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Where's the Floor?

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Abstract
Visual and balance cues concerning the relative orientation of ourselves and our environment combine to direct our steps to select a secure footing. How are visual cues used to select the best support surface? Here we show that, when exposed to tilted, rectangular rooms of various aspect ratios, subjects do not necessarily choose the surface with its normal oriented closest to the gravity-defined vertical. Rather their decision is also strongly biased by the visual area subtended by each candidate surface.

Keywords
Perceived orientation, visual guidance, support surface

1. Introduction

The floor can be defined as the surface in an environment that provides physical support but how do we actually determine which surface that is before actually stepping onto it? In normal environments the floor might be sensibly defined as that visible surface which is closest to orthogonal to the gravity-defined vertical, since that is the surface likely to provide most gravitational stability if stood upon. The choice involves visually assessing the orientation of each surface and comparing it with an internal representation of the perceived direction of gravity. But is this actually how we decide which surface is the floor? Here we are not concerned with the specific cues involved in assessing the orientation of the ground plane (*cf.* for exam-

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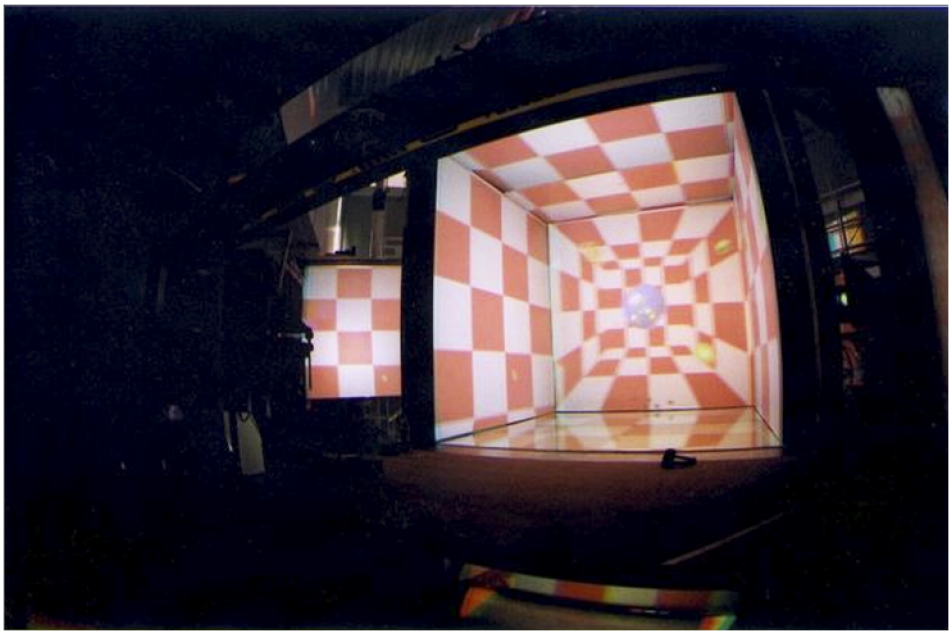

Figure 1. The Immersive Visual Environment at York (IVY): a six-sided projective environment. Subjects sat in this cube and were shown a simple, coloured room (see insets in Fig. 2).

ple, Louw *et al.*, 2007) but, in the event of ambiguity, which surface is most likely to be chosen. Such considerations are relevant to situations where visual cues to orientation are especially important such as underwater (Ross *et al.*, 1969; Massion *et al.*, 1995; Jenkin *et al.*, 2009) or in microgravity (Oman, 2003).

Cats and humans visually acquire the relevant information about surface structure several steps before they contact a new support structure (Wilkinson and Sherk, 2005; Marigold and Patla, 2007). Humans navigating complex ground terrain sample the upcoming terrain continuously in what seems to be an on-line control system for optimum stability which shows increased variability with age (Marigold and Patla, 2008). What rules are used to decide which surface to step on next?

Using a six-sided immersive projected environment (Fig. 1) we presented observers with a choice of floor surface using a simple rectangular room defined only by its five visible surfaces. We rotated the projected virtual room around the naso-occipital axis of the observer into several orientations and, for each orientation, asked observers "which surface is the floor — if you were to walk into this room, which surface would you stand on?" One of four colours (see Fig. 2 insets) was assigned to each of the projected side walls in a way that varied randomly for each trial and the subject used these colours to identify the surface that they chose as the floor. We varied the aspect ratio of the room and calculated the probability with which each floor surface was chosen as a function of the tilt of the room (Fig. 2). From this we assessed the range of tilt angles at which a given surface was chosen more than 50% of the time.

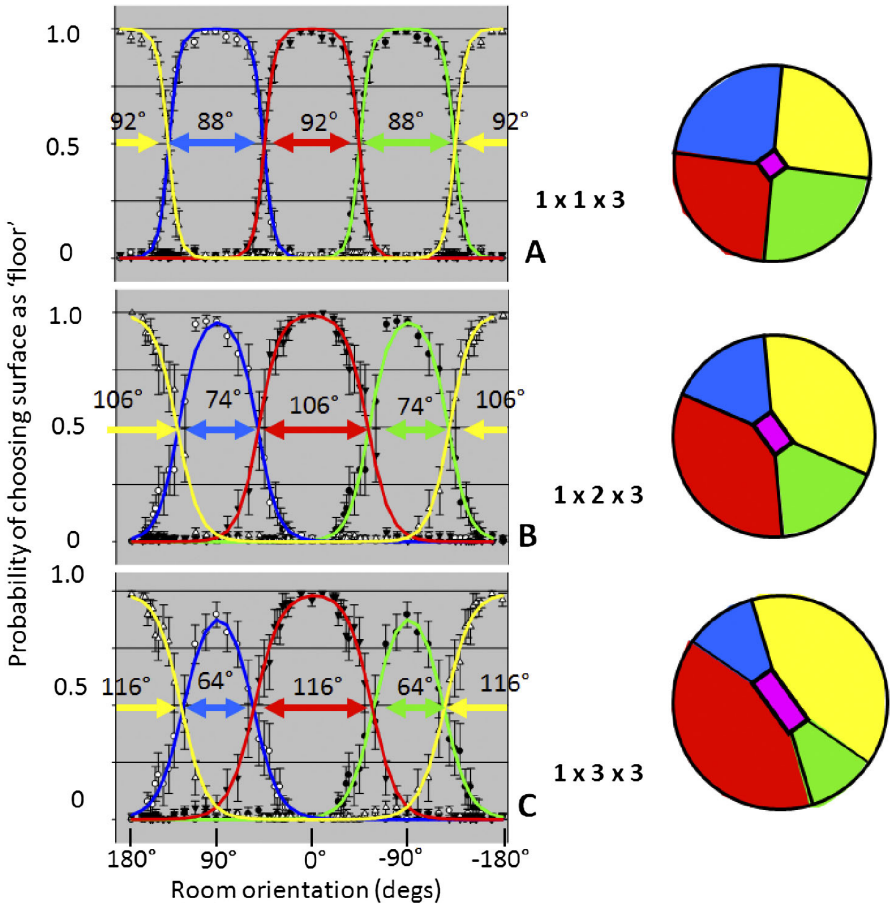

Figure 2. The probability of choosing each surface averaged across all subjects. The probability that a particular surface would be chosen as the floor is plotted for rooms with three different ratios of long to short axes. Standard errors are also plotted. (A) 1 × 1 × 3, (B) 1 × 2 × 3, (C) 1 × 3 × 3. A double sigmoid fit (see text) was plotted through each data set using the colours shown in the inserts on the right. Note that in the experiment, the colours were randomly assigned. The numbers given above each double-headed arrow are the ranges of tilts over which that particular surface was chosen as the floor. The room orientation on the lower axis is relative to the 'reference orientation' of the room with the longest side horizontal relative to gravity.

2. Methods

2.1. Participants

12 observers (8 male, age range 22–49 yrs) participated in these experiments. Observers were recruited from members of the Centre for Vision Research at York University and included four of the authors (LRH, RTD, MRMJ, HLMJ). None of the subjects, including the authors, had any preconceived idea as to how the choice

of floor surface was made. The study was conducted in compliance with the ethical requirements of York University.

2.2. Visual Display

The observer viewed virtual rooms in the Immersive Visual Environment at York (IVY; Robinson *et al.*, 2002). The observer was seated at the centre of a 2.4 × 2.4 × 2.4 m cube, the walls of which were rear projection screens (Fig. 1). Visual stimuli were presented on the six surfaces using eight SONY CRT video projectors running at a 96 Hz frame rate and 1024 × 768 pixel resolution each. The images projected on the floor and ceiling screens of IVY were each generated by a pair of projectors splitting the display surfaces in half, while wall surfaces were each generated by a single projector. Visual images were generated using a nine-node Linux PC cluster with one dedicated machine per projector and one machine controlling and synchronizing the displays. Stereoscopic stimuli were presented using CrystalEyes LCD shutter glasses synchronized to the video signal generating 48 Hz per eye. The observer viewed the display from a head fixed position from the centre of the display facing the centre of one of the vertical projective surfaces.

2.3. Simulated Rooms

Visual stimuli simulated the inside of a multi-coloured room which was 7.2 m deep, 2.4 m high and of width 2.4 m, 4.8 m or 7.2 m. The three simulated rooms thus had a constant depth of 3 units while the width-to-height aspect ratios were 1 × 1, 1 × 2 and 1 × 3. The 1 × 1 room was presented in 16 roll orientations (0°, ±10°, ±20°, ±30°, ±35°, ±37.5°, ±40°, ±42.5°, 45°) while the 1 × 2 and 1 × 3 rooms were presented in 30 roll orientations (0°, ±10°, ±20°, ±22.5°, ±25°, ±27.5°, ±30°, ±32.5°, ±35°, ±40°, ±45°, ±50°, ±60°, ±70°, ±80°, 90°). Rolls were around the central axis of the room, a point which coincided with the observer's viewpoint. A roll orientation of zero corresponds to the room aligned with gravity with a longer side gravitationally horizontal. The simulated wall facing the observer was colored pink while the four other surfaces surrounding the observer were rendered in one of four colours (red, green, blue or yellow). The arrangement of the colours of these four surfaces was chosen randomly for each trial. A circular fixation disk of diameter 0.25 m was simulated 3.4 m in front of the observer. Observer responses were registered using a Sony Gamepad connected to the computer. The Gamepad contained four response buttons colour-coded to match the visible surfaces surrounding the observer (red, green, blue, yellow).

2.4. Procedure

Subjects sat upright inside the virtual room 0.2 m in front of the simulated rear wall with their head gravitationally erect and their chin on a chin-rest to standardize the presentation across trials and across subjects. Each trial consisted of the display of one of the simulated rooms in a particular roll orientation. The simulated room was displayed until the subject pressed a response button to indicate the colour of

the surface that they considered to be the floor, at which time the next trial was presented. Each room orientation × aspect ratio combination was presented seven times to each of the twelve observers. Given the symmetries of these rectangular rooms, the selected roll orientations allowed floor choice probabilities to be computed for each surface over a full 360° rotation of the room.

2.5. Data Analysis

For each aspect ratio and room orientation the probability that a particular surface was chosen to be the floor was computed. These probabilities were averaged over the twelve observers and fit with a double sigmoid (as shown in Fig. 2) given by

$$p(x) = \frac{1}{4}\big(1 - \tanh(\lfloor\theta - \theta_1\rfloor)/w_1\big)\big(1 - \tanh(\lfloor\theta - \theta_2\rfloor)/w_2\big),$$

where $\theta_{1,2}$ and $w_{1,2}$ define the two sigmoids and $\lfloor\theta - \theta_{1,2}\rfloor$ denotes the principal angle in the range $-180° \ldots +180°$. Figure 2 summarizes the subjects' responses and fits for the three simulated rooms.

The fits for adjacent surfaces in the simulated room were used to solve for the orientation at which subjects were least certain as to which surface was the floor (the point of subjective equality, PSE). The range of tilts between these points was the range over which that surface was most likely to be chosen as the floor.

3. Results

When the sides of the simulated room were of equal length, each surface was preferentially chosen when it was within ±45° of the gravitationally defined horizontal (Fig. 2a). But when the sides were not of equal length, the range of tilts for which a given surface was most likely to be chosen as the floor varied with the aspect ratio of the room, as shown by the double-headed arrows in Fig. 2. For example, with an aspect ratio of 3-to-1, the longer surface of the room was more likely to be chosen for a range of tilt angles of ±58° from horizontal. Thus, even when the larger surface (longer length side, rendered red in Fig. 2) was tilted by 58° from horizontal it was still more likely to be chosen as the floor even though the competing smaller surface (shorter length side) was tilted only 32° from the horizontal.

4. Discussion

The variation with room aspect ratio of the probability of a given surface being chosen as the floor indicates that the strategy of choosing the surface the normal of which most closely aligns with the gravitationally defined vertical is, surprisingly, not sufficient to predict the surface that will be chosen. Such a strategy would always result in maximum ambiguity when the room was tilted at 45° independent of the aspect ratio of the room ('the horizontal hypothesis'); clearly this was not the case (see Fig. 2). We then considered whether the orientation of the room at which the room itself was stable might represent the orientation at which two surfaces

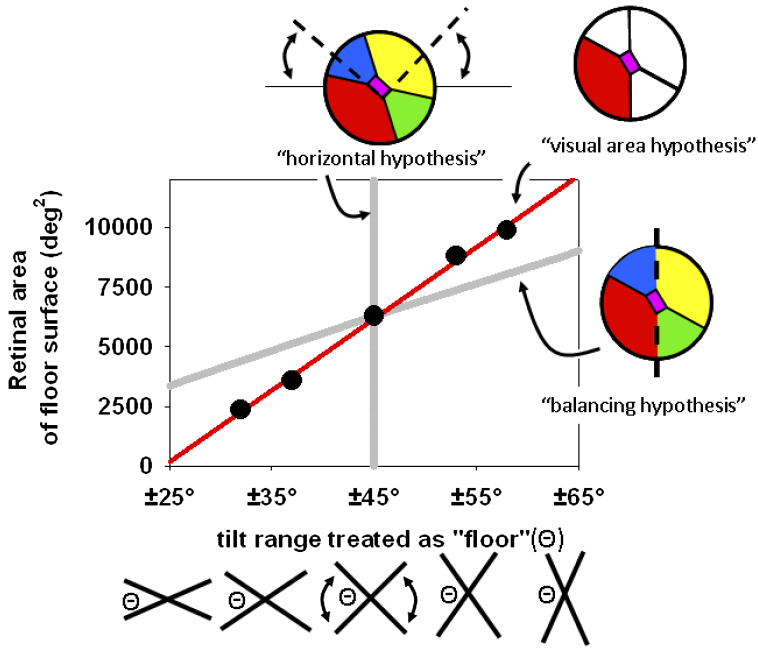

Figure 3. The visual area subtended by each of the surfaces of each room plotted as a function of the range of tilts (relative to the horizontal) over which they were most likely to be selected as the floor. Also shown are the predictions of three models: 'the balancing hypothesis' in which two adjacent sides are equally likely to be chosen when the room is physically balanced on its lower edge; 'the horizontal hypothesis' in which the surface closest to true horizontal is chosen (leading to a constant range of ±45° irrespective of aspect ratio or visual areas); and the 'visual field hypothesis' in which the range of tilts at which a surface is chosen as the floor is proportional to its projection onto the visual field.

would be equally likely to be chosen. That is, the orientation of the room at which its geometric centre was directly above the junction of two surfaces. The predictions of the 'balancing hypothesis' are also shown in Fig. 3. In this model, the range of tilts over which a given floor surface is chosen is between the two tilt angles at which the room would gravitationally balance; that is, when two opposite corners of the room align with gravity (one above the other — see inset in Fig. 3 'the balancing hypothesis'). The balancing hypothesis predicts a much larger range of tilts for the longer surface, and a corresponding smaller range for the shorter surface, than was actually found. We then considered whether the visual field subtended by each surface might contribute to whether it was chosen as the floor. Perhaps a surface with a larger area would be chosen even when it was tilted further from normal than a smaller surface. Figure 3 plots the visual area occupied by each surface (see Appendix) as a function of the range over which that surface was most likely to be chosen as the floor ('visual area hypothesis'). Indeed, the visual area correlated linearly with the range of tilts chosen: the larger the area, the larger range of tilts of the room over which that surface was chosen.

Under natural circumstances, cues that were not available in our rather sparse, static displays are also likely to play a role in the selection of a support surface. For example, when an observer is moving, motion parallax plays a role in defining the perceived orientation of a surface (Reinhardt-Rutland, 1993; Louw *et al.*, 2007). However, this is likely to be a small factor. Louw *et al.* (2007) estimate motion parallax contributes less than 9% to the choice of a surface onto which to place an object.

5. Conclusion

We conclude that the visual extent of the surface as well its inclination relative to gravity dictates an observers' choice of where to step. We have grown up in an environment in which the largest surface usually corresponds to the ground plane. This may therefore provide the basis for a bias towards choosing the surface with the largest visual area as the floor surface. Here we have quantified the extent of this bias and how far it can cause an observer to choose a surface even if it is not the best choice in terms of its tilt relative to gravity. Being able to predict the surface most likely to be selected as the floor from its visual representation could be used in the design of structures where the choice of floor is arbitrary geometrically, but where it is remains desirable that a particular surface is chosen, for example in the design of spacecraft. Our data suggests that freely floating astronauts may be somewhat more likely to spontaneously perceive visually larger interior surfaces as the 'floor'.

Acknowledgements

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References

Jenkin, H. L., Zacher, J. E., Dyde, R. T., Harris, L. R. and Jenkin, M. (2009). How do SCUBA divers know which way is up? The influence of buoyancy on orientation judgements, *J. Vision* **9**, 716a.

Louw, S., Smeets, J. B. and Brenner, E. (2007). Judging surface slant for placing objects: a role for motion parallax, *Exp. Brain Res.* **183**, 149–158.

Marigold, D. S. and Patla, A. E. (2007). Gaze fixation patterns for negotiating complex ground terrain, *Neuroscience* **144**, 302–313.

Marigold, D. S. and Patla, A. E. (2008). Age-related changes in gait for multi-surface terrain, *Gait Posture* **27**, 689–696.

Massion, J., Fabre, J. C., Mouchnino, L. and Obadia, A. (1995). Body orientation and regulation of the center of gravity during movement under water, *J. Vestib. Res.-Equilib. Orientat.* **5**, 211–221.

Oman, C. M. (2003). Human visual orientation in weightlessness, in: *Levels of Perception*, Harris, L. R. and Jenkin, M. R. (Eds), pp. 375–398. Springer Verlag, New York, NY.

Reinhardt-Rutland, A. H. (1993). Perceiving surface orientation: pictorial information based on rectangularity can be overriden during observer motion, *Perception* **22**, 335–341.

Robinson, M., Laurence, J., Zacher, J., Hogue, A., Allison, R., Harris, L. R., Jenkin, M. and Stuerzlinger, W. (2002). Growing IVY: Building the Immersive Visual Environment at York, in: *ICAT, Proc. 11th Int. Conf. on Artificial Reality and Telexistance*, Tokyo, Japan.

Ross, H. E., Crickmar, S. D., Sills, N. V. and Owen, E. P. (1969). Orientation to the vertical in free divers, *Aerosp. Med.* **40**, 728–732.

Wilkinson, E. J. and Sherk, H. A. (2005). The use of visual information for planning accurate steps in a cluttered environment, *Behav. Brain Res.* **164**, 270–274.

Appendix

Calculating the Visual Areas Occupied by the Surfaces

Assuming full field and using the relative distances involved (e.g., depth = 3, horiz = vert = 1), the angular subtense of each side of the simulated room was calculated. The visual area was calculated from area of the relevant segment of a circle (radius 90°) less the area covered by the back wall and is summarized in Fig. 4.

$\Theta = 2 * \tan^{-1}(a/b)$

area of back wall = a*b

area of segment = $\Theta/360 \times \pi.\text{radius}^2$

area of red wall =area of segment – (area of back wall/4)

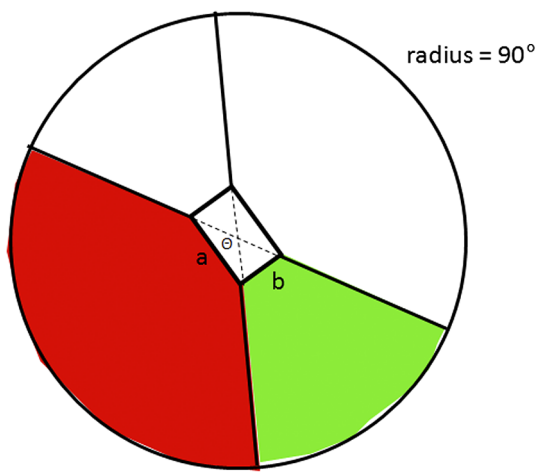

Figure 4. Illustrates how the visual area for each surface was calculated. This figure is published in colour on http://www.ingentaconnect.com/content/brill/sp