he is looking down into a vertical shaft (similar to an elevator shaft). In other words, the visual impression of stimulus type C is directly related to height, while the visual impressions of stimulus types B are not. Note that participants saw the stimuli in full screen mode via video goggles, preventing any further visual reference points other than the moving stimuli presented. Thus, with the exception of stimulus type C, the remaining scenes were perceptually much less related to height cues and consequently were unlikely to induce a conditioned height related fear response. Second, only in two cases the movement of the stimuli referred to the third dimension (that is upward–downward movements in a three-dimensional surrounding; PitT and RotS). Excluding these conditions from the analyses did not alter the reported effects in a significant way. Third, the remaining movements (that is vertical and horizontal movements of a two-dimensional stimulus, forward–backward movements of a three-dimensional stimulus) are clearly not directly related to height scenes. Rather they are much more directly associated with motion not related to height (e.g. sitting in a train looking outside, driving through a snowstorm in a car). Arguably, it is rather unlikely that specific fear of heights is associated with such a generalized class of movement stimuli. Therefore, our findings most likely provide evidence for the role of misleading visual balance information in fear of heights than for the effects of a conditioned anxiety reaction.

In summary, our results support the notion of a hypersensitive visual channel of the balance system in height fearful individuals. At least in part, misleading visual balance information may create conflicting balance information in acrophobic individuals who then experience more dizziness and anxiety and exhibit a greater amount of body sway. Since these group differences occurred solely in visual flow conditions but were not found during baseline, it can be reasoned that the results are not confounded by effects of anticipatory anxiety. Baseline conditions consisted of a black screen which eliminated visual balance information. These effects show an important feature of balance system functioning in individuals with fear of heights: to maintain bodily balance, not visual information per se is important but rather that the visual information is not in conflict with the balance information provided by the other subsystems.

These findings differ from the results reported by Nakahara et al. (2000), who found more body sway in acrophobic individuals during an exposure situation while being blindfolded. Nevertheless, this effect is likely due to effects of acute height anxiety triggered by the situation in which the individuals were tested and should not be interpreted as a pure test of balance system functioning. Notably, two acrophobics in the Nakahara study refused participation because it was too threatening for them. Furthermore, since increased muscle tension is a common symptom during exposure situations in phobic individuals (Hoehn-Saric & McLeod, 2000; Malmo, 1957; Martin, 1961), this could also have caused the increased sway in more anxious individuals in the investigated samples. Nakahara et al. (2000) mentioned trembling in the phobic sample. In the same vein, Alpers and Adolph (2007) reported correlations between anticipatory anxiety and body sway in higher frequency spectra which are not associated with the functioning of the balance system but with skeletal muscle activity and proprioceptive feedback (Diener, Dichgans, Guschlbauer, & Mau, 1984; Fitzpatrick, Gorman, Burke, & Gandevia, 1992; Wada, Sunaga, & Nagai, 2001).

Interestingly, our results indicate that merely receiving conflicting balance information can lead to higher levels of anxiety in individuals with high fear of heights. This finding is of special interest with respect to etiological considerations as presented by Menzies and Clarke (1995b). They criticized that classical conditioning is often assumed to be the primary route to acrophobia. Instead they suggested that sensitivity for internal bodily symptoms may be the most important factor with respect to the onset of height fears. Our results correspond with their hypothesis by demonstrating a hypersensitivity of the balance system for visual information. Possibly, some individuals experience dizziness in height situations where visual balance information is missing. Since feeling dizzy is aversive, it may lead to feelings of anxiety and subsequently to avoidance of situations eliciting such symptoms.

Our results indicate that acrophobic individuals also have more problems in situations characterized by conflicting balance information in general and consequently report higher scores on the situational characteristics questionnaire (SitQ). These differences cannot be attributed to fear experienced in height situations per se because the questionnaire controls for panic and anxiety occurring in these situations. Thus, these scores indeed indicate difficulties in circumstances regarding misleading or missing balance information. Our results, therefore, support the notion that acrophobia is related to space and motion discomfort.

Different from investigations using similar visual flow stimuli with panic disorder patients, we could not find greater sway in individuals with fear of heights occurring in synchrony with the visual flow stimuli oscillation. This may be because we tested an analogue sample with only four individuals fulfilling DSM-IV criteria for acrophobia. Also, our visual flow stimuli were presented for only 30 s which might be too short to reveal differences in very low frequency spectra of body sway Furthermore, Jacob et al. (1995) projected visual flow stimuli on the wall, visible only to one eye and with the peripheral field blocked. In contrast, we presented stimuli with a head mounted binocular display which allowed for some peripheral information. This difference in methodology may have resulted in different effects in the two studies.

A potential limitation of our interpretation is that the abstract stimuli were not modeled from realistic environments and that some of the stimuli may be related to the experience of height. Unfortunately, it is not possible to completely rule this interpretation out, although we have carefully tried to avoid this pitfall with most stimuli.

Taken together, our study supports the assumption of an overreliance on visual balance information in individuals with fear of heights as one pathway towards acrophobia. This finding has implications for treatment in suggesting the addition of vestibular training and therefore reducing the impact of visual balance information in individuals with fear of heights. As Whitney et al. (2005) showed in a case study, acrophobic symptoms can be reduced by vestibular rehabilitation training in addition to situational exposure therapy. Results of our study support the potential of vestibular rehabilitation training as an adjunct in the treatment of acrophobia. Nevertheless, further research is needed to validate the additional benefit of balance training within cognitive–behavioral treatment.

Acknowledgements

This research was supported by the Association for the Advancement of Clinical Psychology and of Training in Psychotherapy, Münster and by a grant from the German Federal Ministry of Education and Research (BMBF; Improving the Treatment of Panic Disorder 01GV0610). The study is part of the Master thesis of the first author, submitted to the University of Münster. We wish to thank Mr. Wuth and Mr. Fatum for their help with building and testing the force platform.

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Volume 47 Number 4 April 2009 ISSN 0005-7967

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ISSN 0005-7967
47(4) 265–352 (2009)

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