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Stereopsis and binocular rivalry are based on perceived rather than physical orientations

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ABSTRACT

Binocular rivalry is an intriguing phenomenon: when different images are displayed to the two eyes, perception alternates between these two images. What determines whether two monocular images engage in fusion or in rivalry: the physical difference between these images or the difference between the percepts resulting from the images? We investigated that question by measuring the interocular difference of grid orientation needed to produce a transition from fusion to rivalry and by changing those transitions by means of a superimposed tilt illusion. Fusion was attested by a correct stereoscopic slant perception of the grid. The superimposed tilt illusion was achieved in displaying small segments on the grids. We found that the illusion can change the fusion–rivalry transitions indicating that rivalry and fusion are based on the perceived orientations rather than the displayed ones. In a second experiment, we confirmed that the absence of binocular rivalry resulted in fusion and stereoscopic slant perception. We conclude that the superimposed tilt illusion arises at a level of visual processing prior to those stages mediating binocular rivalry and stereoscopic depth extraction.

1. Introduction

When we look at objects, their visual appearance do not necessarily reflect their exact physical characteristics. This is because visual awareness is the culmination of multiple computational steps involving transformations of the neural representations of the objects' retinal images. Some of those steps entail contrasting operations that embody powerful context effects – one object's appearance is affected by other objects in its vicinity. These contrasting operations are functionally important and integral to normal visual processing, but they can also produce beguiling visual illusions. Consider, for example, the object attribute of color. Patterns of light wavelengths reflected from surfaces are transduced by three pools of cones broadly tuned to three ranges of wavelength (Dartnall, Bowmaker, & Mollon, 1983). In turn, information about surface color is extracted by an initial contrast between these pools (Mollon, 1982) followed by a second contrast that occurs between the chromatic signal at a specific location and the chromatic context around it. Thus, when two physically identical patches are viewed, they can sometimes appear colored differently because of the chromatic induction that has contrasted the color of the patches with the color contexts around the patches. Using chromatic induction, it is also possible to produce two perceptually identical surface colors that, in fact, reflect distinct patterns of wavelength to the eyes, producing startling color illusions (Shevell & Kingdom, 2008). Illusions like this provide a nifty mean for studying stages of processing in vision. Take, for example, the case of two physically identical stimuli that appear different in color because of induction. What happens if those two stimuli are presented one to each eye? Will they fuse (because they match physically) or will they rival (because they are dissimilar perceptually)? The answer is that they engage in binocular rivalry (Andrews & Lotto, 2004; Hong & Shevell, 2008). Conversely, physically different stimuli can fuse if chromatic induction causes them to appear identical. It appears, then, that rivalry and fusion are decided after the level of processing at which chromatic induction transpires. While this question has been answered for color, a similar question remains open for orientation.

Orientation is an important visual attribute that forms the basis for high level visual tasks such as object recognition (Marr, 1982). Oriented contours are extracted by integrating local activity from aligned contrast-computing cells (Hubel & Wiesel, 1962). Orientations at neighboring or superimposed locations are then contrasted. This computation can generate several distinct illusions of tilt. One is a *center–surround contrast*: the orientation of contours within a central patch appear rotated several degrees away from

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their true orientation when the patch is surrounded by an annulus of contours all tilted at an orientation different from the contours in the central patch (Blakemore, Carpenter, & Georgeson, 1970; Julesz & Tyler, 1976). A second illusion is a *superimposed tilt illusion* wherein the two orientations are displayed simultaneously at the same location (Blake, Holopigian, & Jauch, 1985; Gibson & Radner, 1937).

Rao (1977) reported that center–surround contrast disappears when the surround is suppressed from awareness by a rivalrous high contrast patch, but he provided no quantitative measures of this effect. A few years later, Wade (1980) showed that Rao's report could actually be explained by a 50% interocular transfer of the center–surround repulsion. Wade provided quantitative evidence that the repulsion survives rivalry suppression, suggesting that orientation contrast between center and surround occurs before the level of rivalry suppression. Partial interocular transfer can be interpreted as follows: the repulsion is the sum of two center–surround repulsion effects at monocular and binocular levels. The binocular repulsion does transfer between the eyes while the monocular does not. However, such an interocular transfer was not confirmed in another study (Walker, 1978).

The superimposed tilt illusion has been extensively measured (Gibson & Radner, 1937; O'Toole & Wenderoth, 1977; Over, Broerse, & Crassini, 1972): it leads to a similar repulsion as the center–surround contrast. To the best of our knowledge, it has not been studied in binocular rivalry conditions. The superimposed tilt illusion is very likely related to the Zöllner illusion (Zöllner, 1860). In the Zöllner illusion, the perceived orientation of long lines is influenced by orientation of superimposed short lines (*inducers*, see Fig. 1a). For large angles (50–90°), the superimposed tilt illusion takes the form of a reduction of perceived angles (indirect effect: Gibson & Radner, 1937; O'Toole & Wenderoth, 1977). Lau (1922) and Squires (1956) reported that the orientation deviation produced in the Zöllner illusion could produce stereoscopic depth when orientation is different between eyes. Others have tried but failed to find depth produced from illusory orientation differences in such conditions (Julesz, 1971; Ogle, 1962) but none provided any quantitative measurements. To our knowledge, no other work has attempted to confirm or disconfirm these last reports, so that the level of the superimposed tilt illusion remains unknown.

In addition, there is a lack of data about the nature of the orientations engaged in rivalry: are they oriented like the physical orientations before the occurrence of any contrasts or like the illusory orientations that are generated after those contrasts?

In the present study, both questions were addressed by investigating the transition from fusion/stereopsis to binocular rivalry that occurs when increasingly large orientation disparities are introduced between the two eyes. In our study we measured those transitions under conditions where the orientation difference could be augmented or diminished by the superimposed orientation illusion (based on the Zöllner illusion). Here is our reasoning. When a difference in orientation between monocular grids (orientation disparity) exists (Fig. 1b), observers perceive stereoscopic slant (Fig. 1c). As orientation disparity is increased, fusion fails and the grids engage in rivalry (Fig. 2a). Imagine that grids with the orientation disparity near the transition between fusion and rivalry are displayed and we add short fused lines (inducers) to the grid. If the orientation illusion occurs monocularly, some inducers will increase the orientation disparity of the grids and others will decrease it. If stereopsis and rivalry are based on the illusory orientations, grid orientations could be perceptually changed so that they can now be fused and produce stereoscopic depth, and conversely, they could be pushed into rivalry. Transition points between fusion and rivalry would be shifted by different inducers.

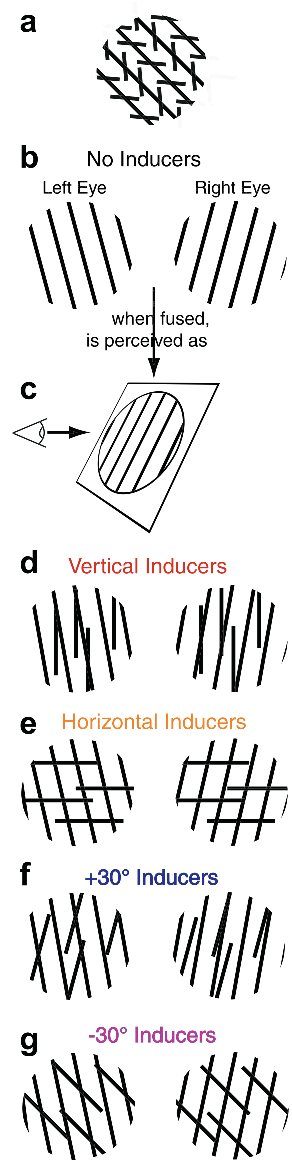

Fig. 1. Stimuli: (a) Zöllner illusion: long lines do not appear parallel although they are parallel. Inducers change the perceived orientations of the long lines; (b) left and right eye images are fused into a slanted surface (c) because of the orientation difference between eyes. Schematics of the left and right eye displays in the conditions with vertical inducers (d), horizontal inducers (e), +30° inducers (f) and −30° inducers (g).

2. Material and methods

2.1. Stimulus and material

Gratings were nearly vertical grids of black lines (width: 0.02°, luminance: 3 cd m^{-2}, spatial frequency: 2 cpd). Luminance of the pattern was spatially shaped by a Gaussian envelope centered on the grating (0.5° at half height). Twenty black segments (inducers) were added to the display in several conditions: their locations were random and their lengths were identical, 0.8°. Stimuli were displayed through a circular aperture of 4.2° with a central red fixation dot: the grating covered the whole area visible through the aperture. Background luminance was 15 cd m^{-2} (line contrast: 0.8). Stimuli were displayed for 2 s (Experiment 1) or 3 s (Experiment 2). Vergence was maintained by a group of small white squares surrounding the stimuli. Dichoptic stimulation was