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CHAPTER 9

Enhancing visual cues to orientation: Suggestions for space travelers and the elderly

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Abstract: Establishing our orientation in the world is necessary for almost all aspects of perception and behavior. Gravity usually defines the critical reference direction. The direction of gravity is sensed by somatosensory detectors indicating pressure points and specialized organs in the vestibular system and viscera that indicate gravity's physical pull. However, gravity's direction can also be sensed visually since we see the effects of gravity on static and moving objects and also deduce its direction from the global structure of a scene indicated by features such as the sky and ground. When cues from either visual or physical sources are compromised or ambiguous, perceptual disorientation may result, often with a tendency to replace gravity with the body's long axis as a reference. Orientation cues are compromised while floating in the weightlessness of space (which neutralizes vestibular and somatosensory cues) or while suspended at neutral buoyancy in the ocean (which neutralizes somatosensory cues) and the ability to sense orientation cues may also be compromised in the elderly or in clinical populations. In these situations, enhancing the visual cues to orientation may be beneficial. In this chapter, we review research using specially constructed virtual and real environments to quantify the contribution of various visual orientation cues. We demonstrate how visual cues can counteract disorientation by providing effective orientation information.

Keywords: microgravity; levitation illusion; field of view; visual gravity; perceived direction of gravity; falls; floor; support surface; balance; cue weighting.

Introduction

Vision is important to most people's conscious perception of the world, but vision also has an important proprioceptive function (Nakayama, 1985) in which it provides information about the orientation and movement of the body. Nonvisual cues to

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orientation are provided by systems that report the direction of the physical force of gravity. These include the otoliths of the vestibular system of the inner ear (Mittelstaedt, 1991, 1999), specialized detectors in the viscera (Mittelstaedt, 1992), and the somatosensory system (Lechner-Steinleitner et al., 1979; Yardley, 1990) that reports the location of pressure from points of contact with the support surface. These sources of information normally work together with visual proprioception to provide robust information about a person's orientation in their environment. Here, we concentrate on visual proprioceptive cues to orientation and how they can potentially be strengthened to compensate for the loss of other cues.

Visual cues to orientation

Figure 1 illustrates some of the visual cues that specify orientation in a typical scene. These cues include: (i) The visual frame (indicated by a rectangle in the figure), comprising the ground plane and features known to be approximately earth vertical or earth horizontal such as trees, walls, ceilings, and floors. The frame cue is inherently ambiguous. Each of the directions indicated by the four arrows could potentially be the direction of "up." (ii) The visual horizon. This cue indicates two possible directions (opposite to each other). (iii) The assumption that light comes from above (Mamassian and Goutcher, 2001). Although this is generally true, it cannot be precise as light can of course come from many directions (Morgenstern et al., submitted for publication). (iv) Support relationships between objects, determined by the laws of physics, such as objects resting on other objects or supported by the ground. Again, this clue is generally true, but even unattached objects can rest on surfaces that are quite tilted relative to gravity, depending on friction to stay in place. (v) The visual polarity cues of objects with a recognizable top and bottom such as people, lamps, and chairs that have a "most-familiar" orientation relative to gravity (Cian et al., 2001). But these objects can be present in an unfamiliar orientation, such as a when a chair is lying down. (vi) Movement such as objects moving on the ground plane or falling through the air. The brain can use visual movement to build an internal representation of gravity (McIntyre et al., 2001; Indovina et al., 2005). In fact, of all these cues, only the direction in which

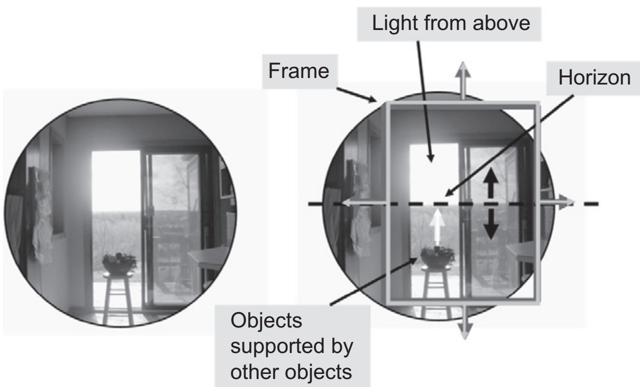

Fig. 1. A typical scene showing examples of the various visual cues to the direction of gravity. On the right, the possible directions reported by the cues in the photograph are detailed. The four possible directions of gravity signaled by the frame, defined by the orientation of the walls, floor, ceiling, and window stripped of their other cues, are indicated by arrows. The two directions indicated by the horizon are shown in black, and the unique direction signaled by the relationships of objects in the world (e.g., the fruit bowl on the stool), the expected orientation of objects (fruit bowl curved side down), and light coming from above is indicated by the pale vertical arrow.

something falls demonstrates the direction of gravity unambiguously and even then the path of lighter falling objects, such as rain or leaves, may be diverted by wind or air resistance. The use of vision therefore requires a best guess based on all available cues. In order to make recommendations for enhancing vision's effectiveness for orientation, we need to quantify the influence of each.

How can perception be influenced by visual cues to orientation?

The power of visual cues in specifying orientation can be demonstrated by separating the directions indicated by vision and other cues. Under some circumstances, vision seems to dominate completely as it does in the "levitation illusion" (Howard and Hu, 2001, Howard et al., 1997), for example. In the levitation illusion subjects are pitched onto their backs while the entire visual environment is moved with them.[1] If they are pitched slowly and smoothly enough so that they are unaware of their change in orientation with respect to gravity, they continue to feel upright and the direction of the floor, indicated entirely visually, is perceived as remaining orthogonal to gravity: vision dominates their overall perceptual experience. However, this illusion speaks more to how vestibular mechanisms for detecting gravity can be fooled rather than the normal importance of vision.

Careful measurement of the quantitative contribution of visual cues under cue conflict conditions has ascertained that visual cues do not usually dominate but rather contribute different amounts of information to different proprioceptive functions. Tasks can be broadly divided into those that are perceptually based and those that involve physically interacting with the world.

The influence of visual orientation cues on perceptual tasks

The influence of the visual cues to orientation contained in a scene on perceptual tasks, such as recognizing faces or objects, has been measured by assessing the influence of visual cues on the perceptual upright. The perceptual upright is defined as the orientation at which objects appear the right way up (Jolicoeur, 1985; Maki, 1986; McMullen and Jolicoeur, 1992). The direction of the perceptual upright can be assessed using the Oriented Character Recognition Test (OCHART; Dyde et al., 2006). OCHART presents an observer with a character with an identity that depends on its orientation. For example, deciding whether a character is the letter "p" or the letter "d" depends on an independent estimate of which way is up. By assessing the orientations at which this character is most ambiguous, the perceptual upright (where it is least ambiguous) can be inferred. The different cues to up (vision, the body, and gravity) can then be put in conflict to assess their relative effect on the perceptual upright. For example, lying on one's side separates gravity from the long axis of the body. The orientation of visual cues can then be manipulated independently by having subjects look at an image viewed through a shroud to remove other visual cues to orientation. Such tests have shown that vision normally contributes about 25% of the information needed to determine the perceptual upright compared to about 25% from gravity, the remainder coming from the orientation of the long axis of the observer's own body (Dyde et al., 2006). This means that if a compelling visual environment is tilted by 90° relative to an earth-vertical observer, the perceptual upright is tilted about 18° away from gravity.[2]

[1]This is achieved using a tumbling room (Allison et al., 1999) in which an observer is firmly held so that their relationship with the room does not change during the maneuver. It is called the "levitation illusion" because unrestrained objects within the room appear to levitate as the room pitches.

[2]To a first approximation, the cues appear to combine by a simple vector summation. In this example, gravity and the body form one vector with vision at 90° to this yielding angle of $\tan^{-1}(25/75) = 18°$. See Mittelstaedt (1991) for a model that includes additional terms.

The influence of visual orientation cues on estimating the direction of gravity

The influence of vision on direct estimates of the direction of gravity can be measured using the subjective visual vertical test: aligning a line to the perceived direction of gravity (Asch and Witkin, 1948; Mittelstaedt, 1986). This probe measures the direct perception of the direction of gravity rather than the consequences of gravity on more perceptual tasks. The influence of vision on this task is considerably less than it is on a perceptual task. Here, vision only contributes about 8% of the information compared to 77% from gravity and 16% from the body (Dyde et al., 2006). This means that if the environment is tilted by 90° relative to an upright observer, the subjective visual vertical is tilted by only about 5°. What does this mean in practice?

The influence of visual orientation cues on estimating which surface is the floor

Imagine you are entering a strange environment. On which surface should you place your feet? It actually takes surprisingly little visual information to influence the choice of which surface is chosen as the floor. Although the direction of gravity restricts the choice, surprisingly the surface closest to orthogonal to gravity is not the surface always chosen as the floor. Rather, subjects bias their selection heavily toward larger surfaces leading to a larger surface sometimes being chosen as the preferred support surface even if a smaller surface is actually closer to earth horizontal (Harris et al., 2010). This phenomenon is summarized in Fig. 2. Thus, in order to provide optimal cues to correctly perceiving the floor surface, it is important to make sure that one potential floor surface is clearly larger than the other possible choices.

When is it desirable to use vision to influence perceived orientation?

If gravity is not available, or its direction is unreliably perceived, vision becomes a more important cue. SCUBA divers often regard tilted surfaces that they see underwater as being earth horizontal (Ross et al., 1969) and astronauts can suffer sudden unsettling feelings of inversion if they see a crew member upside down relative to them (Oman, 2007). However, in such circumstances, the dominant determinant of the perceptual upright is usually the orientation of the body.

The use of vision for orientation when gravity is not present

Humans have been experiencing the weightless environment of space since 1961. In microgravity,

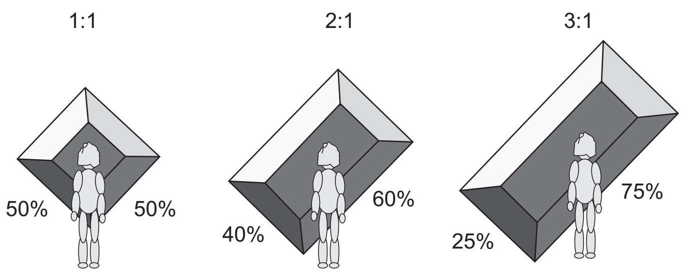

Fig. 2. The effect of changing room aspect ratio on determining the choice of which surface to choose as the support surface. Each of these rooms is tilted at 45° and either of the lower surfaces is thus equally valid as the choice of support surface. The percentages by each surface show the percentage of times each surface was chosen. As the aspect ratio changes, the larger surface is increasingly likely to be chosen, based on visual factors alone. Data from Harris et al. (2010).

the perceived direction of "up" can no longer depend on gravity and thus must be defined by a combination of cues from vision and the body. Paradoxically however, when subjects are exposed to brief periods of microgravity (created by using parabolic flight) the weighting assigned to vision is significantly reduced[3] (Dyde et al., 2009). In fact, many visual effects seem to be reduced under microgravity: the rod-and-frame effect[4] (Villard et al., 2005), the horizontal/vertical illusion[5] and Ponzo Illusion[6] (Clement et al., 2007), and the influence of a tilted background on interpreting shape from the pattern of shading over an object's surface (Jenkin et al., 2004) are altered suggesting a reduced influence of visual cues to orientation under microgravity.

Exposure to microgravity can evoke crippling feelings of disorientation (see Oman, 2007 for a review) and a long-duration interplanetary spaceflight without some kind of artificial gravity is therefore highly undesirable. Attempts to provide artificial gravity to counteract this disorientation have concentrated on regular sessions in a short-arm centrifuge (Young et al., 2001). However, an additional form of "artificial gravity" could be provided by the careful construction of a visual environment to provide consistent "visual gravity" cues. The visual cues provided by a typical spacecraft environment are not in themselves particularly effective at providing an artificial gravity cue because they do not provide a consistent "gravity" direction: no one surface has visual cues to distinguish it from any other as all surfaces are used for mounting equipment and no one surface is larger than the others (see section "The influence of visual orientation cues on estimating which surface is the floor").

The use of vision for orientation by the elderly

A third of people over 65 years of age experience one or more falls every year (Fuller, 2000). The tendency to fall seems to be related to deterioration in the peripheral or central vestibular systems (Matheson et al., 1999) which in turn may lead to postural instability (Campbell et al., 1995). Some aspects of vision, including visual acuity, contrast sensitivity, depth perception, and size of visual field, do not seem to be significantly correlated with the tendency to fall in the elderly (Lamoureux et al., 2010). However, selectively providing active older people with glasses does significantly reduce their tendency to fall (Haran et al., 2010). This implies that some visual cues, especially the higher spatial frequencies (Dyde et al., 2005), are important for the elderly. Providing enhanced visual information may therefore be beneficial in overcoming postural instability in this group also. How can effective visual cues be provided to this population?

How can the contribution of vision be enhanced?

An obvious way to enhance visual cues to orientation is to provide additional information about the direction that we wish to be perceived as "up." For example, arrows or the words "this way up" might be helpful. However, such signs place additional cognitive demands on people that might already be cognitively loaded, such as astronauts or the cognitively impaired, as may be the case for some elderly or clinical populations. Therefore, here we concentrate on enhancing the existing natural cues to

[3]The weighting assigned to vision was ascertained by measuring the perceptual upright using an OCHART probe superimposed on a highly polarized visual background presented in different orientations. The influence of the background on the perception of the probe could thus be measured (Dyde et al., 2009).

[4]The rod-and-frame effect is where the orientation of a rod is influenced by the orientation of a surrounding frame.

[5]The horizontal/vertical illusion is where a horizontal line of the same length as a vertical one appears longer (Prinzmetal and Gettleman, 1993).

[6]The Ponzo illusion is an optical illusion that was first demonstrated by the Italian psychologist Mario Ponzo (1882–1960) in 1913. The upper of two horizontal lines of identical length drawn above each other on converging lines (like railway lines) appears longer.

orientation, the processing of which does not impose additional cognitive loads. Our central question is: which visual factors are important to enable someone to interact comfortably with their environment and to help them to feel correctly oriented?

Enhancing visual orientation with polarized cues

In order to assess the contribution of various visual cues that contribute to specifying the orientation of a room, we used virtual reality to simulate a room in which we could present just the room (walls only), furniture (polarized cues only), or a fully furnished room (both cues) (Harris et al., 2007). The presence of furniture enhanced the ability of the room to determine the perceptual upright. This is summarized in Fig. 3. Polarized cues help most. Can these polarized cues be further enhanced?

Enhancing visual orientation cues by motion

Most natural scenes contain movement and most moving things demonstrate the principles and more relevantly the direction of gravity. We compared the effectiveness of static and dynamic scenes in influencing the perceptual upright (Jenkin et al., 2011). The addition of motion cues significantly increased the influence of the visual background in determining the perceptual upright. The results are summarized in Fig. 4. Polarized objects that move in a way that demonstrates a gravity field can be an effective aid to perceiving orientation.

Enhancing visual cues by compression

It might be assumed that being able to see further in all directions (i.e., as a result of increasing the field of view) would be advantageous in providing better visually defined orientation cues as more polarized objects might be in view. By the same token, having a restricted field of view (brought on by a clinical condition or by wearing a helmet, for example) might be disadvantageous. We assessed the effect of field of view on the power of vision to override gravity cues using the levitation illusion described above. The levitation illusion (Howard and Hu, 2001, Howard et al., 1997) depends, of course, on being able to see the visual environment to suppress any feeling of tilting over backward. How wide a field of view is necessary for visual cues to continue to override gravity cues? Experiments with field-restricting glasses showed that the incidence of the levitation illusion did not depend on the size of the visual field of view *per se*, but rather depended upon what was visible within the field (Jenkin et al., 2007). If what was normally seen in a larger field was made smaller so it could still be seen in a smaller field (Fig. 5), the illusion remained as strong as ever. Wearing an optical device that had the effect of shrinking the visible world so that more of it could be seen at once should thus have an enhancing effect.[7] The visible world also needs to provide strong and effective polarizing cues rather than just being large.

Conclusions

Visual cues to orientation are very important and can be manipulated to make them more important still. To enhance a visual environment so that it provides stronger-than-normal cues to orientation we suggest providing strongly polarized cues that move around in a way that is consistent with gravity in a room with a respectable aspect ratio and viewing it through minifying lenses that expand what can be seen with a given field of view. Environments designed for people with a tendency to lose their balance should avoid tall narrow rooms. Such visually enhanced environments could be helpfully implemented in spacecraft design, in in-helmet visual displays for use during extravehicular space walks or during diving, and in living environments for people with impaired orientation perception.

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[7]One would need to adapt, however, to the changes in perceived distance that such lenses would introduce.

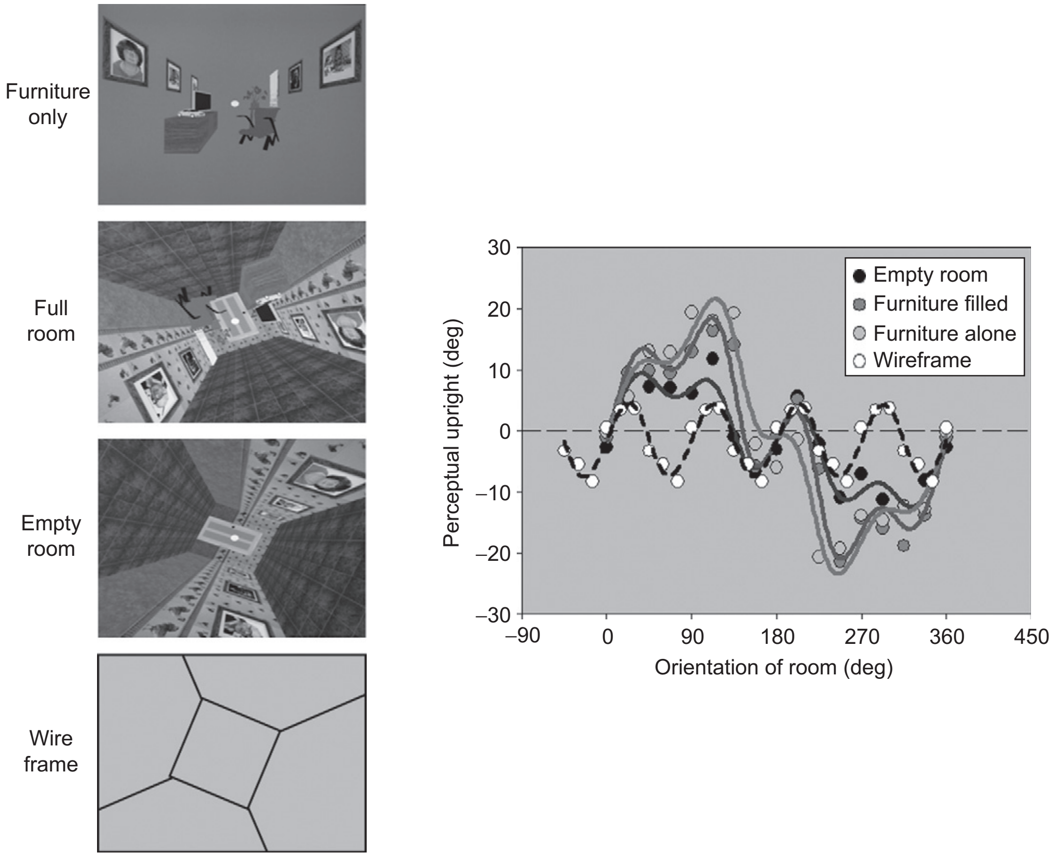

Fig. 3. The relative effectiveness of simulated rooms (left) experienced in virtual reality on the orientation of the perceptual upright. The perceptual upright is plotted in the right hand panel as a function of the orientation of the room where 0 is upright with respect to gravity. The perceptual upright is tilted by ±20° by the furniture, whether or not it is in a room at all! An empty room has less effect. A wire frame room has a small effect which repeats every 90° that it is rotated because of the inherent ambiguity of this component of a room. Lines fitted through the data are the output of a simple vector sum model including the directions indicated by vision, gravity, and the long axis of the body (see Dyde et al., 2006). Data are from Harris et al. (2007).

A caveat: Enhancing vision might not be all good

If visual cues misalign with gravity they tend to pull the perceptual upright (Dyde et al., 2006) and even egocentric judgments about the orientation of the head and body (Barnett-Cowan and Harris, 2008) away from veridical to some intermediate direction that may not actually correspond with the direction of any of the individual cues. Placing too much emphasis on vision when the information they carry is not aligned with other cues can therefore be counterproductive. Misalignment arises in many natural situations such as when getting up from a chair or even reading a newspaper. Patients with Parkinson's disease do tend to put such an overemphasis on vision (Barnett-Cowan et al., 2010) which might contribute to their tendency to fall under such circumstances. When enhancing a visual environment, it is important to ensure that the cues align with the desired direction of the perceptual upright and with gravity.

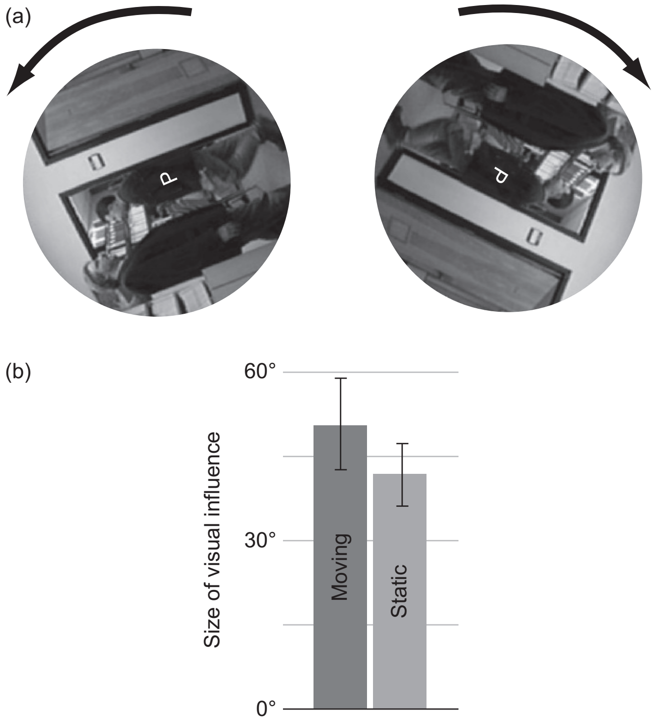

Fig. 4. The effect of adding movement to a visual scene. Backgrounds were presented tilted to the left or right (a) and could be either movies of people walking or stills from the same movie. Also shown is the OCHART probe used for measuring the orientation of the perceptual upright. The moving images had a significantly larger influence on the perceptual upright (b). Data taken from Jenkin et al. (2011).

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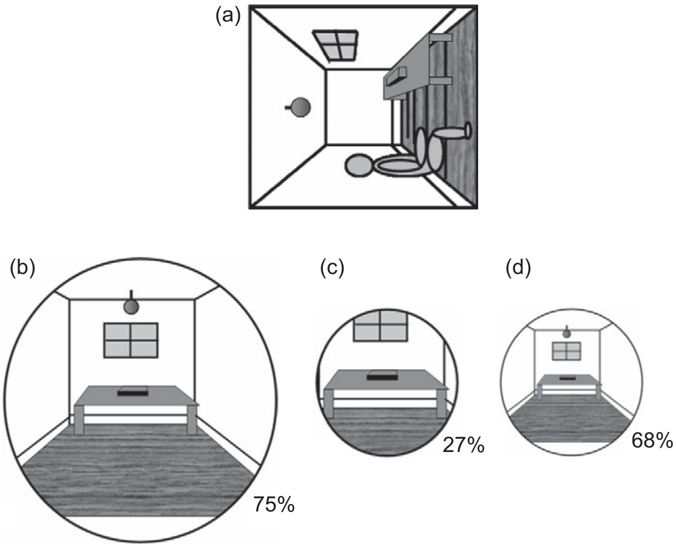

Fig. 5. What is seen is more important than the field of view. When on one's back in a tilted room (a) one may experience the perception of being upright in an upright room (the Levitation Illusion). Under normal viewing conditions (b) the illusion is experienced 75% of the time. When the field is restricted (c) the effectiveness of the illusion is reduced. But if more of the room is visible within the same restricted field of view, the illusion returns. Data from Jenkin et al. (2007).

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