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Authors
Pinna, Baingio
Werner, John S
Spillmann, Lothar

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The watercolor effect: a new principle of grouping and figure–ground organization

Baingio Pinna [a,*], John S. Werner [b], Lothar Spillmann [c]

[a] Facoltà di Lettere e Filosofia, Università di Sassari, Piazza Conte di Moriana, 8, Sassari I-07100, Italy
[b] Section of Neurobiology, Physiology and Behavior, Department of Ophthalmology, University of California—Davis, 4860 Y Street, Suite 2400 Sacramento, CA 95817, USA
[c] Brain Research Unit, University of Freiburg, Hansastrasse 9, D-79104 Freiburg, Germany

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Abstract

The watercolor effect is perceived when a dark (e.g., purple) contour is flanked by a lighter chromatic contour (e.g., orange). Under these conditions, the lighter color will assimilate over the entire enclosed area. This filling-in determines figure–ground organization when it is pitted against the classical Gestalt factors of proximity, good continuation, closure, symmetry, convexity, as well as amodal completion, and past experience. When it is combined with a given Gestalt factor, the resulting effect on figure–ground organization is stronger than for each factor alone. When the watercolor effect is induced by a dark red edge instead of an orange edge, its figural strength is reduced, but still stronger than without it. Finally, when a uniform surface is filled physically using the color of the orange fringe, figure–ground organization is not different from that for the purple contour only. These findings show that the watercolor effect induced by the edge could be an independent factor, different from the classical Gestalt factors of figure–ground organization.

Keywords: Watercolor effect; Color spreading; Filling-in; Gestalt factors; Figure–ground segregation; Grouping; Proximity; Good continuation

1. Introduction

In a previous paper, we (Pinna, Brelstaff, & Spillmann, 2001) described a novel color assimilation phenomenon, called the *watercolor effect*. This effect, illustrated in Fig. 1, is characterized by long-range color spreading from the inner edge of an outline figure onto the enclosed surface area. The color of the flanking contour accompanying the darker border is assimilated within the enclosed area over distances of up to 45 deg. This coloration is uniform, and complete within 100 ms. Thin winding inducing lines with different contrasts to the ground were generally more effective than thick, straight, and equiluminant lines.

The purpose of this study was to evaluate the role of long-range chromatic assimilation for perceptual grouping and figure–ground segregation. In particular, we created stimuli in which the watercolor effect was pitted against the classical Gestalt grouping factors of proximity, good continuation, closure, and symmetry (Wertheimer, 1923), and against the figure–ground segregation factors of convexity (Rubin, 1915, 1921) and amodal completion.

We contend that the watercolor effect is a new and more powerful principle that cannot merely be subsumed under similarity.

2. General methods

2.1. Subjects

Separate groups of 14 naïve observers participated in each of seven experiments. All were adult volunteers (21–27 years of age) with normal vision from the University of Sassari.

* Corresponding author. Tel.: +1-39-079-229705; fax: +1-39-079-229619.
E-mail address: baingio@ssmain.uniss.it (B. Pinna).

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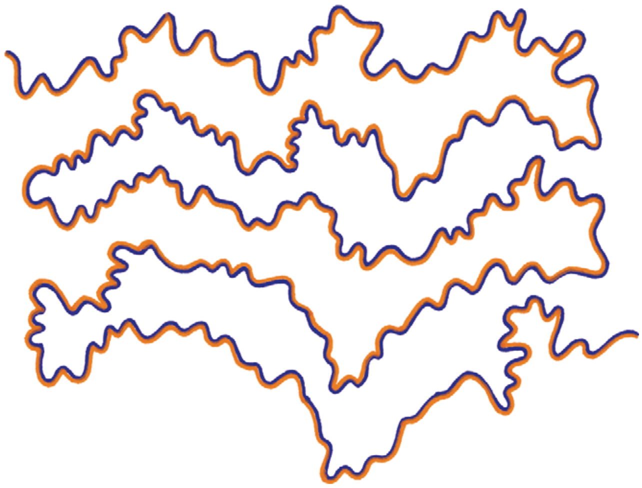

Fig. 1. The watercolor effect. When a purple contour is flanked by an orange edge, the entire enclosed area appears uniformly colored by long-range assimilation of the hue of the edge. For a larger reproduction see Pinna et al. (2001).

2.2. Stimuli

All stimuli were hand-drawn figures using "magic" ink markers and plain white paper. The basic pattern was a wiggly purple contour on a white background. The stroke width of the pen was ≈6 arcmin for these and other chromatic contours. Stimuli subtended ≈5 by 10 deg of visual angle when presented at a distance of 50 cm from the observer. They were viewed binocularly under daylight illumination of about 250 lux. Subjects were free to move their head and eyes as in natural viewing.

Each Gestalt factor was tested in a separate experiment usually involving five stimulus conditions: (i) the purple contour shown in isolation; (ii) the same purple contour flanked by an orange fringe on one side to pit the watercolor effect against the Gestalt factor under consideration; (iii) or flanked by a fringe on the opposite side so as to combine the watercolor effect with the Gestalt factor under consideration; and (iv) the purple contour presented in conjunction with a dark red fringe instead of an orange fringe. This last condition was used for a comparison as the watercolor effect is known to be diminished when the contrast between the two inducing lines is low (Pinna et al., 2001). Finally, as a further control, (v) the purple contour was presented with the entire enclosed surface area filled-in physically with the same ink as the orange fringe. This was done to show that the watercolor effect is not only a similarity effect, but a new factor producing strong grouping and figure–ground segregation by long-range edge-induced spreading.

2.3. Procedure

Before data were collected, each subject was shown some classical reversible figures (e.g., black and white versions of face–vase, rabbit–duck, old woman–young woman) to familiarize them with concepts of figure, ground and reversibility of figures. During this training phase, subjects evaluated the strength of perceived figures and practiced assigning percentages to the relative strength or salience of each figure.

Five variants of each stimulus were presented once in a random sequence. The task was to report which part of the stimulus was perceived as figure and which as ground, and then to scale the relative strength (in percent) of the surface being perceived as figure. Observation time was unlimited.

3. Results

3.1. Experiment 1: watercolor effect versus proximity

Fig. 2 was used to compare the watercolor effect and the Gestalt factor of proximity in determining figure–ground segregation. This factor states that, all else being equal, the closer elements tend to be grouped together. It consisted of nine vertical lines with the interspaces alternating between narrow and wide. The top and the bottom of the figure were closed. The height of the lines was 8 deg. The horizontal distance between the two outer lines, kept constant for all stimuli, was 13.5 deg and the ratio between neighboring interspaces was either 1.0, 0.5, or 0.25. For a ratio of 1, the distance between adjacent lines was 1.72 deg throughout. For a ratio of 0.5 and 0.25, the distances were 1.14 and 2.3, or 0.7 and 2.74 deg, respectively. The three interspace ratios were combined with the five test conditions described above to yield 15 different stimuli.

Mean percentage ratings are plotted in Fig. 3 for each of the five conditions with the ratio between interspaces as a parameter. Ratings refer to the *wide* spaces being perceived as *figure* to emphasize the power of the watercolor effect. (For a ratio of 1, a 50% rating would be expected.) Results for the first condition (purple contour only) clearly confirm that proximity determines what is seen as figure if there is no other competing factor. For example, for an interspace ratio of 0.5, the wide spaces were assigned a relative strength of only 20%, whereas the narrow spaces attracted an overwhelming 80% of the responses. In comparison, results for the second condition (orange fringe in wide spaces) show a complete reversal of figure–ground organization, testifying to the superior strength of watercolor spreading. Here, for the same interspace ratio, the relative strength of the wide spaces being perceived as figure is 95%, leaving only 5% for the narrow spaces. The third condition shows that when the orange fringe was combined with the narrow spaces, subjects assigned these spaces 100% figure status (for a 0.5 ratio), with 0% for the wide spaces. This result suggests summation of watercolor spreading and prox-

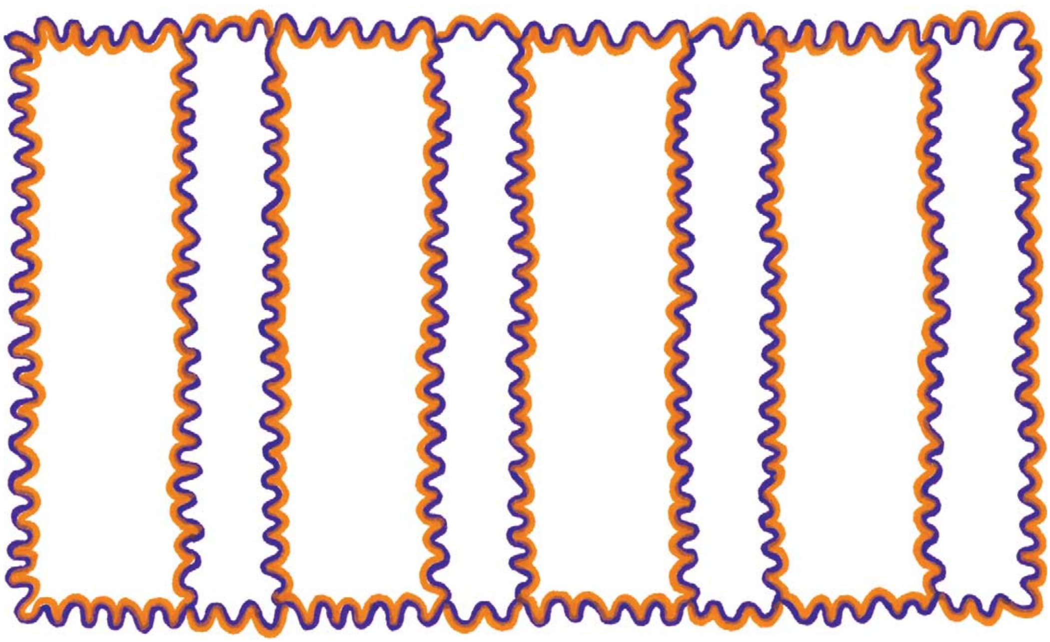

Fig. 2. Stimulus used to test the watercolor effect against the Gestalt factor of proximity in determining figure–ground organization.

imity. In the fourth condition, when the orange fringe in the wide spaces was replaced by a dark red fringe, the relative strength of these spaces was generally reduced vis-à-vis condition (ii), but was still higher than for the purple contour alone (i). Finally in the fifth condition when the wide spaces were uniformly filled with real orange color, for a ratio of 0.5, the wide spaces were assigned a relative strength of 20%. This is not different

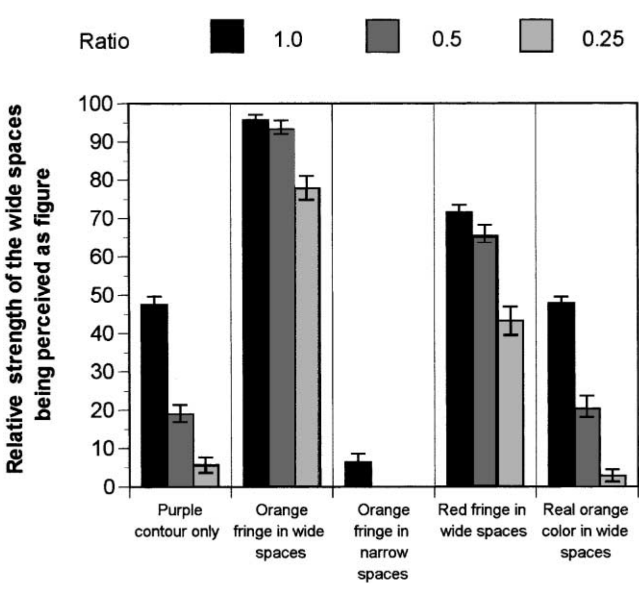

Fig. 3. Results of watercolor effect versus proximity. Mean relative strength of the wide spaces being perceived as figure, plotted for five conditions and three interspace ratios. Wide spaces for ratio 1.0 refers to the same areas as for ratio 0.5 and 0.25. Error bars denote ±1 SD.

from the result in the first condition, when the purple contour was shown in isolation. We therefore conclude that this last response is attributable to proximity only.

Statistical analysis verified what may be inferred from the graphs. A two-way ANOVA shows that the relative strength of the wide spaces being perceived as figure differs significantly among test conditions ($F_{4,195} = 627.6$, $P < 0.0001$) as well as interspace ratios ($F_{2,195} = 183.9$, $P < 0.0001$). The interaction between these two factors is also significant ($F_{8,195} = 12.8$, $P < 0.0001$). In a Fisher PLSD post-hoc analysis, all differences between the five test conditions are significant ($P < 0.0001$), except for the interaction between (i) purple contour only and (v) real orange color in wide spaces.

We replicated this experiment to determine whether these findings can be generalized to a circular variant of Rubin's Maltese Cross, as illustrated by Fig. 4 for both the watercolor effect and physically filled-in color. The ratio between adjacent sector sizes was varied as follows: 45/45, 22.5/67.5, and 11.25/78.75 deg. These three ratios were again combined with the five test conditions mentioned above to yield 15 different stimuli. Statistical analysis using a two-way ANOVA showed that the relative strength of the wide sectors being perceived as figure changes significantly among the five conditions ($F_{4,195} = 469.480$, $P < 0.0001$) as well as the ratio between narrow and wide sectors ($F_{2,195} = 416.769$, $P < 0.0001$). Furthermore, the interaction between the two factors is also significant ($F_{8,195} = 83.619$, $P < 0.0001$). In the Fisher PLSD post-hoc analysis, all differences are significant ($P < 0.0001$) except for that between (i) purple contour

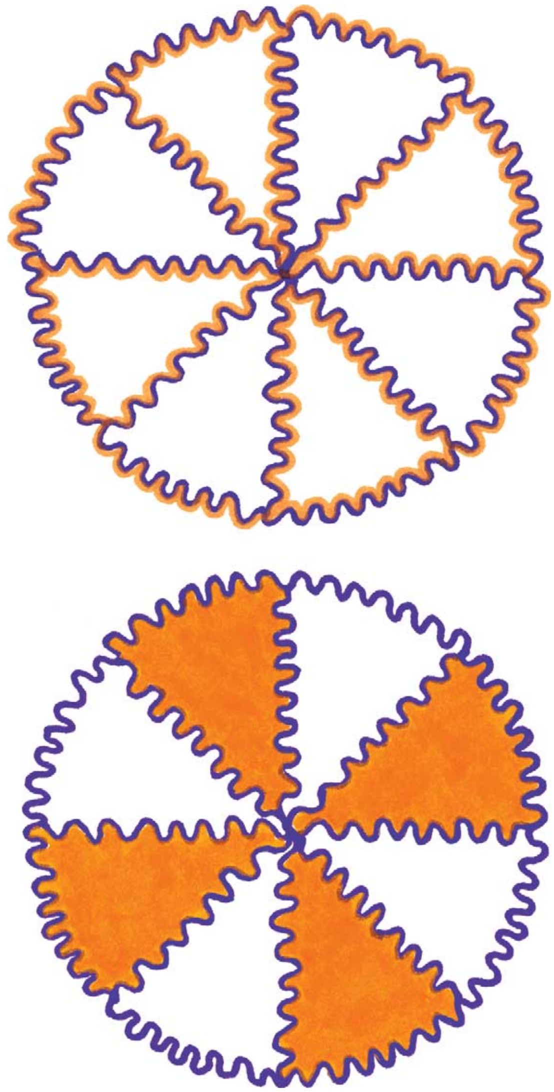

Fig. 4. Rubin's Maltese Cross rendered with the watercolor effect (top) and physically filled-in color (bottom).

only and (v) real orange color in wide sectors ($P = 0.7466$).

These results confirm earlier data described by Pinna et al. (2001) demonstrating that watercolor groups more effectively than the Gestalt factor of proximity.

3.2. Experiment 2: watercolor effect versus good continuation

The Gestalt factor of good continuation states that sections of the stimulus that form a smooth continuation tend to be grouped together. As shown in Fig. 5, this factor was pitted against the watercolor effect using a square-wave pattern reminiscent of an open Greek fret overlaid by a sinusoidal line. The sides of the squares in the fret were 3.43 deg. The sinusoidal line had a spatial frequency of 0.12 cpd and a peak-to-trough amplitude of 1.7 deg; it connected the extreme points of the fret on the left and right. In this way the figure was perceptually closed.

There were six conditions: (i) purple contour only, (ii) orange fringe added to the inner edges of the closed spaces, (iii) orange fringe added to the outside edges of the closed spaces, (iv) orange fringes added to both the inner and outer edges of the Greek fret and sinusoid, (v) red fringe added to the inside edges of the sinusoid with orange fringes lining the Greek fret, and (vi) real orange color uniformly added to the closed spaces.

Mean percentage ratings giving the figural strength of the closed spaces (patches) between the Greek fret and the sinusoidal line are plotted in Fig. 6 for each of the six conditions. In the purple-contour-only condition, there was a near-zero response to the closed spaces, whereas all subjects reported seeing two intersecting line figures: an open fret overlaid by a sinusoid. Thus, good continuation completely dominated the percept. However, when an orange fringe was added to the inner edge of the closed spaces, good continuation was no longer effective. Instead, the closed spaces now exclusively determined the percept by virtue of their uniform watercolor. A similar, but less powerful effect was obtained when an orange fringe was added to the outer edges (open spaces). With this condition, good continuation was largely abolished and the closed sections of the figure appeared as ground or holes. When orange fringes were added to both sides of the contours, the effects obtained by the two previous conditions were completely annulled and good continuation of the Greek fret and sinusoidal line was again perceived.

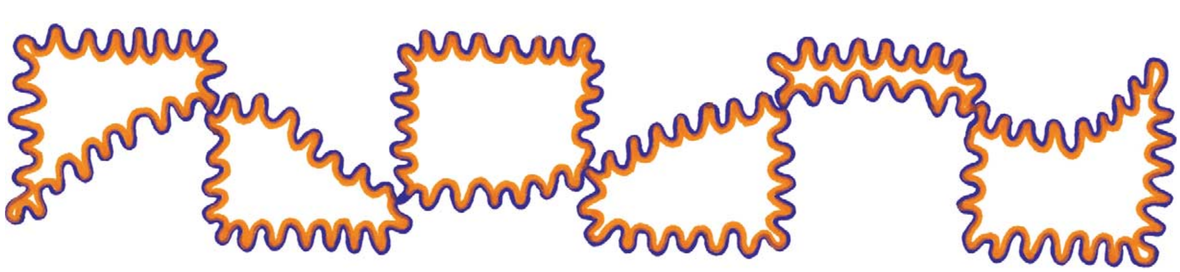

Fig. 5. Stimulus used to test the watercolor effect against the Gestalt factor of good continuation in determining figure–ground organization. Squinting or blurring may facilitate perception of good continuation in this figure.

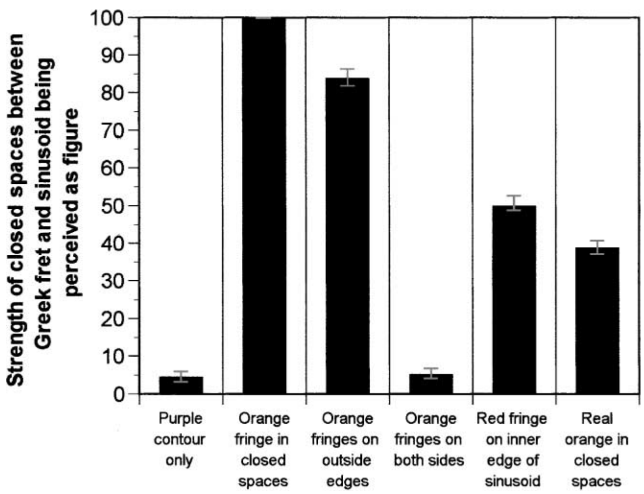

Fig. 6. Results of watercolor effect versus good continuation. Mean relative strength of a Greek fret and sinusoidal line being perceived as figure, plotted for six test conditions. Error bars denote ±1 SD.

However, when a red fringe instead of an orange one was added to the inner edge of the sinusoidal curve, the relative strength of seeing good continuation was only 50%. Presumably, this is because the (weaker) watercolor effect elicited by the dark red fringe counteracted good continuation. Finally, by physically filling the closed spaces with a uniform orange color, the response to the closed spaces was 40% and the relative strength of seeing good continuation was thus reduced to 60%. This is less than for the purple-contour-only condition, where it was 95%, but much higher than when an orange fringe was added to the inner edges (condition (ii)).

A one-way ANOVA showed that the relative strength of seeing both the Greek fret and the sinusoidal curve as open-line figures, each by itself, according to the Gestalt factor of good continuation, differs significantly among conditions ($F_{5,78} = 390.8$, $P < 0.0001$). In the Fisher PLSD post-hoc analysis, all differences between conditions are significant ($P < 0.0001$), except the differences between (i) purple contour only versus (iv) orange fringes on both sides, and (iii) orange fringes on outer edges versus (v) red fringe on sinusoid.

Thus, the watercolor effect vastly exceeds the Gestalt factor of good continuation and it is much stronger in biasing perception than physically filled-in real color.

3.3. Experiment 3: watercolor effect versus closure and surroundedness

The closure principle states that stimulus parts forming a closed figure are grouped together. The surroundedness principle states that when one region is completely surrounded by another, the surrounded region is perceived as figure and the surrounding region as ground. This experiment tested the watercolor effect both against the surroundedness and closure principles. The basic stimulus is shown in Fig. 7. It consisted of four narrow rectangles, each 6.8 deg high × 1.7 deg wide. The distance between neighboring rectangles was also 1.7 deg. They were placed inside a large rectangular frame of 12.4 × 18.8 deg. Both closure of the narrow rectangles and surroundedness by the large rectangular frame induce a strong figure–ground segregation. There were again five different conditions as described in Section 2.

Mean percentage ratings specifying the figural strength of the surrounding frame are plotted in Fig. 8 for each condition. In the purple-contour-only condition the frame was rarely perceived as figure, while the four narrow rectangles were seen as figures on a large ground in the majority of cases. However, when orange fringes were added to the outside of the rectangles, the frame completely assumed the status of figure, while the rectangles were now perceived as windows or holes. In comparison, when orange fringes were added to the inside of the rectangles, the surrounding frame was completely ignored and the rectangles were exclusively perceived as figures. By lining the outer edges of the rectangles with a red fringe, the frame regained figure status, however, not as strongly as with the orange fringe (condition (ii)). Finally, in the control condition in which the area surrounding the rectangles was physically filled with orange color, the result was almost the same as with the purple-contour-only condition.

A one-way ANOVA verified that the relative strength of the frame being perceived as figure differs significantly among conditions ($F_{4,65} = 446.9$, $P < 0.0001$). In the Fisher PLSD post-hoc analysis, all differences between conditions are significant ($P < 0.0001$), except for the difference between (i) the purple contour only and (v) the real orange color in the frame.

From the results, we conclude that the watercolor effect is much stronger than the Gestalt factors of closure and surroundedness under these conditions.

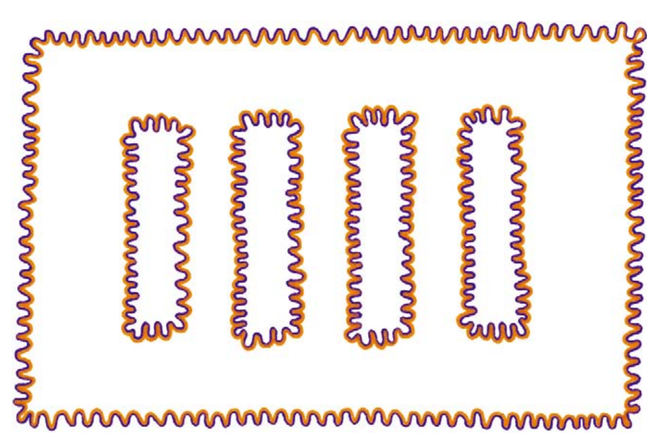

Fig. 7. Stimulus used to test the watercolor effect against the Gestalt factor of closure and surroundedness in determining figure–ground organization. For a larger reproduction see Pinna et al. (2001).

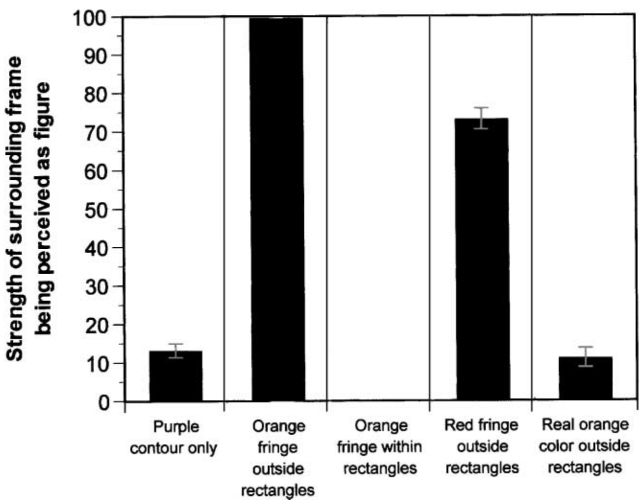

Fig. 8. Results of watercolor effect versus closure and surroundedness. Mean relative strength of the surrounding frame being perceived as figure, plotted for five test conditions. Error bars denote ±1 SD.

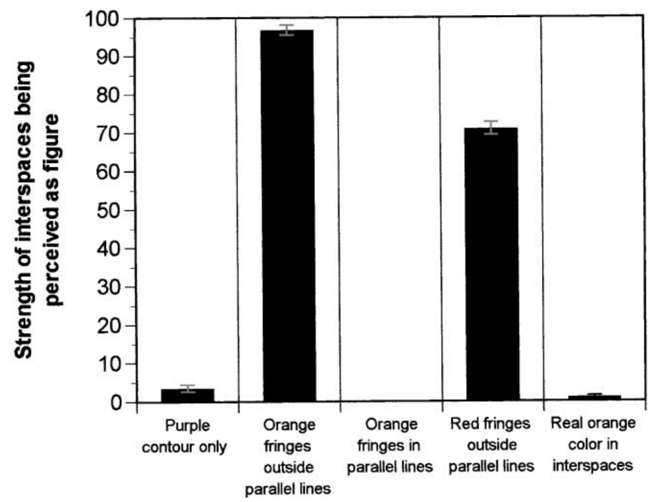

Fig. 10. Results of watercolor effect versus parallelism. Mean relative strength of the interspaces between the three "rivers," being perceived as figure plotted for five test conditions. Error bars denote ±1 SD.

3.4. Experiment 4: watercolor effect versus symmetry

The watercolor effect was next studied relative to the Gestalt factor of symmetry (or Morinaga's, 1942, *Ebenbreite*). According to this principle, parallel contours are grouped together. The stimulus is shown in Fig. 9. It consisted of three pairs of parallel wavy lines inside a large square, with a side length of 12.1 deg. Parallel lines were spaced 1.15 deg apart from each other. In this way a percept comparable to three undulating rivers was created. There were five stimulus variations as described by the conditions in Section 2.

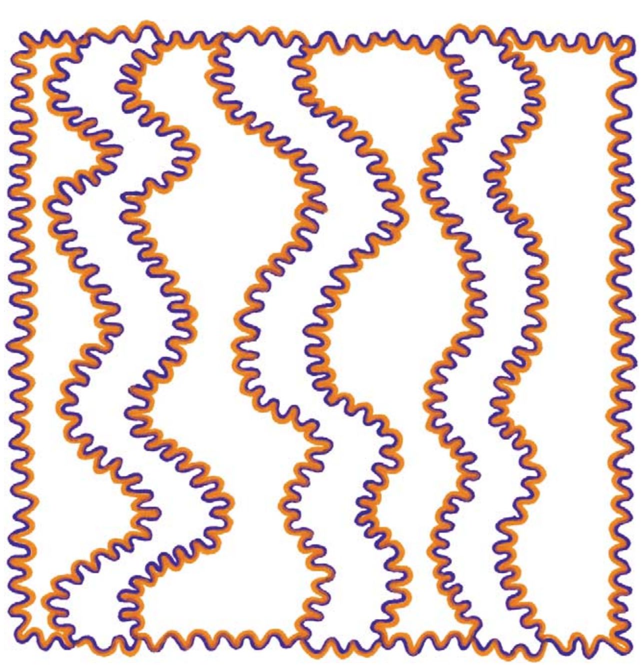

Fig. 9. Stimulus used to test the watercolor effect against the Gestalt factor of parallelism in determining figure–ground organization.

Mean percentage ratings are plotted in Fig. 10. When chromatic fringes (orange and red) were added to the outside of the parallel lines ("rivers"), the interspaces were perceived as figure. In all other conditions, the rivers assumed the status of figure. Results of a one-way ANOVA indicate that the relative strength of the interspaces outside the parallel lines being perceived as figure differs significantly among conditions ($F_{4,65} = 1211.9$, $P < 0.0001$). In the Fisher PLSD post-hoc analysis, the differences that are *not* significant are: (i) versus (iii), (i) versus (v), and (iii) versus (v).

3.5. Experiment 5: watercolor effect versus convexity

Convex regions tend strongly to appear as figure and concave ones as ground. This is known as the *law of the inside*. It was pitted against the watercolor effect using the stimulus shown in Fig. 11. Pairs of concave and convex arcs alternating with each other were inserted in between two horizontal lines of 22.8 deg each separated by a vertical distance of 3.4 deg. Seven such arcs were positioned within the parallel lines so as to yield 3 quasi-circular areas and a half-circle. Arcs were also separated by 3.4 deg from each other. For each of the five conditions described in Section 2, arcs were varied through various degrees of curvature from straight vertical lines (i.e. zero curvature) to curved lines having a radius of 9.0 and 2.9 deg (the example in Fig. 11), and 1.7 deg, respectively. Thus, the total number of stimuli in this experiment was 20.

Fig. 12 presents percentage ratings for each condition with curvature of the arc as a parameter. In general, the concave regions of the stimuli were perceived as figure

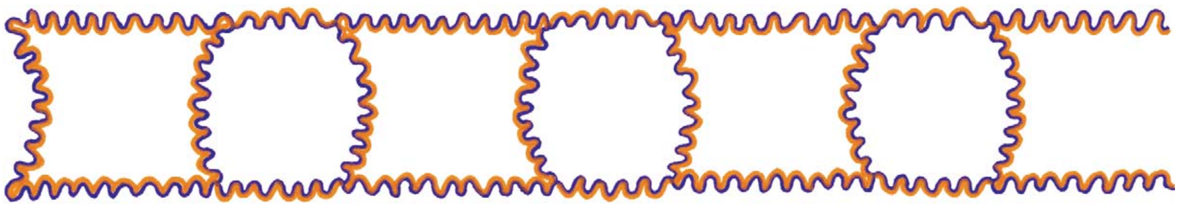

Fig. 11. Stimulus used to test the watercolor effect against the Gestalt factor of convexity in determining figure–ground organization.

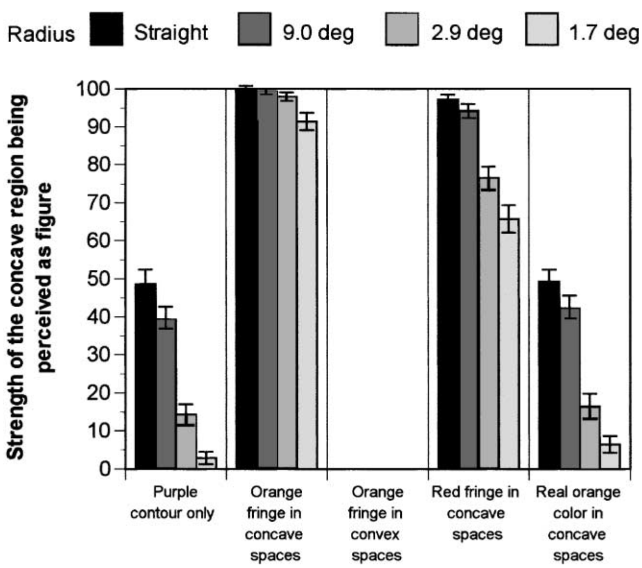

Fig. 12. Results of watercolor effect versus convexity. Mean relative strength of the concave regions being perceived as figure, plotted for five test conditions. Error bars denote ±1 SD.

when lined with orange or red fringes, although the effect for the red fringes became weaker with increasing curvature. However, with an orange fringe added to the inside edge of the convex spaces, figure–ground organization reversed and the "circles" were now always perceived as figures. There was no response to the concave region. Finally, when the concave spaces were filled physically with orange color, the relative strength was nearly the same as for the purple-contour-only condition.

A two-way ANOVA showed that the relative strength of the concave region being perceived as figure differs significantly among test conditions ($F_{4,260} = 1014.286$, $P < 0.0001$) as well as curvatures ($F_{3,260} = 134.4$, $P < 0.0001$). The interaction between the two factors is also significant ($F_{12,260} = 18.518$, $P < 0.0001$). In the Fisher PLSD post-hoc analysis, all differences, both for the test conditions and curvatures, are significantly different ($P < 0.0001$), except for the difference between (i) purple contour only and (v) physically filled-in color.

These results clearly show that under our conditions the watercolor effect is more effective than convexity for determining figure–ground organization.

3.6. Experiment 6: watercolor effect versus amodal completion

Amodal completion, or perception of an object's occluded regions, is not a classical principle of figure–ground segregation, but is definitely linked to the figural organization of our visual world (Michotte, 1951). It is considered an important principle of figural organization as most every object in our visual world is amodally completed. This applies not just to figures, but also to the ground. Here we ask: Can the figural strength of the watercolor effect successfully compete with amodal completion?

The stimulus is shown in Fig. 13. A square, whose side was 5.15 deg long, and a hexagon, whose distance between opposing sides was 5.45 deg, partially occluded a circle, whose radius was 3.15 deg. The three figures (for

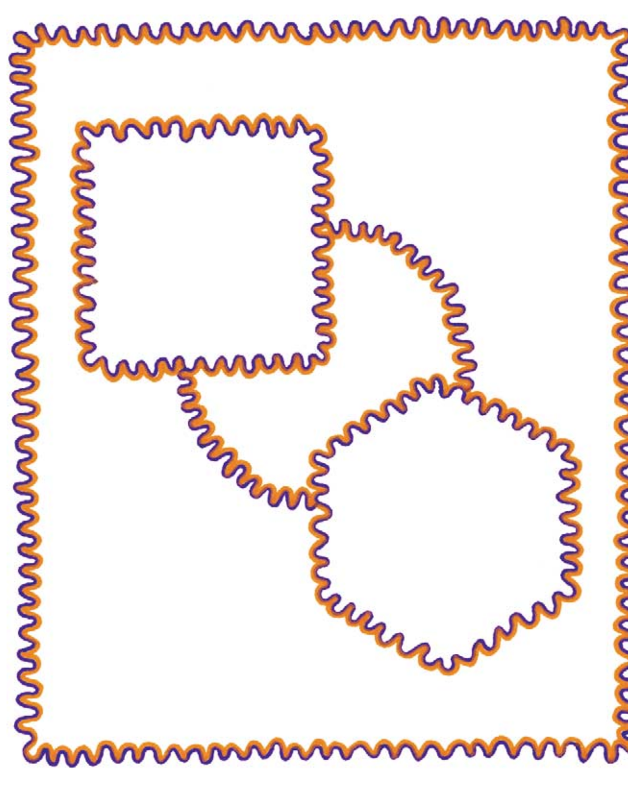

Fig. 13. Stimulus used to test the watercolor effect against amodal completion in determining figure–ground organization.

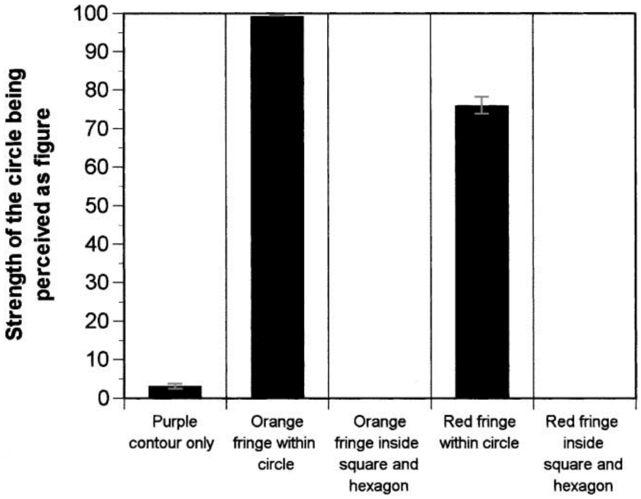

Fig. 14. Results of watercolor effect versus amodal completion. Mean relative strength of the circle being perceived as figure, plotted for five test conditions. Error bars denote ±1 SD.

each of the five conditions in Section 2) were diagonally aligned within a large rectangular frame, the sides of which were 13 × 15.6 deg.

Mean percentage ratings giving the figural strength of the circle, are plotted in Fig. 14. When orange or red fringes were added to the inside of the partial circle, it was perceived as a circle with two parts missing. The square and the hexagon, having no fringes on the inside, appeared as holes. In the two other conditions in which the fringes were added to the inside of the square and hexagon, the results hardly differ from the purple-contour-only condition.

A one-way ANOVA shows that the relative strength of the partially occluded circle being perceived as figure differs significantly among conditions ($F_{4,65} = 978.4$, $P < 0.0001$). In the Fisher PLSD post-hoc analysis, all differences between conditions are significant ($P < 0.0001$), except for those between conditions (i) versus (iii), (i) versus (v), and (iii) versus (v).

In conclusion, the watercolor effect reverses the perceived segregation in depth, thereby abolishing amodal completion.

3.7. Experiment 7: watercolor effect versus past experience

In addition to these figural factors, Wertheimer (1923) acknowledged the importance of past experience in perceptual grouping. Specifically, spaces associated with prior knowledge tend to be grouped together. He concluded that there was some role of past experience, but that it was limited by the inherent Gestalt factors described previously. In this experiment we examine the role of past experience relative to the watercolor effect. The stimulus consisted of the word "LIFE" (Fig. 15) presented under the five conditions described in Section 2.

The percentage ratings plotted in Fig. 16 show that the spaces in between the letters were perceived as figure only when colored fringes were added to the outside edges of the letters. As before, orange fringes produced a stronger effect than red fringes. In all the other cases, the letters emerged according to the past experience factor. The results for the physically-filled color condition were quite similar to the purple-contour-only condition.

A one-way ANOVA verified that the relative strength of perceiving the spaces in between the individual letters

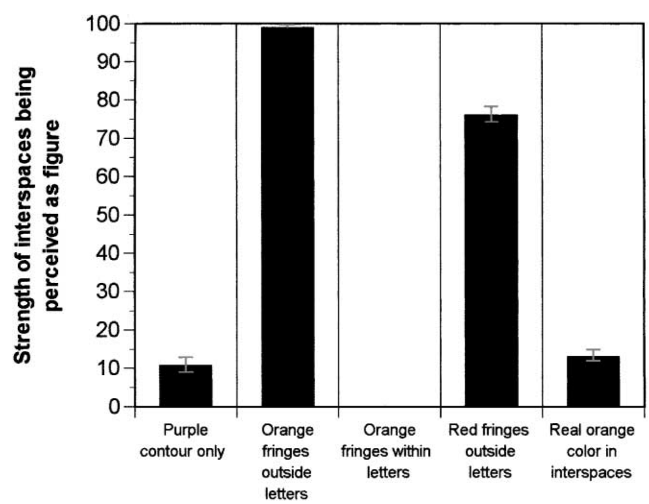

Fig. 16. Results of watercolor effect versus past experience. Mean relative strength of the interspaces between the letters being perceived as figure, plotted for five test conditions. Error bars denote ±1 SD.

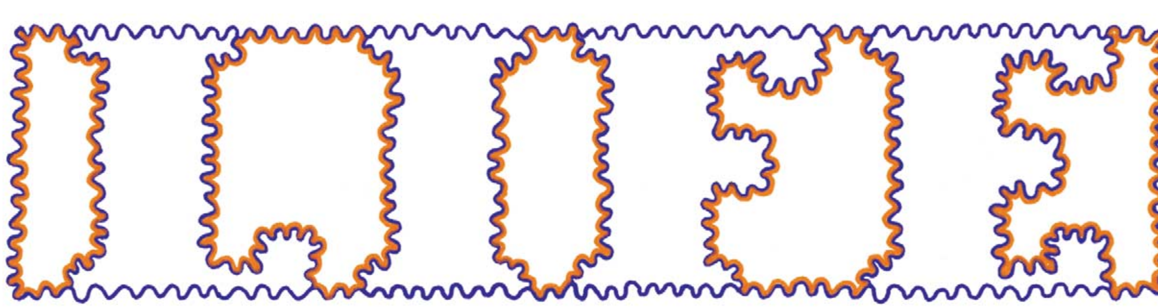

Fig. 15. Stimulus used to test the watercolor effect against past experience in determining figure–ground organization. The original stimulus was larger and displayed the effect more vividly.

as figure differs significantly among conditions ($F_{4,65} = 500.55$, $P < 0.0001$). In the Fisher PLSD post-hoc analysis, all differences between conditions are significant ($P < 0.0001$), except for the difference between (i) purple contour only and (v) physically-filled orange color.

3.8. Additional comparisons with physically filled-in color

We have studied the most important Gestalt factors governing perceptual segregation and grouping vis-à-vis the watercolor effect. For all experiments we used a control condition whereby the region serving as a dependent variable was physically filled using the same orange as the fringe (conditions 5 or 6). We found that this manipulation had little effect on figure–ground organization. However, there is a potential problem: the perceived color of the watercolor effect is not exactly the same color as the fringes themselves, but rather appears lighter and like a veil of orange. Therefore, we also filled-in real color using a light orange similar to that of the illusory watercolor itself. All conditions were thus tested again, in a random order, using fourteen new naïve subjects for each experiment. The task was the same as before. The results were unchanged from those obtained with the darker physically filled-in orange color. Of course, we cannot rule out the possibility that physically filled-in color that is more similar to the induced color would be more effective in creating figural organization. It is not clear why our particular stimuli did not produce a figural effect with physically filled-in color. The watercolor effect, however, typically includes not only induced color, but also apparent depth. This second property is not captured by physically filled-in color.

4. Discussion

Since the first published demonstration of the watercolor effect (Pinna, 1987), it has been shown that the areal assimilation of the lighter chromatic contour is different from the spreading effect of von Bezold (1874) and Helson (1963) because of the figural effect and the spatial extent of the spreading (Pinna et al., 2001). What might be its function? Contrary to border contrast which enhances the differences between figure and ground, assimilation diminishes the difference between the border and the enclosed areas and thereby creates a uniform surface color (similitude). The seven experiments reported here demonstrate the effectiveness of the watercolor effect in grouping parts together by their edge induced color.

The watercolor effect also has strong structural properties in assigning figural status to a surface across which assimilative color spreads. For example, when a colored fringe is added to the inside of a region which according to the classical Gestalt principles would appear as ground, the perceived figure–ground organization will change in favor of the color-fringed region. In other words, what formerly appeared as ground, now becomes figure and vice versa. Indeed, the watercolor effect was more effective than all the classical *Gestalt* factors so far tested when pitted against them. Thus, under our conditions, the watercolor effect is a more important determinant of figure–ground organization than the segregation and grouping principles identified by Rubin (1915, 1921) and Wertheimer (1923) at the beginning of the last century.

It might be suggested that the watercolor effect is an example of the Gestalt factor of similarity. This factor includes many attributes (e.g., color, form, orientation, texture, depth, motion, etc., see Spillmann & Ehrenstein, in press). Because of the generality of this factor, we cannot exclude similarity as the basis of the watercolor effect. Our control experiment with filled-in real color suggests, however, that it is not simply color similarity of the surface area (orange) that is responsible for figure–ground segregation, but perceptual spreading of color, often associated with depth or "volume".

The depth or volume associated with the watercolor effect might be interpreted in terms of transparency, i.e., the filled-in areas produce a transparent layer which lies on top of the background. This might be expected from the recent work of Ekroll and Faul (in press) on neon color spreading or the earlier models of Metelli (1970) and more recently of Grossberg and Mingolla (1985) and Grossberg and Todorovic (1988) We contend that the transparency evident in neon spreading is not present in the watercolor effect. For the stimuli tested in this paper, filling-in by watercolor had a surface quality different from transparency.

The presence of a darker boundary color (purple) is important for delimiting watercolor spreading to one side only. This may be related to a more general characteristic of chromatic processing. For example, it has been shown that a luminance edge enhances color discrimination (Boynton, Hayhoe, & MacLeod, 1977; Cole, Stromeyer, & Kronauer, 1990), whereas without it, there is a tendency of colors to "bleed" together (Eskew & Boynton, 1987). This tendency is especially strong for discriminations mediated by short-wavelength-sensitive cones. These results suggest a threshold mechanism by which a luminance edge enclosing a chromatic patch should enhance sensitivity to color on the inside while preventing color spreading to the outside (Montag, 1997; Gowdy, Stromeyer, & Kronauer, 1999).

If we compare figure–ground segregation with grouping, it is reasonable to think that the former must operate before the latter (Hoffman & Richards, 1984). In fact, the dots and lines (Wertheimer, 1923), on which grouping acts, must be already segregated as figure from ground, otherwise the visual system would not "know" which regions to group. Only figures can be grouped, ground cannot. But if we compare figure–ground segregation with the watercolor effect, it implies that watercolor spreading from edges is likely processed at a level prior to figure–ground organization. Thus, the results of these experiments constrain neurophysiological and computational models of long-range cortical interactions mediating human color and form perception. We suggest (Pinna et al., 2001) that assimilative color spreading may arise in two steps: First, weakening of the contour by lateral inhibition between differentially activated edge cells (local diffusion); and second, unbarriered flow of color onto the enclosed area (global diffusion).

What is the role of the strong figural effect of watercolor spreading vis-à-vis the classical Gestalt factors enounced by Wertheimer and Rubin? We suggest that the watercolor effect serves to reinforce the notion by Rubin (1915, 1921) that the border belongs to the figure (*Zusammmengehörigkeit*—belongingness), a principle which has been termed *border ownership* by Nakayama and Shimojo (1990). It has recently been demonstrated that border ownership may be encoded at early stages of cortical processing, primarily areas V1 and V2 (Heider, Meskenaite, & Peterhans, 2000; Zhou, Friedman, & von der Heydt, 2000), as well as inferotemporal cortex (Baylis & Driver, 2001) and the human lateral occipital complex (Kourtzi & Kanwisher, 2001). Zhou et al. (2000) report that approximately half of the neurons in the early cortical areas are selective in coding the polarity of color contrast (e.g., a neuron may respond to a red–gray border, but not a gray–red border). The watercolor effect strengthens border ownership through a colored fringe added to the boundary. The darker contour in conjunction with the lighter fringe enhances the strength of border ownership and, at the same time reduces the possibility that the boundary could be reversed. In this way, the watercolor effect increases the figural strength of the surface by creating an unambiguous, unilateral direction defining the figure: The outer boundary is the boundary of the figure.

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