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Keywords

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Independent effects of local and global binocular disparity on the perceived convexity of stereoscopically presented faces in scenes

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Abstract. Evidence suggests that experiencing the hollow-face illusion involves perceptual reversal of the binocular disparities associated with the face even though the rest of the scene appears unchanged. This suggests stereoscopic processing of object shape may be independent of scene-based processing of the layout of objects in depth. We investigated the effects of global scene-based and local object-based disparity on the compellingness of the perceived convexity of the face. We took stereoscopic photographs of people in scenes, and independently reversed the binocular disparities associated with the head and scene. Participants rated perceived convexity of a natural disparity (“convex”) or reversed disparity (“concave”) face shown either in its original context with reversed or natural disparities or against a black background. Faces with natural disparity were rated as more convincingly convex independent of the background, showing that the local disparities can affect perceived convexity independent of disparities across the rest of the image. However, the apparent convexity of the faces was also greater in natural disparity scenes compared to either a reversed disparity scene or a zero disparity black background. This independent effect of natural scene disparity suggests that the ‘solidity’ associated with natural scene disparities spread to enhance the perceived convexity of the face itself. Together, these findings suggest that global and local disparity exert independent and additive effects upon the perceived convexity of the face.

Keywords:



1 Introduction

Due to their horizontal separation, our left and right eyes receive different perspective views of the same scene. These binocular image differences (binocular disparities) are known to provide a powerful depth cue, stereopsis, which can produce remarkable impressions of 3-D relief (Wheatstone 1838). The horizontal angular disparity (δ) for a given depth difference (Δd) between two points can be approximated by:

$$\delta \approx \frac{\Delta d \times I}{D^2},$$

where I is the interocular distance and D is the distance from the observer to the point of fixation. This disparity increases with the depth difference (Δd).

When viewing natural scenes, abrupt changes in disparity, such as those occurring at occluding contours, provide information about the depth between objects. Gradual changes, such as those that occur across smoothly connected surfaces, also provide disparity-based information about 3-D shape. Specifically, first and second-order derivatives of disparity provide information about the slant and curvature of surfaces, respectively (Orban et al 2006). Thus, binocular disparity provides information about both the 3-D layout of objects separated in depth and the 3-D shape of those individual objects.

There is evidence of separability between the stereoscopic processing of local 3-D shape and global layout. The hollow-face illusion is the mistaken perception of a convex face with a nose pointing towards you when viewing the concave side of a cast or mask of a face. When viewed in the context of a natural scene, this perceived depth reversal of the cast/mask does not appear to alter the perception of either the scene

or the shapes of other objects within that scene. Yellott (1981) and Yellott and Kaiwi (1979) demonstrated that the disparity-defined depths associated with the rest of the scene (eg those provided by a random-dot stereogram or a Pulfrich pendulum) are not perceptually reversed when seen at the same time as the hollow-face illusion. These demonstrations appear to rule out the possibility of ‘mental pseudoscopy’, the reversal of left and right eyes views by the brain. This would reverse all disparity-defined depth order (ie disparity would imply concave objects are convex, near objects are far and vice-versa). Matthews et al (2011) reported that increasing the magnitude of the disparities in a hollow-face stimulus also increased the perceived depth of the associated illusory convex face percept, even though the sign of these disparities was consistent with a concave surface. Thus the hollow-face illusion appears to involve the perception of locally reversed depth, where the magnitude of this depth is still a function of the disparity magnitude.

Further evidence for a degree of independence between local and global stereoscopic processing comes from observations using a pseudoscope. Pseudoscopes, as defined by Wheatstone (1852), present what would normally be seen by the left eye to the right eye and vice-versa. When viewing natural landscapes through a pseudoscope, Stratton (1898) observed that: “The landscape seen under these conditions shows pseudoscopic reversals, but not so often an apparent change of convex into concave objects, and vice-versa, as a transposition of the relative distances of objects from the observer” (page 635). There are other reports of the converse situation reviewed in Wallin’s (1905) chapter on pseudoscopy where ‘grounds’ do not reverse while ‘free’ objects upon them do. These converging lines of evidence demonstrate that stereopsis is not always globally consistent.

To further investigate this separability, we took stereoscopic photos of human models in naturalistic settings and independently reversed the disparities associated with the person’s face and the background. We then examined the effects of these stereoscopic image manipulations on subjective ratings of the perceived convexity of the face using a scale from 1 ‘definitely concave’, to 9 ‘definitely convex’. This measure was intended to reflect our primary concern with the subjective three-dimensional ‘sticky outness’ of the face rather than to provide a precise measure of relative depth. We expected reversed-disparity faces to, like a hollow mask or pseudoscopically presented face, generally appear convex. However, we predicted perceived convexity for the reversed-disparity face to be less convincing than for the natural-disparity face as there is often a marked instability in perceptual depth reversals (Papathomas and Bono 2004; Wheatstone 1852). We had no clear expectations as to the effect of global disparities on the perceived convexity of the face, but expected this to provide clues to the relationship between local and global processing of binocular disparities.

2 Methods

2.1 Stimuli

Stereoscopic photographs were taken of eight different models, each in a different naturalistic setting. These natural settings included the inside of a bar, a kitchen, and at an outside table. Lighting was not strictly controlled and varied greatly between the different photographs. This was intended to ensure generalisability and ecological validity. The faces and torsos of the eight different models (seven male and one female) were always visible (although in one case the torso was partially obscured by a table top). Images were taken using a Fujifilm Finepix Real 3-D W1 stereo camera (http://www.fujifilm.com/products/3d/camera/finepix_real3dw1/) with an inter-lens separation of 77 mm (all pictures were taken with automatic disparity adjustment). While this camera is not designed for science, it provides a way of easily capturing compelling real-world stereoscopic images which can be used to look at the gross effects of pseudoscopic reversal

(our aim here was not to perfectly simulate human stereoscopic geometry). Individual left and right stereo half-images were 960 pixels wide by 720 pixels high and subtended 10.65×8.02 deg of visual angle when viewed at a distance of 1.5 m.

6 sets of stimuli corresponding to the 2 levels of face disparity type (natural or reversed) and 3 of background disparity type (none/black, natural, or reversed) were created from each of the 8 different original stereoscopic photographs. Figure 1 shows the pairs of half images for the full set of six conditions generated from the original stereoscopic photograph of one model.

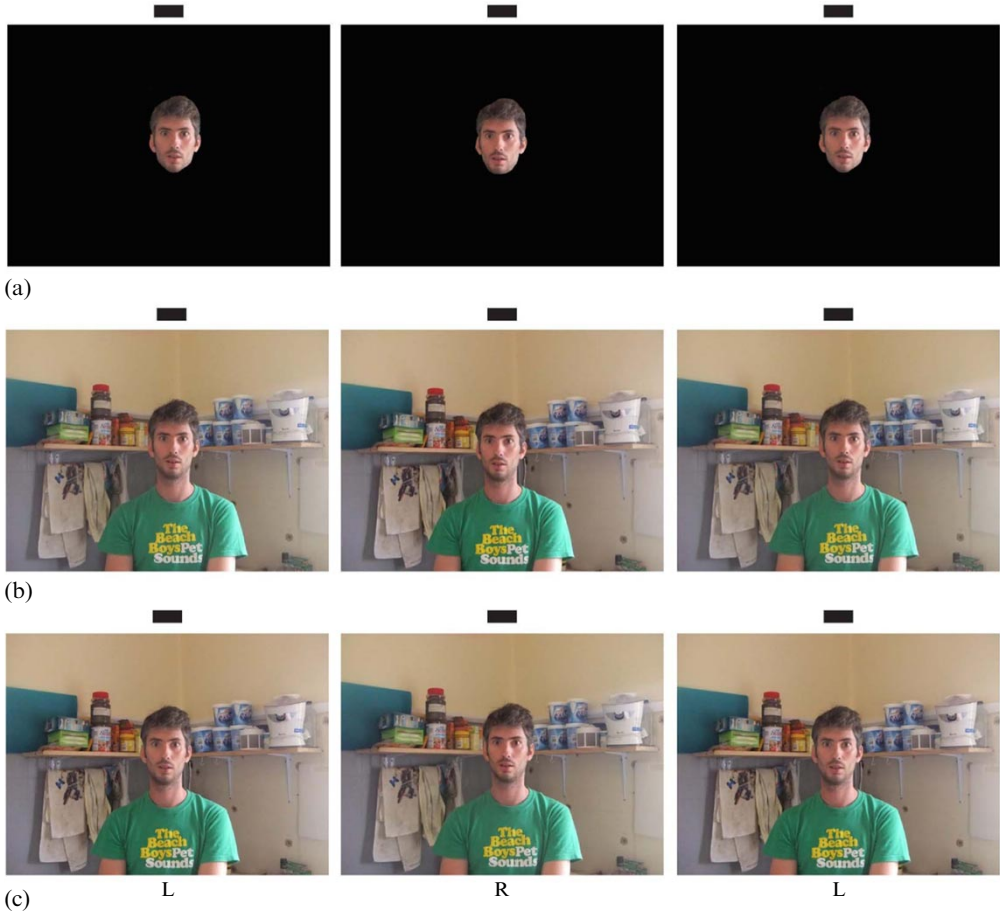


Figure 1. [In colour online, see <http://dx.doi.org/10.1068/p7187>] These stereoscopic photographs show either an isolated head superimposed on a black scene or the same head in the context of the natural scene in which it was taken. When the L–R pairs in the first and second columns are parallel-fused, the binocular disparities represent a convex face (natural face disparities) in either (a) a black scene, (b) a natural 3-D scene, or (c) a reversed 3-D scene. When the R–L pairs in the second and third columns are parallel-fused, the binocular disparities represent a hollow face (reversed face disparities) in either (a) a black scene, (b) a reversed 3-D scene, or (c) a natural 3-D scene. Swap descriptions corresponding to L–R and R–L pairs for cross fusion.

In order to reverse the disparities associated with the head and the scene separately, the heads were isolated using the magnetic lasso tool in Adobe Photoshop CS4 and cut into an independent layer. This allowed the left image of the head to be superimposed on the right image scenery and moved into the exact position occupied by the right image of the head and vice-versa as well as allowing the heads to be presented in isolation against a black background.

2.2 Procedure

This study was approved by the University of Wollongong Human Research Ethics Committee (HE11/049) and all participants gave informed consent prior to starting the experiment. Participants were forty-one undergraduate psychology students from the University of Wollongong who received course credit for their participation. They each completed 2 face disparity type (natural/convex, reversed/concave) \times 3 scene disparity type (none, natural, reversed) \times 8 stimuli models trials. This produced a total of 48 trials which were presented in a random order. Stereoscopic pairs of images were displayed at a distance of 1.5 m on a Wheatstone stereoscope which is described elsewhere (Matthews et al 2011). Image presentation was controlled using Matlab and Psychtoolbox (Brainard 1997; Pelli 1997). In each trial participants rated their certainty whether the face was convex or concave on a scale of 1 ‘definitely concave’, to 9 ‘definitely convex’. A rating of five indicated they were unsure. The stereoscopic displays remained visible until the participants had responded.

The dependent variable was essentially a categorical convex/concave judgment, with an associated confidence rating. We expected this to provide greater sensitivity than a simple categorical judgment, given that we expected the face to be generally perceived as convex. We favoured a rating of certainty over a measure of quantitative depth, as the quantitative depth of perceptual depth reversals can be unstable. Convex and concave percepts are sometimes found to alternate (Papathomas and Bono 2004; Wheatstone 1852); also informal reports collected by Matthews et al (2011) suggested that participants find matching the depth of an actual convex face to that of a reversed-disparity illusory face extremely difficult. We therefore reasoned an index of subjective certainty was appropriate and of value in itself in that it captured the subjective impression of solidity that is a primary contribution of stereopsis over and above any impression of relative depth (Barry 2009; Sacks 2010).

3 Results

Data were initially collapsed across the 8 stimuli models and analysed using a 2 face disparity (natural, reversed) \times 3 scene disparity (none, natural, reversed) repeated-measures ANOVA (see table 1 for descriptive statistics and figure 2 for a graphical representation of the data). The assumption of sphericity was satisfied. All skewness and kurtosis statistics were reasonably consistent with a normal distribution (ie between +1 and -1), except for the natural face with natural scene disparity condition. This was leptokurtic (statistic = 2.975) and negatively skewed (statistic = -1.78), due to the high certainty of convexity associated with this condition. A nonparametric re-analysis was found to yield the same pattern of results as the ANOVA. Thus, since the results of the ANOVA appeared robust to any violation of the normality assumption, they are reported here.

Table 1. Cell means (M) and standard errors (SE).

Face disparity	Scene disparity Total							
	none		reversed		natural		Total	
	M	SE	M	SE	M	SE	M	SE
Reversed	5.45	0.16	5.54	0.19	6.33	0.14	5.81	0.08
Natural	6.04	0.15	6.12	0.11	6.89	0.18	6.31	0.08
Total	5.74	0.11	5.82	0.11	6.61	0.12		

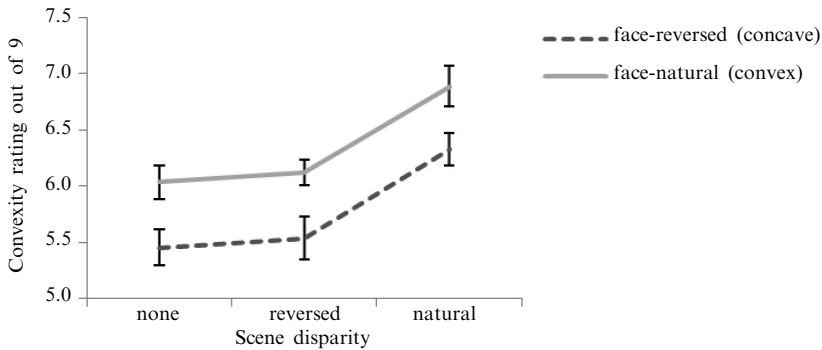


Figure 2. Ratings for both natural- and reversed-face-disparity conditions (1 = ‘certain concave’; 5 = ‘uncertain/falt?’; 9 = ‘certain convex’). The ratings are also shown as a function of scene-disparity type: none, reversed, or natural. Error bars indicate the standard error of the mean with subject error variance removed.

The means of all conditions were greater than 5 indicating that the faces were generally perceived as convex regardless of whether the face disparities were natural or reversed. The ANOVA revealed a main effect of face disparity ($F_{1,39} = 13.36$, $p = 0.001$, $\eta_p^2 = 0.255$) with natural-disparity (convex) faces being more confidently rated as convex than reversed-disparity (concave) faces.

There was also a main effect of scene disparity ($F_{2,78} = 11.69$, $p < 0.001$, $\eta_p^2 = 0.231$). Difference contrasts, which compared each level, except the first, with the mean of the previous levels, were performed. The order of scene conditions was specified as (i) no scene disparity, (ii) reversed-scene disparity, and (iii) natural-scene disparity after visual inspection of the data (please see figure 2). There was no significant difference between the no-scene-disparity and the reversed-scene-disparity conditions ($F_{1,39} = 0.20$, $p = 0.656$, $\eta_p^2 = 0.005$), but confidence that the face appeared convex was significantly higher in the natural-scene-disparity condition ($F_{1,39} = 21.39$, $p < 0.001$, $\eta_p^2 = 0.354$). The face-disparity by scene-disparity interaction was non-significant ($F_{2,78} = 0.01$, $p = 0.993$, $\eta_p^2 < 0.001$).

An items analysis was performed with data collapsed across participants. This showed the same pattern of results with main effects of face disparity ($F_{1,7} = 26.75$, $p = 0.001$, $\eta_p^2 = 0.793$), and scene disparity ($F_{2,14} = 38.33$, $p < 0.001$, $\eta_p^2 = 0.846$) and a non-significant interaction ($F_{2,14} = 0.005$, $p = 0.995$, $\eta_p^2 = 0.001$). As for the subjects analysis, the difference between the no-scene-disparity and reversed-scene-disparity conditions was non-significant ($F_{1,7} = 0.42$, $p = 0.539$, $\eta_p^2 = 0.056$). However, the difference between these two conditions and the natural-scene disparity was again significant ($F_{1,7} = 137.78$, $p < 0.001$, $\eta_p^2 = 0.952$). This shows that the effects reported should generalise across scenes and models as well as participants.

4 Discussion

In this study we investigated the effects of local/object-based and global/scene-based disparity information on 3-D face perception by independently reversing the disparities associated with the face and/or its background context. Faces were generally perceived as convex, even when the local face disparities were reversed (ie local disparity indicated that the face was concave). This finding is consistent with the well-documented hollow-face illusion and may have been due to: (i) the availability of monocular depth cues (eg texture- and perspective-based cues) which continue to indicate that the face was convex even after left–right image reversal; (ii) a general preference for convexity (eg Johnston et al 1992; Langer and Bülthoff 2001; Liu and Todd 2004); and/or (iii) our familiarity with faces as convex (Gregory 1973). While all the faces were generally seen

as convex, natural-disparity (convex) faces were more confidently rated as convex than reversed-disparity (concave) faces. Thus, it appears that selectively reversing the disparities associated with a face resulted in a cost in terms of perceived-convexity compared to natural-disparity faces. This is consistent with perceptual depth reversals being less stable than veridical depth percepts (Papathomas and Bono 2004; Wheatstone 1852).

We also observed an independent effect of scene disparities: natural, unreversed, scene disparities were found to enhance the perceived convexity of the face irrespective of whether the face disparities were reversed or not. These independent effects suggest that the available depth information in these images is being processed separately, without a requirement that the overall 3-D representation be internally consistent (a notion which is consistent with the recent intrinsic constraint model of depth-cue integration—eg Tassinari et al 2008).

The effect of global disparities on local face perception is intriguing. However, in order to understand these findings, it should be emphasised that our dependent variable was essentially a qualitative judgment, which should not be mistaken for a quantitative index of depth. The word ‘stereopsis’ is derived from the Greek words *stereos* and *opsis* and literally translated as ‘solid vision’. It seems possible that natural-scene disparities produce a general impression of solidity, which then spreads, affecting the subjective appreciation of the convexity of discrete objects (or in this case faces) contained within the scene. This effect may help when, for example, [composing](#) figures into backgrounds for three-dimensional movies and would suggest that seeing the hollow face in a natural environment may facilitate the illusion compared to it being presented in a completely darkened room where only the mask was visible. Whether this spread of solidity affects perceived depth quantitatively is a potentially important unanswered question worthy of further study. This may be best performed using veridically convex objects with natural and reversed backgrounds, given some of the problems with using illusorily convex stimuli outlined in the methods.

In conclusion, we observed independent and additive effects of the binocular disparity of both the local face and the global scene on the perceived convexity of stereoscopic photographs of faces. The independent nature of these effects suggests different underlying processes. While natural local disparities associated with the face itself may contribute directly to its perceived convexity, the disparities associated with the overall scene can also enhance the face’s perceived convexity independently of the disparity of the face itself.

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