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When does illusory contour formation depend on contrast polarity?

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Abstract

Performance on a shape discrimination task was used to investigate when, and to what extent, illusory contour formation depends upon contrast polarity. It was found that shape discrimination performance was markedly worse when contrast polarity reversed within inducers, changing abruptly at the corners, than between inducers. This difference was most evident for stimulus durations from 80–320 ms and corresponded to a doubling of the critical stimulus duration for shape discrimination to reach threshold. At longer stimulus durations the performance was at ceiling level for all configurations regardless of the distribution of contrast polarity variations. These data reconcile previous findings that contrast polarity reversals within inducers disrupt illusory contrast formation at an effective stimulus duration of 120 ms but not 1 s. We conclude that the processes involved in the perception of illusory figures are sensitive to contrast polarity variations in a manner constrained by grouping and completion of the inducing elements into occluded regions.

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1. Introduction

It has been widely accepted that illusory contours are equally salient in configurations consisting of inducers of the same or varying contrast polarity (Fig. 1a). These observations are consistent with prominent computational models of illusory contour formation that focus on hard-wired neural mechanisms sensitive to the orientation and contrast magnitude of inducing edges and line ends but insensitive to their contrast sign (Dresp, Salvano-Pardieu, & Bonnet, 1996; Grossberg, 1994; Heitger & von der Heydt, 1993; Shapley, Caelli, Grossberg, Morgan, & Rentschler, 1990).

However, two recent studies claim that illusory contour strength is significantly impaired in configurations with contrast polarity variations. He and Ooi (1998a, 1998b) reported that a new type of illusory contour, Illusory-O is affected by contrast polarity variations in that the contrast polarity of its juxtaposed inducing elements needs to be of the same polarity, i.e. both elements must either be positive or negative in contrast polarity (Fig. 1b, left panel). Illusory-O contours are

much less salient or almost absent in configurations where the juxtaposed inducing elements vary in contrast polarity (Fig. 1b, right panel). Such contrast polarity variations presumably interfere with amodal surface completion between inducing elements which as a consequence impairs illusory contour formation in these configurations (He & Ooi, 1998b). Similarly, Spehar (1999, 2000) has shown that boundary formation in Kanizsa-type illusory figures is seriously degraded when contrast polarity reverses at the intersections of orthogonally oriented edges within each inducer (Fig. 1c). Illusory contours are much weakened in these configurations despite the contrast sign of collinear edges being distributed in a very similar way to either the single polarity or standard mixed polarity configuration (Fig. 1a). These observations suggest the importance of processes that go beyond grouping of spatially separated collinear edge segments. He and Ooi (1998a, 1998b) and Spehar (2000) agree in suggesting that the processes involved in the perception of illusory figures are sensitive to contrast polarity variations in a manner constrained by processes related to grouping and completion of the inducing elements into occluded as well as occluding regions.

In contrast to these findings, Victor and Conte (2000) reported no decrease in illusory contour strength in

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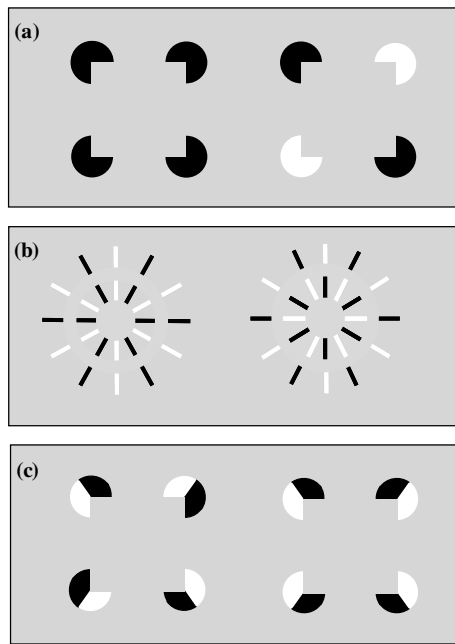


Fig. 1. (a) Illusory contours appear equally salient in configurations with inducers of single contrast polarity (left panel) or mixed contrast polarity. (b) Illusory-O configurations: illusory contours appear more salient in the left panel where the distribution of inducing elements of opposite contrast polarity does not interfere with amodal completion of the inducing elements behind the illusory (occluding) O-configuration. (c) Mixed polarity configurations in which each individual inducer contains segments of opposite contrast polarity positioned at the intersections of orthogonally oriented inducing line segments: illusory contour strength is impaired in both configurations regardless of whether contrast polarity varies or is preserved between spatially separated collinear segments (left and right panels, respectively).

comparable configurations, either under static or flickering conditions. Victor and Conte (2000) used aspect ratio discrimination task (“portrait” vs. “landscape”) and indexed illusory contour strength by the reduction in threshold aspect ratio when an illusory contour was present compared to when it was absent (inward and outward facing inducers respectively). In order to account for the differences in the observed effect of contrast polarity they emphasize the differences in task properties between their study and those of He and Ooi (1998a, 1998b) and Spehar (2000). They suggest as “the most interesting possibility for the discrepancy in results” that “there is a distinction between a low-level process that extracts contours, and a higher-level processes that extracts scene organization”. They argue that such a distinction would account for the absence of polarity effects in the task used by Victor and Conte (2000) but not in tasks “weighted by overall scene organization” (He & Ooi, 1998a, 1998b; Spehar, 1998, 1999). Furthermore, Victor and Conte (2000) suggested that had they used another shape task (for example thin vs. fat judgments as in Ringach & Shapley, 1996) as a function of relative phase, the results would

have been similar to those found with the aspect ratio task.

While it is true that He and Ooi (1998a, 1998b) did not use an objective shape-based measure of illusory contour strength, Spehar (1999, 2000) did. The latter studies utilized the suggested objective measure of illusory contour strength based on discrimination of “thin” vs. “fat” illusory shapes. Contrary to Victor and Conte’s suggestion, the results showed that illusory contour strength depends critically on the distribution of contrast polarity reversals in the inducing configuration.

The reason for the absence of contrast polarity effects in Victor and Conte’s (2000) study might lie in the much longer stimulus duration used in their study: static and flickering configurations were presented for 1 s compared to 120 ms used by Spehar (1999, 2000). Using a backward masking technique, Ringach and Shapley (1996) identified two different phases of illusory contour completion. The first phase (revealed by using local masks) takes approximately 117 ms, presumably reflecting the time taken for the detection of local features such as corners, endpoints and boundary segments. A second phase (revealed by using global masks) lasts for an additional 140–200 ms during which local information is integrated into a global percept.

It is possible that, with shorter stimulus presentation, Victor and Conte (2000) would have found more pronounced effects of contrast polarity on aspect ratio discrimination. Closer inspection of their results reveals higher aspect ratio discrimination thresholds in configurations where contrast polarity changes at corners within individual inducers (Fig. 1c) compared to configurations with uniform inducers of opposite contrast polarity (Fig. 1a, right panel). The difference was not significant but was consistent in direction with the effects observed by Spehar (1999, 2000).

In order to test this conjecture, we performed a direct comparison of both thin–fat shape discrimination and aspect ratio discrimination performance at different stimulus exposure times. The stimulus configurations used in thin–fat shape discrimination and portrait–landscape aspect ratio discrimination are depicted in Fig. 2a and b respectively.

The number of inducing collinear edges of positive or negative contrast polarity is the same in all configurations, but their spatial arrangements within individual inducers differ. The top row shows the standard mixed polarity configurations where the spatially separated collinear edge segments are of the opposite contrast polarity, but there are no spatial variations in contrast polarity within individual inducers. The bottom two rows show the configurations introduced by Spehar (2000) where each inducer contained regions of positive and negative contrast polarity. In these configurations contrast polarity varies within inducers and changes at the points at which inducing edges of different orienta-

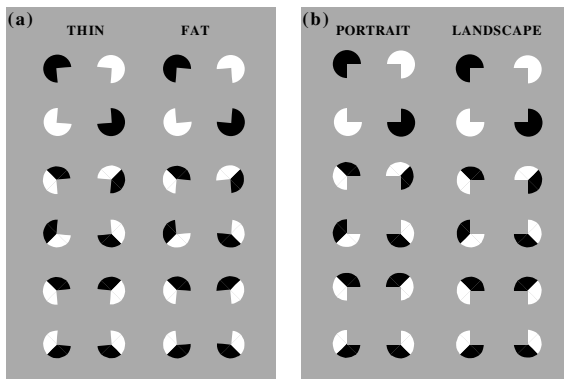


Fig. 2. (a) “Thin” and “fat” illusory shapes in which the inducing elements lying on the two diagonals of the standard illusory square configuration are rotated in the opposite direction (either clockwise or counterclockwise) around their centres (adapted from Ringach & Shapley, 1996). (b) “Portrait” and “landscape” illusory configurations used in this study (see text for additional details).

tion intersect. Spehar (2000) found that thin–fat shape discrimination performance was markedly poorer in such configurations compared to either the single polarity or standard mixed polarity configuration.

2. Methods

2.1. Equipment and stimulus generation

Stimuli were generated using a Cambridge Research Systems Video Stimulus Generator (CRS VSG2/2), running in a Pentium based system. All stimulus presentation and data collection was computer controlled. Stimulus configurations were displayed on an EIZO colour monitor (Flexscan T562-T) with a resolution of 800×600 pixels and a refresh rate of 100 Hz. From the viewing distance of 57 cm, one pixel subtended 2.4 min of visual arc. The mean luminance of the screen was 40 cd/m^2 .

2.2. Stimuli

The basic stimulus design consisted of four inducers of radius 1.2° placed at the corners of a square of side 6.0° , corresponding to a support ratio of 40%. Fat–thin experimental stimuli were created by rotating the each inducer by $\pm 2^\circ$, as schematically depicted in Fig. 2a. Inducers lying on the same diagonal were rotated in the same direction. Portrait–landscape stimuli, schematically presented in Fig. 2b, were created by moving the centres of the inducers by ± 2 pixels, giving a log aspect ratio of 0.0267. The inducers were composed of regions of $\pm 33\%$ contrast with the respect to the grey background. In the portrait–landscape condition, the four inducers were randomly jittered together in position

relative to the fixation point by up to 10 pixels so that the absolute position of any given inducer could not be used as a cue to discriminate the stimuli.

2.3. Procedure

Observers viewed the display binocularly at the distance of 57 cm. The method of constant stimuli was used with 20 presentations for each of seven durations: 20, 40, 80, 160, 320, 640 and 1280 ms. Observers were required to report the order of stimulus presentation across two temporal intervals (i.e. fat–thin or thin–fat for the fat–thin condition; portrait–landscape or landscape–portrait for the portrait–landscape condition).

Prior to the beginning of the experiment the subjects were shown the examples of either “thin” and “fat” shapes or “portrait” and “landscape” shapes, as appropriate, illustrated on a piece of paper which remained in front of them throughout the experimental session. They were then given a short training session. In addition, 20 practice trials were added to the beginning of each experimental session and were not included in data analysis.

Subjects were asked to fixate carefully the fixation mark, which remained at the centre of the screen throughout each trial. The press of a button initiated the sequence of events depicted in Fig. 3. A blank grey screen containing only the fixation mark appeared for 1000 ms, followed by the first illusory figure, followed directly by a 250 ms mask. The mask was followed by a blank screen for 500 ms, followed by the second illusory figure, followed again by a 250 ms mask. Circular masks of radius 1.2° , composed of binary random noise elements (check size, 2 pixels; contrast 33%), were used.

The subject indicated her/his response by pressing one of two buttons, which initiated the following trial. On each trial the duration of presentation of the first and second illusory figures was the same, but between trials the duration varied under computer control according to the method of constant stimuli.

2.4. Observers

A total of 36 UNSW undergraduate volunteers observers participated in the experiments, six in each of the

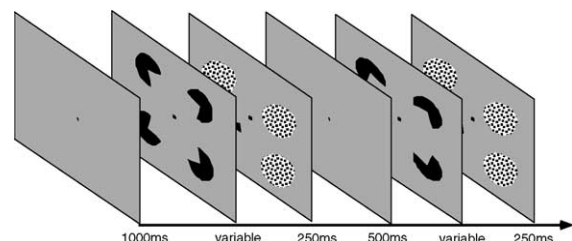


Fig. 3. Temporal characteristics of the experimental sequence.

experimental conditions depicted in the three rows (the type of contrast polarity configuration) and the two panels (“thin–fat” shape discrimination or “portrait–landscape” aspect ratio discrimination task) of Fig. 2. The volunteer observers were naïve to the purpose of the experiments and had very limited experience as observers in psychophysical studies. All observers had normal or corrected to normal vision.

3. Results and discussion

Fig. 4a and b show the average correct identifications at different exposure duration obtained in thin–fat and aspect ratio shape discrimination respectively. Data points represent the average correct identifications as a function of stimulus duration. Weibull functions of the form

$$p(\alpha) = 1 - 0.5 \exp[-(\alpha/\alpha_{th})^\beta], \quad (1)$$

were fitted to the average data, where α_{th} is the threshold at which the estimated performance reaches 81.6% and β the slope of the psychometric function (Watson, 1979). The statistical reliability of the estimated parameters was evaluated by using bootstrap simulations (Efron & Tibshirani, 1993). The mean and standard error of estimated threshold parameters from 200 simulations are shown separately in Table 1.

As the estimated thresholds in Table 1 indicate, the average threshold duration for both tasks was shortest in the standard mixed contrast polarity configuration, around half of those in the two “non-uniform” configurations. The detrimental effect of contrast polarity in configurations where it changes at points at which inducing edges of different orientation intersect is obvious only at shorter stimulus durations.¹ The performance in all three configurations asymptotes after 600 ms, indicating that Victor and Conte (2000) did not observe the effect of contrast polarity simply because the duration of the stimuli in their study was too long (1 s).

Victor and Conte (2000) acknowledged an apparent subjective decrease in the saliency of illusory squares in the two “non-uniform” configurations. We measured these apparent differences in the saliency of illusory contours in the three types of configurations by using a paired comparison procedure as a subjective measure of illusory contour strength. As expected, the illusory contours in the “non-uniform” configuration where contrast polarity changed at the corners were consistently judged as less salient compared to configurations with uniform inducers. However, in configurations where such contrast polarity changes, while still present within the inducers, are shifted from the intersections of orthogonally oriented edges (along one of the component L-junctions’ arms), both saliency of illusory contours and shape discrimination performance is largely restored (Spehar, 2000). Also, the placement of such changes at a different orientation in respect to the intersection of the orthogonal inducing edges has a similar restorative effect on both illusory contours’ saliency and shape discrimination performance in such configurations (Spehar, 2000).

Taken together, these results suggest that illusory contours exhibit sensitivity to contrast polarity variations and that this sensitivity can be assessed by using both objective and subjective indices of illusory contour strength. These lines of evidence are hard to reconcile with the view that a distinction between low-level contour-based and higher-level scene-based mechanisms parallels the absence or presence of contrast polarity

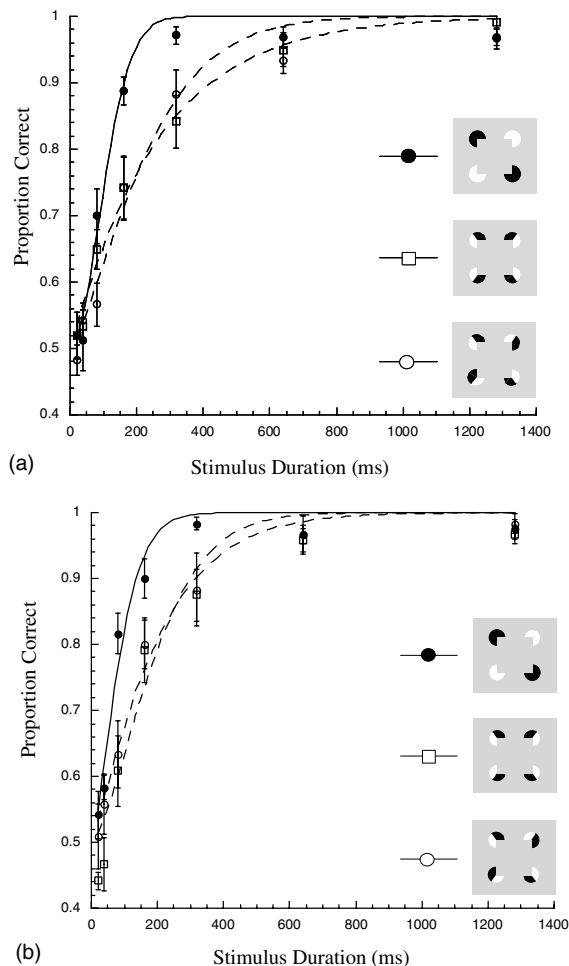
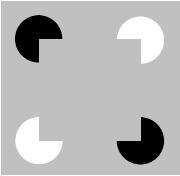
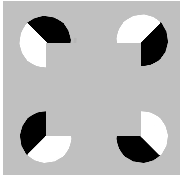
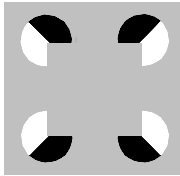


Fig. 4. Average results and psychometric fits in the three experimental conditions: the “standard mixed polarity” condition, in which contrast polarity varied across inducers (filled circles); the two non-uniform conditions in which contrast polarity varied within each inducer (empty squares and empty circles): (a) thin–fat shape discrimination task; (b) portrait–landscape aspect ratio discrimination task.

¹ The data from three practiced observers who participated in all conditions (not shown here) confirm this pattern of results.

Table 1

The mean and standard error of threshold parameters from Fig. 4, estimated using bootstrap simulations

Shape discrimination task		Polarity condition		
				
Thin-fat	Mean (ms)	127.1	265.2	249.1
	SE (ms)	5.4	18.3	13.7
Portrait-landscape	Mean (ms)	97.6	217.2	208.0
	SE (ms)	5.7	11.9	13.5

effects in illusory contour formation. Instead we show that, at stimulus durations longer than 600 ms, shape discrimination can be performed irrespective of the strength or saliency of the illusory contours while, at shorter stimulus durations, we demonstrate a robust effect of contrast polarity on illusory contour formation.

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