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How different types of scenes affect the Subjective Visual Vertical (SVV) and the Perceptual Upright (PU)

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ABSTRACT

Different scenes contain varying cues to the direction of gravity. Do scenes with stronger cues differentially affect the ability of a scene to influence the direction of the Subjective Visual Vertical (SVV) and the Perceptual Upright (PU)? Using indoor, outdoor, natural and man-made scenes we asked participants to judge the orientation of pictures (Scene Upright: SU), viewed through a circular shroud, relative to the gravitationally defined upright. The standard deviation of these judgments was taken as an estimate of the reliability of the cues present in that scene. The SVV and PU were then measured against these scenes. The scenes in the SVV condition were tilted by ±22.5° and the SVV measured using a line. The scenes in the PU condition were tilted by ±112.5° and the PU was measure by a letter probe. The difference in orientation of the probes with the scene in these two orientations was defined as the visual effect. The man-made scenes affected the SVV more than the natural scenes. The visual effect was inversely proportional to the standard deviation with which the scene was judged as upright for the SVV but not PU. In order to be sure that the null result for the PU was not a ceiling effect we measured the SU and PU at brief exposure durations to increase the standard deviations of the SU. There was still no significant correlation between the standard deviations of the SU and the visual effect on the PU. This difference between PU and SVV suggests that the SVV may be more sensitive to global orientation information relevant to spatial orientation (as measured by Scene Upright) than the PU and that the more global spatial orientation a scene contains, the greater its effect will be on the SVV.

1. Introduction

Human perception is very sensitive to the orientation of stimuli. It is generally accepted that recognition of objects, letters, actions and people is faster and more accurate when they are perceived to be ‘the right way up’ (Jolicoeur, 1985; Maki, 1986; McMullen & Jolicoeur, 1992; Rock & Heimer, 1957; Rock, Schreiber, & Ro, 1994). Vision plays an important role in determining the perceived direction of upright. But how scenes vary in their ability to affect perception is not thoroughly understood.

The perceived direction of up has conventionally been assessed by the Subjective Visual Vertical (SVV): the direction at which participants set a line to the apparent vertical (e.g., Mittelstaedt, 1983). However, the SVV is not the only way to measure the perceived direction of up. As such, its direction does not always agree with the perceived directions of up derived from other measures. One of these measures is the Perceptual Upright (PU). The PU corresponds to the orientation at which objects are perceived to be the right way up and is measured using the Oriented CHAracter Recognition Test (OCHART). This task exploits the fact that the letters ‘p’ and ‘d’ rely on their orientation for their identity. The PU and SVV are both determined by a combination of visual and vestibular cues, together with an internal representation of the orientation of the body (Asch & Witkin, 1948a; Dyde, Jenkin, & Harris, 2006; Mittelstaedt, 1986, 1999). The SVV can be conceptualized as a direction that is more related to the orientation of the overall scene and as such is strongly influenced by the direction of gravity. The contribution of gravity to the SVV is almost ten times greater than that of visual cues or the body axis (Dyde et al., 2006). Thus, the SVV is almost entirely determined from vestibular cues. On the other hand, the PU is more related to the orientation of objects and perceptual recognition tasks and is more evenly influenced by the three main cues to orientation: vision, the internal representation of the body, and gravity (Dyde et al., 2006). In this study, we investigated the extent to which PU and SVV are affected by the orientation of different types of scenes.

While most scenes contain some orientation cues, different types of scenes may vary in the amounts and/or types of orientation cues that they provide to the viewer. For example, indoor and outdoor scenes differ with regards to their image statistics (Oliva & Schyns, 2000; Torralba & Oliva, 2003). Outdoor scenes can be further broken into man-made scenes and natural scenes

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and there is some computational evidence showing that image statistics can serve as the basis for classification along this dimension as well (Vailaya, Jain, & Zhang, 1998). Man-made scenes tend to include more vertical lines than do natural scenes (Switkes, Mayer, & Sloan, 1978) and the vanishing points in man-made scenes are more closely aligned with the vertical and horizontal whereas in natural scenes these angles appear more random (Kovač, Peer, & Solina, 2008). In other words, natural scenes contain fewer global orientation cues about the environment than man-made scenes. Thus, since they do not carry as much vertical information, natural scenes may be inherently more ambiguous than man-made scenes with regards to orientation cues and in turn may not influence the SVV or PU as much as man-made scenes.

In this study, we compared the effects of scene orientation on the SVV and PU for indoor, outdoor, natural and man-made scenes. We hypothesized that since man-made scenes contain more straight lines, the degree of certainty with which observers set scenes to upright would be higher for man-made scenes than for natural scenes. We also hypothesized that the certainty with which a given scene is set to upright would be predictive of the magnitude of the visual effect of that scene on both the PU and the SVV. Since most objects possess an axis of polarity that may be more local and less dependent on the global information about the scene, we hypothesized that the relationship between certainty of determining global scene orientation and the magnitude of the visual effect would be stronger for the measure of upright that captures spatial orientation (i.e., the Subjective Visual Vertical) as opposed to that which captures object orientation (i.e., the Perceptual Upright).

1.1. Convention

The orientations of all probe and background scenes are defined with respect to the body mid-line of the observer. 0° refers to the orientation of the body axis. Positive orientations are clockwise ('rightwards') relative to this reference orientation, negative orientations are counter-clockwise ('leftwards'), as seen by the observer.

2. Experiment 1

2.1. Introduction

The first experiment looks at how reliably the orientation of a scene is perceived and then assesses whether reliability can be used to predict the effect of the scene on the Perceptual Upright and the Subjective Visual Vertical.

2.2. Methods

2.2.1. Participants

Thirteen participants between the ages of 23 and 46 (four female and nine male) volunteered in this experiment. All participants were tested on the Scene Upright. Of the 13 participants, a group of eight was also tested in the SVV condition and a partially-overlapping group of eight was tested in the PU condition. Four participants were tested in all conditions. All observers had normal or corrected-to-normal vision. All observers gave their informed consent as required by the Ethics Guidelines of York University which complies with the Declaration of Helsinki.

2.2.2. Display

Stimuli were presented on a 13 in. Apple McBook laptop screen with a resolution of 48 pixels/cm. The screen was viewed at a distance of 25 cm through a black circular shroud that obscured peripheral vision and that reduced the viewing area to a circle subtending 28.5° of visual arc.

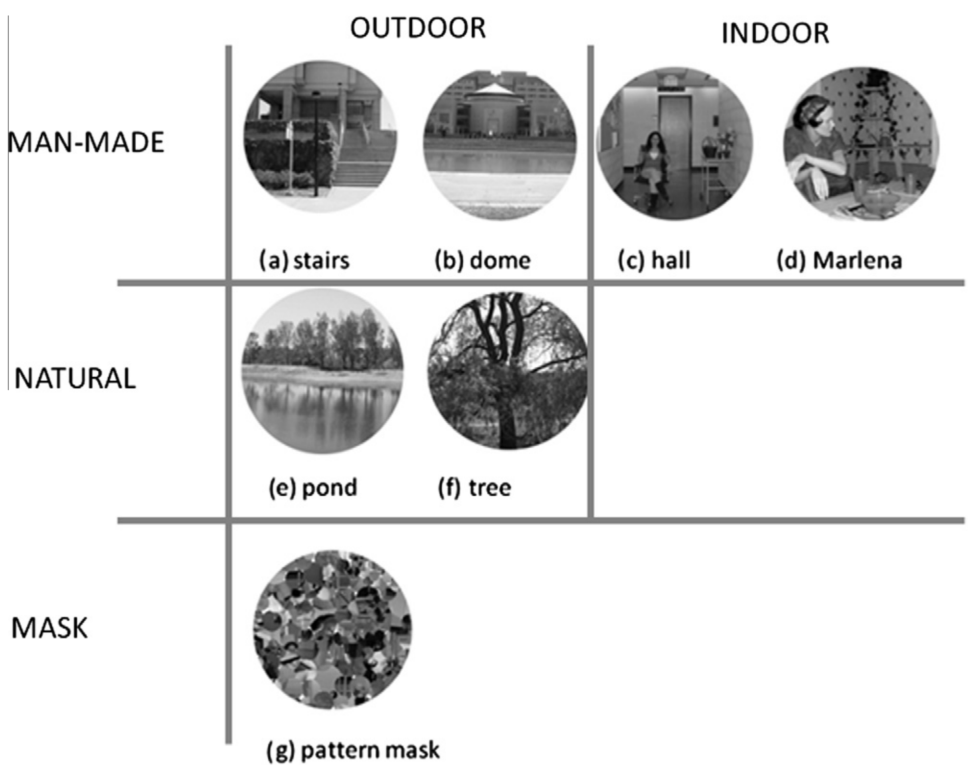

Fig. 1. The stimuli and mask used in this study. We refer to the scenes as (a) stairs, (b) dome, (c) hall, (d) Marlena, (e) pond and (f) tree throughout the text. We chose scenes that were outdoors (a, b, e, f), indoors (c and d), man-made (a–d) and natural (e and f). (g) The pattern mask used in Experiment 2 to limit the processing of the scene to the presentation duration. This mask was constructed by cropping circular bit segments of the scenes and overlaying them on top of each other.

2.2.3. Test for "Scene Upright"

The Scene Upright (SU) is the orientation of the scene when it is judged to be aligned with gravity. To measure the SU, participants were shown a scene and asked whether it was tilted to the right or to the left of the gravitational vertical or 'the direction an object would fall if it dropped'. Six color photographs were chosen as representative of scenes in general. Four of the scenes were of man-made scenes (two indoor and two outdoor) and two were of natural scenes. The scenes are shown in Fig. 1a–f. The method of constant stimuli was used. Each of the six scenes was presented six times at eleven orientations between $-5°$ and $5°$ of their "correct" orientation in $1°$ increments, resulting in a total of 396 (6 scenes $\times$ 11 orientations $\times$ 6 repetitions) presentations. Participants pressed any button on the keyboard to start the experiment. At the start of each trial, a $0.45°$ fixation point appeared against a grey background and stayed on for 100 ms after which the stimulus was presented for 400 ms. The stimulus was followed by a grey screen at which time observers pressed the button to indicate the perceived orientation of the scene relative to the vertical ('left' or 'right'). After the participant responded, the fixation point came on again and the next trial commenced. The experiment was approximately 10 min long and participants were allowed to take breaks. No feedback was given.

2.2.4. Calculating the Scene Upright and its associated standard deviation

The percentage of trials in which a scene was identified as being tilted to the right of vertical was plotted as a function of the scene orientation for each scene. An example is shown in Fig. 2. A cumulative Gaussian function was fitted to each observer's responses to determine the 50% point, i.e., the orientation at which the observer was equally likely to judge the scene as leaning to the left or right. The cumulative Gaussian was defined as:

$$y = \frac{100}{1 + e^{-(x-x_0)/b}}\% \qquad (1)$$

where x_0 corresponds to the 50% point (the point of subjective equality, PSE) and b is the standard deviation. Only the standard deviations are reported since the "Scene Upright" orientation was arbitrary for each photograph.

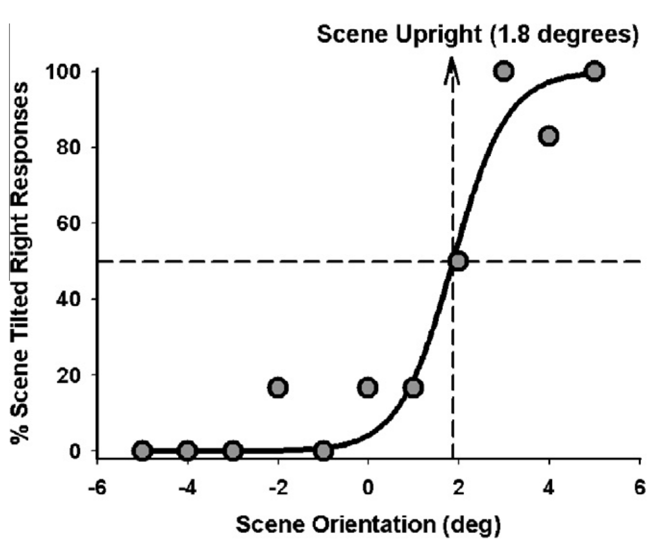

Fig. 2. Typical psychometric functions obtained from a single scene for the Scene Upright. The width or standard deviation of the curve signifies the certainty with which the observer made their Scene Upright judgment which we took as a measure of the reliability of orientation information within the scene.

2.2.5. Test for Subjective Visual Vertical

The Subjective Visual Vertical (SVV) was measured by showing the participants a line ($3.1° \times 0.45°$) superimposed on each scene and asking them whether the line was tilted to the right or to the left of the gravitational vertical. Each of the six scenes (see Fig. 1) was used as a background set at the orientations at which the effect of scene orientation on SVV are known to be maximal: ±22.5° (Dyde et al., 2006). There were 25 line orientations spanning the range from $-12°$ to $+12°$. Each scene/scene orientation/line orientation combination was repeated six times. Thus, there were six scenes and two scene orientations with 25 line orientations presented six times each in a randomized order, resulting in a total of 1800 trials.

Participants pressed any button on the keyboard to start the experiment. At the start of each trial, a $0.45°$ fixation point appeared against a grey background and stayed on for 100 ms after which the stimulus, i.e., an oriented scene with superimposed line, was presented for 400 ms. The stimulus was followed by a grey screen at which time observers pressed the button to indicate the perceived orientation of the line relative to the vertical ('left' or 'right'). After the participant responded, the fixation point came on again and the next trial commenced. This experiment took approximately one hour to complete and participants were allowed to take breaks. No feedback was given.

The percentage of times the line was identified as 'to the right' was plotted as a function of the line orientation. A sigmoidal function (Eq. (1)) was fitted to the observers' responses to determine the 50% point at each scene orientation. The angle at which the participant was most uncertain about their answer (i.e., the 50% point) was taken as the orientation of the SVV under these conditions. The SVV was obtained with the scenes oriented at ±22.5°. The difference between the SVV at these two orientations gave the "visual effect" induced by that scene on the SVV.

2.2.6. Test for the Perceptual Upright

The Oriented CHAracter Recognition Test (OCHART) technique exploits the fact that the perceived identities of some objects depend solely on their orientation (Dyde et al., 2006). Participants were shown the character 'p' at various orientations and asked whether it was a 'p' or a 'd'. The character subtended approximately $3.1° \times 1.9°$ of visual arc. Four scenes (Fig. 1a, b, e and f) were presented at orientations at which the influence of scene orientation on the Perceptual Upright is known to be maximal: ±112.5° (Dyde et al., 2006). A letter probe was presented at the center of these oriented scenes at 18 orientations spanning the range from 30° to 330° in 15 degree increments. Each scene/scene orientation/probe orientation combination was repeated six times. Thus, there were 18 probe orientations presented against 8 (4 scenes $\times$ 2 scene orientations) images presented six times in a randomized order, resulting in a total of 864 trials. Each stimulus was followed by a grey screen and participants were asked to identify the letter probe as a 'p' or a 'd' by pressing one of two buttons. The method of constant stimuli was used to find the two orientations where the character was equally likely to be perceived as a 'p' or a 'd'. Two Gaussian functions (Eq. (1)) were fitted to the observers' responses to obtain the orientations at which the character was maximally ambiguous, i.e., the p–d and the d–p transition orientations. The bisector of the two transition orientations at which the character was maximally ambiguous was taken as the orientation at which its identity was maximally unambiguous and defined as the Perceptual Upright (Fig. 3). This experiment took approximately 20 min to complete and participants were allowed to take breaks. No feedback was given. The difference between the PU at the two scene orientations were taken as the visual effect of the scene on PU.

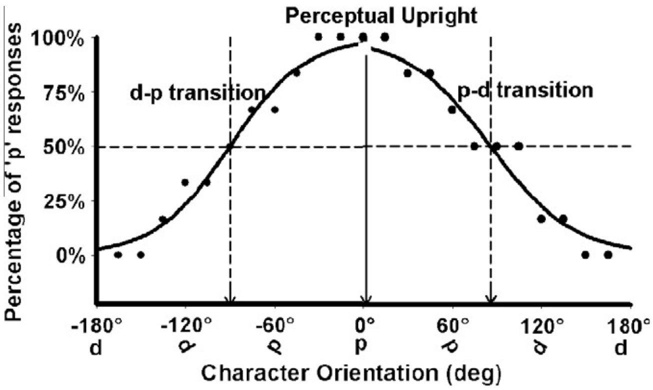

Fig. 3. Typical psychometric function obtained from a single scene for the Perceptual Upright. The orientations of maximum ambiguity of the 'p' character were found in this case to be at −90° and +85° (indicated by the downwards pointing dashed arrows). The PU is defined as being half way between these two orientations (2.5°, in this case illustrated by the downwards-pointing solid arrow).

2.3. Results

2.3.1. The Scene Upright

The standard deviation of each subject's judgment of "Scene Upright" was taken as the reliability with which viewers made their scene orientation judgment (Fig. 2). The mean standard deviation of the Scene Upright for each of the six scenes tested is plotted separately for participants tested in the SVV and the PU conditions in Fig. 4a and c respectively. Typical values varied from 0.5° to 3°. Though there was some variability across visual scenes, the standard deviations did not significantly differ across most scenes for either the group that was also tested in the SVV condition (Fig. 4a) or the group that was also tested in the PU condition (Fig. 4b). For the group that was tested in the SVV condition (Fig. 4a), the only significant difference was found between the 'dome' scene (Fig. 1b) and the 'Marlena' scene (Fig. 1d) $t(7) = -5.57$, $p = .0008$. There was also a trend towards outdoor natural scenes having larger standard deviations than outdoor man-made scenes $t(7) = -2.03$, $p = .063$. For the group that was tested in the PU condition (Fig. 4c), the standard deviations of the Scene Upright were significantly higher for outdoor natural scenes compared to the outdoor man-made scenes $t(9) = -2.73$, $p = .015$.

2.3.2. The "visual effect" of different scenes on the PU and the SVV

The "visual effect" was taken as the difference between the PUs at ±112.5° of scene orientation (see Section 2.2.6). The visual effects of the stairs, the dome, the pond and the tree on PU (see Fig. 1) were 17.6°, 20.8°, 23.9° and 11.7° respectively. The visual effect sizes were analyzed using repeated-measures ANOVA of scene vs. visual effect size. The Mauchly's test of spherecity revealed that the assumption of spherecity had been violated $\chi^2(5) = 13.35$, $p = .021$. Therefore, the degrees of freedom were corrected using the Greenhouse–Geisser correction ($\varepsilon = .627$). Results showed that there were no significant differences between the size of the visual effect across these four scenes $F(1.881, 28.215) = .437$, $p = .638$. We analyzed the visual effect of scenes on the SVV using the same method. The visual effect of the stairs, the dome, the pond and the trees, the hall and Marlena on the SVV were 21.9°, 26.3°, 16.7°, 10.4°, 17.9° and 18.8° respectively. The assumption of spherecity was again violated and we corrected for it using the Greenhouse–Geisser correction ($\varepsilon = .201$). Results revealed no significant differences among the visual effect sizes of different scenes on the SVV $F(1, 7.03) = 1.208$, $p = .308$. The visual effect of the man-made scenes on the PU was no different from that of the natural scenes ($p = .99$). However, a repeated-measures ANOVA of outdoor man-made vs. outdoor natural vs. indoor man-made revealed a significant effect of scene type on the size of visual effect on SVV $F(2, 26) = 7.60$, $p = .003$. Follow up pair-wise contrasts revealed the difference to exist between the visual effect sizes of man-made outdoor scenes vs. man-made natural scenes $t(13) = 3.26$, $p = .006$.

2.3.3. Can Scene Upright standard deviations predict the magnitude of the visual effect of that scene on SVV and/or PU?

We ran a linear regression on the mean visual effect of each scene on the SVV and the mean standard deviation of the Scene Upright for all scenes (Fig. 4b). This regression was quite a good fit ($R^2 = .78$, slope = −6.16 deg of visual effect/deg of standard deviation of Scene Upright) and the overall relationship was significant ($\beta = .88$, $p = .02$). That is, as the difficulty of judging the scene as vertical increased (larger standard deviations), the visual effect size significantly decreased. We also analyzed the PU data using a linear regression model with the standard deviation of the Scene Upright as the predictor and the visual effect of the scene on PU as the dependent variable (Fig. 4d). The overall relationship was not significant ($R^2 = .35$, $\beta = .59$, $p = .41$). That is, the PU was unrelated to how hard it was to set the scene to upright.

2.4. Discussion

Our results support the hypothesis that the certainty with which a scene is set to upright is greater for man-made scenes than for natural scenes. The standard deviations for the orientation discrimination of the natural outdoor scenes were on average significantly larger than those of the man-made outdoor scenes for one of the groups and approaching significance for the other. That is, it was more difficult to determine the orientation of a natural scene than it was to determine the orientation of an outdoor man-made scene. This may be due to the relative abundance of vertical lines in man-made structures such as buildings and stairs (Switkes et al., 1978). This is also in line with our finding that the visual effect of man-made outdoor scenes on SVV was greater than the visual effect of the natural scenes on SVV.

We also found that the greater the certainty with which a scene was set to upright, the larger the effect of that scene was on the SVV but not on the PU. This finding confirms the prediction that that the certainty with which scenes are set to upright is more predictive of the effect size of that scene on SVV (a more global measure of orientation) than on PU (a more local measure of orientation). At first glance, this finding may seem at odds with our previous finding (Dyde et al., 2006) that the PU is more influenced by the orientation of the background scene than the SVV. However, consistent with these previous findings, the visual effect of scenes on the PU was larger than the visual effect of scenes on the SVV (compare the vertical axes in Fig. 4b and d). What we were testing here was the strength of the relationship between the magnitude of the visual effect and the reliability with which the observer made their global orientation judgments. In the case of the PU, the former measure would have reflected local information whereas the latter would have reflected global information from the scene. This may explain the lack of a correlation between the PU and the SD of Scene Upright. By contrast, both measures would have reflected global information for the SVV, thus making the relationship between the SVV and SD of Scene Upright stronger.

That said, we were still surprised to find that there was no relationship at all between certainty of orientation judgments and effect size of scene on PU. We thought that this could be due to the lack of a big enough range in the standard deviations of the SU judgment to capture this potentially more subtle relationship between the certainty of orientation discrimination and PU effect size. We therefore varied the difficulty of the task by presenting the scenes using increasingly brief presentations.

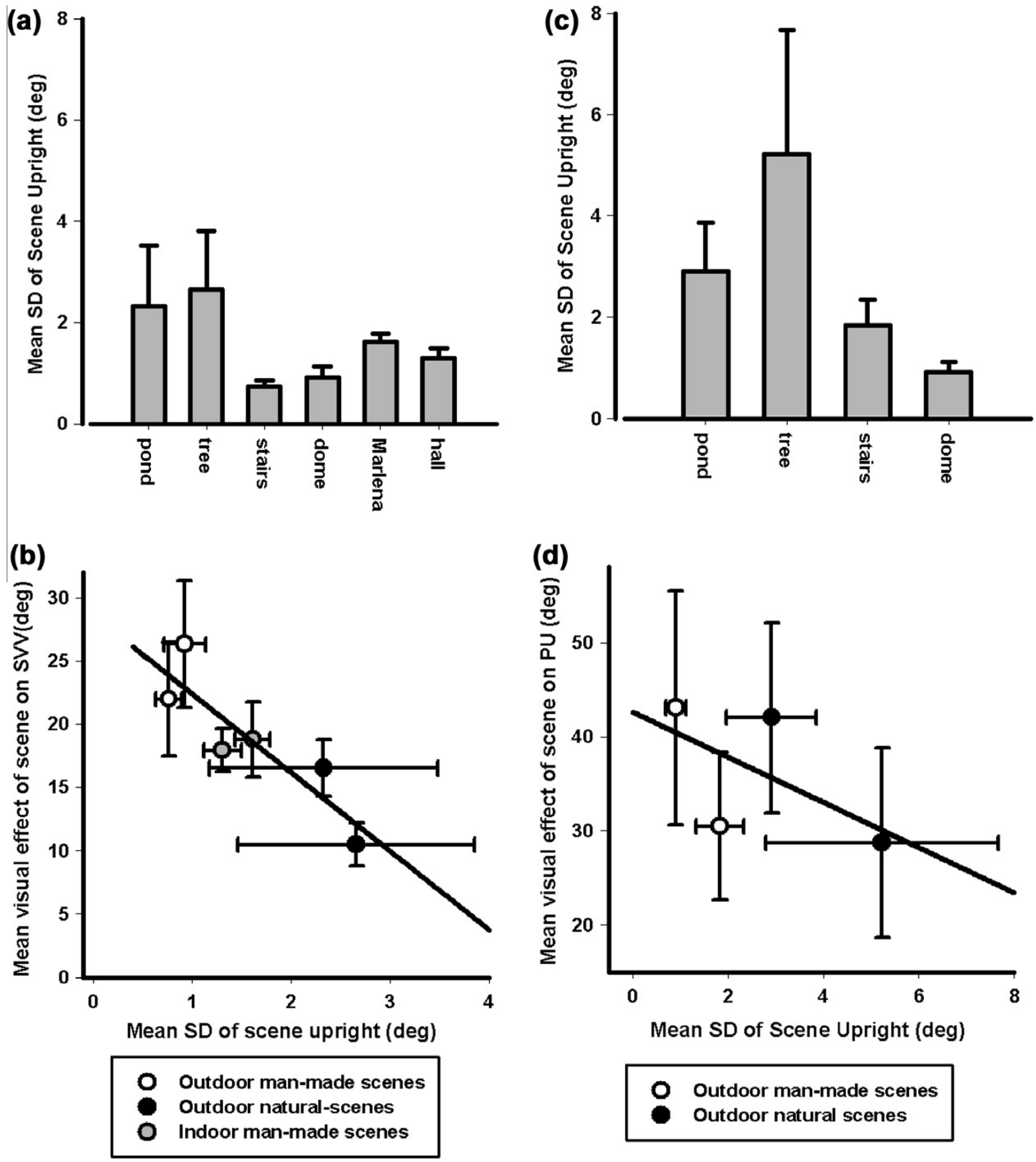

Fig. 4. (a) Mean standard deviation for each of the scenes for the group that was also tested in the SVV task. The error bars represent the between-subjects standard error for each group. The only significant difference found in this group was between the dome and the Marlena scenes ($p = .0008$). (b) Mean standard deviation of the Scene Upright is plotted against the mean visual effect on SVV for all participants. The vertical error bars represent the between-subjects standard error for visual effect size. The horizontal error bars are taken from part (a). The overall correlation was significant ($p = .02$). (c) Mean standard deviation for each of the scenes for the group that was also tested in the PU task. Natural outdoor scenes (i.e., tree and pond) have significantly larger standard deviations than the man-made outdoor scenes (i.e., stair and dome) ($p = .015$). This could be due to the fact that the mean standard deviation of the tree scene is much larger here than it is in (a). (d) Mean standard deviation of the Scene Upright is plotted against the mean visual effect on PU for all participants. The vertical bars represent the between-subjects standard error for visual effect size. The horizontal error bars are taken from part (c).The overall correlation was not significant ($p = .41$).

3. Experiment 2

3.1. Introduction

We have previously shown that the scene exerts its effects on PU within 60 ms (Haji-Khamneh & Harris, 2009). The scenes used in Experiment 1 were presented for 400 ms. Thus the OCHART task was being performed under conditions where the standard deviations were at a minimum. We therefore presented scene/probe combinations for periods of between 50 and 400 ms in order to make the task harder and to increase the range of standard deviations.

3.2. Methods

3.2.1. Participants

A group of eight observers (three female and five male) between the ages of 24 and 47 years volunteered in the timed Scene Upright test and the timed OCHART experiment. All observers had normal or corrected-to-normal vision. All observers gave their informed consent as required by the Ethics Guidelines of York University which complies with the Declaration of Helsinki.

3.2.2. Test for the effect of exposure duration on the standard deviation of the Scene Upright

We chose a subset of the images from the previous experiment including one natural scene, one outdoor man-made scene and one indoor man-made scene (Figs. 1b,c,f). Stimuli were presented on a 21 inch Dell P1110 Trinitron monitor with a resolution of 28.3 pixels/cm and a mean luminance of 43.2 cd/m^2 at a refresh rate of 120 Hz (i.e., 8.33 ms/frame). Stimuli were composed one frame at a time and presented using Psyscope 1.2.5 (Cohen, Macwhinney, Flatt, & Provost, 1993). A pattern mask was constructed in Adobe Photoshop CS 2.0 by randomly sampling circular portions of the stimulus at different orientations (see Fig. 1g). These circular portions had radii ranging from 0.5 to 1 cm and were randomly overlaid on top of each to form a pattern mask.

Because the timing of the stimulus and mask presentation on the computer screen was critical for this experiment we verified the timing of the stimuli carefully. The timing of the stimulus presentation on the computer screen was calibrated using a photodiode viewed on a Tektronix TDS 224 oscilloscope. We adjusted the stimulus presentation duration as specified in Psyscope until the desired oscilloscope time measurements were consistently achieved over a 50 trial block.

Participants pressed any button on the keyboard to start the experiment. At the start of each trial, a 0.45° fixation point appeared against a grey background and stayed on for 100 ms (12 frames) after which an oriented scene was presented for either 6, 12, 24 or 48 frames (i.e., 50–400 ms). The scene was followed immediately by a pattern mask for 100 ms. The mask was followed by a grey screen at which time observers pressed the button to indicate the perceived orientation of the scene (‘right’ or ‘left’). After the participant responded, the fixation point came on again and the next trial commenced. There were a total of 792 trials (3 scenes $\times$ 11 orientations $\times$ 4 exposure durations $\times$ 6 repetitions) in this experiment which took roughly 15 min to complete.

3.2.3. Testing the effect of exposure duration on the visual effect size on PU

Participants completed the OCHART task at the same four exposure durations using the same three scenes (Figs. 1b, c, f) as used in the SU test described above. The scene was presented at ±112.5°, orientations known to maximize the effects of scene orientation on the Perceptual Upright. The probes were presented at 18 orientations between 30° and 330° in 15 degree increments. Thus there were 36 (2 $\times$ 18) probe/background combinations which were each presented six times in a randomized order with presentation times of 50, 100, 200 and 400 ms resulting in a total of 2592 (3 scenes $\times$ 2 scene orientations $\times$ 18 probe orientations $\times$ 4 presentation times $\times$ 6 repetitions) presentations. This experiment was approximately one hour long and the participants were allowed to take breaks. No feedback was given.

Participants pressed any button on the keyboard to start the experiment. At the start of each trial, a 0.45° fixation point appeared against a grey background and stayed on for 100 ms (12 frames) after which a probe/background stimulus combination was presented for either 6, 9, 18 and 60 frames (i.e., 50, 100, 200 or 400 ms). The probe/background stimulus was followed immediately by the same pattern masks as in the Scene Upright task for 100 ms. The mask was followed by a grey screen at which time observers pressed the button to indicate the perceived identity of the symbol (‘p’ or ‘d’). After the participant responded, the fixation point came on again and the next trial commenced.

We took the difference between the Perceptual Upright at ±112.5° as the visual effect of the scene.

3.3. Results

3.3.1. Influence of exposure duration on Scene Upright standard deviation

As expected, the shorter exposure times dramatically increased the range of standard deviations for judgments of Scene Upright. While the standard deviations from Experiment 1 ranged between 0.5° and 3°, the standard deviations in this experiment ranged up to 16°. We fitted a three-parameter exponential decay function to the standard deviation as a function of the exposure duration for the Scene Upright judgments for all participants (Fig. 5a). The three-parameter exponential decay function was defined as

$$y = y_0 + a\,e^{-x/\tau} \tag{2}$$

where a is the size of the exponential, y_0 is the plateau level to which it falls, x is the exposure duration and τ is the time constant of decline. As the exposure duration increased, the mean standard deviation exponentially and significantly decreased ($p = .007$, $R^2 = .38$). The time constant was 40.5 ms.

We compared the variation in the size of the visual effect on PU with the size of the standard deviation of Scene Upright for each exposure duration. In Fig. 5b, we plot the magnitude of the mean visual effect of all scenes as a function of the mean standard deviation of Scene Upright of all scenes at each exposure duration. Even when timing was varied for both the Scene Upright and the OCHART task and the range of standard deviations was thus significantly increased, the mean standard deviation was still not a significant predictor of the size of the visual effect on PU($p = .45$, $R^2 = .058$).

3.4. Discussion

While reducing the exposure duration somewhat increased the range of standard deviations for the discrimination of the Scene Upright, the standard deviations were still not a reliable predictor of the size of the visual effect of the scene on PU. We conclude that the lack of a correlation between the visual effect of a given background and the strength of the visual cues to upright that it contained were not due to a ceiling effect and that there is no relationship between the size of standard deviation for Scene Upright and the magnitude of visual effect of a scene on the Perceptual Upright over the range we tested here. The range tested comprises naturalistic scenes with exposure durations as low as 50 ms which is essentially below threshold for evoking a visual effect at all (Haji-Khamneh & Harris, 2009). The amount a scene can influence the Perceptual Upright does not seem to depend on the strength or reliability of orientation cues within the scene once it is visible.

4. General discussion

In this study, we found that while the effect size of scene orientation on SVV can be predicted from the certainty with which participants make their SU judgments, the same is not true of PU. Why is the strength of scene orientation cues important to one measure of upright and not the other?

4.1. Subjective Visual Vertical vs. Perceptual Upright

The Subjective Visual Vertical (SVV) and the Perceptual Upright (PU) measure are related but distinct directions of perceived upright. Historically, the direction of upright has been assessed by

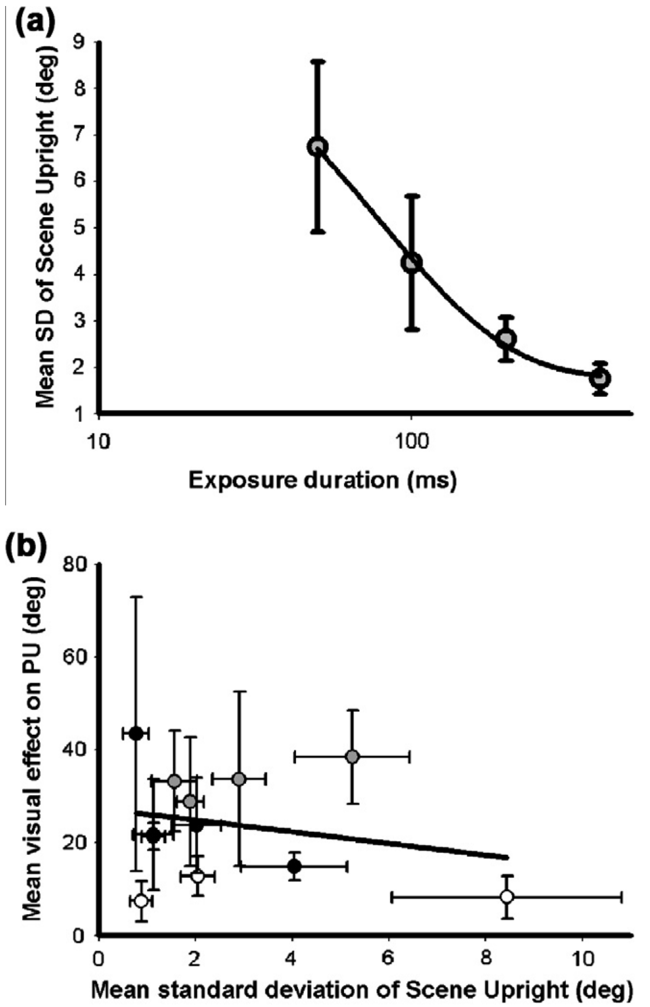

Fig. 5. (a) The mean standard deviation of SU for each scene and for all participants plotted as a function of exposure duration. The grey dots represent the mean standard deviation of SU for each exposure duration. The error bars represent the between-subjects standard errors. We fitted a three-parameter exponential decay function to this plot and the time constant was found to be 40.5 ms. (b) The mean visual effect size of scenes on PU plotted as a function of the mean standard deviation for Scene Upright. The black, grey and white circles represent the data for the dome, Marlena, and tree scenes respectively. The data for each scene is averaged across participants at each of the exposure durations. The vertical error bars represent between-subject standard errors for the visual effect and the horizontal error bars the between-subject standard errors of the standard deviation for each and at each exposure duration.

setting a line to the apparent vertical and the visual and vestibular cues that contribute to determining it have been thoroughly investigated over the years using a variety of visual cues and body orientations (e.g., Asch & Witkin, 1948b; Bischof, 1974; Guerraz, Poquin, & Ohlmann, 1998; Howard & Childerson, 1994; Koffka, 1935; Mittelstaedt, 1983, 1986; Witkin, 1949). However, experiments using other paradigms, such as the shape-from shading technique (Jenkin, Jenkin, Dyde, & Harris, 2004) and ambiguous figures (Rock & Heimer, 1957; Rock et al., 1994), have found a direction of up that is distinct from the SVV. Therefore, Dyde et al. (2006) developed the OCHART (Oriented CHAracter Recognition Test) task (see Section 3.2) which captures PU, a direction of upright that is more important for perceptual recognition than the SVV.

While PU is more related to the preferred orientation of letters and objects, the SVV is more related to spatial orientation and balance (Dyde et al., 2006) and has been put forward as a sensitive clinical test for assessing utricular function (Böhmer & Mast, 1999a, 1999b). In a previous study, we showed that the visual cues which convey mostly spatial and geometrical layout took about the same amount of time to exert their effect on object processing (as measured by PU) as cues concerning learned relationships (Haji-Khamneh & Harris, 2009). This difference between PU and SVV suggests that the SVV might be less sensitive to the global orientation information concerning spatial orientation available in a scene and thus some scenes may affect it more than others. This is in line with studies that have shown a dissociation between orientation tasks that are sensitive to global vs. local information (Corbett, Handy, & Enns, 2009).

4.2. Natural vs. man-made scenes

In this study we found that the effect of tilted scenes on the SVV was larger for man-made scenes than it was for natural scenes. We also found that the inter-subject variability for judging the Scene Upright appears to be larger for natural scenes than for man-made scenes as indicated by larger errors in Fig. 4a and b for the tree and pond scenes. We speculate that this may be because natural scenes contain relatively less orientation information compared to man-made scenes.

Scenes belonging to each category share a similar "spatial envelope" which is defined as the spatial structure which can be used to describe the 'shape' of the scenes (Oliva & Torralba, 2001; Torralba & Oliva, 2002, 2003). According to this theory, the spatial envelope of natural landscapes contain more textured zones and undulating contours whereas man-made scenes contain more straight horizontal and vertical lines. For example, the hall scene (Fig. 1c) contains a long and narrow space with many horizontal and vertical lines including perspective. In contrast, the tree scene (Fig. 1f) is filled with dense textures and few if any straight lines or perspective cues. Thus, perhaps the reason why man-made scenes are more capable of exerting an effect on SVV is because the vertical lines and perspective cues help increase the reliability and usefulness of spatial orientation information to the viewer. Of course, the natural scenes were also capable of exerting a smaller effect on the SVV. The extraction of the spatial envelope means that the brain is able to rapidly and accurately utilize summary statistics from the scene such as the average orientation of peripheral elements (Parkes, Lund, Angelucci, Solomon, & Morgan, 2001). Thus perhaps natural scenes are still able to exert an effect on SVV using summary statistics from the spatial envelope of the scene which may be less reliable due to the lack of orientation information.

5. Conclusion

We have shown that the reliability with which viewers judge the orientation of a given scene is predictive of the size of the effect that scene exerts on the SVV but not on the PU. This lends further support to the notion that there exist multiple directions of up and that each of these perceived directions is employed by the brain to carry out different types of perceptual tasks. We have also shown that man-made scenes with more orientation information influence our perception of orientation to a larger extent than natural scenes. This may be due to the abundance of global intrinsic information (i.e., frame cues) and is a testament to the importance of global orientation information of a scene in the perception of up. Thus, according to these findings, changing the orientation of the overall visual scene would disrupt us most while performing a spatial navigation task (such as flying) in an urban setting rather than performing a perceptual recognition task (such as reading) in a natural setting. Further experiments are required to further illuminate the type of visual orientation information that is extracted from different types of scene and that is able to affect the PU.

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References

Asch, S. E., & Witkin, H. A. (1948a). Studies in space orientation. 1. Perception of the upright with displaced visual fields. *Journal of Experimental Psychology, 38*(3), 325–337.

Asch, S. E., & Witkin, H. A. (1948b). Studies in space orientation. 2. Perception of the upright with displaced visual fields and with body tilted. *Journal of Experimental Psychology, 38*(4), 455–477.

Bischof, N. (1974). Optic-vestibular orientation to the vertical. In H. H. Kornhuber (Ed.), *Handbook of sensory physiology* (pp. 309–330). Berlin-Heidelberg, New York: Springer-Verlag.

Böhmer, A., & Mast, F. (1999a). Assessing the otolith function by the subjective visual vertical. *Annals of the New York Academy of Sciences, 871*, 221–231.

Böhmer, A., & Mast, F. (1999b). Chronic unilateral loss of otolith function revealed by the subjective visual vertical during off center yaw rotation. *Journal of Vestibular Research Equilibrium & Orientation, 9*(6), 413–422.

Cohen, J., Macwhinney, B., Flatt, M., & Provost, J. (1993). Psyscope – An interactive graphic system for designing and controlling experiments in the psychology laboratory using Macintosh computers. *Behavior Research Methods Instruments & Computers, 25*(2), 257–271.

Corbett, J. E., Handy, T. C., & Enns, J. E. (2009). When do we know which way is up? The time course of orientation perception. *Vision Research, 49*(1), 28–37.

Dyde, R. T., Jenkin, M. R., & Harris, L. R. (2006). The subjective visual vertical and the perceptual upright. *Experimental Brain Research, 173*(4), 612–622.

Guerraz, M., Poquin, D., & Ohlmann, T. (1998). The role of head-centric spatial reference with a static and kinetic visual disturbance. *Perception and Psychophysics, 60*, 287–295.

Haji-Khamneh, B., & Harris, L. R. (2009). How long does it take for intrinsic and extrinsic cues to exert their effect on the perceptual upright? *Vision Research, 49*, 2131–2139.

Howard, I. P., & Childerson, L. (1994). The contribution of motion, the visual frame, and visual polarity to sensations of body tilt. *Perception, 23*, 753–762.

Jenkin, H. L., Jenkin, M., Dyde, R. T., & Harris, L. R. (2004). Shape-from shading depends on visual, gravitational, and body-orientation cues. *Perception, 33*, 1453–1461.

Jolicoeur, P. (1985). The time to name disoriented natural objects. *Memory & Cognition, 13*, 289–303.

Koffka, K. (1935). *Principles of Gestalt psychology*. London: Lund Humphries.

Kovač, J., Peer, P., & Solina, F. (2008). Automatic natural and man-made scene differentiation using perspective geometrical properties of the scenes. In G. Rozinaj (Ed.), *International conference on systems, signals and image processing IWSSIP '08* (pp. 507–510), Bratislava, Slovakia, June 2008.

Maki, R. H. (1986). Naming and locating the tops of rotated pictures. *Canadian Journal of Psychology, 40*, 368–387.

McMullen, P. A., & Jolicoeur, P. (1992). Reference frame and effects of orientation on finding the tops of rotated objects. *Journal of Experimental Psychology – Human Perception and Performance, 18*(3), 807–820.

Mittelstaedt, H. (1983). A new solution to the problem of the subjective vertical. *Naturwissenschaften, 70*, 272–281.

Mittelstaedt, H. (1986). The subjective vertical as a function of visual and extraretinal cues. *Acta Psychologica, 63*, 63–85.

Mittelstaedt, H. (1999). The role of the otoliths in perception of the vertical and in path integration. *Annals of the New York Academy of Science, 871*, 334–344.

Oliva, A., & Schyns, P. G. (2000). Diagnostic colors mediate scene recognition. *Cognitive Psychology, 41*(2), 176–210.

Oliva, A., & Torralba, A. (2001). Modeling the shape of the scene: A holistic representation of the spatial envelope. *International Journal in Computer Vision, 42*, 145–175.

Parkes, L., Lund, J., Angelucci, A., Solomon, J. A., & Morgan, M. (2001). Compulsory averaging of crowded orientation signals in human vision. *Nature Neuroscience, 4*, 739–744.

Rock, I., & Heimer, W. (1957). The effect of retinal and phenomenal orientation on the perception of form. *American Journal of Psychology, 70*, 493–511.

Rock, I., Schreiber, C., & Ro, T. (1994). The dependence of two-dimensional shape perception on orientation. *Perception, 23*, 1409–1426.

Switkes, E., Mayer, M. J., & Sloan, J. A. (1978). Spatial frequency analysis of the visual environment: Anisotropy and the carpentered environment hypothesis. *Vision Research, 18*, 1393–1399.

Torralba, A., & Oliva, A. (2002). Depth estimation from image structure. *IEEE Pattern Analysis and Machine Intelligence, 24*, 1226–1238.

Torralba, A., & Oliva, A. (2003). Statistics of natural images categories. *Network: Computation in Neural Systems, 14*, 391–412.

Vailaya, A., Jain, A., & Zhang, H. J. (1998). On image classification: City images vs. landscapes. *Pattern Recognition, 31*(12), 1921–1935.

Witkin, H. A. (1949). Perception of body position and the position of the visual field. *Psychological Monographs, 63*, 1–63.