Effect of Image Articulation on Perceptual Transparency

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Abstract

When a pair of surfaces is partially covered by a transparent filter, the ratios of cone excitations for the surfaces viewed directly are almost identical to those when the surfaces are viewed through the filter. We have previously shown that in simulations of Mondrian-like patterns partially covered by filters the invariance of the cone-excitation ratios predicts psychophysical performance in discrimination tasks.[1] In this paper we investigate whether the number of surfaces in the display affects the strength of the transparency percept when observers are required to discriminate between displays with almost perfect invariance of cone-excitation ratios and similar displays where the ratios have been perturbed by noise. We find that discrimination performance increases with the increasing number of surfaces in the display. We also find that noise added to the S-cone class alone did not affect discrimination performance.

Introduction

Perceptual constancy is the tendency for objects to give rise to the same perceptual experience despite the fact that their physical characteristics may change. Visual constancies provide an explanation of how we can recognise objects that change as they move or as we move around them. The colour signal from an object changes as it moves, as the illumination changes, as a shadow passes across it, or as a transparent filter covers it. The stable perception under changing environmental conditions allows the visual system to correctly recognise the original colour of the object.

It has been demonstrated that observers can discriminate between a Mondrian-like pattern partially covered by a transparent filter and a similar pattern viewed directly, based simply on the spatial arrangement of colour signals from the two stimuli.[1-3] It has been proposed that such discrimination performance can be explained by a constancy in the ratios of cone-excitations for two or more opaque surfaces when viewed directly and when viewed through a transparent filter.[1,4] It is not clear, however, what role will be played by image articulation in the generation of transparent percepts. In particular, although it is already established that transparency perception requires certain figural constraints.[6,7] and some computational models for transparency perception make use of X-junctions in an image,[8,9] this paper addresses the issue of whether the strength of the transparency percept for an image will be influenced by the number of opaque surfaces that are partially covered by a transparent filter.

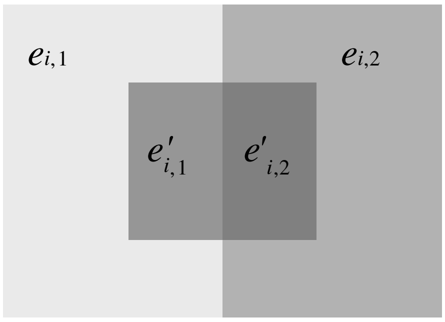

Figure 1. Two opaque surfaces (bigger rectangles) covered by a homogeneous transparent filter. $e_{i,1}$, $e_{i,2}$, are the opaque surfaces' cone excitations and $e'_{i,1}$, and $e'_{i,2}$ the filtered surfaces' cone excitations.

Consider a simple image composed of two opaque surfaces partially covered by a homogeneous transparent filter (Figure 1). The cone excitations $e_{i,j}$ of cone class i (where $i \in \{L, M, S\}$ denoting long-, medium, and short-wavelength-sensitive cone classes) for a surface j seen directly are given by

$$e_{i,j} = \int E(\lambda)\, R(\lambda)\phi_i(\lambda)\, d\lambda \tag{1}$$

where $E(\lambda)$ is the illuminant spectral power distribution, $R(\lambda)$ is the surface reflectance, and ϕ_i are the cone sensitivity functions.

Whereas $e'_{i,j}$ is the cone excitation for surface j covered by a filter and is given by

$$e'_{i,j} = \int E(\lambda)\, R(\lambda)\, [T(\lambda)\,(1 - r)^2]^2 \phi_i(\lambda)\, d\lambda \tag{2}$$

where $T(\lambda)$ is the filter transmittance and r is the internal reflectance of the filter.

The principle of invariance of cone-excitation ratios states that the ratio between two opaque surfaces and the ratio between the same surfaces covered by a filter is almost statistically invariant. This can be expressed by the equation

$$e_{i,1}/e_{i,2} = e'_{i,1}/e'_{i,2}\,. \tag{3}$$

In previous studies we tested equation 3 by performing numerical simulations and psychophysical experiments. In a numerical simulation[5] we found that for achromatic filers Equation 3 holds perfectly, whereas for chromatic filters (defined by Gaussian-shaped transmission properties with standard deviation σ in the range [5nm, 200nm]) the equivalence was found to approximately hold for many filter parameters.

The equivalence depends upon the transmission properties of the filter. For filters with broad spectral transmission properties the equivalence was strong whereas for filters with narrow spectral transmission properties the equivalence was much weaker. Our hypothesis is that Equation 3 defines the chromatic constraints that are necessary for perceptual transparency. The Monte-Carlo simulation is consistent with this hypothesis since it seems reasonable to assume that the perceptual transparency of coloured filters with broad transmission spectra would be stronger than those with narrow transmission spectra. The hypothesis that the chromatic constraints required for transparency perception are defined by Equation 3 has been tested by a series of psychophysical experiments.[1,2,10] In one of these experiments, observers viewed simulations of two illuminated Mondrians in temporal sequence in a 2-alternative-forced-choice (2AFC) paradigm. Each Mondrian was partially covered by a transparent filter. In one presentation, the filter was a simulation of a physically plausible transparent filter. In the other presentation, the filter was a modification of the physically plausible filter and was obtained by making the short-, medium-, and long-wavelength-sensitive cone excitation ratios of the filtered colour signal closer to being invariant, or farther from being invariant, with respect to the physically plausible filter. Observers were asked which of the two presentations simulated a homogeneous transparent filter lying on the Mondrian. We found that filters generating ratios closer to invariance are preferred.

Does the number of surfaces (and thus the number of invariant ratios) have an influence on the perception of transparency? If we assume that invariance holds then we can reasonably expect that for a sample of surfaces and filters the average ratio will tend towards the population mean of 1 as the sample size increases. If the visual system computes the spatial-average ratio as a cue for transparency perception, then the strength of the percept would be expected to increase (on average) for stimuli containing larger numbers of surfaces.

Experimental

Aims

In this paper, we investigate whether the degree of invariance (and hence the degree of perceptual constancy) is dependent on image articulation. In particular, we test the hypothesis that increasing the number of surfaces in an image makes the average ratios tend towards invariance and thus makes the filter more likely to be perceived to be transparent. Our experi-mental design also allows the relative contributions of short-, medium-, and long-wavelength cone classes to transparency perception to be studied.

Methods

In order to test our hypothesis we performed a psychophysical experiment in which the image articulation was manipulated by varying the number of opaque surfaces composing the stimulus. The number of surfaces composing the stimulus pattern was either 2, 4, 6, or 8 (Figure 2).

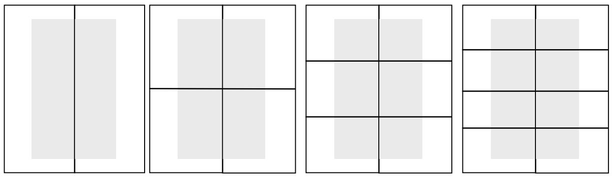

Figure 2. Schematic representation of stimuli used in the experiment. Stimuli varied according to the number of opaque surfaces (2, 4, 6, and 8) present in each image. Lighter areas represent opaque surfaces, darker areas represent transparent filters.

Stimulus patterns contained Mondrian patterns (4.52 × 3.58 degrees of visual angle) partially covered by simulated transparent filters (3.38 × 2.95 *deg*). The colours of the filters were generated using a simple physical model of transparency[5] and the parameters of the model were selected so that the stimuli were perceptually transparent. The cone-excitation ratios in these *physical* stimuli were not exactly invariant but were always close to invariance. These stimuli were compared with noisy *comparison* stimuli where the colours of each transparent patch of the transparent patch were subject to up to 4% noise. In each trial the two stimulus patterns (the one covered by the physical filter and the one covered by the comparison filter) were presented sequentially in random order.

In a 2AFC paradigm, a transparent filter (*test stimulus*) whose cone-excitation ratios were approximately invariant and partially covering a Mondrian was compared with (a) simulations where cone-excitation ratios for all three cone classes were perturbed; (b) simulations where cone-excitation ratios for individual cone classes were perturbed; (c) simulations where cone-excitation ratios for pairs of cone classes were perturbed.

It is clear that we cannot perfectly isolate the cone-class mechanisms using this experimental paradigm. However, although the M- and L-cone responses are highly correlated[11] it is reasonable to expect that noise added to the L- and M-cone classes will have only a small effect on the S-cone class, and vice versa. For example, when noise is added to the L-cone class there will also be an effect on the M-cone class but the effect on S-cone class will be relatively small. If transparency perception is mediated mainly by the L- and M-cone classes alone then we expect a relatively small change in performance when noise is added to the S-class alone. We also expect the task to be easier when we add noise to both L- and M-cone classes than when we add noise to only one of these classes simply because the amount of noise added is greater.

In total there were 7 different combinations. Three naïve observers participated in the experiment. All of them had normal or corrected-to-normal visual acuity and had been assessed as colour-normal on the Farnsworth-Munsell 100-Hue test. None of them was aware of the nature and purpose of the experiment.

Observers were asked which of the two stimulus patterns simulated a uniform transparent filter over opaque surfaces.

Each presentation lasted two seconds on screen. The inter-stimulus interval lasted one second. The next trial was presented two seconds after the subject indicated their response with a button press. Each trial was repeated three times for a total of 168 trials (3 (repetitions) × 7 (combinations of cone-classes perturbed) × 4 (number of surfaces) × 2 (randomised presentation order)). The complete session of 168 trials was repeated twice. A training run of twenty trials was given before each session and subsequently discarded. No feedback was provided during the experiment.

Our hypothesis is that if the perception of transparency is based upon the spatially averaged invariance of cone-excitation ratios, subjects' discrimination performance will increase with the number of surfaces in the pattern.

Results

Performance was quantified by the discriminability index *d prime* (*d'*) of signal detection theory. Values of *d'* equal to zero indicate chance performance (*d'* greater than zero indicates preference for the *test stimulus*; *d'* less than zero indicates preference for the comparison).

We found that observers were able to discriminate between simulations of filters with ratios close to invariance and similar simulations where noise had been added to violate the invariance. We also found that discrimination performance increased with the number of surfaces in the display for filters generating invariant ratios against filters where the invariance had been violated by adding noise (Figure 3).

We also found that when the test stimulus was compared with simulations where noise had been added selectively to the individual cone classes, or to specific combinations of cone classes, observers' discrimination performance was almost always above chance except when the noise was added to the S-cone class alone.

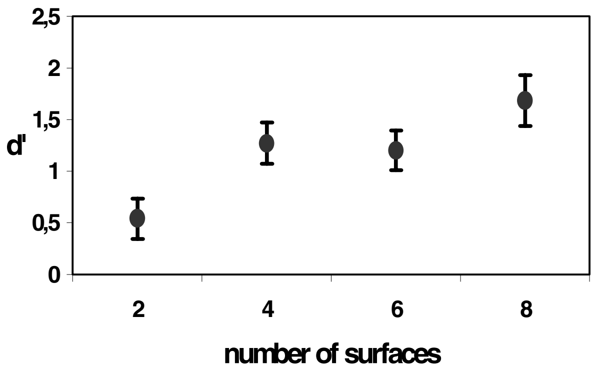

Figure 3. Mean values of d' as function of number of surfaces composing the stimulus patterns.

Conclusions

Our hypothesis was that with an increased number of surfaces there would be a corresponding increase in the number of pairs of surfaces from which invariant cone-excitation ratios could be recovered. For computational models of perceptual transparency that make use of X-junctions and T-junctions[9,12] the number of X-junctions also increases with the number of surfaces in the image. We found a general trend that discrimination performance in our task increased with increasing number of surfaces.

We are aware that in our experimental design we did not fully control the variable image complexity. In fact, in our design varying the number of surfaces also corresponded to varying the number of different cone-excitation ratios in the image. It would be interesting to test whether keeping constant the number of surfaces and varying the number of different cone-excitation ratios would lead to the same results.

It is likely that the number of surfaces is one of several factors that could affect the strength of psychophysical cues; we might reasonably expect other factors to include the variance[13] of the surfaces and their spatial relationships. For real scenes we would expect many additional factors (such as surface specularity and the degree of spatial uniformness of surfaces) to be involved.[14,15]

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Biography

Caterina Ripamonti received her B.A. degree in Experimental Psychology from the University of Trieste, Italy in 1998. She started her Doctoral degree at Keele University in England and then moved to the Colour and Imaging Institute at the University of Derby, England. Her doctoral dissertation is concerned with the perception of transparency. Her primary research interests are: colour vision, surface perception, spatiochromatic statistics of natural scenes, and binocular vision.