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Grouping by achromatic color and surface segregation

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Abstract The study explored the achromatic-color determinants of grouping of uniform surfaces. The stimuli were a set of separate uniform achromatic disks on either a uniform or a bipartite achromatic background. The participants rated the salience of grouping of these disks for different combinations of stimulus luminances. The results show that achromatic color similarity alone could not sufficiently explain the pattern of obtained factorial curves but this factor coupled with the factor of surface segregation could. Luminance contrast similarity per se was found to be unimportant for grouping.

Introduction

Uniform surfaces may form single groups of separate surfaces, as for example the groups of disks in Fig. 1, or may form single mosaiclike groups of adjacent surfaces, as for example the overlapping transparent squares in Fig. 2 (Metzger, 1936; Wertheimer, 1923). Salience of grouping is defined as the strength of the subjective impression that one single group of two or more surfaces stands out over the subgroups of one or more of the surfaces that form the group (Beck, Graham, & Sutter, 1991; Singh & Hoffman, 1998). Salience of grouping increases with the similarity in achromatic color of the component surfaces (Hochberg & Silverstein, 1956; Metzger, 1936, p. 109; Morinaga, 1952). For example, in Fig. 1 the salience of the group of all disks increases in passing from Fig. 1a to b. Similarly, in the transparent square on the right of each pattern in Fig. 2, the salience of grouping of the small central square with the L-shaped surface increases in passing from Fig. 2a to b (Gyulai, 1976; Metelli, 1976).

Perceived surface segregation is the impression determined by luminance contrast of how well a surface is seen as standing out in front of the background, with luminance contrast being defined as the absolute difference in luminance between the surface and the background (Fry, Bridgman, & Ellerbrock, 1949). In overlapping transparent surfaces as those in Fig. 2, luminance contrast has been found to influence the salience of transparent surfaces independently of the similarity of the achromatic colors within these transparent surfaces (Masin, 2000). This finding suggests that surface segregation and/or luminance contrast codetermine along with achromatic color similarity the salience of grouping in transparent surfaces. The present study tried to verify whether these factors also influence the salience of grouping of separate surfaces.

Indeed, it is uncertain whether luminance contrast influences grouping of separate surfaces. Luminance contrast has been reported to influence grouping of dots in dot patterns and in Glass patterns (Dakin & Bex, 2001; Earle, 1999; Zucker, Stevens, & Sander, 1983) and to influence grouping of surfaces in textures (Beck et al., 1991; Beck, Sutter, & Ivry, 1987), in visual search (Gilchrist, Humphreys, Riddoch, & Neuman, 1997), in apparent motion (Ma-Wyatt, Clifford, & Wenderoth, 2005), and with modulation of luminance (Shapiro & Hamburger, 2007). However, the processes that produce grouping in these stimulus conditions may differ from the processes that produce grouping of separate static surfaces in normal viewing conditions (Beck, 1982; Ben-Av & Sagi, 1995).

Some data indicate that grouping of separate surfaces could be independent of luminance contrast per se. Beck et al. (1991) found that perceived segregation of two

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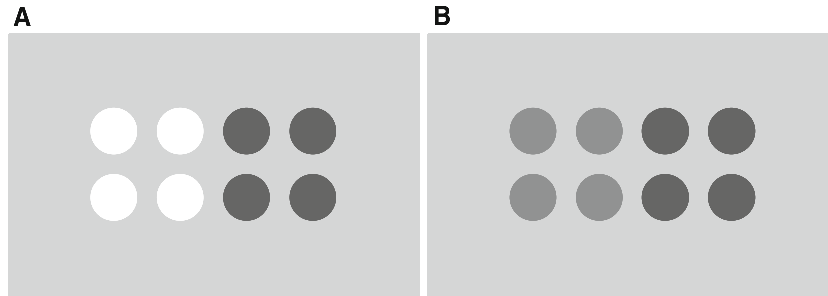


Fig. 1 Examples of salience of grouping. The group of eight disks looks more salient in the pattern on the right

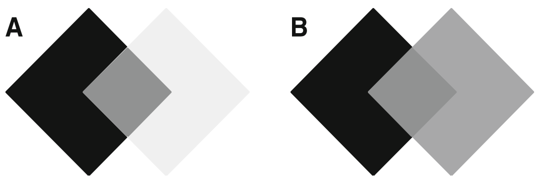


Fig. 2 Illustration of two patterns each consisting of two overlapping transparent squares. The transparent square on the right of a pattern looks more salient in the pattern on the right (Metelli, 1976)

populations of intermixed separate achromatic surfaces was a single-valued function of the difference in achromatic color between these surfaces. When a shadow was cast on part of a set of separate achromatic surfaces, Rock, Nijhawan, Palmer, & Tudor (1992) found that participants perceptually grouped these surfaces disregarding the shadow and thus showing that grouping depended on achromatic color rather than on retinal luminance.

That luminance contrast similarity could influence grouping of separate surfaces is indicated by the recent finding that grouping of a separate surface with a surface inside another surface increased with the similarity in luminance contrast of the grouped surfaces (Masin, 2003). The following discussion shows that this finding may not be conclusive.

Figure 3 shows the stimuli used in the just mentioned study. The letters x, y, and z denote the luminance of the respective uniform area. The luminance of the central square was equal to that of the background, z. In Fig. 3a, by simultaneous contrast, the black horizontal rectangle makes the central square look light-gray and, in Fig. 3b, the white horizontal rectangle makes the central square look dark-gray. The results revealed two groups of participants, which we may call Participants A and B.

In Fig. 3a, Participants A reported that the white square grouped with the central square and, in Fig. 3b, that the black square grouped with the central square. These reports indicate that achromatic color similarity determined grouping. Participants B produced reports opposite to those of Participants A. In Fig. 3a, they reported that the black square grouped with the central square, and in Fig. 3b, that the white square grouped with the central square. These reports suggest that similarity in luminance contrast could have determined grouping since in this case $|x - z| = |y - z|$.

However, the reports of Participants B can be reinterpreted by the recently discovered factor of induced grouping (Vickery, 2008). In Fig. 3a, the bottom black square and the black rectangle grouped by achromatic color similarity, and in Fig. 3b, the top white square and the white rectangle also grouped by achromatic color similarity. Due to induced grouping, Participants B may have reported that, in Fig. 3a, the black square grouped with the central square because the group formed by the bottom black square and the black rectangle perceptually contained the central square. Similarly, Participants B may have reported that, in Fig. 3b, the white square grouped with the central square because the group formed by the top white square and the white rectangle perceptually contained the central square. Thus, due to induced grouping, the results obtained from Participants B do not allow concluding that luminance contrast similarity was a determinant of grouping.

In the present study the possibility that luminance contrast similarity determines grouping of separate surfaces was tested using stimuli that excluded induced grouping.

Method

Participants

The participants were 100 university students with normal or corrected-to-normal vision.

Stimuli

In a dark room, stimuli were presented in the middle of a 320 mm × 170 mm achromatic area of the frontal parallel 20 cd/m^2 screen of a computer display. The remaining area of the screen was covered with black cardboard. The viewing distance was held at 0.7 m by a head-and-chin rest.

Figure 4 illustrates the stimuli. They consisted of two vertically aligned rows of four 9-mm disks in the middle of

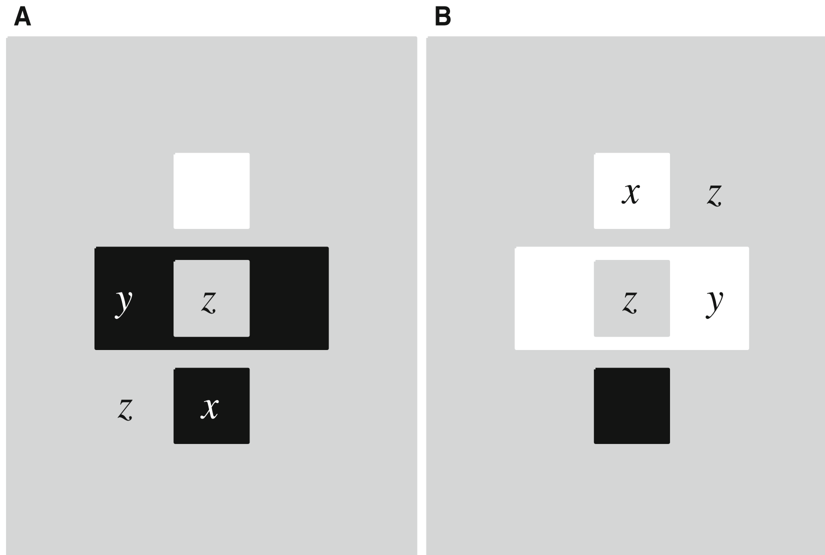


Fig. 3 Stimuli used by Masin (2003). The letters *x*, *y*, and *z* denote the luminance of the respective uniform area of the stimulus

a uniform (4a) or a bipartite background (4b) measuring 75 mm × 60 mm. The vertical and horizontal gaps between disks were 8 and 9 mm, respectively.

In Fig. 4, the letters *x* and *y* denote the luminance of the respective disk. In Fig. 4a, *z* denotes the luminance of the background. In Fig. 4b, *m* and *n* denote the luminances of the left and right halves of the background, respectively.

There were three sets of stimuli with uniform background, named stimulus sets 1, 2, and 3, and two sets of stimuli with bipartite background, named stimulus sets 4 and 5.

Stimulus set 1. In each stimulus $x = y$ with *x* equal to 0.5, 1, 3, 8, 15, 25, 35, 55, or 85 and *z* equal to 0.05 or to 120 cd/m^2. These stimuli served to test whether luminance contrast determined grouping.

Stimulus set 2. The value of *x* was 0.05, that of *y* 120, and that of *z* 0.5, 1, 3, 8, 15, 25, 35, 55, or 85 cd/m^2. These stimuli served to test whether luminance contrast similarity per se determined grouping.

Stimulus set 3. The value of *x* was 0.5, 1, 3, 8, 15, 25, 35, 55, or 85, that of *y* 0.5 or 85, and that of *z* 0.05 or 120 cd/m^2. These stimuli served to test the combined effects of surface segregation and achromatic color similarity on grouping.

Stimulus set 4. The value of *m* was 0.5, 1, 3, 8, 15, 25, 35, 55, or 85, that of *n* 0.5 or 85, and those of *x* and *y* 0.05 and 120 or 120 and 0.05 cd/m^2, respectively. These stimuli served to test the importance of background luminance on grouping.

Stimulus set 5. The value of *x* was 0.5, 1, 3, 8, 15, 25, 35, 55, or 85, that of *y* 0.5 or 85, and those of *m* and *n* 0.05 and 120 or 120 and 0.05 cd/m^2, respectively. These stimuli served to test the importance of surface luminance on grouping.

There was one stimulus for each combination of the luminances used for stimulus sets 1–5. Each of these stimuli was duplicated and rotated 180° making a series of 270 stimuli. For each participant, this series was presented once with stimuli in random order.

Procedure

The participants were asked to rate the salience of the group of eight disks in each stimulus. During the instructions, they were shown a white paper with a drawing representing the contours of these disks without the contours of the background. The participants were told that the stimuli contained two horizontal rows of disks arranged as

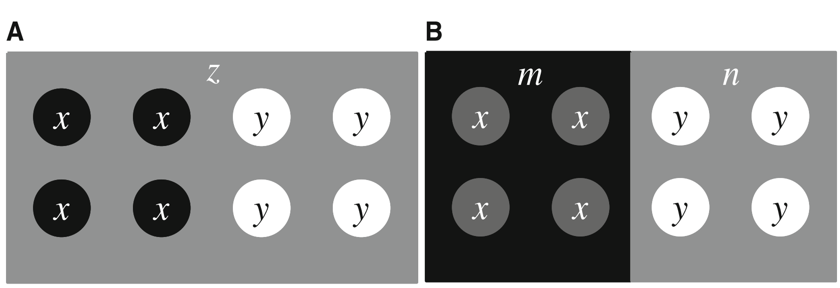


Fig. 4 Stimuli used for the present study. The letters *x*, *y*, *z*, *m*, and *n* denote the luminance of the respective uniform area of the stimulus

in the drawing and that for each stimulus there could be the impression that the disks formed one group of eight disks or that the disks formed subgroups as for example, but not only, two square-shaped subgroups of disks. For each stimulus, the participants were asked to rate how strong was their impression that the disks formed one single group of disks. The integers from 0 to 10 were used for rating with 0 defined as the lack of any impression and 10 as an absolutely definite impression. Before the experiment proper started, each participant was presented ten randomly selected stimuli for familiarization with the procedure.

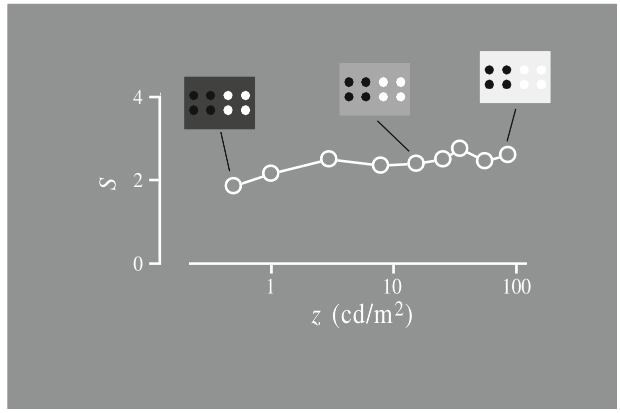


Fig. 6 Mean rated salience, S, plotted against z for fixed x and y (Fig. 4a). Insets depict the stimuli for the lowest, middle, and highest value of z

Results

Hereafter, S will denote the mean rating of the salience of grouping. In Figs. 5, 6, 7, 8, 9, insets depict the stimuli with the lowest, middle, and highest values of the quantity plotted on the abscissa. The abscissa is logarithmic to allow compact presentation. Standard errors of S are not represented to avoid clutter. They were about 0.15 for the Ss reported in Fig. 5, about 0.25 for those in Figs. 6, 8, and 9, and varied from about 0.1 to 0.25 for those in Fig. 7.

Stimuli with uniform background (Fig. 4a)

Stimulus set 1. Figure 5 shows S plotted against x for the luminance combinations indicated by the insets. S increased with luminance contrast. This effect was stronger for the black background. The linear trend was significant for stimuli with black background and was marginally significant for stimuli with white background, $F(1, 99) = 16$, $p < 0.001$, and $F(1, 99) = 3.3$, $p = 0.07$, respectively.

Stimulus set 2. Figure 6 shows S plotted against z for stimuli with black and white disks. S increased with z. The linear trend was significant, $F(1, 99) = 13$, $p < 0.001$. The quadratic trend was not significant, $F(1, 99) = 3.1$.

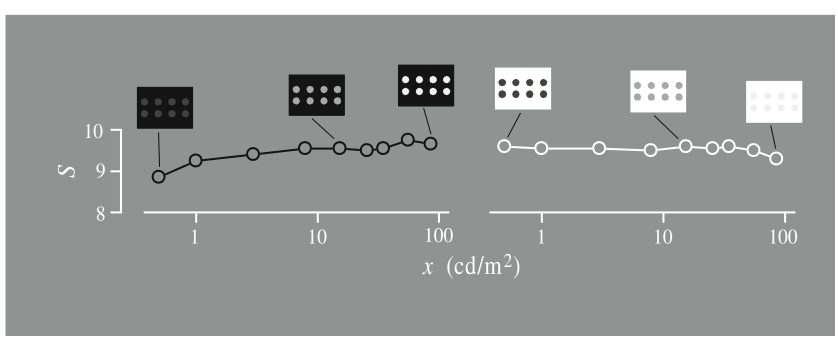
Stimulus set 3. Figure 7 shows S plotted against x for the luminance combinations indicated by the insets. In the left diagram, the curve for the black background is lower than that for the white background. A 2 (background) × 9 (x) analysis of variance showed that the effect of background and the interaction were significant, $F(1, 99) = 159$ and $F(8, 792) = 16$, $p < 0.001$, respectively. In the right diagram, the curves for the black and white backgrounds intersect. The effect of background was not significant and the interaction significant: $F(1, 99) = 3.5$ and $F(8, 792) = 17$, $p < 0.001$, respectively.

Stimuli with bipartite background (Fig. 4b)

The results in Fig. 6 show that S varied in a small range when the luminance of the background varied widely. The results in Fig. 7 show that S varied widely when the luminance of disks varied widely. Stimulus sets 4 and 5 allowed to test the importance for grouping of the variation in luminance of the background and of the disks, respectively.

Stimulus set 4. Figure 8 shows S plotted against m for the luminance combinations indicated by the insets. The wide variation in m produced small changes or no significant change in S. The linear trend was significant for the data in the left-top and left-bottom diagrams and was not significant for the data in the right-top and right-bottom

Fig. 5 Mean rated salience, S, plotted against x for $x = y$ and for fixed z (Fig. 4a). Insets depict the stimuli for the lowest, middle, and highest value of x



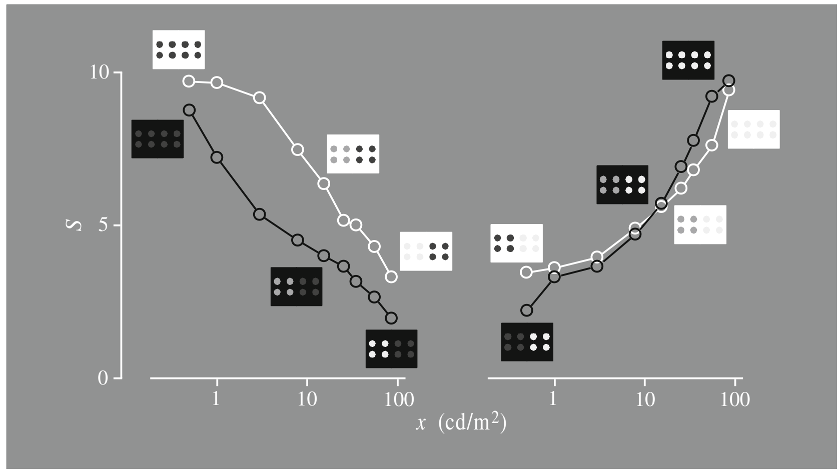


Fig. 7 Mean rated salience, *S*, plotted against *x* for a fixed *y* and for fixed *z* (Fig. 4a). Insets depict the stimuli for the lowest, middle, and highest value of *x*

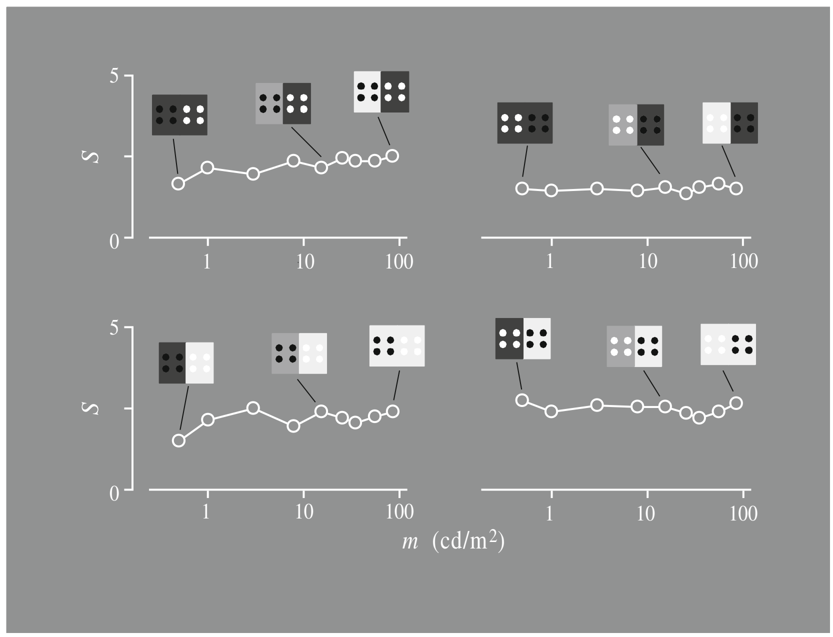


Fig. 8 Mean rated salience, *S*, plotted against *m* for various combinations of *x*, *y*, and *n* (Fig. 4b). Insets depict the stimuli for the lowest, middle, and highest value of *m*

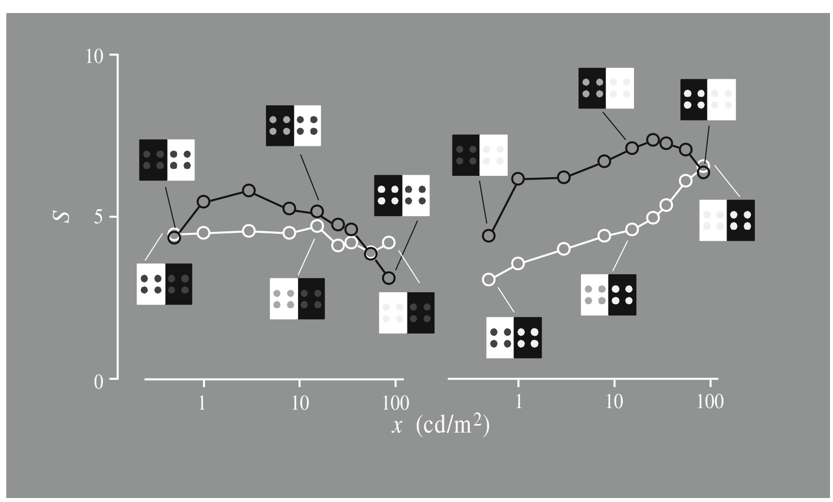


Fig. 9 Mean rated salience, *S*, plotted against *x* for various combinations of *y*, *m*, and *n* (Fig. 4b). Insets depict the stimuli for the lowest, middle, and highest value of *x*

diagrams, $F(1, 99) = 16$, $p < 0.001$, $F(1, 99) = 3.3$, $p = 0.05$, $F(1, 99) = 0.21$, and $F(1, 99) = 0.87$, respectively.

Stimulus set 5. Figure 9 shows the results for the same stimuli that produced the results in Fig. 7 with the only difference that the right part of the background was changed from black to white or from white to black. The results in Fig. 9 show that bipartite backgrounds caused a flattening and a change in relative position of factorial curves.

Bipartite backgrounds involved the factor of common region (Palmer & Beck, 2007) and a change in contrast polarity and in surface segregation for some of the disks. Since the factor of common region and the difference in contrast polarity were the same for all stimuli, one could expect that the effect of these factors was the same for each stimulus. The results in Fig. 9 show that one or more of these factors interacted with surface luminance. A 2 (stimuli) $\times$ 9 (x) analysis of variance for the data in the left and right diagrams showed that the interactions were significant; $F(8, 792) = 6.9$ and $F(8, 792) = 14$, $p < 0.001$; that the effect of x was significant, $F(1, 99) = 12$ and $F(1, 99) = 52$; and that the effect of stimuli was not significant and significant, $F(1, 99) = 1.8$ and $F(1, 99) = 82$, respectively.

Discussion

Surface segregation

In Fig. 5, the results show that S increased with luminance contrast. These results agree with the possibility that S increases with surface segregation since surface segregation increases with luminance contrast (Farnè, 1977; O'Shea, Blackburn, & Ono, 1994; Rohaly & Wilson, 1999). For comparable luminance contrasts, the results show that S for dark disks on dark backgrounds was smaller than S for light disks on light backgrounds, indicating that dark disks on dark backgrounds were less segregated than light disks on light backgrounds. This asymmetry of effects most probably reflects nonlinearities of the visual response to luminance contrast (Kingdom, 2003; Whittle, 1994).

Unimportance of background luminance and importance of surface luminance

In Figs. 6 and 8, for stimuli with disks with opposite-contrast polarity, the results for uniform backgrounds and bipartite backgrounds show that background luminance was unimportant for grouping since it caused no change or small changes in S.

For uniform backgrounds, the results in Fig. 7 show that surface luminance was obviously important for grouping since S varied widely as the luminance of disks varied widely. For bipartite backgrounds, the results in the diagram on the right of Fig. 9 show that surface luminance was important for grouping also when opposite-contrast polarity and surface segregation adversely affected grouping.

Unimportance of luminance contrast similarity

In Fig. 7, S increased as the absolute value of the difference $|x - z| - |y - z|$ decreased. Since perceived contrast increased with $|x - z|$ or $|y - z|$, similarity in luminance contrast could have determined S. The following consideration excludes this possibility. For the stimuli that produced the results in Fig. 6, the absolute value of $|x - z| - |y - z|$ was relatively large when z was close to x or y and was zero or close zero for some value of z between x and y. Thus, S should have varied curvilinearly with z if luminance contrast similarity had determined grouping. The results in Fig. 6 exclude this possibility.

Patterns of factorial curves

The above results strongly support the idea that grouping of separate surfaces is determined only by achromatic color similarity (Beck et al., 1991; Palmer, Neff, & Beck, 1996; Rock et al., 1992). However, in the left diagram in Fig. 7 the curve for the black background is lower than the curve for the white background, and in the right diagram these curves intersect. Achromatic color similarity cannot explain these patterns of factorial curves, whereas this factor together with the factor of surface segregation can.

Consider first the left diagram. For each x, S for the black background was lower than S for the white background since black disks on the black background were less segregated than black and white disks on the white background (Fig. 5). Now consider the right diagram. When x was low, S for the black background was lower than S for the white background since black disks on the black background were less segregated than black and white disks on the white background. When x was large, S for the white background was lower than S for the black background since light disks on the white background were less segregated than light disks on the black background.

General conclusion

Grouping depends on achromatic color similarity. The present results show that grouping additionally depends on surface segregation with luminance contrast similarity per se being an unimportant factor of grouping. Considering that surface segregation has a large effect on grouping, awareness of this factor is particularly important in modeling of grouping.

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