Exposure to heights in a theme park:
Fear, dizziness, and body sway

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Abstract

Fear of heights results in the experience of dizziness and measurable body sway. We investigated the relationship between fear, dizziness, and body sway during height exposure 16 m above ground. Thirty five healthy participants stood on a force-plate to measure sway before, during, and after exposure and an ECG was recorded. Self-report measures were anticipated fear and dizziness before exposure, as well as actual fear and dizziness during the three situations. For all participants, fear, dizziness, and body sway were increased during exposure. Anticipated fear most reliably predicted body sway during exposure. In addition, persons scoring high on trait fear of heights anticipated and experienced more fear during exposure, but this relationship was not found for any objective measure. There was no evidence that vestibular function moderates the relationship between sub-clinical fear and body sway. The results underline the importance of cognitive factors, like anticipatory anxiety and overestimation of bodily symptoms, in fear of heights.

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Dizziness, or feeling unsteady are common symptoms in states of heightened anxiety (Beck & Emery, 1985; Sklare, Konrad, Maser, & Jacob, 2001). Dizziness has often been reported to be associated with agoraphobia (Balaban, 2002; Jacob, Whitney, Detweiler-Shostak, & Furman, 2001) but it is especially typical in fear of heights, or acrophobia (Brandt, Arnold, Bles, & Kapteyn, 1980). In all forms of anxiety states, dizziness is a particularly impeding symptom and is often the reason why patients report to neurological practice (Furman & Jacob, 2001; Strupp et al., 2003). Interestingly, the subjective experience of dizziness is one of the symptoms which can be easily verified objectively when participants stand on a force-plate with which the change in center of pressure can be measured (Chiari, Rocchi, & Cappello, 2002). It is therefore well suited to study the often neglected association between experienced symptoms of anxiety and measurable bodily responses (see Wilhelm & Roth, 2001).

Keeping balance is a complex neurological function mostly based on input from the vestibular organs (Guyton & Hall, 1996). It has long been suggested that people who are afraid of heights frequently suffer from vestibular dysfunctions (Pogány, 1958) and a close but unspecific association between anxiety and balance control has

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since been confirmed for several anxiety disorders (Sklare et al., 2001). In addition, a high comorbidity of anxiety disorders and balance disorders in general has been reported repeatedly (Asmundson, Larsen, & Stein, 1998; Balaban & Jacob, 2001; Clark, Hirsch, Smith, Furman, & Jacob, 1994; Furman & Jacob, 2001; Jacob et al., 1989; Yardley, Owen, Nazareth, & Luxon, 2001). From an etiological perspective, some anxiety disorders may be an offshoot of a subclinical balance dysfunction (Erez, Gordon, Sever, Sadeh, & Mintz, 2004). However, the correlation of bodily imbalance and fear of heights has not been examined in much detail yet.

In healthy people, dizziness during exposure to heights has been explained by the lack of visual reference points when being remote from a stable background (Brandt, 2000). Indeed, destabilization was observed to be greatest when participants were at a height of 15 m or more which increases the distance of stable surroundings to the eye or in the complete absence of visual information (i.e., when blindfolded) (Brandt et al., 1980). The hypotheses that increased body sway in anxiety disorders in general may be mediated through impaired vestibular functions and therefore greater reliance on visual information is widely accepted in the literature (e.g., Jacob, Redfern, & Furman, 1995; Redfern & Furman, 1994; Redfern, Yardley, & Bronstein, 2001; Wada, Sunaga, & Nagai, 2001).

However, data from a pilot study suggests that cognitive factors may also play a role in fear of heights. When the two participants with acrophobic fear were led onto a roof while being blindfolded, they showed an increase in body sway after the blindfold was removed, whereas healthy controls showed a decrease when visual depth cues became available (Nakahara, Takemori, & Tsuruoka, 2000). Thus, only when visual depth cues provided information about the height, phobic patients responded with fear, dizziness, and body sway. The cognitive style of how potentially disturbing experiences are evaluated may have a profound influence on how the experience of being exposed to heights leads to an increase in anxiety, dizziness, and body sway. Anticipatory anxiety (see: Alpers, Abelson, Wilhelm, & Roth, 2003; Phelps, O’Connor, Gatenby, Gore, Grillon, & Davis, 2001) may be a particularly suitable predictor of anxious responding to exposure to demanding environments (see: Roth et al., 2002). Indeed, acrophobic patients report higher levels of anticipatory anxiety prior to an exposure to heights and they overestimate the risk of falling and getting seriously injured compared to healthy control participants (Menzies & Clarke, 1995). Although these authors study reported significant influences of risk estimations on anxiety, the influence of anticipatory anxiety on actual anxiety experienced during exposure were not reported. Closing this gap was the first goal of this study.

Another goal was to more closely examine different parameters of body sway. While standing upright, subtle movements of a participant’s body in the anterior–posterior and lateral direction can be observed. In a typical experiment, participants are asked to stand as quietly as possible on a force plate with which this body sway can be assessed as the movement of the center of pressure (CoP) over the force-plate and this information can be recorded across time. Several parameters can be extracted from the resulting data. One common method is to calculate the sway path, which represents the movement of the CoP in cm/s.

In addition, body sway can be examined in specific frequency components. In healthy people, sway can be observed in a broad spectrum (Kapteyn et al., 1983; Kitabayashi, Demura, & Noda, 2003; Soames & Atha, 1982). For example, it has been suggested that low frequencies (i.e., sway about 0.4 or 0.7 Hz) are associated with functions of the vestibular organ (Gantchev & Popov, 1973), which is of vital importance for the control of balance. Furthermore, in keeping balance, an interaction between input from different sensory channels (i.e., visual, vestibular or interoceptive information) is needed (Day, Guerraz, & Cole, 2002) and these inputs refer to different frequency bands within the overall frequency range of body sway (for a discussion of the effects of state anxiety on different frequency bands see: Wada et al., 2001). To disentangle specific disturbances in processing specific sensory information in fear of heights, it is therefore important to further examine whether activity in specific frequency bands is related to anxiety. Specifically, to test the theoretically proposed vestibular dysfunction in fear of heights, a correlation of fear and sway in the lowest frequency band should be found.

If fear of heights were related to an impairment of the vestibular system patients would need to rely on visual information to a greater extend. Exposure to heights should therefore result in more body sway when visual depth cues are not available. First, this should be evident in greater baseline-sway when fearful participants close their eyes, making visual cues unavailable. Second, it should result in greater increase from baseline to height exposure when fearful participants have their eyes open, because visual input helps them to stabilize on ground level (many visual cues are available) but at greater height visual reference points are less salient. So far, these analyses have not been reported in the literature.

To summarize, our goal was to more closely examine the relationship between self reported fear and
dizziness, and objective measures during a naturalistic exposure to heights. As opposed to other challenging environmental stressors such as parachuting (Deinzer, Kirschbaum, Gresele, & Hellhammer, 1997; Fenz & Jones, 1972; Lewis, Ray, Wilkinson, Doyle, & Ricketts, 1984; Roth, Breivik, Jorgensen, & Hofmann, 1996; Ursin, Baade, & Levine, 1978), this allowed us to examine a specific symptom, namely dizziness or body sway, without engaging the subject in vigorous physical activity (for a discussion see: Alpers, Wilhelm, & Roth, 2005). We therefore assessed subjectively experienced and objectively measured effects of a challenging exposure to a platform 16 m above the ground in an outdoors theme park. The experience of fear and dizziness, as well as body sway, were measured before, during and after the exposure. We assessed trait anxiety, trait fear of height and prior experience with height situations by questionnaire.

We closely explored the effects of trait fear of heights and its correlation with objectively measured body sway. In addition, we examined what the best predictors were for the experience of fear during the exposure. To this end, the effect of visual depth cues was experimentally manipulated by an instruction to stand on the force-plate with eyes open or with eyes closed. Putative predictors of fear and body sway proposed in previous work which are trait variables, and therefore not amenable to experimental manipulation, were examined in a multiple regression analysis approach (predictors were vestibular balance control by a baseline measure of sway on the ground, cognitive factors by scores on anticipatory anxiety, the expectation of experiencing dizziness, and trait acrophobia).

In short, we aimed to extend previous findings of greater body sway during exposure to heights under more ecologically valid conditions (previous studies use limited to relatively low scaffolds or indoor exposure). We expected more subjectively experienced dizziness and anxiety during exposure as compared to pre or post-exposure. We further hypothesized that cognitive variables, such as anticipatory anxiety, play a crucial role in subjective and objective symptoms of fear of heights.

1. Method

1.1. Participants

Participants were 35 healthy males between 18 and 42 years of age ($M = 28.3$, S.D. = 6.4). Participants were invited on a parking lot adjacent to the theme park to participate in the experiment. In order to increase the range of sub-clinical trait fear of heights we also invited members of the local mountain rescue service in Garmisch-Partenkirchen located in the Alps. We expected that they would be low in fear of heights. All participants signed informed consent.

In order to avoid possible confounds due to gender differences, we only recruited male participants. Their mean body height was 178.77 cm (S.D. = 6.16) and their mean weight was 76.37 kg (S.D. = 7.91). Two participants were excluded from the analysis due to equipment failure during recording of the sway data.

1.2. Questionnaires

Fear of heights was assessed with the Acrophobia Questionnaire (AQ, Cohen, 1977) which had sufficient internal consistency in our sample (Cronbach’s alpha, $r_a = 0.79$). The AQ assesses fear of heights on two subscales. First, anxiety across different situations related to heights (ACRO) on a seven-point scale (0: not at all anxious, 6: extremely anxious). Second, avoidance behavior across different situations (AVOI) on a three-point scale (0: I would not avoid this situation, 2: I would definitely avoid this situation). Cohen (1977) and Baker, Cohen, and Saunders (1973) reported mean values for acrophobic outpatients to range from 48 to 60 for the ACRO, and from 10 to 14 for the AVOI subscales, prior to treatment. Post-treatment values ranged from 19 to 32 for the ACRO and from 4 to 14 for the AVOI subscale.

In the present study, mean values for the subscales were within a subclinical range with a mean of 11.94 (S.D. = 9.50) in case of the ACRO, and 2.12 (S.D. = 2.43) for the AVOI subscale but our sample included a good range of fear of heights (range 0–38 for ACRO and 0–8 for AVOI).

Our own questionnaire on experience with heights consists of nine questions asking about prior experience with different height related activities on a nine-point scale (0: I never did this before, 8: I do this regularly). Activities include, for example, parachuting, rock climbing, mountaineering, or working on roofs. Values on this scale ranged from 1 to 30 (maximum: 45) with a mean of 9.46 (S.D. = 7.82). It showed good internal consistency (Cronbach’s alpha, $r_a = 0.84$).

Trait anxiety was assessed with the trait form of the State Trait Anxiety Inventory (STAI-T, Laux, Schaffner, Glanzmann, & Spielberger, 1981) with sufficient internal consistency (Cronbach’s alpha, $r_a = 0.83$). The sample’s mean was in the normal range with a mean of 33.97 (range 23–49; S.D. = 6.10). As expected, trait anxiety scores were positively but barely sig-
significantly correlated with trait fear of heights as measured with the ACRO subscale of the AQ ($r = 0.34$, $p = 0.054$).

1.3. Data recording

Body sway was assessed with a custom-made steel force-plate, which measured center of pressure (CoP) through 4 strain sensors (LY11-6, 120 Ω; Hottinger-Baldwin Messtechnik GmbH, Germany). The plate was calibrated to measure CoP displacement up to 16.25 cm in the anterior–posterior and medio-lateral direction. For the present purpose, only sway in the anterior–posterior direction was examined as a standard measure for sway (see, Jacob et al., 1995; Ohno, Wada, Saitoh, Sunaga, & Nagai, 2004; Wada et al., 2001). The ECG was recorded with 2 large Ag/AgCl electrodes filled with electrode gel which were placed on the clavicle and the lowest rib on the left. Output from the two force-plate channels and physiological data was recorded with a 16-bit Varioport system (Becker Meditec, Karlsruhe, Germany) at sampling rates of 64 Hz (body sway) and 512 Hz (ECG).

1.4. Procedure

Prior to the experiment, each participant completed a questionnaire to assess his experience with activities requiring exposure to heights, the AQ and the STAI-Trait. The experimental procedure consisted of three relevant situations during which each participant was instructed to stand quietly for 30 s with eyes open (providing visual depth cues) and 30 s with eyes closed (eliminating visual depth cues) on a force-plate: first, before exposure (pre-exposure situation) on the ground, second, during height exposure on a platform elevated by 16 m and, third, after exposure (post-exposure situation). During the eyes-open epoch of all three situations, participants were asked to look at the same fixation point at eye level to control for head position. In order to ensure constant foot position between trials foot position was marked on the plate for each participant.

After each epoch, characterized by combinations of visual input (eyes-open or closed) and the three situations (pre-exposure, exposure, post-exposure) the participants were asked to rate their actual fear (0: no fear, 9: very strong fear) and dizziness (0: no dizziness, 9: very strong dizziness). In addition, anticipated fear and anticipated dizziness were assessed on equivalent scales during the pre-exposure situation where the participant were asked to estimate the degree of dizziness and fear which they expected to experience during the actual exposure situation.

1.5. Data reduction and preprocessing

Sway data was first normalized for body weight according to a calibration procedure for the sway data. After that, to reduce the impact of high frequency artifacts, the data was filtered with a cut off frequency of 5 Hz. To obtain mean body sway, two common indicators were analyzed, frequency and sway path. First, we assessed the mean displacement of the center of pressure (CoP) as the sway path (cm/s), a standard posturographic parameter (Jacono, Casadio, Morasso, & Sanguineti, 2004). For this we used an established algorithm programmed in Matlab (Sway Density Analysis, Bioengineering Centre Hospital 'La Colletta’, Arezano, Italy). This measure uses both the anteposterior and the lateral channels of the force plate. The length of the path describing the anterior-posterior displacement during a trial is then standardized with respect to the respective epoch’s duration.

Second, we used Fast Fourier Transform (FFT) to analyze the power of frequencies contained in our sway data. We determined the power in specific frequency bands. This is interesting because normal sway is primarily characterized by relatively slow body sway (swinging). Correspondingly, the highest power in the sway frequency spectrum for healthy people is in the lower range, i.e., below 3 Hz (see, Kapteyn et al., 1983; see, Kitabayashi et al., 2003). Approximately 90% of power in the spectrum lies below 2 Hz (i.e., two cycles per second) (Soames & Atha, 1982). In addition, it has been suggested that very low frequencies (i.e., below 0.4 Hz) are associated with basic functions of the vestibular organ (Gantchev & Popov, 1973). Consequently, to test whether anxiety has an impact in a specific frequency range, we separately analyzed mean power within the lower frequency band (i.e., <0.5 Hz) and three frequency bands above 0.5 Hz (i.e., 0.5–1 Hz; 1–1.5 Hz; 1.5–2 Hz). The frequency data was normalized prior to averaging.

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2 The calibration was done by using two weights of 2.5 kg each. First, the signal provided by the strain sensors was obtained with no weight on the force-plate (baseline-recording). After that the weights were placed at the very ends of the force-plate in every direction consecutively (medio-lateral direction: left versus right; ante-posterior direction: fore versus aft). Hereby, the displacement of center of pressure (in cm) to the very middle of the plate and the signal change provided by the strain sensors (in μV) were measured. By subtracting the obtained value from the baseline-recording and after normalizing for weight and the covered distance of center of pressure, we obtained the change (in μV) for one kilogram weight and one centimeter displacement of center of pressure on the force-plate.
To assess heart rate inter-beat intervals were determined and transformed to mean beats per minute for each 30 s epoch (pre-exposure, height exposure and post-exposure, each with eyes-open and closed).

1.6. Statistical analysis

First, an ANOVA with the factors situation (pre-exposure, height exposure, post-exposure) by visual input (eyes open versus eyes closed) was run with the sway path data. Second, an ANOVA with the factors situation (pre-exposure, height exposure, post-exposure), visual input (eyes open versus eyes closed), and frequency band (<0.5 Hz; 0.5–1 Hz; 1–1.5 Hz; 1.5–2 Hz) was run. We followed-up on significant main effects with "t"-tests.

To assess the influence of trait fear of height on actual and anticipated body sway, as well as experienced and anticipated fear, Pearson correlations were run. Because pre-exposure may be contaminated by anticipated fear (see, Menzies & Clarke, 1995), we used the post-exposure baseline to calculate response scores (height-exposure - post-exposure) for the cardiac and sway data before calculating the correlations (for a detailed discussion see, Alpers et al., 2005). After that, to investigate the influence of height exposure on these correlations, a set of partial correlations were run.

To more closely examine the influence of vestibular functioning on body sway, we examined the association of fear of heights and the power in different frequency bands of body sway. To this end we correlated the mean response scores of power of sway separately for the four frequency bands with trait fear of heights as well as with trait anxiety. These correlations were then also calculated for self report of anticipated fear and actual fear in the pre-exposure situation. The same set of correlations with self-report measures was then calculated for mean power of baseline sway.

To examine which variables predict body sway and fear during the exposure situation multiple regression analysis was used. Body sway (eyes open and eyes closed), fear during the pre-exposure situation, anticipated fear, anticipated dizziness, and experience with heights were entered as potential predictor variables.

2. Results

2.1. Self-reported fear and dizziness

All self-report measures were elevated during exposure, as compared to the pre or post exposure. The MANOVA with self-report measures revealed different levels of anticipated fear and dizziness, and of actual fear and dizziness during pre-exposure, exposure and post-exposure, F(6, 192) = 10.68, p < 0.001, see Table 1. A follow-up ANOVA showed that levels of anticipated and actual fear in the three situations differed significantly from each other, F(3, 96) = 22.32, p < 0.001.

2.1.1. Fear

Participants experienced less fear during pre-exposure, t(32) = 4.25, p < 0.001, and post-exposure, t(32) = 5.14, p < 0.001, than during exposure. Fear was also greater during pre-exposure as compared to post-exposure, t(32) = 2.46, p < 0.019. Anticipated fear and actual fear during exposure did not differ, t(32) = 0.83, p = 0.414.

2.1.2. Dizziness

Dizziness also differed between pre-exposure, exposure and post-exposure, F(3, 96) = 17.36, p < 0.001. Participants experienced less dizziness during pre-exposure, t(32) = 2.65, p = 0.012, and post-exposure, t(32) = 4.02, p < 0.001, than during exposure. Dizziness was also greater during pre-exposure as compared to post-exposure, t(32) = 2.80, p = 0.009. Different from the findings for fear, participants anticipated more dizziness than they actually experienced during exposure, t(32) = 2.57, p = 0.015.

2.1.3. Correlations among self-report variables

During exposure there was a strong correlation between anticipated anxiety and body sway on the one
hand, and actual anxiety and body sway on the other hand. Participants who experienced more intense anticipated fear reported more actual fear during exposure, \( r = 0.67, p < 0.001 \).

2.2. Effects of height exposure on body sway

2.2.1. Sway path

Mean sway path data are shown in Fig. 1. The sway path analysis with all participants revealed that body sway differed between the pre-exposure, height-exposure and post-exposure situations, \( F(2, 64) = 51.50, p < 0.001 \). Increased body sway was evident during exposure in comparison to the pre-exposure situation (eyes open: \( t(32) = 6.95, p < 0.001 \), eyes closed: \( t(32) = 5.26, p < 0.001 \)) and the post-exposure situation (eyes open: \( t(32) = 8.47, p < 0.001 \), eyes closed: \( t(32) = 7.19, p < 0.001 \)). In all situations, body sway was less with eyes open compared with eyes closed, \( F(1, 32) = 93.63, p < 0.001 \). Follow-up comparisons showed that this was significant for all situations (pre-exposure: \( t(32) = 8.66, p < 0.001 \), exposure: \( t(32) = 8.16, p < 0.001 \), post-exposure: \( t(32) = 6.46, p < 0.001 \)).

Moreover, a significant interaction of situation by visual input indicates that the participants showed different sway patterns in different situations depending on whether they had their eyes open or closed, \( F(2, 64) = 9.20, p < 0.001 \). The mean sway path did not differ between the pre and post-exposure situation when the participants had their eyes open, \( t(32) = 1.75, p = 0.090 \), but was greater in the pre-exposure than the post-exposure situation when participants had their eyes closed, \( t(32) = 4.15, p < 0.001 \). To further test this interaction, we calculated difference scores between the mean sway path during the post-exposure situation as a baseline and the exposure situation for the eyes open and eyes closed condition. Unexpectedly, a follow-up test revealed that the decrease was greater for the eyes closed condition although there was no change in visual input, \( t(32) = 3.55, p = 0.001 \).

2.2.2. Power spectra of body sway

The three-way ANOVA revealed a significant interaction for situation by visual input by frequency band, \( F(6, 192) = 5.30, p < 0.001 \), see Fig. 1b. Follow-up ANOVAs revealed that mean power of body sway showed the same patterns for the three bands from 0.5 to 2 Hz, but were different for the frequency band below 0.5 Hz.

2.2.3. Frequency band below 0.5 Hz

Mean power in the frequency band below 0.5 Hz differed between the pre-exposure, exposure and post-exposure situation, \( F(2, 64) = 5.68, p = 0.005 \). Visual input alone had no effect on mean power of body sway in this frequency, \( F(1, 32) = 0.18, p = 0.676 \), but a significant interaction indicated that the mean power varied between the three situations as a function of visual input, \( F(2, 64) = 3.49, p = 0.037 \). With eyes open, mean power did not differ between the pre-exposure and the exposure situation, \( t(32) = 1.32, p = 0.196 \), but was lower in the post-exposure situation (post-exposure versus pre-exposure, \( t(32) = 4.78, p < 0.001 \), post-exposure versus exposure situation, \( t(32) = 3.69, p = 0.001 \)). With eyes closed, mean power did not differ significantly between the three situations (pre-exposure versus exposure situation, \( t(32) = 0.26, p = 0.795 \), exposure situation versus post-exposure situation, \( t(32) = 0.18, p = 0.855 \), pre-exposure versus post-exposure situation, \( t(32) = 0.43, p = 0.795 \)). However, there were significant differences between situations for the eyes open and eyes closed condition. During the post-exposure situation mean power was significantly less for the eyes open condition, \( t(32) = 2.33, p = 0.026 \), that is, visual input

Fig. 1. (A) Sway path (cm/s) during exposure, prior to exposure, and after exposure, there are separate lines for eyes open (triangles) and eyes closed (circles). (B) Normalized power of all frequencies up to 3 Hz prior to exposure (pre), during exposure (height) and after exposure (post).
helped participants to stabilize at the end of the experiment. However, visual input had no effect for pre-exposure \((t(32) = 1.03, p = 0.313)\) and exposure \((t(32) = 0.34, p = 0.740)\).

2.2.4. Frequency band above 0.5 Hz

Because the results for the three frequency bands above 0.5 Hz were very similar, only the results of the frequency band adjacent to the one just described will be reported in detail (from 0.5 to 1 Hz)\(^3\). Mean power differed between the three situations, \(F(2, 64) = 39.13, p < 0.001\), with more power during the exposure situation, as compared with the pre- and post-exposure situation. This was the case when participants had their eyes open (pre exposure versus exposure, \(t(32) = 4.31, p < 0.001\); post exposure versus exposure, \(t(32) = 6.31, p < 0.001\)) and closed (pre exposure versus exposure, \(t(32) = 4.31, p < 0.001\); post exposure versus exposure, \(t(32) = 6.31, p < 0.001\)). Furthermore, mean power was greater during the pre-exposure, as compared to the post-exposure situation, both with eyes open, \(t(32) = 2.90, p = 0.007\), and closed, \(t(32) = 2.21, p = 0.035\).

A significant main effect for visual input, \(F(1, 32) = 42.47, p < 0.001\), indicates that mean power differed between the eyes open and closed condition. In all three situations, mean power was greater with eyes closed than open (pre exposure, \(t(32) = 4.03, p < 0.001\); exposure, \(t(32) = 5.18, p < 0.001\), post exposure, \(t(32) = 3.90, p < 0.001\)).

Finally, we found that mean power of body sway varied between the three situations as a function of visual input (interaction situation by visual input, \(F(2, 64) = 6.09, p = 0.004\)). The same difference scores as for the sway path data were calculated to follow-up on this interaction. A \(t\)-test revealed that the decrease in mean power was greater for the eyes closed, \(t(32) = 3.13, p = 0.004\), than for the eyes open condition.

2.2.5. Correlations between self-report and sway

Participants who anticipated more dizziness also experienced more intense body sway (measured as response scores of the sway path) during the exposure situation, both with eyes closed, \(r = 0.44, p = 0.010\), and eyes open, \(r = 0.48, p = 0.005\).

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\(^3\) Results for the remaining frequency bands (the directions of the effects are the same as for the frequency band between 0.5 and 1 Hz): 1–1.5 Hz: main effect for situation: \(F(2, 64) = 32.05, p < .001\), main effect for visual input: \(F(1, 32) = 42.36, p < .001\), interaction: \(F(2, 64) = 32.05, p < .001\). 1.5–2 Hz: main effect for situation: \(F(2, 64) = 42.68, p < .001\); main effect for visual input: \(F(1, 32) = 16.06, p < .001\); interaction: \(F(2, 64) = 3.11, p < .001\).

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2.3. Correlates of sway in different frequency bands

2.3.1. Trait fear of heights

There was no correlation between trait fear of heights and the power of baseline body sway (at post-exposure) in the lowest frequency band (<0.5 Hz). In addition, there were no significant correlations between trait fear of heights and trait anxiety with any response score of mean power of body sway.

2.3.2. State fear

Anticipated and actual fear correlated with greater body sway. In detail, greater anticipatory fear was related to greater response scores of mean power of body sway in the frequency band of 1–1.5 Hz with eyes closed, \(r = 0.40, p = 0.022\), and eyes open, \(r = 0.38, p = 0.031\), and in the frequency band of 1.5–2 Hz with eyes closed, \(r = 0.46, p = 0.007\), and eyes open, \(r = 0.34, p = 0.055\). In addition, greater actual anxiety before the exposure situation was positively correlated with greater response scores in the frequency band between 1.5 and 2 Hz with eyes closed, \(r = 0.468, p = 0.006\). There were no other significant correlations between mean power of baseline sway, or response score in any frequency band.

2.4. Correlates of trait fear of heights: anticipation and exposure

Trait fear of heights was strongly related to anticipated self-report measures prior to exposure, as well as actual dizziness and fear during exposure.

2.4.1. Anticipation

Greater fear of heights as assessed with the ACRO lead to more fear directly before exposure, \(r = 0.47, p = 0.004\), more anticipated fear, \(r = 0.64, p < 0.001\) and more anticipated dizziness, \(r = 0.53, p = 0.002\).

2.4.2. Exposure

As expected, greater fear of heights (ACRO) correlates with self-reported fear, \(r = 0.39, p = 0.020\), and dizziness, \(r = 0.54, p = 0.001\), during exposure. Surprisingly, fear of heights did not correlate significantly with the increase in actual body sway (response scores of sway path, eyes closed, \(r = 0.21, p = 0.231\), and eyes open, \(r = 0.28, p = 0.109\))\(^4\) and heart rate (HR response scores, \(r = 0.10, p = 0.571\)).

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\(^4\) In addition to sway path, we tested correlations with mean power in the four frequency bands, none of which were significant.
2.4.3. Control for experience with heights

Partial correlations were calculated in order to examine the potential influence of experience with heights on the correlations between fear of heights and anticipated as well as experienced fear and dizziness during exposure. The results showed strong effects of prior exposure to heights on experienced fear during the exposure situation. However, the partial correlation between trait fear of heights and fear during the pre-exposure situation ($r_p = 0.49$, $p = 0.004$) and anticipated fear ($r_p = 0.50$, $p = 0.003$), as well as dizziness during the exposure situation, $r_p = 0.42$, $p = 0.017$ and anticipated dizziness, $r_p = 0.39$, $p = 0.029$, remained significant none the less.

2.5. Predictors of fear and body sway

Three separate multiple regression analyses were run to examine a set of meaningful predictors of fear experienced during exposure and actual body sway (eyes open or closed) during exposure. Results are reported in Table 2.

2.5.2. Body sway

Results from two separate multiple regression analyses to predict body sway (with eyes open or closed) included the predictors experienced fear, fear during pre-exposure, anticipated fear, anticipated dizziness, and experience with heights (see Table 2). Anticipated and actual fear before exposure, as well as sway before exposure predicted sway during exposure with eyes closed. Different from this, only anticipated fear remained a significant predictor of sway during exposure when eyes were open.

3. Discussion

Dizziness is a common symptom which is in many ways associated with fear of heights. We examined fear, dizziness, and body sway in response to a challenging height exposure under naturalistic conditions. The level of experienced fear and dizziness as well as an objective measure of body sway were assessed before the exposure to heights, during exposure on a platform 16 m above ground, and after exposure.

As expected, body sway (measured as sway path with a force-plate), was greater during the exposure situation than during the pre or post-exposure baselines. In all three situations, participants showed increased body sway when they had their eyes closed as compared to the eyes open condition. This underlines the importance of visual information for keeping balance. First, in the eyes open condition visual depth cues were available to help participants to stabilize. Second, participants were able to fixate on stable close-by objects when measured on the ground whereas this was not possible during exposure to heights. While standing on the platform 16 m above ground level stable objects

<table>
<thead>
<tr>
<th>(A) Sway path (eyes closed)</th>
<th>(B) Sway path (eyes open)</th>
<th>(C) Experienced fear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anticipated fear</td>
<td>0.53</td>
<td>0.52</td>
</tr>
<tr>
<td></td>
<td>0.002</td>
<td>0.002</td>
</tr>
<tr>
<td>Sway path before</td>
<td>0.42</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>0.005</td>
<td>ns</td>
</tr>
<tr>
<td>Actual fear pre-exposure</td>
<td>−0.35</td>
<td>−0.22</td>
</tr>
<tr>
<td></td>
<td>0.033</td>
<td>ns</td>
</tr>
<tr>
<td>Experience with heights</td>
<td>−0.05</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Anticipated dizziness</td>
<td>0.06</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.39</td>
<td>0.27</td>
</tr>
</tbody>
</table>

Bold values mark significant predictors. Predictors on the left are listed in the order in which they entered the regression model for sway path (eyes closed).

$^a$ The model reported in the table refers to sway path before with eyes closed, a model using eyes open yielded similar results ($\beta = 0.088$, n.s., $R^2$ korr. = 0.47).
were too remote to provide for suitable reference points. This replicates previous findings which showed that healthy individuals’ stance is less stable when exposed to heights, or when visual input is not available (e.g. Nakahara et al., 2000; Ohno et al., 2004).

However, although there were no differences in visual input when they had their eyes closed, participants showed more body sway when they were standing on the platform (exposure) compared to standing on the ground (pre or post-exposure). Therefore, fear and cognitive factors (i.e., knowing about being exposed to heights) probably contributed to the enhanced body sway we observed during exposure to heights.

That trait fear of heights was not correlated with increase in actual body sway either in the condition where participants had their eyes open or in the one where they had their eyes closed may be interpreted as a contradiction to the theoretically proposed impairment in visual processing of anxious individuals (Brandt, 2000). Although this theory would not predict a change in the eyes closed condition, a correlation would be expected in the eyes open condition. Instead, our findings correspond better with the notion that a lack of visual information increases anxiety, uncertainty, and tension (Peake & Leonard, 1971; Wright, 1980) and that this produces physiological activation in an unknown environment (Ponchillia, LaDuke, & LaGrow, 1984).

Moreover, there were no correlations between mean power of baseline sway in the lower frequency band, which has been suggested to reflect functioning of the vestibular system, and any measure of fear or anxiety, neither with eyes open nor with eyes closed. Also, there were no correlations between any measure of fear or anxiety with the increase in power in sway in the lower frequency band, neither with eyes closed nor with eyes open. Furthermore, in the lower frequency band mean power of body sway did not differ significantly between the three situations in the eyes closed condition. Therefore, our data from healthy individuals do not support the proposed relationship between vestibular functioning and anxiety. This needs to be examined more closely in samples with formally diagnosed height phobia.

In our sample the changes related to exposure are apparent only in the higher frequency bands of body sway. In the higher frequency bands (i.e., >0.5 Hz), mean power was greater during the exposure situation than during the pre or post-exposure situations and with eyes closed as compared to the eyes open condition. Also, increases in body sway in higher frequency bands are correlated with state measures of fear. Specifically, anticipated fear was positively related to an increase in power of body sway in the higher frequency band, both with eyes open and closed. In addition, when sway was measured with eyes closed, mean increase in power in a frequency band between 1.5 and 2 Hz was related to actual anxiety during pre-exposure. Mean power of baseline sway in the higher bands did not correlate with any measure of fear or anxiety. Also, the increase in mean power in the higher frequency bands from baseline to the exposure situation was related to greater anxiety. In the same vein, we found that anticipated fear was the best predictor for body sway (measured as sway path) during the exposure situation. Together, these findings further support the importance of situational influences on body sway, but provide no evidence for a specific role of vestibular dysfunctions in otherwise healthy individuals.

Ratings of fear and dizziness, as well as body sway, were greater in the pre-exposure than in the post-exposure situation, suggesting that the anticipation of being exposed to the elevated platform leads to an increase in fear (see: Alpers et al., 2003, 2005) and body sway. This too, corroborates the assumption that anxiety can have a destabilizing effect even outside of acrophobic situations (Wada et al., 2001), both on the experiential and objective level. Moreover, anticipated fear, as measured during the pre-exposure situation, did not differ from fear as actually experienced during the exposure situation. This suggests that participants accurately anticipated their level of fear during the exposure situation. A questionnaire measure of trait fear of heights only predicted self-report responses to the challenge but not the objectively measured variables: Participants with higher levels of trait fear of heights reported more anticipated fear and dizziness, more actual fear during the pre-exposure and more actual fear and dizziness during the exposure situation. This relationship was not found for fear related autonomic arousal or actual body sway, indicating a pronounced discordance between different indicators of anxiety (Rachman & Hodgson, 1974). An overestimation of bodily symptoms is common in anxiety disorders, especially in panic disorder (for an overview see, Austin & Richards, 2001; McNally, 1994). Specifically for acrophobia, a bias to interpret ambiguous bodily sensations as threatening and to over-report bodily sensations of anxiety has been reported (Davey, Menzies, & Gallardo, 1997).

Our data from a non-clinical population further support and extend on these findings. Interestingly, in studying fear of heights we were able to document such discordance in another domain, namely dizziness and...
sweat, than those which have been observed before (e.g., palpitations and heart rate, see Alpers et al., 2005). The body-sway measure lends itself for future research with clinical populations because body sway can be measured non-invasively under naturalistic conditions and it is directly linked to central phobic symptoms while at the same time providing non-redundant data.

Taken together, there are several lines of evidence in the current work which underscore the important role of cognitive evaluation in fear during a typical phobic situation. First, the frequency analyses show that the underlying disturbance is not likely to be due to vestibular dysfunction. Second, information about being in a specific situation is most likely to drive fearful responses. Third, more fearful individuals tend to over-estimate bodily responses. Fourth, the best predictor of sway is anticipated fear.

Although cross sectional in nature and based on a non-clinical population these data are relevant for the non-associative models of phobia development as well for which fear of heights has been one of the key models (Menzies & Parker, 2001; Poulton, Waldie, Craske, Menzies, & McGee, 2000; Poulton, Waldie, Menzies, Craske, & Silva, 2001). Partial correlations show that previous experience with heights had a strong influence on the relationship between trait fear of heights and experienced fear during the exposure situation. Although correlational, this result suggests that more frequent exposure to heights can reduce experienced fear in such situations. Moreover, the possible relevance of cognitive factors in the etiology of acrophobia is supported (Davey et al., 1997). Also, this supports current treatment approaches for fear of heights which recommend prolonged exposure to heights (Menzies, 1997; Ressler et al., 2004). Although it has been documented that successful behavior therapy reduces self-reported dizziness (Heinrichs, Hahlweg, Moschner, Wessel, & Fiegenbaum, 2003) it has not been examined in controlled trials whether this is also the case for measurable body sway. Future research could use the methods described here to more closely examine treatment outcome independent from self-report.

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References


