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Effects of background and contour luminance on the hue and brightness of the Watercolor effect

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ABSTRACT

Conjoint measurement was used to investigate the joint influences of the luminance of the background and the inner contour on hue- and brightness filling-in for a stimulus configuration generating a water-color effect (WCE), i.e., a wiggly bi-chromatic contour enclosing a region with the lower luminance component on the exterior. Two stimuli with the background and inner contour luminances covarying independently were successively presented, and in separate experiments, the observer judged which member of the pair's interior regions contained a stronger hue or was brighter. Braided-contour control stimuli that generated little or no perceptual filling-in were also used to assess whether observers were judging the interior regions and not the contours themselves. Three nested models of the contributions of the background and inner contour to the judgments were fit to the data by maximum likelihood and evaluated by likelihood ratio tests. Both stimulus components contributed to both the hue and brightness of the interior region with increasing luminance of the inner contour generating an assimilative filling-in for the hue judgments but a contrast effect for the brightness judgments. Control analyses showed negligible effects for the order of the luminance of the background or inner contour on the judgments. An additive contribution of both components was rejected in favor of a saturated model in which the responses depended on the levels of both stimulus components. For the hue judgments, increased background luminance led to greater hue filling-in at higher luminances of the interior contour. For the brightness judgments, the higher background luminance generated less brightness filling-in at higher luminances of the interior contour. The results indicate different effects of the inner contour and background on the induction of the brightness and coloration percepts of the WCE, suggesting that they are mediated by different mechanisms.

1. Introduction

Color appearance is not determined only by the local light signals from each object but is also influenced by global contextual features. The watercolor effect (WCE) is an interesting phenomenon for studying such processes (Pinna, 1987; Pinna, Brelstaff, & Spillmann, 2001). A pair of wiggly contours composed of a light chromatic contour (e.g., orange) surrounded by a darker chromatic contour (e.g., purple) bounding an achromatic surface area elicits a filling-in of the hue of the lighter contour over the entire enclosed area (Fig. 1a). The WCE is distinguished from other assimilation illusions by its large spatial extent; the phenomenon has been observed over distances of up to 45 deg (Pinna et al., 2001). In addition to the assimilative color spreading, the subjectively colored area is perceived as figure while the surrounding area appears as ground (Pinna & Tanca, 2008; Pinna, Werner, & Spillmann, 2003; Tanca & Pinna, 2008).

Studies of the WCE have typically examined the effects of the inducer configuration producing the WCE. For example, the intensity of the filling-in percept appears greater with increases in luminance contrast between the inner and outer contours for an achromatic WCE (Cao, Yazdanbakhsh, & Mingolla, 2011) and for a WCE that has both luminance and chromatic components (Devinck, Delahunt, Hardy, Spillmann, & Werner, 2005; Devinck & Knoblauch, 2012). Devinck et al. (2005) noted that observers did not need to modify significantly the luminance of the enclosed area in a matching experiment. Other critical characteristics of the inducing contours that modulate the strength of the WCE include the continuity and contiguity of the contour pairs (Devinck & Knoblauch, 2012; Devinck & Spillmann, 2009).

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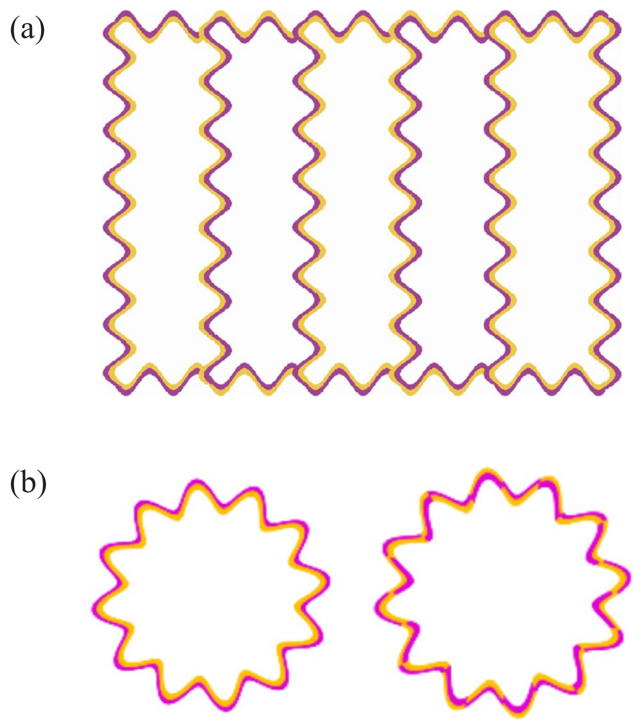

Fig. 1. (a) Example of the Watercolor Effect. When a light orange contour is surrounded by a dark purple contour, the enclosed area takes the tint of the orange border. (b) Example of stimuli using a Fourier descriptor as test stimulus (presented on the left side) and using a braided contour as control stimulus (displayed on the right side). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Recent demonstrations of the sensitivity of the phenomenon to contour adaptation provide additional support for a role of contour integration mechanisms in the WCE (Coia & Crognale, 2017). The strength of the phenomenon was found to be size-tuned with the strongest WCE observed for a contour width of about 15 arcmin and was optimal for equal contour widths (Devinck, Gerardin, Dojat, & Knoblauch, 2014a). While the WCE has been reported for linear contours (Pinna et al., 2001), its strength is nearly independent of the amplitude of contour undulation but increases with contour frequency up to an asymptotic level (Gerardin, Devinck, Dojat, & Knoblauch, 2014). Finally, Pinna et al. (2001) demonstrated that several different color pairs can generate the coloration effect (see also Devinck et al., 2005). Specifically, Devinck, Hardy, Delahunt, Spillmann, and Werner (2006) demonstrated that the coloration effect is stronger when the chromatic contrast is larger. Thus, the coloration effect depends on a conjunction of chromatic and luminance contrasts but also on spatial parameters of the inner and outer contours.

The WCE is perceptually salient but has proved difficult to quantify with precision showing large variability within and across observers (Cao et al., 2011; Devinck et al., 2005; von der Heydt & Pierson, 2006). More recently, the WCE was quantified by using paired-comparison methods that have been extended to estimate perceptual scales within a signal detection framework (Devinck & Knoblauch, 2012). Two such procedures are Maximum Likelihood Difference Scaling or MLDS (Knoblauch & Maloney, 2008, 2012; Maloney & Yang, 2003) and Maximum Likelihood Conjoint Measurement or MLCM (Ho, Landy, & Maloney, 2008; Knoblauch & Maloney, 2012). Difference scaling is useful for measuring perceptual strength along a single physical dimension, whereas conjoint measurement was conceived to assess the combined effects of several dimensions on appearance (Falmagne, 1985; Knoblauch & Maloney, 2012; Krantz, Luce, Suppes, & Tversky, 1971; Luce & Tukey, 1964; Roberts, 1985). MLCM has been successfully applied to estimate perceptual scales associated with different sets of physical continua including surface material properties (Hansmann-Roth & Mamassian, 2017; Ho et al., 2008; Qi, Chantler, Siebert, & Dong, 2015), color appearance (Gerardin et al., 2014; Rogers, Knoblauch, & Franklin, 2016) and time perception (Lisi & Gorea, 2016). The signal detection decision model allows specifying the perceptual scales in terms of the signal detection parameter *d’* (Gerardin et al., 2014; Knoblauch & Maloney, 2012).

The aim of the present study is to estimate perceptual scales for two dimensions, the luminance elevation of the inner contour and the luminance elevation of the background. While the luminance contrast between the inner and outer contours has been tested intensively in the WCE, experiments evaluating the influence of the background luminance are scarce. Indeed, the WCE has generally been demonstrated for a background of higher luminance than both inner and outer contours. Although the surround (e.g., the background) is known to be an important influence of color appearance (Brenner & Cornelissen, 2002; Brown & MacLeod, 1997; Shevell, 1978; Walraven, 1976), it has not been systematically explored for the coloration effect in the WCE. In addition, most studies of the WCE focus solely on its coloration effect. Here, we also investigate the influences of the background and inner contour luminances on the perceived brightness of the interior region. In summary, we employed conjoint measurement to study how both the background and the inner contour luminances influence judgments of both the hue and brightness in the WCE.

2. General methods

2.1. Observers

Four observers participated in these experiments. Three were naïve and the fourth was one of the authors. Observers ranged in age between 26 and 40 years. All had normal color vision as tested with the Farnsworth Panel D15, and had normal or corrected-to-normal visual acuity. Experiments were performed in accordance with the principles of the Declaration of Helsinki for the protection of human subjects.

2.2. Apparatus

Stimuli were presented on a NEC MultiSync FP2141sb color CRT monitor driven by a Cambridge Research ViSaGe graphic board with a color resolution of 14 bits per gun (Cambridge Research Systems, Rochester, United Kingdom). The experimental software was written to generate all stimuli, control stimulus presentation and collect responses in MATLAB 7.9 (MathWorks, http://mathworks.com), using the CRS Toolbox extensions. The monitor was calibrated using an OptiCal photometer with the calibration routines of Cambridge Research Systems. Observer position was stabilized by a chinrest and observer-to-screen distance was 80 cm. Experiments were performed in a dark room. Both eyes were used for viewing.

2.3. Stimuli

The stimuli were constructed as Fourier descriptors (Zahn & Roskies, 1972). Each stimulus was defined with respect to a circle of 3.2 deg diameter whose radius, r, was modulated sinusoidally as a function of angle according to the equation:

$$R(\theta) = r + A\sin(2\pi f\theta) \quad (1)$$

where R is the stimulus radius at angle θ, r the average radius of the stimulus, A the modulation and f the frequency in cycles per revolution (cpr). In the present study, the frequency was fixed at $f = 10$ cpr and the amplitude of both contours at $A = 0.36$ (Fig. 1b, left).

All stimuli were composed of three colors: an orange inner contour (x,y = 0.44, 0.43) with the luminance varying from 30.02 cd/m^2 to 62.74 cd/m^2 and a purple outer contour (x,y = 0.31, 0.11; Y = 21.12 cd/m^2), presented on a neutral white background