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Visual orientation in a mirror world tilted 90°

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Abstract. Previously, we showed that many supine observers in a furnished room tilted 90° perceive themselves and the room as upright. We called this the "levitation illusion" because the arms feel weightless when held out from the body. We now report that a familiar scene viewed by supine observers through a mirror at 45° appears vertical when, optically, it is horizontal and above the head. However, the body feels pitched upright only partially. This visual-righting effect, like the levitation illusion, is due to the polarity axis of the scene being accepted as vertical even in the presence of conflicting information from the gravity sense organs. In experiment 1 we tested the potency of objects containing either intrinsic polarity (due to familiar tops and bottoms) or extrinsic polarity (due to support relationships) to generate a visual-righting illusion. To almost all observers, a blank surface seen in the mirror appeared like a ceiling. A scene containing an object with intrinsic polarity, such as a chair or person, seen in the mirror appeared vertical to almost all observers. A scene containing a pair of objects with only extrinsic polarity, such as a ball on a shelf (but not a ball under a shelf), also appeared vertical to most observers. In experiment 2 we found that a polarised scene was more likely to produce a visual-righting illusion when it was arranged as a view through a window rather than as a picture inside a room.

1 Introduction

In a previous study (Howard and Hu 2001) we placed supine observers in a furnished room tilted 90° so that the up–down polarity axis of the room was congruent with the body axis. Many observers reported that they and the room appeared upright. We called this the "levitation illusion" because the arms felt weightless when moved out from the supine body and objects hanging down from above appeared to be floating in front of the observers. The proportion of observers experiencing the levitation illusion increased with age from 20% for 12-year-olds to 80% for 70-year-olds (Howard et al 2000).

Recently, the senior author wondered whether supine observers would experience a levitation illusion when viewing a vertical scene through a mirror inclined at 45° to the vertical. A vertical scene viewed through a mirror inclined at 45° is optically above the head and horizontal, and is similar to that created when a supine observer is placed in a room tilted back 90°. The mirror must face away from the torso, as shown in figure 1a, so that the observer does not see the reflection of the torso. We placed the observer and mirror on a horizontal board 1.2 m above the ground. We call this the mirror bed.

In preliminary trials, we placed the mirror bed in real outdoor scenes containing buildings, trees, and people, or a richly furnished room with people. All supine observers perceived such scenes as normal vertical scenes. They thus experienced a 90° visual-righting illusion with respect to the optical orientation of the scene. We also found that most observers on the mirror bed perceived a blank vertical surface as a horizontal ceiling above them. Thus, they experienced no righting illusion when the scene did not contain polarised features. Observers typically felt that their torsos were inclined feet down by about 20° but with the head tilted forward closer to vertical, as depicted in figure 1b. The arms did not feel weightless when held out from the body. Supine people in a 90° tilted room can see their own bodies so that any reorientation illusion must

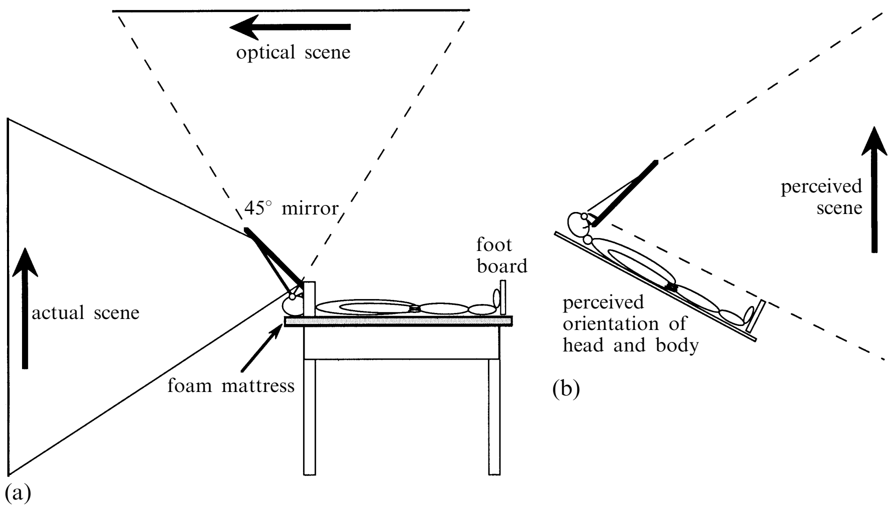

Figure 1. (a) The mirror bed showing the actual and reflected scene. (b) The perceived position and orientation of the scene for an observer experiencing a reorientation illusion. Typically, the torso feels pitched up by about 20° and the head feels pitched up to a greater degree. Note that the observer cannot see his or her own body.

affect both room and body. Supine people on the mirror bed cannot see their bodies and are therefore at liberty to see the scene as upright but feel the body to be nearly supine, as if they are reclining on a couch with the head pitched forward. The conflicting information from the gravity senses is therefore less severe on the mirror bed than in the tilted room. This could explain why only about 50% of supine observers experienced a reorientation illusion in the tilted room while all observers experienced a visual-righting illusion when viewing natural scenes on the mirror bed.

There have been a few reports of viewing a scene through a tilted mirror. Wertheimer (1912) asked observers to look through a tube at the reflection of a room in a tilted mirror. The image of the room was optically tilted 45°, rather than 90°. After some time, the room appeared upright. Gibson and Mowrer (1938) had observers look at indoor and outdoor scenes optically tilted between 10° and 45°. They reported only partial righting of the visual scenes. Asch and Witkin (1948) repeated the experiment with a mirror that tilted the image of a room 30°. Out of forty-nine observers, thirty-two reported that the room appeared within 2° of vertical and set a rod to apparent vertical accordingly. A few observers did not experience the illusion and others were unable to make consistent judgments.

In all these experiments, the observers were upright so that the polarity axis of the scene was tilted with respect to gravity and with respect to the body axis. The results were discussed in terms of the tilt of the main lines and surfaces of the scene with respect to the observer. Howard and Hu (2001) showed that the levitation illusion is more likely to occur when the visual axis of the room and the body axis are congruent, with both tilted at 90° to gravity. Under these conditions, the main lines and surfaces in the scene remain parallel to or orthogonal to both the body and to gravity. The levitation illusion is therefore not due to tilt of the visual frame relative to the body axis or to tilt of the visual frame to gravity. The levitation illusion is therefore not the same as the tilted-frame effects studied by Witkin and Asch (1948a, 1948b). The levitation illusion and the visual-righting illusion are due entirely to the orientation of the polarity axis of the visual scene being accepted as the gravity frame of reference. The levitation illusion was absent in a room lined with dots, that is, in a room with no visual polarity.

Two features determine the polarity axis of a visual scene. The first feature is the intrinsic polarity of familiar objects such as buildings, people, and trees. Such objects have a top and a bottom and are normally oriented to gravity in a consistent way. The second feature is the extrinsic polarity of objects, arising from the way in which objects support each other against gravity. For example, a ball hanging by a string and a box sitting on a shelf exhibit extrinsic polarity. The objects may have no intrinsic polarity.

In the present experiments we used a mirror tilted at 45° to reflect a vertical visual scene so that it was optically in a horizontal plane above the observer's head, with the axis of the supine body congruent with the polarity axis of the mirrored scene. Compared with a tilted room, this procedure allowed us to rapidly change the contents of the visual scene so that we could determine what features of the scene induce a visual-righting illusion. There have been no previous studies of the potency of polarity features of a scene to induce disorientation in the absence of tilt of the main lines of the scene. In experiment 1 we measured the potency of intrinsic and extrinsic polarity features in inducing a visual-righting illusion. In experiment 2 we measured the incidence of the visual-righting illusion produced by a polarised scene when the scene appeared like a view through a window compared with when the same scene appeared as a picture inside a room. The experiment was designed to test the hypothesis that a distant scene is a more reliable indicator of the direction of gravity than is a near scene.

2 Experiment 1

2.1 *Methods*

2.1.1 *Observers*. We tested thirty-three observers between the ages of 16 and 73 years, although three observers did not complete all conditions. All but three observers were naïve with respect to the purpose of the experiment. All had good vision or wore their corrective lenses.

2.1.2 *Apparatus and stimuli*. The mirror bed apparatus is depicted in figure 1a. The observer lay supine on a foam mattress placed on a table 1.2 m high. A mirror, 1 m wide by 1 m high, was suspended at an angle of 45° at one end of the table. A profile of a human head was cut out of the centre of the lower edge of the mirror to allow the head of the observer to pass beneath it. The mirror prevented observers from seeing their own bodies. The observer looked up at the inclined mirrored surface so that a vertical surface beyond the head of the observer projected as a horizontal surface above the head, as shown in figure 1a. A board at the other end of the bed was adjusted so that it applied some pressure to the soles of the feet.

The mirror bed was placed in a room with the mirror facing a blank white vertical surface. Masks on the surface of the mirror restricted the view to a 243 cm × 243 cm square region in the centre of the vertical surface, which subtended 116° of visual angle. Optically, the surface was 2 m from the observer's eyes and was illuminated by a hidden 100 W lamp on each side. We will call this the blank test surface. Various objects were introduced in front of the test surface. One set of objects was designed to investigate the potency of intrinsic polarity in generating a visual-righting illusion. The objects were: an upright chair, or a human manikin, 1.65 m high. They were both suspended in the centre of the wall by an invisible support. A second set of objects was designed to investigate the potency of extrinsic polarity. The objects were: a ball with no visible means of support, a horizontal shelf, a ball on a shelf, a ball under a shelf, and a ball hanging on a visible string. Each object was in the centre of the test surface. We also introduced a real person standing on the floor. This stimulus had both intrinsic and extrinsic polarity. The order in which the objects were presented was randomised over observers.

2.1.3 *Procedure.* The observers were helped onto the bed with eyes closed. The test objects for a given trial were put in place and the observer was asked to open the eyes and report the perceived orientation of the test surface and test objects over a period of 1 min. The observer closed the eyes while the experimenter changed the test objects, which took about 1 min.

We found in preliminary trials and in the main experiment that almost all responses fell into one of two categories. Observers saw the test display as a vertical, or near-vertical, wall facing them or as a horizontal, or near-horizontal, ceiling surface above them. We will call these responses "wall" and "ceiling" responses when they persisted over the 1 min period of observation. Sometimes the response was unstable and alternated between a "wall" response and a "ceiling" response. One observer reported that the surface was a floor. Brogan (1983) reported a similar tendency of supine observers to interpret a ceiling as a floor. We call responses other than "wall" or "ceiling" responses "unstable" responses. We regard a "ceiling" response as veridical because, optically, the surface was above the observer. A "wall" response indicates that the observer had experienced a 90° illusory reorientation of the visual scene with respect to gravity. We recorded the proportion of "wall" and "ceiling" responses for each type of display.

2.2 *Results*

The results for objects with intrinsic visual polarity are shown in figure 2. It can be seen that all but one observer saw the blank surface as a horizontal ceiling. The one observer alternated between a "wall" response and a "ceiling" response. When the chair or the manikin was presented against the surface, approximately 82% of observers gave a "wall" response. A standing person generated 86% of "wall" responses.

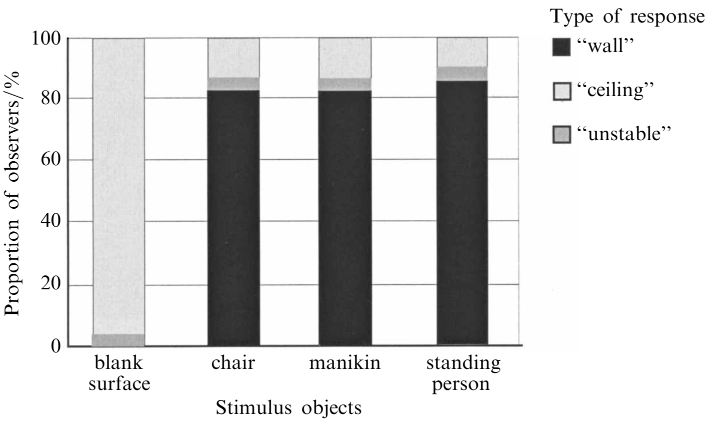

Figure 2. The effects of objects with intrinsic polarity on the percentage of observers experiencing the visual-righting illusion. Observers experiencing the illusion reported the test display as vertical ("wall" response). Others reported the display as horizontal and above the head ("ceiling" response), or gave unstable or confused responses.

The results for objects with extrinsic polarity are shown in figure 3. There were significant differences between conditions ($\chi^2_{5,\,182} = 84.93$, $p < 0.0001$). There were no "wall" responses to the ball alone and only three "wall" responses (9%) to the horizontal shelf alone. When the ball was on the shelf there were 64% of "wall" responses and when the ball was suspended on a visible string there were 71% of "wall" responses. There were significantly fewer "wall" responses (27%) when the ball was under, rather than on, the shelf ($\chi^2_{1,\,58} = 13.33$, $p < 0.0013$). When the ball was under the shelf there were marginally more "wall" responses than when only the ball or only the shelf were present ($\chi^2_{1,\,63} = 7.94$, $p < 0.0188$). The ball under the shelf produced 17% of unstable responses, the highest percentage of all conditions.

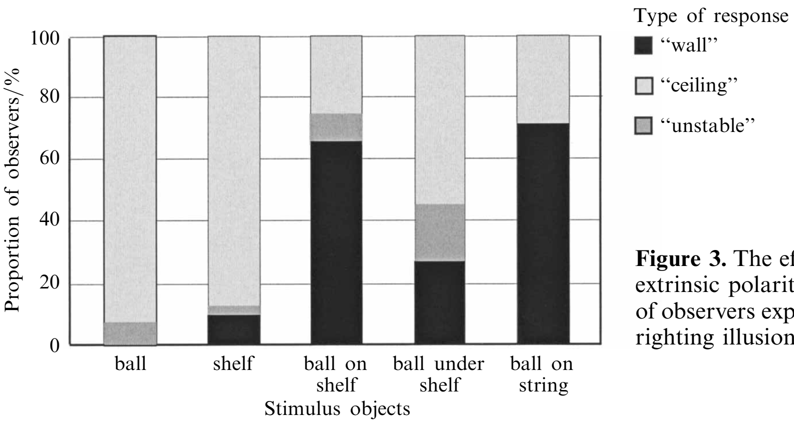

Figure 3. The effects of objects with extrinsic polarity on the percentage of observers experiencing the visual-righting illusion.

2.3 *Discussion*

There were very few unstable responses, most observers either had a visual-righting illusion or did not have an illusion. All but one of thirty supine observers looking through a mirror inclined at 45° perceived a blank white vertical surface as a ceiling above them. Optically, this is where the surface was. In other words, the proximal stimulus was identical to that created when a supine observer views a ceiling. Therefore, with respect to the proximal stimuli, this response is not illusory.

When a chair, a manikin, or a real person was placed against the vertical test surface most of observers saw the surface and the object as upright to gravity. Thus, a single intrinsically polarised object induces a visual-righting illusion in most observers.

A ball in the centre of the vertical test surface looked like a ball on a ceiling to all but one observer. A horizontal shelf evoked a visual-righting illusion in only three observers. But the ball on the shelf or suspended on a string evoked a visual-righting illusion in twenty of the thirty observers. Thus, objects with no intrinsic polarity (tops and bottoms) can evoke a visual-righting illusion in a significant proportion of observers when the objects have extrinsic polarity.

The observers reported some inclination of their own torso and head but none of them reported that the body felt upright. Since observers could not see their own bodies, they were at liberty to perceive the torso as only slightly inclined.

3 Experiment 2

3.1 *Introduction*

Observers sitting upright in a cylindrical textured drum that is rotating around its vertical axis feel that they are rotating and that the drum is stationary. This is known as circular vection. Ohmi et al (1987) found that vection is induced by the more distant of two superimposed textured displays that subtend the same visual angle. Howard and Heckmann (1989) exposed observers to a central textured display moving laterally, surrounded by a similar display moving in the opposite direction. Vection was generated by whichever display was more distant. A distant display is, in general, less likely to be in motion than is a near display that subtends the same visual angle. A far display therefore provides a better frame of reference for judging motion of the self.

We hypothesised that the visual-righting illusion produced by viewing the world through a 45° mirror follows the same rule as vection. Thus, we surmised that a scene viewed through a 'window' in a surrounding surface would be regarded as a real environment, and thus adopted as a better indicator of vertical than the same scene suspended like a picture in front of a wall.

Howard and Hu (2001) placed supine observers in a furnished room tilted at 90° to gravity. When the body axis was aligned with the up–down axis (polarity axis) of the room most observers felt that they and the room were upright to gravity. We called this the "levitation illusion". The illusion was less likely to occur when the body axis of the supine observer was not congruent with the room's polarity axis. We hypothesised that supine observers viewing a vertical polarised scene through a mirror at 45° are more likely to experience the visual-righting illusion when the scene is congruent with the body axis rather than inverted with respect to the body axis.

3.2 *Method*

3.2.1 *Observers.* Twenty observers (seven men, thirteen women) participated in the experiment. Their mean age was 30 years (range 16–71 years). All but one observer were naïve as to the purpose of the study. Thirteen observers had not previously been in the mirror-bed apparatus.

3.2.2 *Stimuli.* Observers lay supine on the same mirror bed as in experiment 1. The display area was a 244 cm × 244 cm central vertical wall, flanked by two side walls, a floor, and a ceiling. All the surfaces were white. Optically, the eyes of the observer were 208 cm away from the central wall, and opposite its centre. A 135 cm × 190 cm photograph of the interior of a solarium, containing many visually polarised objects, such as furniture, ornaments, and plants, was mounted on a board. It subtended 51 deg of visual angle horizontally, and 36 deg vertically. A molded wooden frame was placed round the photograph. The back of the board was plain white and framed in the same way. The board was suspended by invisible fishing line 12 cm in front of the vertical wall and centred on the wall. Optically, the board was horizontal and above the observer's head. It could hang with either the pictorial side or the blank side facing the observer. Physically, the pictorial side could be either erect or inverted so that its polarity axis was either congruent or reversed with respect to the observer's body axis. We refer to each of these as the central display.

The central display was surrounded by wooden panels with vertical wood grain but no up–down polarity. The panels filled the entire wall except for a 112 cm × 160 cm hole cut in the centre. The hole was framed with the same molded wood as that used to frame the central display. This surround could be placed either 4 cm behind or 32 cm in front of the central display. When the surround was in front, it occluded the frame of the central display. The central display then looked like a scene viewed through a framed window. When the central display was in front of the surround, the hole and the frame in the surround were hidden. The central display then looked like a framed picture hanging inside a room. The central display always subtended the same visual angle. Thus, the contents of the central display were kept constant while the distance of the surround relative to the centre was changed. The whole display was illuminated by lamps on either side, out of the observer's view.

3.2.3 *Design and procedure.* The three factors of the experiment were:
Visual polarity: the central display could be a polarised scene or blank.
Relative depth: the surround could be 4 cm behind, or 32 cm in front of the central display.
Scene orientation: the pictorial central display could be erect or inverted to gravity.
Each observer saw each of the following display configurations:

(i) Pictorial central display in front and upright.
(ii) Pictorial central display behind and upright.
(iii) Pictorial central display in front and inverted.
(iv) Pictorial central display behind and inverted.
(v) Blank central display in front.
(vi) Blank central display behind.

Initially, the observer lay supine on the mirror bed with eyes closed while the display was changed. The observer was asked to open his/her eyes and examine the scene. After 1 min the observer was asked to report the perceived orientation of the scene. A "wall" response was recorded if the observer had a stable percept that the facing surface was vertical. A "ceiling" response was recorded if the observer had a stable percept that the surface was horizontal and above, like a ceiling. An "ambiguous" response was recorded if the observer was confused about the orientation of the surface, or if the perceived orientation alternated between vertical and horizontal without stabilising.

Observers responding "wall" or "ambiguous" on a given trial were asked to report their body orientation. A "no body-pitch illusion" response was recorded if the observer felt that the body remained horizontal. A "body-pitch illusion" response was recorded if the observer reported an illusory pitch-forward inclination of the head or torso.

3.3 *Results*

The perceived orientations of the display for trials 1 to 4 are shown in figure 4a. A Pearson χ^2 test revealed that observers were more likely to make a "wall" response when the central display was vertical compared with when it was inverted ($\chi^2_2 = 10.533$, $p = 0.005$). Overall, there was no difference in the perceived orientation of the display related to the depth relationship between the centre and the surround ($\chi^2 = 4.133$, ns). However, when the four observers who did not see the pictorial display as vertical in any display configuration were excluded from the analysis, the effect of relative depth on perceived orientation was significant ($\chi^2_2 = 6.067$, $p = 0.048$). Their results are shown in figure 4b. Thus, observers who sometimes experienced a visual-righting illusion were more likely to experience the illusion when the central display was behind the surround compared with when it was in front of the surround. This difference was not merely the result of moving the surround in depth. When the central display was blank, the incidence of "wall" responses was not influenced by the depth relationship between the central display and the surround ($\chi^2 = 2.386$, ns).

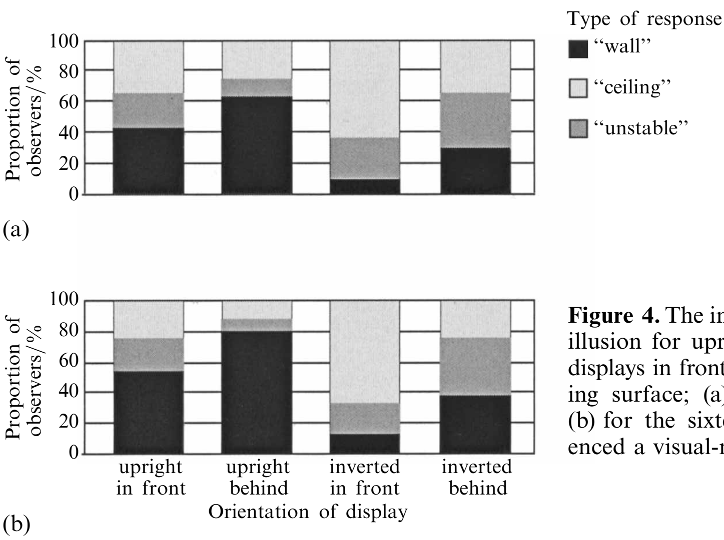

Figure 4. The incidence of a visual-righting illusion for upright and inverted pictorial displays in front of or behind the surrounding surface; (a) for all twenty observers; (b) for the sixteen observers who experienced a visual-righting illusion.

Observers reported a change in body pitch in the direction of being upright more often when the central display was in the background than when it was in front of the surround ($\chi^2_1 = 8.576$, $p = 0.003$). The body-reorientation illusion was not affected by whether the pictorial central display was congruent with the body axis or 180° reversed with respect to the body axis ($\chi^2 = 0.071$, ns).

Figure 5 shows the incidence of the visual-righting illusion for conditions in which the central display was a blank, pictorial and upright, and pictorial and inverted. Observers were more likely to perceive the scene as vertical when the central display was pictorial and upright, compared with when it was inverted or blank. There was no difference in response frequencies between an inverted pictorial centre and a blank centre ($\chi_4^2 = 14.020$, $p = 0.007$).

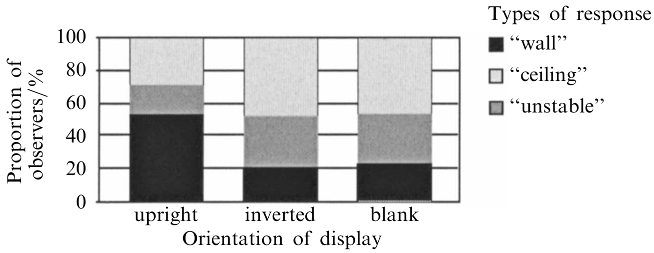

Figure 5. The incidence of a visual-righting illusion with an upright pictorial display, an inverted pictorial display, and a blank display.

4 General conclusions

For all observers that we tested, a natural visual scene containing many familiar objects, when projected by a mirror into a horizontal plane above the head, was perceived as a vertical scene. We call this the visual-righting illusion. In experiment 1 we showed that even a single familiar object such as a chair or manikin, or a pair of objects with extrinsic polarity such as a ball on a shelf, induced a visual-righting illusion in most observers. Most observers also experienced some upward pitch of the body and head. Almost all observers perceived the reflection of a blank surface as being horizontal above the supine body.

Previous experiments in this laboratory showed that visually induced self-motion (vection) is evoked by the more distant of two displays. We hypothesised that the visual-righting illusion follows the same rule. As predicted, we found in experiment 2 that observers who sometimes experienced the visual-righting illusion were more likely to do so when a large display containing many familiar polarised objects looked like a scene through a window compared with when it looked like a picture hanging inside a room. In the real world, a large distant display is likely to be part of the stationary and erect scene. A near display of the same angular size is often an object that may move or be tilted. Thus, distant displays provide a more reliable frame of reference for judging both self-motion and orientation than do near displays. After reaching orbit the space shuttle flies inverted with respect to the Earth. Astronauts frequently feel they are upside down when they look out of the window and see the Earth above them. They also experience an inversion illusion when another astronaut approaches them in the reverse orientation.

The levitation illusion experienced by supine observers in a room tilted 90° and the visual-righting illusion experienced by supine observers on the mirror bed are both evoked entirely by the presence of familiar objects with recognisable tops and bottoms (visual polarity) or by objects with extrinsic polarity. In both cases, the visual scene is tilted 90° to gravity so that all the main lines and surfaces of the scene are either vertical or horizontal, both with respect to gravity and with respect to the observer's body. Therefore, these illusions are not induced by a tilted frame, as studied by Witkin and Asch (1948a). We showed previously (Howard and Hu 2001) that the levitation illusion is most likely to occur when the polarity axis of the scene is congruent with the body axis. The results of experiment 2 show that the visual-righting illusion experienced on the mirror bed is also most likely to occur when body axis and scene axis are congruent.

The main finding from our experiments is that the visual polarity of familiar objects is a powerful factor in determining our sense of what is up and what is down. We have shown previously that the incidence of orientation illusions induced by visual polarity increases with age. This means that older people with reduced sensitivity of the vestibular organs become more dependent on visual cues to the direction of gravity. They are likely to become disoriented when there is an absence of familiar polarised objects, as in a stair well. Astronauts frequently experience disturbing sensations of being upside down. In space, there is no non-visual information to indicate orientation, and the interior of the space shuttle and the space station are almost devoid of visually polarised objects. We recommend that available blank surfaces contain pictures of familiar scenes, which will provide a consistent frame of reference for self orientation. They will also make astronauts feel more at home on a long journey.

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