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Effect of field of view on the Levitation Illusion

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Abstract. Supine subjects inside a furnished room in which both they and the room are pitched 90° backwards may experience themselves and the room as upright relative to gravity. This effect is known as the levitation illusion because observers report that their arms feel weightless when extended, and objects hanging in the room seem to "levitate". This illusion is an extreme example of a visually induced illusion of static tilt. Visually induced tilt illusions are commonly experienced in wide-screen movie theatres, flight simulators, and immersive virtual reality systems. For technical reasons an observer's field of view is often constrained in these environments. No studies have documented the effect of field-of-view (FOV) restriction on the incidence of the levitation illusion. Preliminary findings suggest that when concurrently manipulating the FOV and observer position within an environment, the incidence of levitation illusions depends not only on the field of view but also on the visible scene content.

Keywords: Visual orientation, self tilt, perceived orientation, gravitational vertical

1. Introduction

Visual displays are frequently used in vehicle simulators, amusement parks, wide-screen movies, and virtual reality (VR) training systems to create compelling illusions of static tilt. However, the user's field of view (FOV) is often restricted. For example, the binocular field of view of many VR head-mounted displays is around 60° (horizontal) x 30° (vertical) or smaller. The goal of this investigation was to determine whether field-of-view restriction reduces the effectiveness of static visual scenes in altering the direction of the perceived gravitational vertical.

In our normal day-to-day life the various cues to our orientation within the environment are congruent and the direction of "down" is cued by many consistent factors. But how is self-orientation – a fundamental concept that provides a foundation for a wide variety of perceptual effects – estimated by our perceptual system?

The brain relies on at least three cues to judge self-orientation (see [4] for a review): vestibular information (signalled primarily from the otolith division of the vestibular system), orientation of the body, and visual cues from the environment. These cues are normally congruent. However it is possible to place these cues to the direction of self-orientation in conflict and generate a self-orientation perception that is not aligned with the gravity vector. The Haunted Swing – a fairground device built in the 1890's – is perhaps the first record of this. In the Haunted Swing observers sat in a gently swinging gondola in a furnished room that was rotated about them. Observers felt that the room was stationary and that they had rotated physically completely upside down about their pitch axis [16]. This is an example

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of a *dynamic* visual orientation illusion. *Static* visual orientation illusions also occur [2,3,15]. Howard and colleagues [5–8] put observers inside a cubic 2.44 m $\times$ 2.44 m $\times$ 2.44 m room that could be pitched about an earth horizontal axis ("The York Tumbling Room" see Fig. 1). Observers were firmly strapped into a chair that was attached to the room. When the room and observer were pitched, they felt they had remained upright even when they were in fact supine with respect to gravity. Observers reported that their arms felt weightless when extended and that objects hanging from the wall in front of them appear to levitate. Howard et al. [6] therefore termed this phenomenon the "Levitation Illusion". The levitation illusion (LI) is an example of a static visual orientation illusion.

Since 1997 a number of studies have investigated factors that influence the incidence of visual orientation illusions in the Tumbling Room. Howard, Jenkin and Hu [8] concluded that the static levitation illusion depends on learned visual cues arising from the perceived tops and bottoms of familiar objects and the spatial relationships between them. This work built upon earlier work [5] that categorized the visual cues used to make judgments about the direction of gravity as being the visual frame, the visual polarity, and the motion of the visual scene. The visual frame refers to the distinct horizontal and vertical lines and surfaces such as walls and ceilings that are typically parallel with or perpendicular to gravity. Visual polarity refers to the fact that objects such as people and furniture exhibit an intrinsic visual polarity from their identifiable top and bottom and an extrinsic visual polarity due to their relationship with surfaces of support. Motion cues include the direction in which objects fall when dropped.

Although it is clear that the presence of compelling visual cues is essential for observers to experience the levitation illusion, it was not clear which properties of the visual scene are most important for producing static tilt illusions. Allison, Howard and Zacher [1] studied the effect of visual field size, head motion and scene rotational velocity on dynamic illusory self-tilt produced while the room continuously rolled around an erect subject. They found that the incidence of the illusory tilt from vertical for dynamic presentations increased with increasing field of view and with increasing rotational velocity but found no effect of head-fixed versus head-free viewing. They noted that as the size of FOV increased, different portions of the world enter the visual display. In this way, increasing the FOV changed not only the extent of what could be seen, it also changed the scene content. The Tumbling Room provided significant visual frame cues around the edges of the room, creating a potential confound for how changes in FOV might have their effect. Allison et al. [1] argued that the changing scene content was controlled through the comparison of head-fixed versus head-free viewing, since head-free viewing allows the observer to see the whole scene, at least sequentially. However a more explicit control for visual content is desirable. Pilot experiments conducted with subjects wearing a $60^\circ \times 30^\circ$ binocular color stereo HMD and viewing a virtual visual simulation of the York tumbling room yielded a low incidence of LI. Was this finding attributable to the narrower field of view, or the smaller number of frame and polarity cues in the visual scene? Here we compare the effect of the extent of FOV with what can be seen within the FOV by co-varying field size and distance of the observer from the scene.

2. Method

2.1. Subjects

Twenty-eight observers (18 male, 10 female, ages 23 to 46) with no history of visual, vestibular or proprioceptive dysfunction participated in the study. Subjects read and signed a York University informed consistent form, and were informed of the risks associated with the experiment and that they could terminate the experiment at any time.

2.2. Apparatus and stimulus

The stimulus consisted of a furnished cubic 2.44 m $\times$ 2.44 m $\times$ 2.44 m room – the York Tumbling Room [6–8] – that is decorated with a rich array of visual polarity and visual frame cues, such as a set table and a seated mannequin (see Fig. 1). Observers entered the room in its upright configuration and were secured either sitting in the centre of the room ("near" condition: 1.22 m from the wall) or standing against the far wall ("far" condition: 2.44 m from the wall). Observers in the "far" condition were twice as far away from the front wall of the room as observers in the "near" condition (Fig. 2a). In both conditions the observer was secured in position by thick foam that reduced proprioceptive cues to gravity. Observers had little pressure information as both the chair and the wall support structure were well padded with foam and observers were firmly strapped into position at both locations. The subthreshold rotation into supine position altered the po-

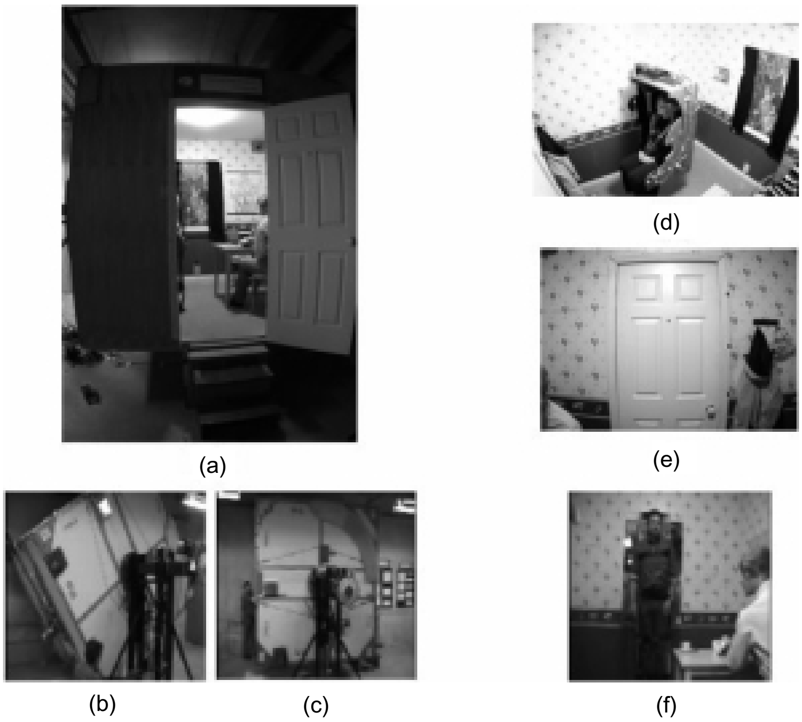

Fig. 1. The York Tumbling Room. Seen from outside (a, b and c) and inside (d, e and f). (d) Shows the observer strapped into the seat in the "near" condition and (f) shows the observer strapped to the wall in the "far" condition, (e) is the unobstructed view from the "far" position.

tency of proprioceptive cues to orientation very gradually. Observers were provided with a two-way radio system to communicate with the experimenter, and a hidden video system allowed the experimenter to view the subject for safety and to ensure subject compliance with the experimenter's instructions.

The observer's field of view (FOV) was restricted by the use of one of a set of pairs of occluding glasses that provided a rectangular, binocular, reduced field of view of 60° × 30°, 40° × 30°, 30° × 15° or 20° × 15° (horizontal x vertical).

2.3. Procedure

Observers wore one of the pairs of obscuring goggles and, once secured in position, closed their eyes, and were pitched slowly backward with an acceleration that was below the threshold for detection of rotation up to a rate of 30°/min which was maintained until they were physically supine with respect to gravity (Fig. 2). The room remained visually upright relative to the observer's head and body. Observers were instructed to open their eyes and to view the interior of the room for one minute and then to report:

1. Their self-orientation with respect to gravity (estimated in degrees away from either a gravitationally horizontal or vertical imagined reference).
2. The room's orientation with respect to gravity (estimated in degrees away from either a gravitationally horizontal or vertical imagined reference).

For eyes-closed trials observers were asked to estimate their self-orientation with respect to gravity without opening their eyes. Before data collection observers made several practice orientation judgements about hypothetical situations to become familiar with the reporting methodology.

Observers' responses were coded as "upright" when they reported that they and the room were within 10° of gravitational upright. Responses were coded as "supine" if observers reported that they and the room were within 10° of gravitational horizontal. All other responses were coded as "confused" as in those cases observers' reported being unable to report their position as the percept was not constant but alternated between feeling "upright" and "supine". Observers were asked to report without moving their heads. After making their judgement, they were asked to close their eyes and the room and observer were returned to the gravitationally vertical orientation, the subject's goggles were

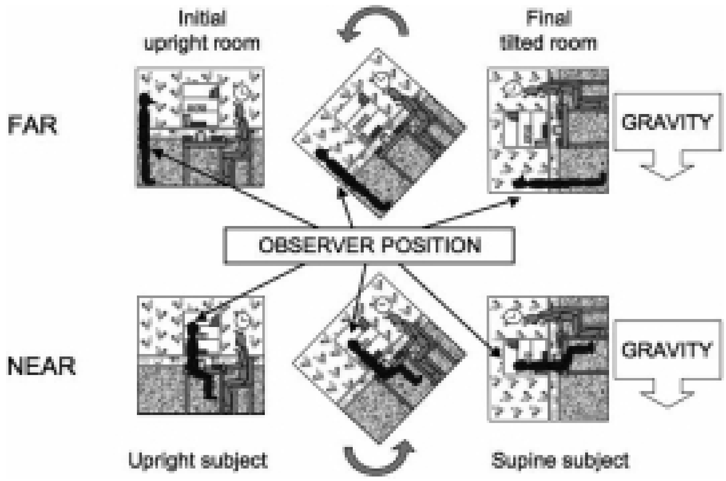

Fig. 2. The observer's position in the York Tumbling Room in both "near" (sitting: bottom row) and "far" (standing: top row) viewing distances. The observer was initially upright (left panels), rotated slowly (middle panels) until reaching a final supine orientation (right panels).

exchanged for the next condition, and the procedure repeated.

Observations were made for each of the ten combinations of goggle sizes, distances and eyes open or closed listed in Table 1. Conditions were presented in a randomized order to each observer to control for order effects. Figure 3 depicts the different FOV conditions with different scene content. In all conditions except unobstructed and FOV 60° × 30° (when viewed from the "far" position), observers had a view of the planar front wall of the room, no sidewalls or ceiling/floor edges were visible. In the FOV 60° × 30° the sidewalls were visible to the observers but no ceiling/floor edges were seen. Observation eye height in the room varied with observer height. Results were pooled across subjects to obtain percentage responses of confused, upright or supine by experimental condition.

Table 1
Experimental viewing conditions

	View	Distance
1.	Eyes open	Near
2.	Eyes closed	Near
3.	Eyes open	Far
4.	Eyes closed	Far
5.	60° × 30° FOV	Near
6.	60° × 30° FOV	Far
7.	40° × 30° FOV	Near
8.	40° × 30° FOV	Far
9.	30° × 15° FOV	Far
10.	20° × 15° FOV	Far

Different fields of view were used at "near" (1.22 m) and "far" (2.44 m) viewing distances. Thus conditions 5 and 9 had different FOV but the same scene content. Likewise conditions 7 and 10 had different FOV but the same scene content.

3. Results

3.1. Incidence of the Levitation Illusion for the two viewing distances

The Levitation Illusion was defined as having occurred when a visually upright but physically supine observer reported that they (and the room they were in) were upright with respect to gravity. Figure 4 summarizes observers' perceived self-orientation when actually supine with eyes closed (left two bars) and eyes open and unobscured by glasses (right two bars) for the 1.22 m and 2.44 m viewing distances. 87.5% of supine observers correctly reported being supine with their eyes closed although some observers reported this to be a very difficult task when no vision was available. 76.8% of supine observers experienced the Levitation Illusion with unrestricted viewing (thinking they were upright even when they were actually supine). This finding replicated earlier reports of the levitation illusion Levitation Illusion [7,8]. Position in the room had no impact on the incidence of LI, observers reported similar LI incidence from both "near" and "far" locations with unobstructed views.

3.2. The incidence of the levitation illusion by FOV

Figure 5 presents the incidence of the Levitation Illusion for each FOV and viewing distance. For a given viewing distance, reducing the FOV systematically

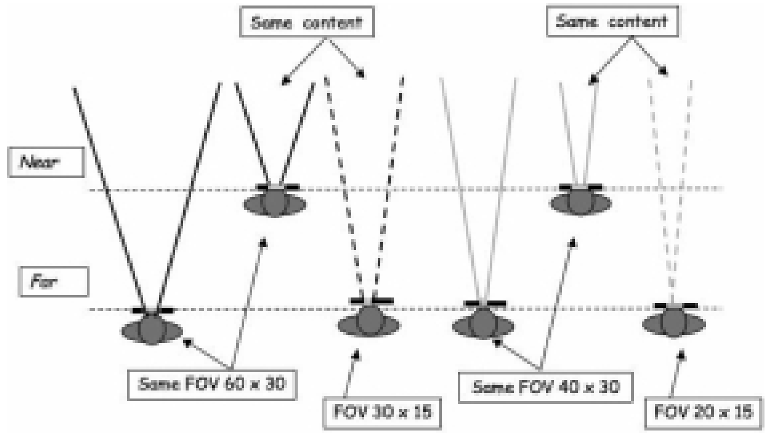

Fig. 3. Diagram depicting the FOV of each set of glasses worn at both viewing distances. FOV sizes and viewing distances were carefully chosen so that scene content could be compared independently of FOV, as indicated by "same content" labels.

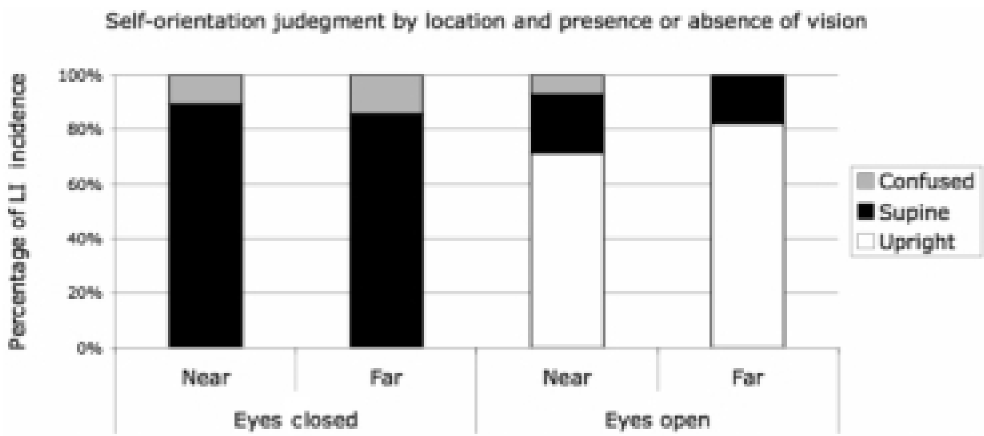

Fig. 4. Self-orientation judgements for each viewing distance and visual condition for supine subjects. Bar charts indicate the relative incidence of the levitation illusion with the eyes closed (left 2 bars) or with eyes open (right 2 bars) for the "near" and "far" viewing conditions. The percentage of times their orientation was judged as 'confused' (grey), 'supine' (black), or 'upright' (white) is indicated. "Upright" corresponds to subjects experiencing the levitation illusion.

reduced the incidence of the Levitation Illusion in eyes open conditions. The reduction from the no-goggles control was statistically significant in the "near" viewing distance for both the $60^\circ \times 30^\circ$ and $40^\circ \times 30^\circ$ conditions (χ^2 (1, $n = 28$) =8.59, $p < 0.01$, χ^2 (1, $n = 28$) = 10.5, $p < 0.01$, respectively). From the "far" viewing distance the reduction in LI incidence was significant for FOVs of less than $60^\circ \times 30^\circ$ (FOV $40^\circ \times 30^\circ$ χ^2 (1, $n = 28$) = 4.02, $p < 0.05$; FOV $30^\circ \times 15^\circ$ χ^2 (1, $n = 28$) = 6.88, $p < 0.01$; and for FOV $20^\circ \times 15^\circ$ χ^2 (1, $n = 28$) = 10.5, $p < 0.01$). While the incidence of Levitation Illusions was reduced with FOV modifications, of interest is the fact that the LI rate was indistinguishable in those conditions where scene content was held constant despite FOV reduction (cf. $60^\circ \times 30^\circ$ viewed from 1.22 m with $30^\circ \times 15^\circ$ viewed from 2.44 m (χ^2 (1, $n = 28$) = 0, $p > 0.05$); or $40^\circ \times 30^\circ$ viewed from 1.22 m with $20^\circ \times 15^\circ$ viewed from 2.44 m (χ^2 (1, $n = 28$) = 0.266, $p > 0.05$)).

4. Discussion

Observers with unrestricted viewing reported a rate of incidence of the Levitation Illusion that was consistent with earlier studies using the Tumbling Room [7, 8]. Although the incidence of the Levitation Illusion varied with the field of view, the incidence did not depend on the size of the field of view per se, but rather on what was visible within the field. When the visual

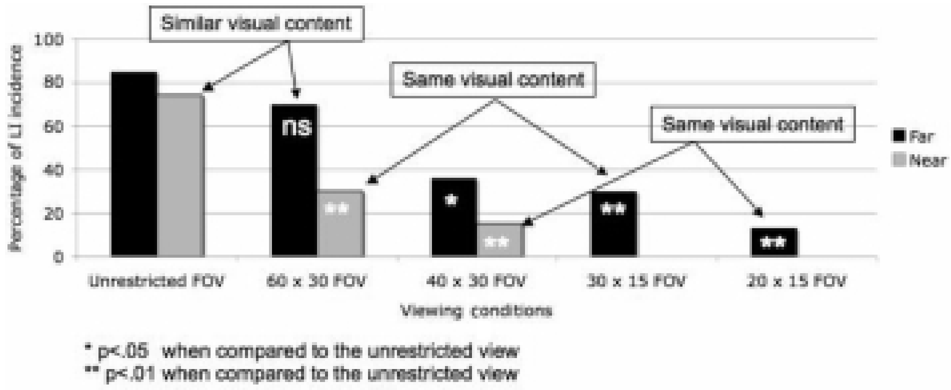

Fig. 5. Incidence of Levitation Illusion for each viewing distance and visual condition while subjects were supine. Again scene content can be compared independently of FOV, as indicated by "same visual content" labels. Significant differences in LI incidence when compared to the "no glasses" conditions are indicated by the stars (*$p < 0.05$, **$p < 0.01$). The 60 × 30° FOV "far" case was not significantly different from the unobstructed "near" case. Physically the only difference was that views of the floor and ceiling were masked while the sidewalls were in view.

content was kept constant by reducing the field by half while viewing from twice the distance, the incidence of the Levitation Illusion was the same. Thus we have demonstrated that the reduction of the Levitation Illusion was not caused by reducing the FOV per se but rather by the change in the parts of the scene that could be seen. Not all factors apart from "scene content" could be kept constant as the observer's position in the room was varied. For example, many cues such as spatial frequency content, texture, texture gradients, object size, and stereoscopic cues would be present that might contribute to an observer being able to distinguish between the views. Further experiments involving magnifying lenses, monocular viewing, and other visual manipulations are needed to identify the mechanism of the effect we have demonstrated.

There is evidence [9] that visual cues perceived to be in the environmental background (e.g., a photograph of an outside scene viewed as through a window in a tilted room) provide more effective frame and polarity cues than the identical cues perceived to be in the foreground (e.g., the identical photograph mounted on the inside wall, rather than viewed through a window). However, we believe this difference in effectiveness is due to the perceptual reference frame assigned to the cue, rather than to viewing distance. In the present experiment, we expected objects mounted on the wall of the room to have similar potency when viewed in either the "near" and "far" position, since they were perceived to be "on the wall" under both conditions.

Observers in the "near" condition were seated while observers in the "far" condition were standing. The physically elevated position of the subject's feet in the "near" condition may have had some influence on LI, as suggested by the incidence of VRI in weightlessness being influenced by altered distribution of body fluids [12]. Observers did report slightly more LI while standing than while seated but this was not significant when vision was unrestricted. Changes in body posture with condition ("seated" supine with legs raised versus lying supine) may also provide differential orientation cues [11,14].

In retrospect, it is not surprising that the incidence of LI depends on the visual content rather than the FOV since even a complete Ganzfeld could not provide useful orientation cues. But it might be imagined that the effectiveness of a given visual stimulus might depend on its size. Although size constancy removes this effect for object perception [10], the effectiveness of a visual cue to orientation has been shown to depend on its size [1], with objects seen in peripheral vision being generally regarded as more effective [13]. The present results suggest that there may also be some form of size constancy helping to determine the contribution of visual objects in the scene to perceptual stability.

In future work, observers' perception of their body orientation within the room could be explored to understand the bi-stable nature of the "confused" response when physically supine but "visually" upright. Although this study reports only preliminary results, we have shown that not only does the incidence of the levitation illusion depend upon the size of the field of view but also what is visible within that view. Small fields can be as effective as large ones in producing static visual tilt illusions if polarity cues are used wisely. Further experiments need to be conducted which more fully control the equivalence of the contents of the displays in the various conditions, body postures and physical distance to the stimulus.

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