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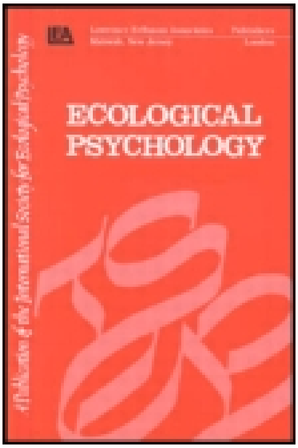

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On the Role of Vertical Texture Cues in Height Perception

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On the Role of Vertical Texture Cues in Height Perception

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When people judge height from the top looking down they tend to overestimate vertical distance. Initial findings suggest that this perceptual bias may be in part due to the experienced fear of falling. However, previous studies did not control for potentially relevant optical invariants, especially vertical texture gradient cues, that may inform such perceptual judgments. In this study, we examined to what degree texture gradient cues may account for the perceptual bias in height perception. To this end, in 2 different conditions in which vertical texture gradient cues were either present or absent, participants provided distance and size judgments from an elevated position (5.68 m) and from the ground. Results revealed a systematic overestimation of vertical extent and object size when judged from a height. Yet, the absence or presence of texture gradient cues did not differentially influence these judgments. Finally, although fear levels were reported to be larger at the elevated position than on the ground, fear levels did not correlate with the perceptual bias, thereby demanding further research into the mechanisms underlying the perceptual bias in height perception.

Perception of geometric properties of the environment, such as size, distance, angle, and so on, has been shown to not only depend on optical information of the spatial layout but also on, for example, physiological and emotional states of the perceiver. For instance, perceptual estimates have been shown to be modulated by fatigue (Proffitt, Stefanucci, Banton, & Epstein, 2003), phys-

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iological potential (Bhalla & Proffitt, 1999), and anxiety (e.g., Cañal-Bruland, Pijpers, & Oudejans, 2010; Nieuwenhuys, Pijpers, Oudejans, & Bakker, 2008). Based on these and similar findings, Proffitt advocated the idea that perception is "embodied" (Proffitt, 2006a, 2006b) rather than a modular process (e.g., Marr, 1982; Pylyshyn, 2003), thereby emphasizing the influence of factors such as behavioral opportunities, energetic costs, and emotional states on perception.

With respect to the latter, Stefanucci and coworkers (Stefanucci & Proffitt, 2009; Stefanucci & Storbeck, 2009; Teachman, Stefanucci, Clerkin, Cody, & Proffitt, 2008) performed an innovative set of experiments in which participants were standing on the top of a balcony and were asked to look down and provide perceptual judgments about the distance to the ground. Interestingly, looking down resulted in a substantial perceptual distortion. That is, perceivers tended to overestimate vertical distance when facing downward relative to judging the same distance from the ground (facing up). In addition to this (direct) measure of distance perception, the authors tested a second (indirect) perceptual measure. They reasoned that due to the well-established size-distance constancy relationship, judgments about objects' sizes could well provide another window into the extent to which distance perception is biased. Stefanucci and colleagues put this hypothesis to the test and found that when participants viewed the height from the top they indeed judged objects on the ground to be larger compared with when judging the size of the same objects from the ground (Stefanucci & Storbeck, 2009; Teachman et al., 2008). Moreover, the authors found not only that the top-viewing condition induced subjective fear of falling but also that the degree of overestimation of extent and size was positively correlated with self-reported fear of falling (Stefanucci & Proffitt, 2009). Therefore, it seems reasonable to conclude that emotional states such as fear of falling may be among the factors modulating perception. Stefanucci and Storbeck (2009) also demonstrated that the perceptual bias was even greater when participants had just seen highly arousing images with emotional content. It follows that emotional arousal is another physiological candidate that may influence perception.

Although overestimation of distance from a height is a robust finding, the two critical conditions in the setup used by Stefanucci and coworkers may be difficult to compare as they differed not only in height but also in the availability of optical cues, a factor the authors themselves also identified in their Discussion (Stefanucci & Proffitt, 2009, p. 436). When facing up toward a target at the balcony the perceiver sees the texture gradient of the wall underneath the balcony (e.g., brickwork and shadows; see Figures 1 and 11 in Stefanucci & Proffitt, 2009). But when looking down from the top of the balcony the texture of the wall underneath is not visible, and the perceiver likely exploits other distance cues such as convergence and motion parallax. Consequently, the poorer estimate of vertical extent from the top of the balcony may have been partly due to the lack of optical cues specifying depth, rendering this a potential confound. In

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the current study, we tested whether the presence or absence of texture gradient affects perceptual judgments of vertical extent.

Notably, the role of texture gradients in estimations of distance is far from clear. For example, Wu, Ooi, and He (2004) demonstrated that a lack of texture gradient may actually lead to an underestimation of distance, which stands in direct contrast to the findings reported earlier. However, whereas Wu et al. (2004) examined perception of distance in the horizontal plane, the work of Stefanucci and colleagues as well as the current experiment examined perception of extent in the vertical plane, including the associated potential of falling from a height, rendering a direct comparison between the two paradigms difficult.

The aim of this experiment was twofold: First, we aimed to provide a conceptual replication of earlier studies that demonstrated overestimations, using both direct (distance judgments) and indirect (size judgments) measures of perceived distance when viewed from the top. Second, we sought to investigate the putative contribution of a vertical texture gradient with respect to these estimations, using an extension of the setup used in previous studies. That is, in two different conditions in which vertical texture gradient cues were either present or absent, participants provided distance and size judgments standing either on the top of a balcony or at the bottom. If overestimation from a height is due to lack of optical cues, rather than the experience of standing at a height, then the presence of a vertical texture gradient during perceptual judgments should greatly reduce the perceptual bias.

MATERIAL AND METHODS

Participants

Sixty participants (38 males, 22 females, mean age 22.7 years) took part in the experiment. The majority of participants were undergraduate students at the Faculty of Human Movement Sciences in Amsterdam. Participants provided written consent prior to participation and the experiment was conducted in accordance with the local institution's ethical guidelines.

Apparatus and Stimulus

The experiment took place inside a large well-lit gym, which contained two walkways suspended in the air that could be moved independently along a track firmly attached to the ceiling. The walkways consisted of a metal grid, with a railing on both sides at chest height. The walkways were 8.3 m long, 90.5 cm wide, and the distance between the floor and the top of the railing was 5.68 m. Climbing onto and walking along the walkway required no special training. As

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a safety precaution, both the participant and the experimenter had to empty their pockets in case an object dropped out. Additionally, we took care that no other visitors in the hall walked underneath the walkway during the measurements. An orange cardboard disk (22.4 cm diameter) was used to mark estimates of size and extent.

State fear was marked using a so-called anxiety thermometer. The anxiety thermometer consisted of a 10-cm visual analog scale on which participants rated their subjective fear by putting a mark somewhere along a 10-cm line with a pencil. The left side of the scale (0) corresponded to *no fear at all;* the right side of the scale (10) corresponded to *extremely anxious.* After the experiment the fear level was determined using a ruler, and the value was entered into a computer. The anxiety thermometer was validated by Houtman and Bakker (1989) and has been successfully used in various studies (e.g., Cañal-Bruland et al., 2010; Pijpers, Oudejans, & Bakker, 2005).

Procedure

One walkway was positioned in close proximity (50 cm) to a climbing wall (for a schematic illustration of the situation see Figure 1a). The climbing wall consisted of gray laminate panels with numerous equally spaced predrilled holes for handgrips. A number of randomly spaced handgrips of various colors protruded from the wall (see Figure 1b). This rich texture gradient, combined with sufficient ambient lighting and unrestricted viewing, provided a rich source of information specifying the layout and extent of the surface. The other walkway

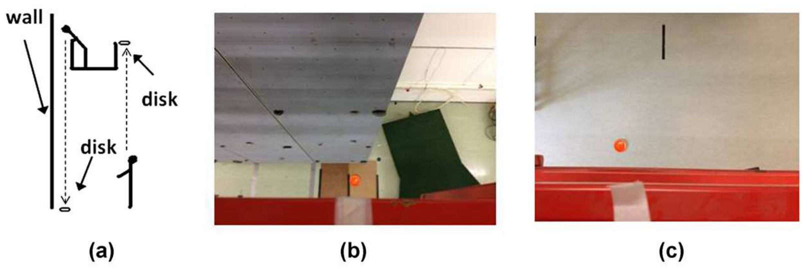

FIGURE 1 Overview of the experimental situation. Panel (a): Schematic illustration of the wall condition, with a participant facing downward, over the railing of the walkway (left), and a participant facing upward (right). In both viewing conditions (top and bottom) the distance to the orange disk was to be assessed. Panel (b): View downward from the walkway while overlooking the metal railing. The walkway was adjacent to a climbing wall with rich vertical texture. Panel (c): View downward from the walkway in midair, with very little vertical texture. The orange disk can be seen lying on the floor. (color figure available online)

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was suspended in midair so that vertical texture gradient was a relatively poor source of information for height perception (see Figure 1c). We used a between-subjects design, with half the participants providing judgments from the walkway near the wall and the other half providing judgments from the walkway in midair (labeled the "no wall" condition). All participants provided judgments of extent and size both when standing on the top (facing down from the walkway, as shown in Figure 1b and 1c) and when standing at the bottom (facing up to the walkway), so that viewing position was our within-subjects factor. Note that previous studies tended to use a complete between-subjects design, with some participants facing down and others facing up. A merit of such a design is that potential order effects are ruled out, but a clear disadvantage is its limited statistical power relative to a within design. In order to rule out potential order effects associated with the repeated perceptual judgments, we counterbalanced order of viewing position (top and bottom). We additionally tested whether the accuracy of the second perceptual judgments was affected by the judgments made from the first viewing position.

When standing on the top participants judged the vertical extent between the railing and a target (the orange disk) lying on the ground using a matching procedure. This procedure involved positioning the experimenter—who held another orange disk in his hand—on the walkway at the same horizontal distance from the participant along the walkway as the participant was to the target disk (cf. Stefanucci & Proffitt, 2009). Positioning was done by giving verbal commands to the experimenter (e.g., saying "farther" or "nearer"). In order to prevent the potential impact of demand characteristics on participants' judgments (e.g., Woods, Philbeck, & Danoff, 2009; for a recent discussion on this matter see also Firestone, 2013; Proffitt, 2013), the experiment was run by the same two experimenters across all participants. In addition, the experimenters were trained on the experimental procedures during pilot work, specifically focusing on displaying the same behaviors (including the pacing of their steps) with every participant. When standing at the bottom participants judged the vertical extent between the floor and the orange disk attached to the railing of the walkway using the same matching procedure, that is, positioning the experimenter standing on the ground. There was no time constraint, and participants could look back and forth at the target and the experimenter as often as they liked. As soon as the participant was confident that the orange disk held by the experimenter and the target disk were equidistant, the experimenter marked the judged location by sticking a small piece of white adhesive tape to the railing or the floor. The permanent viewing location of the participant was also marked with adhesive tape, and at the end of each height judgment the distance between the two pieces of tape was measured with a ruler, and the piece of tape was immediately removed.

Estimates of size perception involved judging the diameter of the same orange disk. This was done by having participants draw a straight line on a large sheet of paper (42 cm in width) corresponding to perceived size. This was done again in both viewing conditions (top and bottom). After the experiment the length of the line was measured. The judgments of extent and size provide estimates of participants' degree of over- or underestimation of height. It should be noted that judgments made from the walkway near the wall involved looking downward from the side of the walkway that was adjacent to the wall. It should also be noted that the two size judgments were performed on different sheets of paper, so that participants could not compare their size judgment with the previous one. Each participant first judged vertical extent, followed by size. After these estimates state fear was rated using the anxiety thermometer.

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Data Analysis

Estimates of extent and size were entered into a mixed-factors analysis of variance (ANOVA), with viewing position (judgments made from the top or from the bottom) as within-subjects factor and the availability of vertical texture (wall vs. no wall) as between-subjects factor. State fear was analyzed using a paired t test (top and bottom). Associations between fear and perceptual judgments were analyzed using Pearson correlations. Effect sizes are reported as partial eta-squared values.

RESULTS

Height

Participants systematically overestimated vertical extent when standing on the top (on average 5.99 m; 4%), but there was a modest underestimation of perceived extent when standing at the bottom (5.6 m; −1.5%). The ANOVA revealed a main effect of position, $F(1, 58) = 12.60, p < .001$, partial eta-squared = 0.18. The between-subjects factor involving presence of the wall (present or absent) was not significant; nor was its interaction with position. Means for the four conditions are shown in Figure 2. Although the means suggest that the presence of the wall induced somewhat larger estimates of vertical extent, this was not significant ($p = .27$). The same ANOVA performed with viewing order as additional between-subjects factor (first viewing from the top vs. first viewing from below) yielded no significant main or interaction effects involving this factor, so that order effects seemed to be absent.

Size

Participants systematically overestimated the diameter of the target disk, both when made at the top (27.1 cm; 21%) and when made at the bottom (25.1 cm;

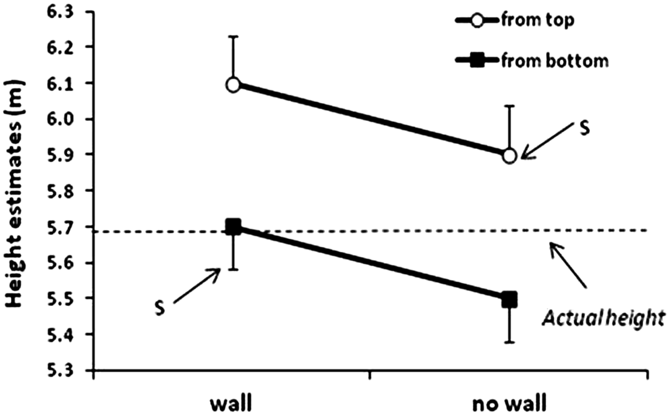

FIGURE 2 Mean values of estimates of vertical extent as a function of the availability of vertical texture (wall vs. no wall) and viewing condition (judgments made from the top or from the bottom). The dashed line represents the actual vertical distance. Error bars represent standard errors of the mean. The "S" corresponds to the conditions tested by Stefanucci and Proffitt (2009).

12%). The ANOVA revealed a main effect of position, $F(1, 58) = 39.2$, $p < .001$, partial eta-squared = 0.4. Again, there was no main effect involving presence of the wall or a significant interaction. Means for the four conditions are shown in Figure 3. The same ANOVA performed with viewing order as additional between-subjects factor yielded no significant main or interaction effects involving this factor. Raw scores of the height and size judgments for each participant are presented in Table 1.

Fear

Although fear was overall low, it was significantly higher on the top (Mean fear = 1.2 cm) than when rated at the bottom (.54 cm), $F(1, 58) = 24.73$, $p < .001$, partial eta-squared = 0.3. Presence or absence of the wall did not significantly influence fear judgments. We also correlated the fear levels collected on the top with the perceived height and size judgments (across the two wall conditions), but none of these correlations attained significance (both $r < .02$).

DISCUSSION

The aim of this experiment was to examine the role of vertical texture as a potential cue that could account for patterns of overestimation of vertical

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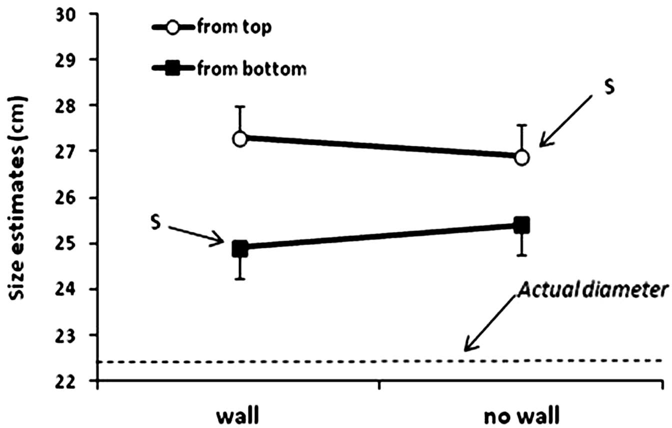

FIGURE 3 Mean values of estimates of the diameter of the target disk as a function of the availability of optical texture (wall vs. no wall) and viewing condition (judging from the top or from the bottom). The dashed line represents the actual diameter of the disk. Error bars represent standard errors. The "S" corresponds to the conditions tested by Stefanucci and Proffitt (2009).

extent and apparent size when standing at a substantial height. Previous studies repeatedly found that judgments of geometric properties of the environment made from a height were poorer than when the same judgments were made at the bottom (e.g., Stefanucci & Proffitt, 2009; Stefanucci & Storbeck, 2009; Teachman et al., 2008). Judgments were poorer regarding both perceived vertical extent (direct measure of distance) and perceived size of a remote object (indirect measure). Although the precise reason for this perceptual bias is still a matter of dispute, it has been shown that the bias is in part modulated by fear experienced when standing at a height (Stefanucci & Proffitt, 2009). In order to corroborate this conclusion and to help develop a solid theoretical base for these and similar findings, it is essential that (a) the findings are replicated and (b) possible confounds are identified, controlled for, and potentially ruled out. To this end, we attempted to replicate the findings obtained with height perception using a different lab, using a different method of elevation (metal walkway as opposed to a solid brick balcony), with different participants (European vs. American undergraduate students), and using a within-subjects design with regard to judgments from the top and the bottom. Most important, we aimed to examine an alternative explanation, namely, whether the presence or absence of vertical texture gradient may account for the perceptual distance biases reported in Stefanucci and her colleagues' work. More specifically, we controlled for one possible confound that was present in earlier studies, namely, the availability

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TABLE 1
Estimates of Vertical Extent (Estimates of Size in Parentheses; Both Estimates in Centimeters) for Each Participant Across the Two Experimental Conditions

Wall		*No Wall*	
From Top	*From Bottom*	*From Top*	*From Bottom*
606 (28.1)	493 (23.9)	625 (25.1)	543 (22.9)
615 (32.6)	543 (26.3)	605 (27.4)	513 (24.8)
555 (29.6)	559 (27.1)	610 (37.7)	585 (36.5)
469 (21.5)	593 (21.9)	511 (28.4)	498 (26.4)
763 (26.4)	568 (21.8)	495 (21.5)	611 (24.9)
693 (26.7)	473 (24.4)	571 (22.0)	513 (22.4)
586 (24.8)	526 (19.2)	667 (31.3)	452 (28.9)
592 (24.9)	466 (22.7)	563 (26.6)	508 (27.2)
600 (30.7)	553 (25.0)	529 (20.1)	588 (18.0)
489 (26.5)	442 (20.9)	499 (30.3)	585 (29.5)
725 (21.8)	497 (25.0)	543 (26.6)	606 (27.8)
633 (25.9)	676 (25.9)	608 (22.7)	586 (23.1)
621 (29.5)	619 (29.3)	569 (30.0)	524 (27.4)
620 (27.8)	582 (25.7)	624 (29.6)	585 (27.7)
583 (31.1)	540 (24.9)	551 (26.7)	462 (23.3)
531 (30.2)	556 (27.5)	652 (22.7)	661 (17.7)
743 (32.8)	594 (28.0)	613 (29.4)	574 (27.5)
568 (35.5)	653 (28.3)	606 (25.8)	516 (21.0)
635 (24.5)	735 (23.9)	603 (21.2)	551 (21.6)
548 (29.0)	549 (27.2)	557 (26.1)	502 (29.3)
647 (27.4)	538 (25.0)	493 (25.0)	424 (24.0)
635 (25.0)	593 (23.3)	549 (25.6)	442 (22.3)
581 (25.6)	573 (26.6)	634 (33.8)	609 (33.4)
509 (27.3)	563 (28.2)	740 (31.4)	652 (33.8)
648 (29.6)	629 (27.2)	411 (26.8)	552 (22.1)
570 (23.6)	584 (23.3)	723 (33.2)	483 (26.0)
640 (28.8)	580 (25.7)	489 (25.1)	503 (24.3)
742 (24.6)	617 (23.9)	745 (26.9)	738 (22.2)
580 (23.9)	541 (21.1)	657 (21.0)	604 (20.9)
539 (24.8)	556 (22.7)	627 (27.5)	642 (24.0)

Note. The presence of the wall was the between-subjects factor, whereas the viewing location (from top vs. from the bottom) was the within-subjects factor. Actual distance was 568 cm; actual size was 22.4 cm.

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of vertical texture, which could potentially greatly assist in attaining veridical perceptual judgments. To this end, one set of perceptual judgments was made while standing on a walkway in close proximity to a wall, which provided rich optical texture along the line of sight, and another set of judgments while standing in the middle of the gym in midair, with very little vertical texture.

Our results indicated that viewing a height from above yields a substantial overestimation of both vertical extent and size. In line with Stefanucci and Proffitt (2009), our results revealed that when standing on the walkway participants overestimated the distance to the ground relative to judging the same distance from the ground. Similarly, when standing on the same walkway, an orange disk on the ground was judged to be larger compared with when judging its size from the ground. It is important to note that these effects were not modulated by the presence of a large wall with abundant texture, which could potentially aid accurate distance perception.[1]

Our direct measure of height perception yielded on average an overestimation of 4%. Although significant, this value is smaller than other values reported in the literature. With respect to the amount of overestimation, two factors are of key importance. The first factor relates to the height being tested. Stefanucci and Proffitt (2009) compared three balcony heights across a series of experiments: 1.6 m (Experiment 1B), 8 m (Experiment 1A), and 10.06 m (Experiment 1C). Comparing these three heights, it appeared that overestimation scales with height: 14%, 60%, and 74%, respectively; so, the greater the height, the larger the overestimation in both absolute and relative terms. The second factor relates to fear of heights, that is, acrophobia. Jackson (2009) showed that fear of heights had a strong positive correlation with estimates of vertical distance. Judging from Figure 3 of the Jackson study, it appears that extremely fearful individuals overestimate height from a top by more than 200%. It could be the case that our participant group simply had very low fear levels. Most of our participants are engaged in various sports activities, and this could mean that they were relatively insensitive to the fear associated with heights.

Nonetheless, standing at a height reliably induced state fear, although fear levels were somewhat lower in our experiment when compared with Stefanucci and Proffitt (2009). In contrast to previous work, however, the fear levels in our study did not correlate with perceptual bias. As such, although our findings replicate and thereby corroborate the typically reported overestimation biases from heights, our results do not provide further support that self-reported fear is

[1]It is well known that texture gradients actually contain three different gradient cues that can be manipulated independently, namely, perspective gradients, compression gradients, and density gradients (for details see Cutting & Millard, 1984). If the presence of the wall were to have a discernible effect on perceptual judgments, it would certainly be worthwhile to assess the relative contribution of each of these three gradients on perception.

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a contributing variable explaining the perceptual biases. However, the predicted impact of fear on the perceptual estimates may be less robust than initially assumed. In this regard, Stefanucci and Proffitt found substantial positive correlations between fear and height estimates ($r = .42$) in their Experiment 1A, whereas the same correlation in their Experiment 1C was low and nonsignificant, leading the authors to conclude that "conclusions about fear (state- or trait-level) influencing perception are tentative at best" (p. 431). Our findings seem to be in agreement with this statement, and as such they certainly ask for further experimentation to examine the influence of fear on perception.

To conclude, our results revealed that judgments of extent and size were equally (in)accurate with or without the vertical texture. If anything, when viewed from a top the estimates of vertical extent were even less accurate in the presence of the wall than in the no-wall condition (Figure 2), although this effect was not significant. In other words, texture did not remove the perceptual bias. It might be argued that participants simply did not attend to the wall, so it is perhaps not surprising that both conditions yielded comparable effects. Although we cannot completely rule out this interpretation, we deem it unlikely for the following reasons: First, the wall was large and in plain view and occupied a substantial portion of visual space. In practice, it was impossible to ignore such a large nearby structure during viewing. Second, participants were encouraged to provide accurate size and distance judgments by any means necessary, and they repeatedly looked at the target disk, they rotated their head and eyes, and so on. We believe it is unlikely that participants—for whatever reason—exploited distance cues such as convergence and accommodation and at the same time ignored the rich and abundant texture cues.

Finally, in our view future experimentation is needed to scrutinize whether it is fear of falling (state or trait), physiological arousal (e.g., Geuss, Stefanucci, de Benedictis-Kessner, & Stevens, 2010; Stefanucci & Storbeck, 2009), assessing the injurious consequences of a fall (Stefanucci, Gagnon, Tompkins, & Bullock, 2012), or the perception of action possibilities (cf. Proffitt, 2006a, 2006b) that accounts for perceptual distortions in height perception. It would also be interesting to test whether individuals who are not fearful, or who have extensive climbing skills, perform better on these types of perceptual tasks.

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