Individual differences in distance perception

Russell E. Jackson*

*Department of Psychology, California State University at San Marcos, 333 South Twin Oaks Valley Road,
San Marcos, CA 92096, USA*

Distance perception is among the most pervasive mental phenomena and the oldest research topics in behavioural science. However, we do not understand well the most pervasive finding of distance perception research, that of large individual differences. There are large individual differences in acrophobia (fear of heights), which we commonly assume consists of an abnormal fear of stimuli perceived normally. Evolved navigation theory (ENT) instead suggests that acrophobia consists of a more normal fear of stimuli perceived abnormally. ENT suggests that distance perception individual differences produce major components of acrophobia. Acrophobia tested over a broad range in the present study predicted large individual differences in distance estimation of surfaces that could produce falls. This fear of heights correlated positively with distance estimates of a vertical surface—even among non-acrophobic individuals at no risk of falling and without knowledge of being tested for acrophobia. Acrophobia score predicted magnitude of the descent illusion, which is thought to reflect the risk of falling. These data hold important implications in environmental navigation, clinical aetiology and the evolution of visual systems.

Keywords: individual differences; distance perception; evolved navigation theory; descent illusion; acrophobia; navigation

1. INTRODUCTION

Distance perception is an indispensible component of most animal interaction with the environment. It occurs constantly during most human activity, making it one of the most ubiquitous cognitive processes known. Research on distance perception is extensive and predates the late nineteenth century founding of empirical psychological science (Fick 1851, cited in Finger & Spelt 1947; Oppel 1854, cited in Hicks & Rivers 1906). A pervasive, but often unacknowledged, finding in this literature is large individual differences (Norman *et al.* 2005).

Attempts to explain these individual differences have relied on numerous independent proximal explanations, such as gender (Walters 1942), age (Brosvic *et al.* 2002) and target location (Loomis *et al.* 1996). Such attempts leave us without understanding the cause and context in which to place one of the oldest researched and most common mental phenomena.

Acrophobia, or the extent to which individuals fear heights, may illuminate the origin of individual differences in distance perception. Clinically acrophobic individuals appear to experience pronounced fear from viewing the same heights that non-acrophobics perceive with little fear. Researchers and clinicians consider acrophobia as an exaggerated fear or response to viewing heights that are perceived normally (Menzies & Clarke 1995; Fredrikson *et al.* 1996; Davey *et al.* 1997). The present *Diagnostic and statistical manual of mental disorders* (4th edn. text revision, American Psychiatric Association 2000) describes the fear in acrophobia as 'excessive or unreasonable' (p. 449) and says of all such specific phobias that 'The essential feature of Specific Phobia is marked and persistent fear of clearly discernible, circumscribed objects or situations' (p. 443). Scientists, practitioners and laypeople tend to assume that acrophobia results from an abnormal reaction to a stimulus perceived normally.

Evolved navigation theory, however, suggests that acrophobia may result from a more normal reaction to a stimulus perceived abnormally. Evolved navigation theory (Jackson 2005; Jackson & Cormack 2007), or ENT, is a research approach that focuses on how navigational costs over evolutionary time may have shaped perception and navigation. A basic logic used by ENT is that fitness costs over time can shape biological systems to decrease those costs. This derives directly from evolution by natural selection (Darwin 1858, 1859; Wallace 1858).

ENT specifically proposes that *distance perception* is a primary mechanism for relaying fitness costs over evolutionary time into differential navigation decisions. A key prediction under ENT is that observers may overestimate the distance of navigationally costly surfaces. Organisms tend to pursue the nearer of equivalent navigational goals (Somervill & Somervill 1977) and so distance overestimation decreases the likelihood of navigating a surface. Selection over evolutionary time could thus result in distance overestimation of navigationally costly surfaces, and preliminary data support this claim (Jackson & Cormack 2007, 2008).

This logic derives from evolution by natural selection. However, this approach could be framed as an application of error management and signal detection. The principle of error management describes signal detection by describing how the differential costs of different errors shape decision-making processes under uncertainty and risk (Green & Swets 1966; Haselton & Buss 2000; Nesse 2005). Systematically committing the least costly errors across multiple signal detection tasks lowers fitness costs in a variety of domains. ENT is an implementation of error management (anonymous reviewer 2008, personal communication) and signal detection in the domain of

*rjackson@csusm.edu

navigation. Furthermore, it specifies distance perception as an important mechanism on which selection has acted in the evolution of navigational systems.

ENT provides an alternative to isolated proximal factors for distance estimation individual differences, such as age and gender. This approach suggests that such individual differences reflect differential navigation costs across individuals in the environments in which humans evolved. ENT provides a framework for predicting individual differences in distance perception across environments. Specific to acrophobia, falling probably posed a prominent cost of navigation over human evolution (Jackson & Cormack 2007). Differential perception of falling risks should thus correspond with distance estimation individual differences for surfaces with falling costs. This research approach makes three key predictions.

(a) Prediction 1
Greater fear of heights should correspond with greater amounts of overestimation while standing at the top of a height. If distance overestimation reflects falling risks, then increased overestimation of falling risks should generate increased distance overestimation. This prediction alone, however, would not suggest that overestimation of heights *produces* greater fear, since participants standing at the top of a height would be more fearful, and the fear could produce greater height estimates.

(b) Prediction 2
Greater fear of heights should correspond with greater amounts of overestimation even when the observer is at no immediate risk of falling, such as while standing on the ground at the bottom of a height. Vertical surfaces, even when viewed from below on safe ground, still pose falling costs if navigated. Thus, from ENT it is predicted that greater fear of heights would correspond with greater overestimation of a height even without immediate risk of falling. Support for this prediction would suggest that either height fear produces increased distance estimates or that both are caused by a third factor, such as the falling costs posed by the surface estimated.

(c) Prediction 3
Greater fear of heights should correspond with greater degree of the descent illusion. The descent illusion (Jackson & Cormack 2007) is the phenomenon wherein observers overestimate heights more from above than below. The descent illusion is thought to reflect the greater likelihood and severity of falling while descending than while ascending. If this illusion reflects falling costs, then observers who most overestimate falling costs should also experience this illusion at the highest magnitudes.

2. MATERIAL AND METHODS
(a) Fear of heights
Forty-three adults volunteered to participate in this study in order to fulfil course requirements. Participants were selected from a larger population based on breadth in height fear. Potential participants completed a composite pre-screening questionnaire from two weeks to three months before participation in the present study and without knowing which pre-screening items corresponded to the present study. The pre-screening questionnaire required roughly 45 min
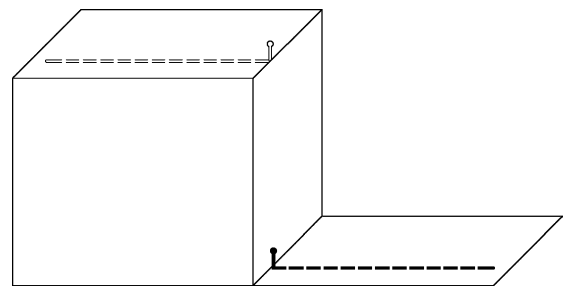
Figure 1. Participant position during the top (double lines) and bottom (solid line) estimates. Dotted icons represent the same participant during each estimate. Dashed lines represent the horizontal path in estimating the vertical height at each position. Not to scale.

and contained items for the present research, as well as items from several entirely unrelated studies. Responses from one additional participant were not analysed because he was unable to understand basic instructions clearly.

The pre-screening items of interest consisted of the 20-item acrophobia questionnaire, or AQ (Cohen 1977). The AQ is the most widely used assessment for fear of heights and consists of 20 seven-point Likert-scaled items. Each item features a height situation, such as 'walking over a sidewalk grating', where participants are asked to rate their anxiety in response to the situation.

The AQ measures fear of heights continuously over a range from 0 to 120. Average scores among individuals without a pronounced fear of heights commonly fall below 30, while average scores among acrophobic populations commonly fall above 50 or 60 (Menzies *et al.* 1998; Menzies & Parker 2001). Participants were selected from a broad range of AQ scores extending from below the average non-acrophobic score to above a high score among acrophobics (range from 2 to 82, $M = 36$, s.d. $= 17$).

Baker *et al.* (1973) previously demonstrated the test–retest reliability, internal consistency and convergent validity of the AQ (cited in Menzies & Clarke 1995; Menzies & Parker 2001). The present sample had a high test–retest reliability ($r_{xx}(41) = 0.781$, $p < 0.001$) with a mean retest interval of six points.

(b) Procedure
After pre-screening selection, participants met a research assistant on campus and walked to a vertical outdoor surface. Participants estimated the height of the surface while standing at its bottom and top. Both positions were open to the sky and the direction of estimation extended away from the vertical surface across cement or asphalt in both positions. Estimate order was also randomized, with roughly half of participants starting with the estimate from the top and half starting with the estimate from the bottom.

Participants estimated vertical height by adjusting a horizontal distance to look equal to the vertical height (14.39 m). This distance matching method of adjustment is probably the most widely used method of realistic outdoor distance estimation (Chapanis & Mankin 1967; Higashiyama 1996; Yang *et al.* 1999; Jackson & Cormack 2007). Participants stood next to the vertical surface and directed a research assistant to walk away until the distance from the research assistant to the vertical surface looked equal to the height of the vertical surface (figure 1). Participants used hand signals and could make as many adjustments, and take
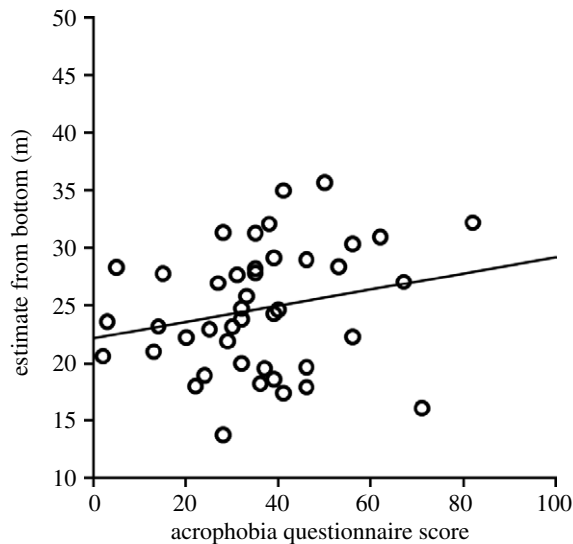
Figure 2. Participant AQ score by distance estimates while standing at the bottom of the 14.39 m vertical surface ($r = 0.227$). Note that the *y*-axis begins at 10 m (no estimates fell outside of the plotted area).

as much time, as desired. The research assistant then precisely measured the distance estimated.

3. RESULTS

Data support the three experimental predictions derived from ENT. High AQ scores corresponded with the greatest distance estimates at both the top and bottom of the height and AQ score predicted degree of descent illusion. These data suggest that a person with no height fear will slightly overestimate the height of a large vertical surface, but a person with high height fear will perceive the exact same surface as nearly twice its actual height.

(a) *Results: predictions 1 and 2*

Greater fear of heights corresponded with greater amounts of overestimation while standing at both the top and bottom of the height (figures 2 and 3). AQ score correlated positively with estimates at the top ($r(41) = 0.404$, $p_{rep} = 0.97$) and the bottom ($r(41) = 0.227$, $p_{rep} = 0.87$). The term p_{rep} indicates the probability of replicating an effect of equal or greater magnitude (Killeen 2005) and these values suggest a high probability of finding correlations as large as, or larger than, those observed here among most human observers.

This observed effect of height fear on distance estimates was large. Participants with the highest five AQ scores ($M = 68$) estimated an average of 3 m (21%) more at the bottom and 12 m (86%) more at the top of the 14 m height than those with the lowest five AQ scores ($M = 8$). This estimate difference between low acrophobia individuals and high acrophobia individuals was roughly equal to the height of a bus or a basketball hoop, while standing at the bottom of the height. The estimate difference between low acrophobia individuals and high acrophobia individuals while standing on top of the height was nearly the same length as the actual height, which was a five-storey building. This is a large effect in experimental settings and in everyday visual perception in the real world.
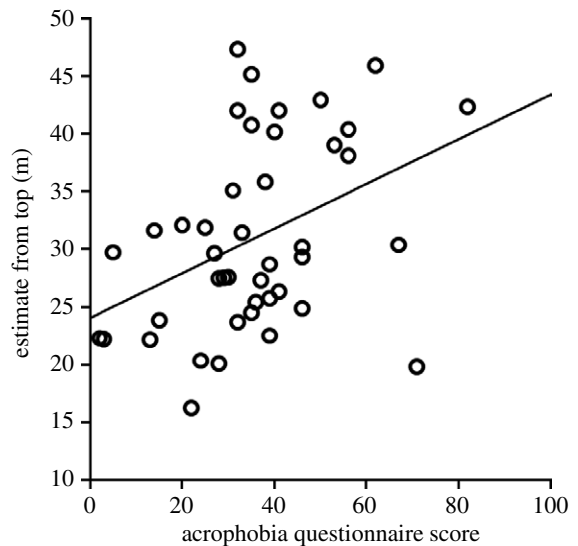
Figure 3. Participant AQ score by distance estimates while standing at the top of the 14.39 m vertical surface ($r = 0.404$). Note that the *y*-axis begins at 10 m (no estimates fell outside of the plotted area).

Additional data strongly support this evidence that degree of height fear predicts degree of vertical distance overestimation.

ENT predicts that individual AQ items should correlate positively with distance estimates. Out of 20 AQ items, 17 correlated positively with distance estimates at the bottom of the height (ranging from -0.15 to 0.43). The binomial probability of 17 or more AQ items correlating positively with distance estimates, if there was no true positive correlation between AQ and height estimation, is $p = 0.001$. Nineteen AQ items correlated positively with distance estimates at the top of the height (ranging from -0.02 to 0.52), which corresponds to a binomial probability of $p = 1.9 \times 10^{-5}$.

If distance estimates from the bottom were affected by the same causes as estimates from the top, then we should also expect the pattern of correlations between individual AQ items and distance estimates to be similar across top and bottom positions. This was indeed the case ($r(18) = 0.834$, $p_{rep} > 0.99$). It is exceedingly likely that degree of acrophobia corresponds with degree of height overestimation from the top and bottom of a height.

(b) *Results: prediction 3*

Greater fear of heights corresponded with greater degree of the descent illusion. The magnitude of the descent illusion correlated positively with AQ scores ($r(41) = 0.334$, $p_{rep} = 0.94$; figure 4). Average estimate of the 14.39 m height while standing at the bottom was 24.67 m ± 1.63 and while standing at the top was 30.98 m ± 2.51 (with 95% confidence intervals). Participants in general over-estimated height from both the top and bottom, but did so to a greater degree from the top ($t(42) = 6.526$, $p_{rep} > 0.99$) and this effect increased with AQ score. Greater degree of acrophobia corresponded with larger magnitudes of an illusion thought to have evolved in response to falling. This is an important individual difference.

(c) *Additional results*

High scorers on the AQ estimated greater distance at both the top and bottom of the height than did low AQ scorers,
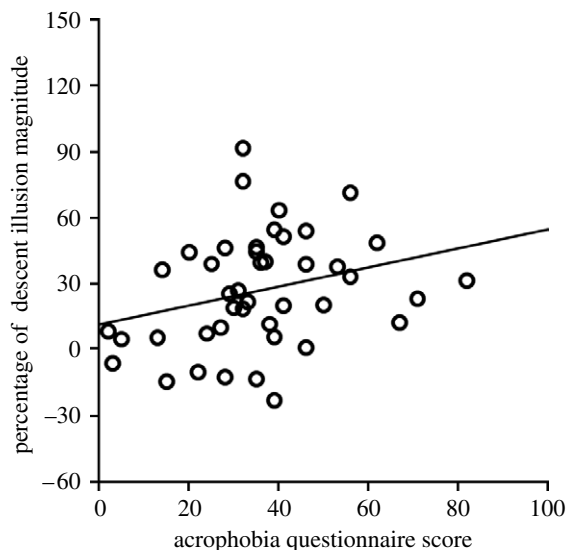
Figure 4. Descent illusion magnitude by AQ score ($r=0.334$). Descent illusion magnitude equals $(et-eb)/eb$ where et and eb are distance estimates from the top and bottom, respectively.

regardless of order. However, participants starting at the top of the height estimated greater distances, on average, at the top (32 m) and bottom (26 m) than did participants who started at the bottom of the height (30 m at the top and 23 m at the bottom). Nonetheless, Bonferroni-corrected independent samples *t*-tests suggest that estimate order (i.e. starting at top or bottom) failed to significantly alter distance estimates or difference scores between the two estimates (the largest of which: $t(41)=1.918$, $p=0.186$). Participants who overestimated height most at the top were also those who overestimated height most at the bottom, with a high correlation between the two distance estimates ($r(41)=0.709$, $p_{rep}>0.99$).

4. DISCUSSION

Participants overestimated the height of a vertical surface to the degree that they feared heights, whether or not they were standing on top of the vertical surface. Greater overestimation while standing on top of a height does not alone suggest that abnormal perception produces greater fear, because fear in response to standing at a height could produce overestimates.[1] However, participants at the bottom of the height were in no danger of falling (some of whom also had nearly no fear of heights). This suggests that abnormal distance perception may produce fear more than fear produces abnormal distance perception, or that both are the result of the perceived falling costs of navigating a surface.

Acrophobia treatment might therefore benefit as much from training distance estimation as it does from training fear and anxiety management. Distance estimation itself may serve as an index of acrophobia and, thus, a continuous metric for measuring acrophobia and treatment efficacy. This suggests that some acrophobia assessment and treatment could occur without the risk of falling and without demand characteristics apparent to patients. Exposure to a high anxiety-provoking environment may not always be necessary in order to gauge extent of acrophobia or efficacy of treatment, in lieu of height estimates while positioned safely on the ground below. This method of indirect assessment further applies to

occupations where height estimates are important, such as piloting or construction, by administering the AQ in order to anticipate distance estimation accuracy and error on the job. Distance estimates and fear of heights can be measured independently, but the present research suggests that they may derive from dependent underlying factors.

(a) *Additional applications*

The greatest usage of this research may be that these results were predicted from an underlying theory that places distance perception individual differences within a causal framework. Distance perception researchers commonly find large individual differences, but have been unable to predict such differences well or to understand their origin. This obstacle has impeded understanding of one of the oldest known and most researched mental phenomena. ENT attempts to fill this gap by proposing that distance perception reflects navigation costs in the environments in which such mechanisms are evolved. Such an approach unifies previously isolated findings and facilitates additional predictions in distance perception and environmental navigation.

Gibson & Walk (1960) found that infants are willing to move onto a visual cliff until the stage of development in which they begin to crawl. Around crawling age, infants begin to show great distress when their mothers try to coax them across a visual cliff. It is interesting under ENT that even infant navigation appears specified, not only to falling costs, but also to the appropriate developmental stage when such falling costs become possible. Additional developmental variables, such as childhood climbing and falling history, body composition as a predictor of falling costs and differential falling costs over lifespan, probably comprise important components of distance perception individual differences over developmental trajectories.

Individual differences in distance perception also pose important applications in piloting. The periods of greatest risk during flights are commonly during take-off and landing, while height perception is an important human-factors task at such points. Pilot screening, training and retraining benefits from knowing how to index distance estimation differences, as well as understanding how best to train appropriate distance estimation for specific aircraft and piloting scenarios. The present research suggests that life-history questionnaires can provide important information on individual differences in piloting tasks.

The present research also suggests that falling probably shapes distance perception. Falling is the second leading cause of workplace injury and workers' compensation in environments as diverse as agriculture and office work (Cohen *et al.* 2006). Falls comprise the greatest source of accidental injury and death to elderly (Stevens *et al.* 2008) and other adults in many developed countries (Koskinen & Alaranta 2008). Since the costs of falling probably shape distance perception, determining how distance perception shapes the risk of falling is an important direction towards understanding this major cause of accidental injury and death.

5. CONCLUSION

This research explains some of the large individual differences in distance estimation, which have been

a pervasive, but poorly understood, finding of one of the earliest and the most prolific areas in behavioural science. This research is important due to the ubiquity of distance perception in visual systems. Because navigation is prerequisite to nearly all animal behaviour, navigational costs implicitly precede the costs of most other behaviours. This makes navigational costs a powerful selective force in behavioural evolution across domains. Understanding these individual differences thus helps us understand some of the most basic differences within and between humans and other animal species.

ENDNOTE

[1]Recent work by Teachman *et al*. (2008), published while the present paper was under review, suggests that fear of heights determines distance perception; however, this work did not test the hypothesis that distance perception could produce fear of heights.

REFERENCES

American Psychiatric Association 2000 *Diagnostic and statistical manual of mental disorders*, 4th edn. Washington, DC: American Psychiatric Publishing, Inc.

Brosvic, G. M., Dihoff, R. E. & Fama, J. 2002 Age-related susceptibility to the Mueller-Lyer and the horizontal–vertical illusions. *Percept. Mot. Skills* **94**, 229–234. (doi:10. 2466/PMS.94.1.229-234)

Chapanis, A. & Mankin, D. A. 1967 The vertical–horizontal illusion in a visually-rich environment. *Percept. Psychophys.* **2**, 249–255.

Cohen, D. C. 1977 Comparison of self-report and behavioral procedures for assessing acrophobia. *Behav. Ther.* **8**, 17–23. (doi:10.1016/S0005-7894(77)80116-0)

Cohen, M. A., Clark, R. E., Silverstein, B., Sjostrom, T. & Spielholz, P. 2006 Work-related deaths in Washington State, 1998–2002. *J. Safety Res.* **37**, 307–319. (doi:10. 1016/j.jsr.2006.02.007)

Darwin, C. R. 1858 Extract from an unpublished work on species. Presented to the Linnean Society of London, London, July.

Darwin, C. R. 1859 *On the origin of species*. London, UK: Murray.

Davey, G. C. L., Menzies, R. & Gallardo, B. 1997 Height phobia and biases in the interpretation of bodily sensations: some links between acrophobia and agoraphobia. *Behav. Res. Ther.* **35**, 997–1001. (doi:10.1016/S0005-7967(97)10004-3)

Finger, F. W. & Spelt, D. K. 1947 The illustration of the horizontal–vertical illusion. *J. Exp. Psychol.* **37**, 243–250. (doi:10.1037/h0055605)

Fredrikson, M., Annas, P., Fischer, H. & Wik, G. 1996 Gender and age differences in the prevalence of specific fears and phobias. *Behav. Res. Ther.* **34**, 33–39. (doi:10. 1016/0005-7967(95)00048-3)

Gibson, E. J. & Walk, R. D. 1960 The 'visual cliff'. *Sci. Am.* **202**, 64–71.

Green, D. M. & Swets, J. A. 1966 *Signal detection theory and psychophysics*. Oxford, UK: Wiley.

Haselton, M. G. & Buss, D. M. 2000 Error management theory: a new perspective on biases in cross-sex mind reading. *J. Pers. Soc. Psychol.* **78**, 81–91. (doi:10.1037/ 0022-3514.78.1.81)

Hicks, G. D. & Rivers, W. H. R. 1906 The illusion of compared horizontal and vertical lines. *Br. J. Psychol.* **2**, 243–260.

Higashiyama, A. 1996 Horizontal and vertical distance perception: the discorded-orientation theory. *Percept. Psychophys.* **58**, 259–270.

Jackson, R. E. 2005 Falling towards a theory of the vertical–horizontal illusion. In *Studies in perception and action*, vol. VIII (eds H. Heft & K. L. Marsh), pp. 241–244. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Jackson, R. E. & Cormack, L. K. 2007 Evolved navigation theory and the descent illusion. *Percept. Psychophys.* **69**, 353–362.

Jackson, R. E. & Cormack, L. K. 2008 Evolved navigation theory and the environmental vertical illusion. *Evol. Hum. Behav.* **29**, 299–304. (doi:10.1016/j.evolhumbehav.2008. 03.001)

Killeen, P. R. 2005 An alternative to null-hypothesis significance tests. *Psychol. Sci.* **16**, 345–353. (doi:10. 1111/j.0956-7976.2005.01538.x)

Koskinen, S. & Alaranta, H. 2008 Traumatic brain injury in Finland 1991–2005: a nationwide register study of hospitalized and fatal TBI. *Brain Injury* **22**, 205–214. (doi:10.1080/02699050801938975)

Loomis, J. M., Da Silva, J. A. & Philbeck, J. W. 1996 Visual perception of location and distance. *Curr. Dir. Psychol. Sci.* **5**, 72–77. (doi:10.1111/1467-8721.ep10772783)

Menzies, R. G. & Clarke, J. C. 1995 The etiology of acrophobia and its relationship to severity and individual response patterns. *Behav. Res. Ther.* **33**, 795–803. (doi:10. 1016/0005-7967(95)00023-Q)

Menzies, R. G. & Parker, L. 2001 The origins of height fear: an evaluation of neoconditioning explanations. *Behav. Res. Ther.* **39**, 185–199. (doi:10.1016/S0005-7967(99)00177-1)

Menzies, R. G., Harris, L. M. & Jones, M. K. 1998 Evidence from three fearful samples for a poor insight type in specific phobia. *Depress. Anxiety* **8**, 29–32. (doi:10.1002/(SICI)15 20-6394(1998)8:1<29::AID-DA6>3.0.CO;2-0)

Nesse, R. M. 2005 Natural selection and the regulation of defenses: a signal detection analysis of the smoke detector principle. *Evol. Hum. Behav.* **26**, 88–105. (doi:10.1016/ j.evolhumbehav.2004.08.002)

Norman, J. F., Crabtree, C. E., Clayton, A. M. & Norman, H. F. 2005 The perception of distances and spatial relationships in natural outdoor environments. *Perception* **34**, 1315–1324. (doi:10.1068/p5304)

Somervill, J. W. & Somervill, C. Z. 1977 Descent behavior of rats and chicks in a cliff and non-cliff situation. *Percept. Mot. Skills* **45**, 391–397.

Stevens, J. A., Mack, K. A., Paulozzi, L. J. & Ballesteros, M. F. 2008 Special report from the CDC: self-reported falls and fall-related injuries among persons aged ≥65 years—United States, 2006. *J. Safety Res.* **39**, 345–349. (doi:10.1016/j.jsr.2008.05.002)

Teachman, B. A., Stefanucci, J. K., Clerkin, E. M., Cody, M. W. & Proffitt, D. R. 2008 A new mode of fear expression: perceptual bias in height fear. *Emotion* **8**, 296–301. (doi:10.1037/1528-3542.8.2.296)

Wallace, A. R. 1858 On the tendency of varieties to depart indefinitely from the original type. *J. Proc. Linn. Soc.* **3**, 53–62.

Walters, A. 1942 A genetic study of geometrical-optical illusions. *Psychol. Monogr.* **25**, 101–155.

Yang, T. L., Dixon, M. W. & Proffitt, D. R. 1999 Seeing big things: overestimation of heights is greater for real objects than for objects in pictures. *Perception* **28**, 445–467. (doi:10.1068/p2854)