Dissociation of color and figure–ground effects in the watercolor illusion

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Abstract—Two phenomena can be observed in the watercolor illusion: illusory color spreading and figure–ground organization. We performed experiments to determine whether the figure–ground effect is a consequence of the color illusion or due to an independent mechanism. Subjects were tested with displays consisting of six adjacent compartments — three that generated the illusion alternating with three that served for comparison. In a first set of experiments, the illusory color was measured by finding the matching physical color in the alternate compartments. Figureness (probability of ‘figure’ responses, 2AFC) of the watercolor compartments was then determined with and without the matching color in the alternate compartments. The color match reduced figureness, but did not abolish it. There was a range of colors in which the watercolor compartments dominated as figures over the alternate compartments although the latter appeared more saturated in color. In another experiment, the effect of tinting alternate compartments was measured in displays without watercolor illusion. Figureness increased with color contrast, but its value at the equivalent contrast fell short of the figureness value obtained for the watercolor pattern. Thus, in both experiments, figureness produced by the watercolor pattern was stronger than expected from the color effect, suggesting independent mechanisms. Considering the neurophysiology, we propose that the color illusion follows from the principles of representation of surface color in the visual cortex, while the figure–ground effect results from two mechanisms of border ownership assignment, one that is sensitive to asymmetric shape of edge profile, the other to consistency of color borders.

Keywords: Watercolor illusion; figure–ground segregation; border ownership; surface color; neural coding of contour.

INTRODUCTION

The watercolor illusion (Pinna et al., 2001) is a phenomenon that can be observed when a figure is defined by a contour consisting of a pair of parallel lines on white background — a dark line, and a lighter colored line on the inside. The interior
of the figure then appears slightly tinted with the hue of the lighter colored line. Pinna and coworkers further showed that configurations of lines that produce the watercolor illusion also influence the perception of figure and ground. In displays like the one shown in Fig. 1A, the watercolor regions tend to be perceived as 'figures' and the surrounding regions as ground (Pinna et al., 2003).

These findings might suggest that the 'figureness' effect is a consequence of the color illusion. The appearance of the illusory color tint suggests a filling-in process: color signals generated by the light-colored lines spread in visual cortex until they reach a contour boundary (Gerrits and Vendrik, 1970; Cohen and Grossberg, 1984); the dark lines of the watercolor displays form boundaries that limit the spread of color signals which thus fill the enclosed space evenly. The resulting color signals might then act exactly like real color signals, and the filled-in space would thus stand out as a figure against the surrounding white space, just like a colored region stands out against a white background.

An alternative possibility is that illusory color and figureness are produced in parallel, by independent mechanisms that are both activated by the double lines. The color might be the result of one process (e.g. filling-in, as sketched above), and figure–ground segregation might be produced by another process that is also triggered by the double lines. For example, the double lines of different contrast might activate cortical neurons that respond selectively to edges with asymmetric luminance (or color) profile and such neurons might contribute to the definition of border-ownership (Zhou et al., 2000).

The aim of the present study was to distinguish between these alternative hypotheses. If the figure–ground effect of the watercolor pattern is a consequence of a color filling-in process it should covary with the strength of the color illusion. If the illusory color behaves just like a veil of physical color, it should be possible to null the color contrast subjectively, for example by adding the appropriate amount of physical color to the white of the surrounding space, and the figure–ground effect should then disappear. However, if a figure–ground effect persists after nulling of the subjective color contrast, this would indicate that at least some of the figure–ground process is independent of the process that generates the color illusion.

**GENERAL METHODS**

The stimuli were designed and presented using commercial software (Corel Draw, MS Powerpoint), and displayed on a 19" computer monitor (Gateway VX900), with a resolution of 1280 × 1024. Subjects were seated in a dimly lit room and viewed the monitor at a distance of 210 cm.

The stimuli consisted of 6 adjacent compartments defined by wavy double lines, as shown in Fig. 1A–B. The colors of the lines were dark purple and orange. In three of the compartments, the orange line was on the inside, and in the alternate compartments it was on the outside. The pattern subtended 7.5 by 5 deg of visual angle. The width ratio of alternating compartments was varied between 1 : 1, 1 : 2,