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# Perceptual Upright: The Relative Effectiveness of Dynamic and Static Images Under Different Gravity States

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#### Abstract

The perceived direction of up depends on both gravity and visual cues to orientation. Static visual cues to orientation have been shown to be less effective in influencing the perception of upright (PU) under microgravity conditions than they are on earth (Dyde *et al.*, 2009). Here we introduce dynamic orientation cues into the visual background to ascertain whether they might increase the effectiveness of visual cues in defining the PU under different gravity conditions. Brief periods of microgravity and hypergravity were created using parabolic flight. Observers viewed a polarized, natural scene presented at various orientations on a laptop viewed through a hood which occluded all other visual cues. The visual background was either an animated video clip in which actors moved along the visual ground plane or an individual static frame taken from the same clip. We measured the perceptual upright using the oriented character recognition test (OCHART). Dynamic visual cues significantly enhance the effectiveness of vision in determining the perceptual upright under normal gravity conditions. Strong trends were found for dynamic visual cues to produce an increase in the visual effect under both microgravity and hypergravity conditions. © Koninklijke Brill NV, Leiden, 2011

#### Keywords

Perceptual upright, cue combination, visual gravity, microgravity, hypergravity, perceived visual orientation, space flight, parabolic flight

#### 1. Introduction

The perception of self and object orientation is fundamental to many aspects of perception. The perceptual upright (PU) — the orientation at which objects are

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most easily recognized (Dyde *et al.*, 2006; Jolicoeur, 1985) — is determined by a combination of information from different sources and especially from vision and from the otolithic division of the vestibular system. An internal representation of the orientation of the body's long axis — the idiotropic vector (Mittelstaedt, 1983, 1986) — also contributes to determining the PU. These cues are obligatorily combined into a single direction of up using statistically optimal rules (Dyde *et al.*, 2006), from which the contributors cannot be individually identified and which can be modeled as a weighted vector sum (Dyde *et al.*, 2006; Mittelstaedt, 1986). When standing upright in a normal environment the various cues to the PU are in agreement: we walk upright in a visually upright world surrounded by a constant one-*g* gravitational field. In unusual conditions, such as when underwater, in the microgravity of outer space, during a high-*g* aerobatic maneuver, or even just when trying to read in bed, these cues can become misaligned, ambiguous or misleading, potentially distorting the perception of the direction of up.

A typical visual scene contains many cues to orientation. Previous research has emphasized the contribution of static cues and measured their relative effectiveness using various probes to perception including the subjective visual vertical (Asch and Witkin, 1948; Mittelstaedt, 1983), rod and frame effect (Bringoux *et al.*, 2009; Cian *et al.*, 2001), shape-from-shading (Jenkin *et al.*, 2004), perceived eye level (Li *et al.*, 2001; Matin and Fox, 1989) and ambiguous figures (Dyde *et al.*, 2006). Static visual cues to up can produce a perceived tilt away from the gravity- and body-defined vertical by as much as  $30^{\circ}$ .

A natural scene also contains dynamic cues that can help disambiguate its structure (Braunstein *et al.*, 1993; Cornilleau-Peres and Droulez, 1994; Tittle and Braunstein, 1993). Motion cues are created by the movement of the viewer (such as parallax and optic flow) and external movements. Motion of animals or objects, either falling or in motion along the ground plane, can demonstrate the direction of gravity. Although motion may be used to create an internal model of the laws of gravity (Indovina *et al.*, 2005; McIntyre *et al.*, 2001), relatively little is known about the effect of dynamic content in a visual display in influencing the perception of up.

Being able to enhance visual cues to up is potentially useful in environments where other cues to up are degraded or missing. Such environments include neutral buoyancy (underwater) environments as well aerospace environments and microgravity. Such environments can produce dangerous disorientation (see Oman, 2007, for a review). When gravity is not available it might be expected that the relative weighting of vision would increase. Although such an increase is found when body orientation is manipulated out of the testing plane (Dyde *et al.*, 2006; Li *et al.*, 2001), experiments using short duration microgravity flight (e.g., Dyde *et al.*, 2009; Glasauer and Mittelstaedt, 1992), and space flight (e.g., Oman *et al.*, 2003) have shown a general reduced emphasis given to the visual cue, significantly shifting the perceived direction of up towards the orientation of the body. When gravity is increased during parabolic flight (Dyde *et al.*, 2009) or in a centrifuge (e.g., DiZio *et al.*, 1997; Mast, 2000) a similar reduction in weighting of the visual cue is found.

One suggested countermeasure to the effects of loss of non-visual orientation cues is to develop visual displays that reinforce a sensation of the direction of up and create a 'visual gravity'. But what kinds of visual display generate the most effective visual cue to the direction of up? Here, we explore the relative effectiveness of static *versus* dynamic visual displays in a microgravity environment known to threaten the use of visual cues: is it possible to reverse the reduced influence of vision under altered gravity states through the use of dynamic cues?

# 2. Methods

# 2.1. Participants

Six participants (5 male, 1 female, aged between 23 and 55 years) took part in the experiment. All participants had normal or corrected-to-normal vision and reported no history of vestibular dysfunction. Each participant completed an informed consent agreement that conformed to the ethical guidelines of York University and the Treaty of Helsinki.

# 2.2. Apparatus

Experiments were conducted on board the National Research Centre of Canada's (NRC's) Microgravity Facility, a Falcon-20 airframe modified for microgravity flight (Fig. 1). Four flights were conducted over a one-week period and the aircraft performed four parabolas per flight. When configured for microgravity flight with seated subjects, the aircraft accommodated six experimental subjects plus one safety spotter per flight. Three participants sat facing forward, three sat facing aft, each with a laptop computer fixed semi-rigidly in front of them (see Fig. 1). For safety reasons all participants were loosely restrained by seat belts throughout the flight.



**Figure 1.** Data collection on board the NRC Microgravity Facility. Subjects viewed a laptop screen occluded by a cylindrical tunnel (left). Data were collected onboard the Falcon-20 (right) as it underwent maneuvers that manipulated the effective g state experienced by subjects within the aircraft.



**Figure 2.** Sample *g*-states measured relative to Earth normal during microgravity flight. Symbols indicate times at which responses were recorded. Microgravity conditions were obtained for periods of about 22 s at a time.

During flight, participants remained seated with their body aligned with the gravity vector (during the normal and hypergravity phases). Each flight consisted of a period of 1 g level flight followed by four parabolas each of which had a microgravity (22 s) and hypergravity (22 s) phase and ending with a second period of level flight. Data collection started soon after takeoff and continued until the second period of level flight. Thus a total of 16 parabolas were flown producing 352 s of microgravity.

Stimuli were presented separately to each subject on an Apple iBook laptop computer with a resolution of 48 pixels/cm (21 pixels/deg: the OCHART characters were approximately  $7^{\circ} \times 5^{\circ}$ ). The computer screen was masked to a circular aperture subtending  $35^{\circ}$  when viewed at 25 cm through a black circular shroud that obscured peripheral vision (Fig. 1). The shroud also acted as a semi-rigid, padded head restraint to control both the viewing distance and the orientation of the observer's head relative to the screen. The laptop was mounted within an aluminium frame to maintain the screen at a fixed angle and to hold the shroud in place.

Each microcomputer was connected via a USB cable to an ADXL311 dual axis digital accelerometer (Phidgits Inc.) that was rigidly mounted to the aluminium frame holding the microcomputer to the shroud. X and Y accelerations in the plane of the testing screen were recorded at stimulus onset and at the point of the observer's responses. The average of these two accelerometer values was taken as the magnitude of the *g*-state of the experimental trial. Figure 2 shows the *g*-state record of one of the experimental flights.

## 2.3. Procedure

Throughout the flight the instantaneous direction of the perceptual upright was measured using the oriented character recognition test (OCHART) probe (Dyde *et al.*,



**Figure 3.** Ten frames spanning the video stimuli used are shown at an orientation of  $0^{\circ}$ . The video consists of a short segment showing two of the authors walking along the ground plane. The imagery provides prominent and easily recognizable cues to orientation (doors, walls, floor and people). The motion sequence was designed to provide little net motion — objects move both from left to right and right to left — while still emphasizing the ground plane. The OCHART probe, here at an orientation where it is clearly a 'p', is overlaid. Static stimuli were chosen randomly for each presentation from the frames making up the clip. This figure is published in color in the online version.

2006). OCHART estimates the perceptual upright by presenting the subject the ambiguous symbol ' $\Omega$ ' in various orientations for each experimental condition, and scores the number of times the symbol is identified as a 'p' *versus* being identified as a 'd'. The orientations of perceptual equality (PSE) where the symbol ' $\Omega$ ' is identified equally as being a 'p' or a 'd' are identified. The midpoint of these two orientations is the perceptual upright (see Dyde *et al.*, 2006 for details).

All trials consisted of a stimulus formed by the probe character superimposed on either a stationary or animated visual background. Backgrounds were either a video clip (see Fig. 3) or a still frame chosen randomly from the same video clip. Each stimulus, static or dynamic, was presented for 1500 ms after which the display was replaced with a blank screen containing a centrally positioned circular fixation marker which remained on until the subject made their response. The visual display can provide cues to the perception of up with a display time of as little as 50 ms, although the efficacy of the stimulus improves with stimulus duration (Haji-Khamneh and Harris, 2009). The choice of 1500 ms was a compromise between the need to collect data quickly due to the short duration of micro- and hypergravity periods available, and the desire to generate strong visual cues to orientation. Participants chose between the 'p' or 'd' percepts by pressing one of two keys on a gamepad (Gravis Gamepad Pro) input device mounted to the aluminium frame within which the laptop was mounted. The participants' responses were blocked by the controlling software until stimulus offset and the appearance of the fixation point. Once the response was made, the next trial was initiated after an approximately 150 ms delay.

The symbol 'd' was presented rotated at orientations  $\pm 10^{\circ}, \pm 50^{\circ}, \pm 90^{\circ}, \pm 130^{\circ}$ and  $\pm 170^{\circ}$  where 0° is aligned with the body and positive is clockwise. The visual background was presented at  $\pm 110^{\circ}$ . These two background orientations were chosen because they have been found, in previous Earth-based studies (Dyde *et al.*, 2006), to be associated with large shifts of the perceptual upright. The percentage of times the OCHART probe was identified as a 'p' was plotted as a function of the orientation of the character. Each combination of probe orientation  $(\pm 10^{\circ}, \pm 50^{\circ}, \pm 90^{\circ}, \pm 130^{\circ}$  and  $\pm 170^{\circ}$ ) and background orientation  $(\pm 110^{\circ})$  was presented in a block consisting of seven repetitions for both stationary and dynamic background scenes. Elements in each block were presented in pseudo-random order. Multiple blocks were presented until the flight ended. Over all four flights, approximately eight repetitions of each stimulus combination were accumulated spread across the microgravity and hypergravity phases.

#### 2.4. Data Analysis

Flight data were pooled for each subject by gravity level: microgravity ( $g \le 0.5$ ), normal gravity ( $0.5 < g \le 1.5$ ) and hypergravity (g > 1.5). For each condition and background a psychometric function was created of the percentage of time one identity of the character was chosen, as a function of character orientation. The product of two hyperbolic tangents (equivalent to two sigmoidal functions) was fitted to each data set using:

$$p = 0.5 \times (1 - \tanh((\theta - \theta_1)/\sigma) \times \tanh((\theta - \theta_2)/\sigma)).$$

where p is the fraction of time the probe was identified as a 'p',  $\theta$  is the orientation of the character ('d' at  $\theta = 0^{\circ}$ ),  $\theta_1$  and  $\theta_2$  are the two orientations or points of subjective equality (PSE) and  $\sigma$  is a parameter representing the sensitivity of the probe. The mean of the two PSE's was taken as the perceptual upright. Figure 4 shows typical responses and data psychometric function fitted through the data obtained from one subject over the twelve experimental conditions (3 × gravity states — microgravity, normal gravity, hypergravity, 2 × background orientations — ±110°, and 2 × background states — still or video). Subject responses are plotted in polar form, with clockwise angles being positive and 12 o'clock corresponding to  $\theta = 0^{\circ}$ . Radial distance is (1 + p). Constant response curves are drawn at r = 1 and r = 2. The perceptual up (PU) for each condition is also shown.

#### 3. Results

The orientation cues to up contained in both the video and the still images (taken from the same video) influenced the direction of the perceptual upright (PU). The strength of the visual background's influence on the PU was examined by calculating the 'visual effect', defined as the difference in the direction of the perceptual upright when the background was tilted 110° clockwise compared to when it was tilted 110° counter-clockwise from the body axis. The visual effects for each in-



**Figure 4.** Sample subject responses and fits for one typical subject for microgravity (left column), normal gravity during level flight (middle column) and for hypergravity (right column). The top two rows represent the data using a moving video display and rows 3 and 4 using stills. Each panel shows the data as a polar plot where the distance from the centre represents the percentage probability that the character represents a 'p'. The inner circle represents 0% (i.e., 100% 'd') and the outer circle represents 100% 'p' (i.e., 0% 'd'). The fit is the product of two hyperbolic tangents (see text) from which the 50% points were obtained. The perceptual upright (PU), defined as halfway between the two 50% points (PSEs), is indicated by a radial line. If the PU were upright, this line would be vertical. This figure is published in color in the online version.

dividual under each gravity state are shown in Fig. 5 and the average visual effect (VE) for each experimental condition is shown in Fig. 6.

A two-way repeated measures ANOVA was conducted using SPSS 17 to compare the effects of gravity state (3) × stimulus type (2) on the visual effect. Mauchly's test (Mauchly, 1940) indicated that the assumption of sphericity had not been violated. There was a significant main effect of stimulus type F(1, 5) = 13.29, p < 0.05. The visual effect of a moving background was significantly larger than the vi-



**Figure 5.** The size of the visual effect for each individual subject (each subject has a different symbol — see inset) for all six conditions is plotted to compare the influence of 'videos' and 'stills'. Mean visual effect sizes are also plotted (filled vertical triangles) with standard error bars.



Figure 6. Visual effect size in degrees for each experimental condition averaged across the six subjects. Error bars show one standard error.

sual effect associated with a static background. *Post-hoc* tests revealed that although the VE under normal gravity was significantly higher for a moving display than for a static display (t(5) = 2.98, p < 0.05) this was not the case for either the microgravity or hypergravity conditions although strong trends were found for dynamic visual images also to increase the VE under these conditions (t(5) = 2.19, p = 0.08n.s. for microgravity and t(5) = 2.34, p = 0.07 n.s. for hypergravity). There was no effect of gravity state on visual effect size overall (F(2, 4) = 1.8, p = 0.273 n.s.). The interaction between gravity state and stimulus type was also not significant (F(2, 4) = 0.79, p = 0.51 n.s.). A second two-way repeated measures ANOVA was conducted on the visual effect using SPSS 17 to compare the effects of the static stimulus alone. This was to permit a more straightforward comparison with the results reported in Dyde *et al.* (2009). No effect of gravity state on the visual effect was found (F(2, 10) = 1.738, p = 0.225 n.s.).

#### 4. Discussion

Dynamic visual cues enhanced significantly the effectiveness of vision in determining the perceptual upright under normal gravity conditions. There were also strong trends for an increase in the visual effect size under microgravity and hypergravity (see Note 1).

Surprisingly, gravity state was not found to have a significant effect on the visual effect in either the full dataset analysis nor in an analysis of the static dataset alone. This is in contrast to our earlier work (Dyde *et al.*, 2009) which found a significant reduction in the visual effect under microgravity compared to normal gravity conditions using a static visual display. Dyde *et al.* (2009) used a pre-flight bracketing procedure to sample that portion of the OCHART response that was near the PSE for the p-to-d and d-to-p transitions while the study here sampled the entire OCHART response function. The decision here to use the entire response range was made to ensure that data collection captured the p-to-d and d-to-p transitions for all conditions at the cost of reducing the accuracy with which the measurement is made. Although the data here follows the same trend on average (a VE of 42 degs under normal gravity compared to a VE of 30 degs under microgravity) as that reported in Dyde *et al.* (2009), in the current study the gravity state did not have a significant influence on the visual effect.

Similarly, no significant change in the extent of influence of visual cues on the visual effect under hypergravity conditions relative to normal gravity conditions was found in the present study. The reduction from  $46^{\circ}$  ( $\pm 7.2^{\circ}$ ) to  $43^{\circ}$  ( $\pm 9.0^{\circ}$ ) was not significant although we did report a similar trend for the size of the visual effect to reduce with hypergravity relative to normal gravity in Dyde *et al.* (2009). A reduction in visual influence as gravity increased would suggest that the relative weighting given to gravity increased with the magnitude of 'g'. This was also suggested by the finding that tilted visual fields have less effect on perceived eye level at higher-than-normal gravity levels (Chelette *et al.*, 1995; DiZio *et al.*, 1997).

Why might dynamic cues make the visual cue more effective than static cues? We postulate that the addition of motion enhances the scene by, for example, adding depth information as well as demonstrating the laws of physics in operation and that this in turn 'strengthens' the effectiveness of vision as a contributor to the perception of up. Within the brain the ventral intraparietal (VIP) region contains cells that have been implicated in the representation of allocentric space (Zaehle *et al.*, 2007) and that are multimodal with both vestibular input (Bremmer *et al.*, 2001) and a visual component that strongly prefers motion (Duhamel *et al.*, 1998). Our demonstration that the presence of motion in the visual scene also enhances vision's role in determining the perceived direction of up may correspond to a more optimum activation of this area.

The dynamic visual display used in this study was naturalistic in that it depicted normal motion along the horizontal plane, not motion with explicit direction-ofgravity information indicated by, for example, falling objects. Both static and dynamic cues to orientation were therefore present and it is possible that the motion merely increased the effectiveness of the static cues. We therefore cannot conclude that it was the dynamic cues *per se* that were effective in contributing to the increased effectiveness of the image. However our findings suggest that visual displays containing explicit gravity information in the absence of static cues (e.g., falling water) might also be effective in providing a 'visual gravity'.

Understanding how to enhance the effectiveness of 'visual gravity' may be useful in designing orientation aids during temporary removal of vestibular activation in the aerospace environment and also in other situations where orientation cues are degraded. Elderly patients and patients suffering from disease or damage of the vestibular system may encounter changes of their perception of up (see Sharpe, 2003). It may be beneficial to decorate such people's homes with material that provides highly polarized dynamic visual cues, including dynamic cues, to the direction of up to strengthen the visual signal available to counteract disorientation and falls.

## Notes

1. The microgravity experiments reported here were conducted on a specially modified aircraft that produces 22 s of microgravity followed by a period of hypergravity. The transient nature of the microgravity stimulus may cause an underestimation of any gravity induced effects (Glasauer, 1995; Vingerhoets *et al.*, 2006). Furthermore, since periods of microgravity follow periods of hypergravity, there may be some influence of this transition.

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