Perceived ranking of feature dimensions in texture similarity ratings

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Combinations of plain or textured patterns were presented to human observers to see which features are most important for texture identification and which ones might eventually be ignored. Pairwise ranking of features and feature domains was measured from spontaneous decisions on the similarity of simultaneously displayed test patches. In plain patches differing in color or luminance, color predominated the similarity ratings until luminance differences became very strong and affected the perceived hue of color patches. In line textures, both color and luminance were more important than any of the spatial features line size, line density, and line orientation. In textures without color or luminance variations, line size and density were more important than orientation. Altogether, the results reveal a systematic ranking of features in similarity estimates that was, with gradual variations, seen across all observers. Color was the most important and, surprisingly, orientation the least important feature domain.

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INTRODUCTION

When looking at textured surfaces, two perceptual phenomenons can be observed. One is the spontaneous *segregation* of regions with the instantaneous percept of borders between them. Systematic studies of this phenomenon have revealed interesting observations of textures that do, and others that do not, perceptually segregate, even when the texture differences can be recognized and distinguished (Beck, 1966, 1982; Julesz, 1975, 1981). Particular interest has been given to the perceived segmentation of textures with different orientations and the possibly underlying mechanisms (Olson & Attneave, 1970; Mayhew & Frisby, 1978; Caelli, 1980; Nothdurft, 1985, 1991a, 1992; Nothdurft & Li, 1985; Knierim & Van Essen, 1992; Lamme, Van Dijk, & Spekreijse, 1992; Nothdurft, Gallant, & Van Essen, 2000; Li, 2000).

The other phenomenon is the *identification* of texture fields, the classification of textures and the evaluation of similarities between texture patches (e.g., Harvey & Gervais, 1981; Gurnsey & Fleet, 2001). Texture identification should be important in "technical" applications like the evaluation of histological slices (for a review, see Li, Li, Rahaman *et al*, 2022), material identification (e.g., Balas & Greene, 2023) and the detection of potential quality failures in production. It should be also important in many cognitive processes such as the interpretation of three-dimensional surfaces (Bravo & Farid, 2001; Burge, McCann, & Geisler, 2016; Chen & Saunders, 2020) or when different surface sections have to be matched for similarity. This is the topic of the present paper.

Are there features that are particularly important in texture identification? In preliminary experiments I noticed that observers when rating textures for similarity might have ignored some texture variations but not others. To search systematically for such rankings, I set up a full study in which various feature dimensions were compared for their role in texture identification and the evaluation of texture similarities. In the present paper, I used line textures at different colors and luminance contrast, at various line densities and sizes, and with different (orthogonal) line orientations. In various test runs, always two texture features were compared, and subjects were asked to group different combinations of texture patches for highest similarity. The paradigm is illustrated, for color and orientation, in Figure 1. Five texture fields with red or green lines at two orthogonal orientations can be perceptually grouped to form either a vertical or horizontal global bar with texture fields of same color or same line orientation. Subjects had to indicate in which global bar the patches looked more similar. In Figure 1, the frequent observation was that the three horizontal patches were chosen, that is, most observers preferred color over orientation when grouping the texture fields for similarity (Nothdurft, 2024). Analogous observations with other feature combinations suggested a hierarchy of texture features, among which color and luminance appeared to be the strongest, and orientation the least strong feature dimensions for similarity ratings. In certain combinations, however, the feature hierarchies were not fixed but depended on the perceived salience of feature variations in both dimensions. For example, strong luminance differences were rated as more important for similarity grouping than weak or medium size variations, and *vice versa*.

For the relative weighting of luminance and color differences, and for variations obtained with different color saturation levels, I used homogeneous, non-structured fields (Section I). For the interaction of color or luminance with variations in orientation or spatial frequency, I used texture like line patterns as those in Figure 1 (Section II). A direct comparison of spatial features in noise patterns has already been published (Nothdurft, 2024), together with an early report about the relative ranking of color and orientation variations.

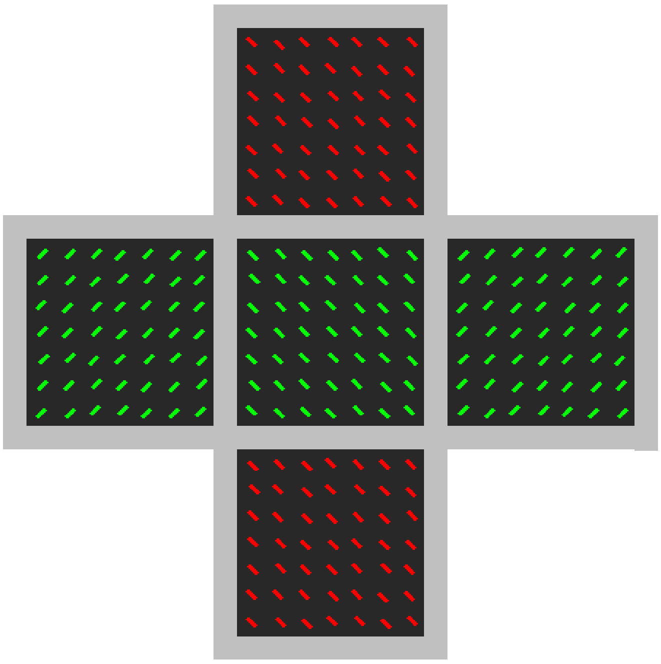

Figure 1. *Similarity matches of texture fields.* Observers saw patterns with different texture fields in which two feature dimensions were varied, here color and line orientation. They had to indicate which fields looked more similar, the three vertical or the three horizontal ones. In this example, lines in the vertical texture fields have the same orientation but differ in color, while lines in the horizontal fields share the color but are differently oriented. Most observers select the horizontal texture fields as looking more similar, thus indicating that they prefer color over orientation in similarity grouping.

METHODS

Tests were performed on nine observers with normal or corrected-to-normal visual acuity and non-impaired color vision (Ishihara tests). Eight observers were students (in the age of 19 to 37 years; four male, four female) and were paid for the time they spent in the experiments; the ninth observer was the author (75 years). One of the student observers had joined the experiment at a later stage and could not participate in all runs.

In all test series, observers saw patterns like those in Figures 1 and 2 and had to report whether the three vertical or the three horizontal texture fields appeared more similar. Each observer performed up to four sessions of maximally two hours each. During tests, observers set relaxed in front of a monitor (73 cm away from the eyes) where stimuli occurred. Test patterns were shown for 2 s with no request for fixation; during this time observers could freely explore the pattern. The presentation time was long enough to recognize details of the texture fields but short enough to force observers to make a spontaneous decision based on their perceptual impression. The importance of global similarity impressions between texture patches was explained at the beginning of each session. Observers entered their responses by pressing one of two keys on a computer keyboard. After the response and a short pause (1-2 s), a new test pattern was shown.

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Test patterns were computer-generated (DOS VGA) and displayed on a monitor (Sony multiscan 17se II) at a refreshing rate of 60 Hz. Single texture fields were 4.6 deg by 4.6 deg large; in the used configuration of three by three fields plus surrounding frames (0.6 deg wide), the entire test pattern was about 16 deg by 16 deg large. Similarity ratings in color were made with red and green stimuli, which had been adjusted for subjective iso-luminance using heterochromatic flicker minimization. Luminance was set to the maximum achieved with the monitor for red (27.2 cd/m²).

Testing was made in altogether 12 test runs with 20-82 test conditions in various repetitions. Runs were performed in pseudo-randomized sequence and each repeated several times. Within a single test run, only one pair of parameters was compared, like, e.g., color vs. orientation, as in Figure 1; across runs, however, various comparisons were tested.

RESULTS

I. Similarity ratings with plain color or luminance patches

Test series A. Color and Luminance

What is more important in grouping for similarity, the color or the brightness of patches (Figure 2)?

Overview

Overall, color is a dominant attribute to identify textures (or, here, homogeneous fields), and fields of similar color were easily grouped together even when they slightly differed in luminance and brightness (Fig. 2a). However, when the luminance difference between the fields was too large (e.g., Fig. 2b, c), observers changed their preference and sometimes grouped patches for the similar brightness (or darkness) instead of color (Fig. 3). In this preference shift, some observers showed a bias that depended on the relative brightness of the center field. When the central color patch was dark and the luminance difference between patches above a certain level (like, e.g., in Fig. 2b), *all* observers selected the dark color patches as similar and thus preferred luminance as the grouping parameter (preference for the horizontal patches in Fig. 2b). When the center field was bright however, at that same contrast (like in Fig. 2c), four of the eight observers preferred color similarity with the central patch even across large contrast variations (again preference for the horizontal color patches in Fig. 2c). The other half of the observers preferred the similar brightness of patches (vertical configuration in Fig. 2c) as with dark central patches. This variation is reflected in the mean rating data (Fig. 3). With dark center patches, the transition from color grouping (values near 100%) to luminance grouping (values near 0%) was nearly complete (Fig. 3a). With bright center patches, however, the transition was incomplete (Fig. 3b) because half of the observers continued to prefer color grouping in these patterns.

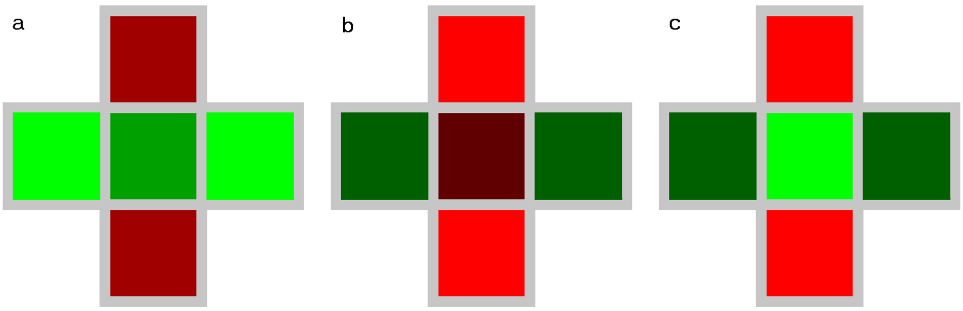

Figure 2. *Test series A: Color and Luminance.* In section I (test series A and B), plain color patches were used instead of line textures. **a-c.** Examples of test patterns. Feature dimensions here were color (red, green) and luminance (bright, dim); the contrast was varied within the test series). When luminance differences were not too large, observers grouped patterns for color (horizontal configuration in *a*). But when luminance contrast was increased (and the luminance of some color patches strongly reduced), most observers found patches of equal luminance looking more similar than patches of the same color (horizontal configuration in *b*, vertical configuration in *c*). Half of the observers however could not rate the different colors of bright patches in *c* as similar and continued to prefer color grouping even across stronger luminance variations, when the center patch was bright (horizontal configuration in *c*; see text for details). In the tests, all color patches were adjusted to equal luminance with other patches at the same luminance level.

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Details and Discussion

Similarity ratings were made at three luminance levels, 27.2 cd/m², 24.6 cd/m², and 18.0 cd/m², each compared with patches at same or four to eight lower luminance levels (down to 6.6 cd/m²). At each level, colors were subjectively adjusted to iso-luminance. To prevent observers from looking exclusively at color differences, a number of pure luminance differences (no color) at a higher luminance level (39.5 cd/m²) were included. Observers grouped these patterns correctly, with an overall error of <1%. All test conditions were randomly mixed in one single test series, which was repeated several times. Conditions with dark or bright central patches (cf. Fig. 2b, c) were distinguished. Eight observers participated in the test.

Figure 3 shows the mean preferences in similarity grouping when the center color field was either dark (Fig. 3a) or bright (Fig. 3b). All observers preferred similar colors (ratings near 100%) when luminance variations were small but switched to similar brightness (ratings towards 0%) when the luminance contrast was increased. The switch was complete in patterns with dark center fields (Fig. 3a) but incomplete in patterns with bright center fields (Fig. 3b). As already mentioned, the difference is caused by four observers (50%) who continued to group patches for color when center patches were bright, despite strong variations in luminance; when center patches were dark, all observers grouped patches for equal luminance. The reason for this divergence may be understood when looking at the examples illustrated in Figures 2b and c. It is relatively easy to see some similarity between the darker patches in Figure 2b, but it might be more difficult to rate the bright patches in Figure 2c as

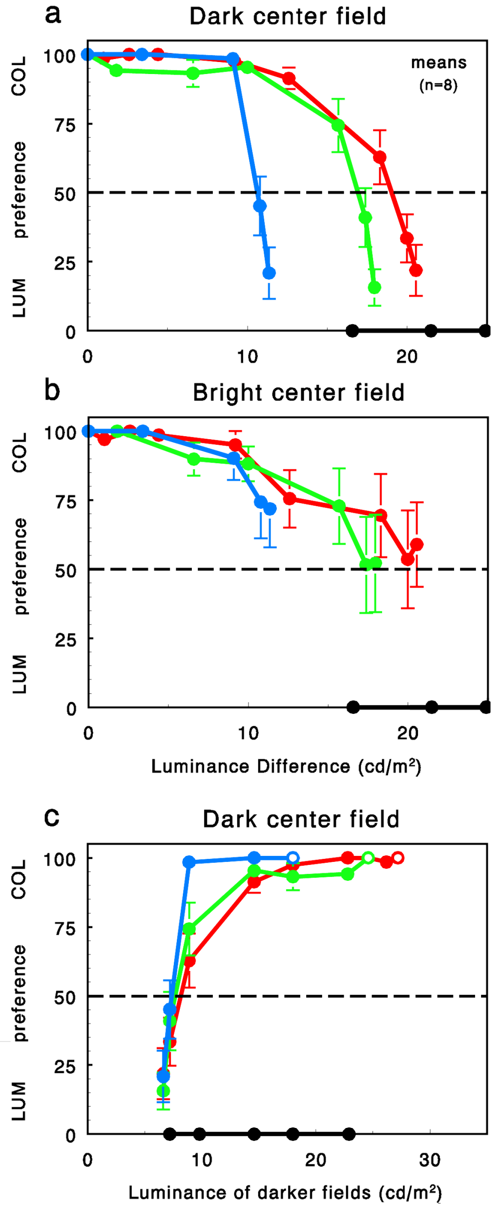

Figure 3. *Test series A: Color and Luminance.* Mean rating data (and standard errors of the means, *s.e.m.*) of eight observers. Data plot the selection frequencies of same luminance (0%) or same color (100%), for three series of luminance variations (different curves). In each series, a bright set of color patches (open circles in *c*) was compared with color patches at various lower luminance levels. With an increasing luminance difference between patches, rating preferences shift from color to luminance; dashed lines at 50% indicate the level of equal ratings. Black data points represent measurements with patterns in which colors had been removed and similarity ratings could only be based on luminance differences (which were perfectly seen; all data points at 0%). **a,b.** Test patterns with dark and bright center fields were distinguished. With dark center fields *(a)* all observers performed a reliable preference shift; the transitions from color to luminance occurred with the smallest luminance settings tested. With bright center fields *(b)* half of the observers did not change their preference but grouped patches, even across large luminance variations, according to their similar color. In the mean data, the resulting transition is thus incomplete. ***c.*** Data from *a* replotted for the luminance of the darker patches. Luminance settings of the bright color patches in a series are indicated by open symbols. The close overlap of curves with dark center fields indicates that luminance grouping was generally preferred for patches below 10 cd/m² where color impressions were reduced. The much stronger colors of bright patches explains why half of the observers could not group these patches for their similar brightness (see text). Standard errors of the means are plotted when larger than symbol size.

similar, since they strongly differ in color. Apparently, the strong hue differences between bright patches had made half of the observers to group patterns like this for color and not luminance, since the bright and dark green patches look more similar than the red and green bright patches.

Preference ratings along the three curves in Figure 3a do not change at the same luminance difference. But when the curves are replotted against the luminance of the darker color fields (Fig. 3c), the preference transitions at low luminance levels closely overlap. This suggests that observers might not have preferred strong luminance variations over color differences but were merely confused by the hue of very dark color patches. According to Figure 3c, color ratings were strongly preferred in all patches above 10-14 cd/m². In darker patches, however, where colors looked different (cf. Fig. 2), and color ratings might have been more difficult, observers had likely grouped the patches by their similar darkness instead. In Figure 2b, for example, the horizontal dark green patches and the central dark red (brownish) patch appear to look more similar than the vertical bright red patches and the and the central (brownish) patch. All observers switched to this rating at low luminance levels. In Figure 2c, however, all bright patches differ considerably from the dark green patches on either side. But to rate the red and green patches as similar, despite their dissimilar hues, was apparently not easy for some observers, who then, instead, grouped the patches for the similar colors green and dark green (horizontal configuration). This might explain why some observers showed the bias between dark and bright center patches.

In consequence, the findings imply that color was much more powerful than luminance, in similarity ratings, and was only replaced when hue impressions were deteriorated at low luminance levels.

Statistics. To proof significance of preference variations between strong color grouping (on the left-hand sides of curves in Fig. 3a and b) and increased luminance grouping (at the right-hand sides), the left-most and right-most data points of each curve were compared in a Wilcoxon signed-rank test. These differences were significant for both dark (n=23; T=0, T_{crit}<35; $p<0.001$) and bright center patches (n=14; T=5, T_{crit}<9; $p<0.005$); the smaller n in the latter comparison is due to the similar preferences of four observers in both conditions. Interestingly, even the right-most data points on the curves (largest luminance difference tested) were still significantly different from ratings in color-free control conditions (black data points) (n=19; T=11, T_{crit}<18; $p<0.001$). This indicates that the preference for color was not completely abolished in these conditions.

Test series B. Hue and Saturation

As just discussed, strong luminance reductions of color patches in test series A had also changed their apparent hue. Thus, the better grouping of low luminance patches might have been partly caused by the reduced color similarity of red or green fields at strongly different luminance levels. It should therefore be interesting to see whether color saturation might affect the general preference for color in a similar way. For that, test series A was repeated but instead of varying the luminance between patches, color saturation was changed by adding white light (cf. Fig. 4). All color patches were adjusted to iso-luminance.

Overview

The grouping for color (hue) remained strong and reliable when color saturation was only little varied between patches (cf. Fig. 4a). But the more the color saturation was reduced, the more deviations from this preference were seen and observers might sometimes have grouped patches for similar saturation rather than same color (e.g., the horizontal instead of the vertical patch configuration in Fig. 4b). At low saturation all color patches look faint, and the common impression of faintness among highly saturated colors may generate a stronger similarity cue than identical hues. This preference transition is reflected in the rating data (Fig. 5). Hue identity predominated the mean ratings between higher and slightly reduced saturation levels (e.g., 1 : .8; 1 : .5; 0.5 : .2; 0.2 : .1), but in combinations with even lower saturation levels (e.g., 1 : .2, 1 : .1; 0.5 : .1) the rating preferences shifted to similar faintness (Fig. 5, cf. the variations across histogram groups). Notice, however, that hue again became important when *all* patches were presented at the lower saturation level (0.5 : .2 and 0.2 : .1, in the second and third histogram groups). This can be also seen in the examples of Figure 4. While most readers will likely group the color patches in Figure 4b for saturation (horizontal patches) rather than hue (vertical patches), hue grouping will dominate when all patches show low saturation (Fig. 4c). This suggests that the sensitivity for hue is not lost at lower saturations but that

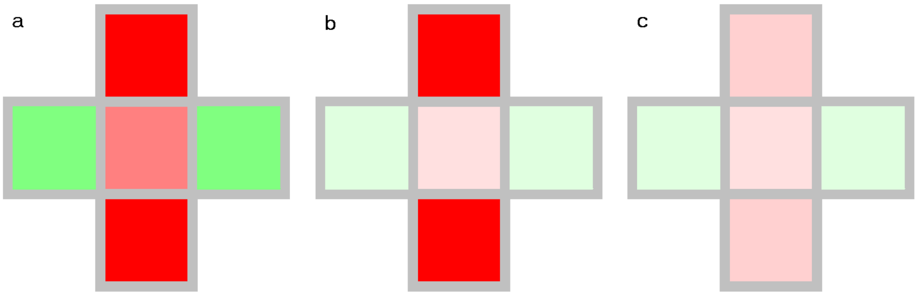

Figure 4. *Test series B: Color (hue) versus Saturation.* Observers saw plain color patches in different colors (always at maximal hue contrast) at various saturations. Along three test series, patches of higher saturated colors were compared with less saturated colors; similarity ratings could be made either for the same color or for the same saturation level. **a.-c.** Examples of test patterns. For small variations in saturation *(a)*, always the same colors were rated as similar (vertical, in this example). With strongly increased differences in saturation *(b)*, observers often preferred the equally saturated patches with faint colors, even across different hues (horizontal, in the example). But the different hues were still distinguished and selected when all patches showed similarly low color saturation *(c*; vertical).

similarity grouping is taken over by other visual parameters, like faintness or, perhaps, even transparency.

Details and Discussion

Comparisons were made at three saturation levels, high (1.0), middle (0.5), and low (0.2), corresponding to white contents of 0%, 50%, and 80%, respectively. At each of these levels, patches were compared with patches at same saturation and different hue (red or green) or patches at same (or different) hue and lower saturation (down to 0.1, corresponding to 90% white), as illustrated in Figure 4. By selecting the patches that looked more similar, observers indicated their preference for hue or saturation in a given pattern. The data are plotted in three groups (Fig. 5), with saturation pairings of 1:1 down to 1:0.1 (first group of histograms), 0.5:0.5 down to 0.5:0.1 (second group of histograms), and 0.2:0.2 and 0.2:0.1 (third group of histograms). For control, also patterns with white patches and no color variations were included; their ratings summed up to about 50% preference for vertical or horizontal patch configurations (right-hand histogram bars in Fig. 5). All test combinations were randomly intermixed in one single test run. Rating variations within histogram groups show the decreasing preference for hue similarities against saturation when saturation differences increase.

Statistics. Across observers, all same saturation color ratings (1:1; 0.5:0.5; 0.2:0.2) together differed significantly from the no-color (0:0) ratings (Wilcoxon signed-rank test; n=19; T=0, T_{crit}<18; p<0.001). This indicates that the preference for color in equally saturated color patches was highly significant. As far as preference shifts are concerned, all transitions from hue preferences (left-hand histogram bars of each data group in Fig. 5) to saturation preferences (right-hand histogram bars of the same group) together were highly significant (n=13; T=0, T_{crit}<2; p<0.001). An interesting issue are the rating variations with patterns at a given saturation level (e.g., 0.2) in combination with higher saturated patches (1:0.2 and 0.5:0.2, respectively) which were then often grouped for saturation, or with patches at the same saturation level

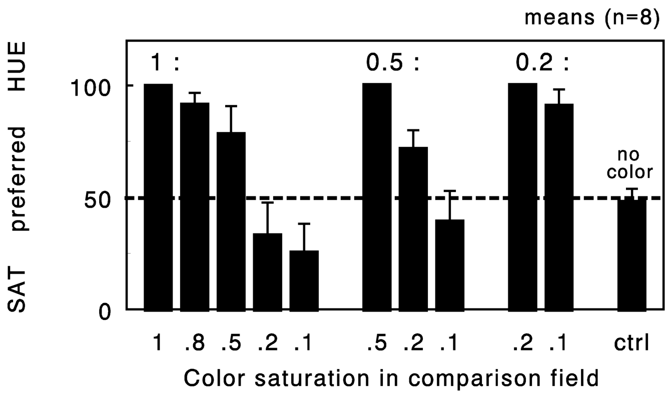

Figure 5. *Test series B: Color (hue) versus Saturation.* Mean rating data (and s.e.m.) of eight observers. Histogram bars plot the preference for equally saturated patches (0%) or patches of the same color (hue) (100%). In three test series, higher saturated patches (numbers above histogram groups) were compared with less saturated ones (numbers below histogram bars); saturation varied from 1.0 (fully saturated colors) to 0.1 (10% saturation; 90% white). For control, also a pattern with white patches (0% saturation) was tested. Its ratings should be indifferent near 50% ("ctrl").

(0.2:0.2) where the preference for color hue was predominant (n=11; T=0, T_{crit}<5; p<0.01).

Conclusions from section I

Altogether, color was a powerful feature dimension in similarity grouping that was not easily overridden by luminance variations across patches (test series A). Only at very low luminance levels when the visibility of hue differences was reduced, was color grouping sometimes also affected by luminance. Similar dark patches, even those of different colors, were then more easily grouped together than bright patches with strongly different hues.

Hue grouping was preferred over saturation (text series B) when the variations in color saturation were not too strong. Faint color patches, however, were frequently grouped for faintness (saturation), not color (hue), but only when the color patches displayed large variations in saturation. If all patches looked similarly faint, color (hue) grouping again became dominant.

II. Similarity ratings with line textures

In the following experiments similarity grouping was tested with texture-like line patterns which allowed me to combine color or luminance variations with spatial texture properties. I tested two spatial feature dimensions, orientation and spatial frequency (implemented by size and density variations of line elements). In different test series, they were compared with variations in luminance (test series C and D), color (test series E and F), and finally both directly compared in iso-luminant black and white patterns (test series G).

Methods

Three rasters with 3x3, 5x5, or 7x7 line elements at different sizes (0.66 deg x 0.15 deg, 0.50 deg x 0.15 deg, and 0.30 deg x 0.10 deg, respectively) and raster widths (1.71 deg, 0.93, and 0.64 deg) at one of two oblique orientations (45°, 135°) were tested. Test patterns are illustrated in Figures 1, 6, 8, 10, 12, and 14 (but different to the examples all lines in the test series were bright on dark background). Lines were regularly arranged with a small positional jitter (0.28 deg, 0.18 deg, and 0.11 deg, respectively) that was refreshed in every new pattern presentation. Line sizes and raster widths were linked to the number of elements in a patch; line elements in the 3x3 raster were large, in the 7x7 raster small, and had middle size in the 5x5 raster. Beside the raster, lines in different texture patches could vary in color, luminance, and orientation. All lines within a single texture patch were identical, i.e., had the same size, orientation, color and luminance.

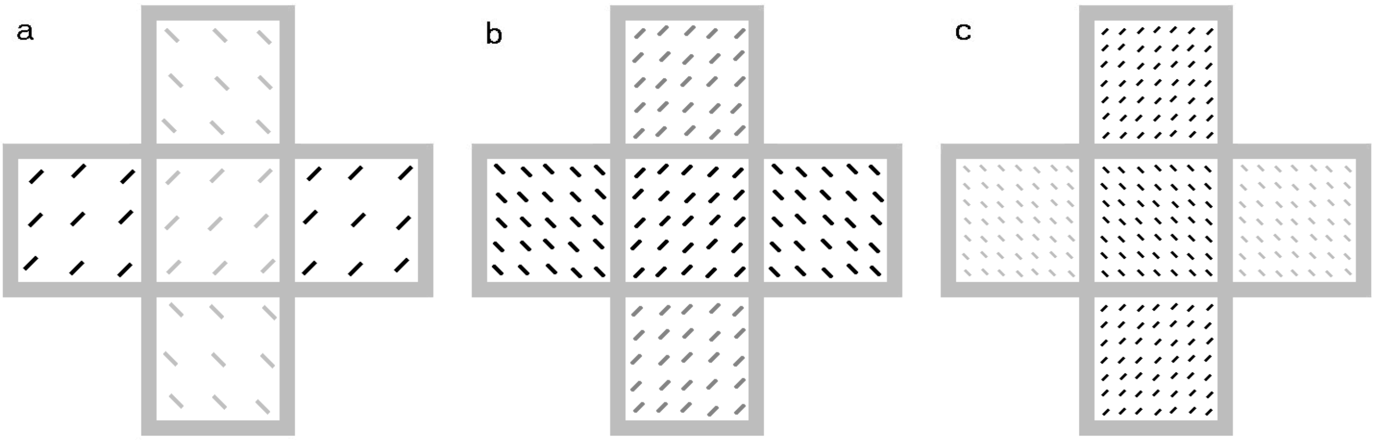

Figure 6. *Test series C: Luminance and Orientation.* In section II (all remaining test series, C-G), similarity ratings were made with texture fields made of line arrays that differed in two feature dimensions, here luminance and orientation. Observers had to indicate which global configuration of texture fields, horizontal or vertical, looked more similar. **a.-c.** Sketches of test patterns to illustrate variations and grouping preferences; in experiment, lines were white on dark background. Tests were performed on three line rasters *(a, b, c)* with 3x3, 5x5, and 7x7 line elements, respectively. The similarity grouping for line contrast (luminance) was generally strong and texture fields with similar line luminance were often selected even across different line orientations.

Test series C. Luminance and Orientation

The first test series in this section combined luminance and orientation. All texture fields of a given test pattern displayed the same line raster, but different fields could vary in line contrast and/or line orientation (cf. Fig. 6). All three line rasters were tested, in different patterns.

Overview

With all rasters, a clearly visible luminance difference between line patterns was sufficient to let observers group texture patches for luminance, not orientation (Fig. 7; cf. examples in Fig. 6). Fields with same line luminance, at different orientations, apparently looked more similar than fields with same orientation but different line contrast. Even at the smallest luminance difference tested (Δlum = 11.5 cd/m²; cf. Fig. 7), orientation was not reliably preferred and mean ratings did not fall below 50%. In the means, performance variations were nearly identical for the three raster variants tested.

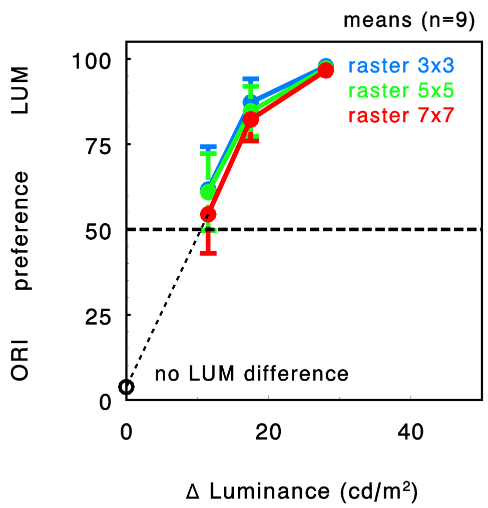

Figure 7. *Test series C: Luminance and Orientation.* Mean rating data, and s.e.m., of nine observers. Data plot the grouping preferences for orientation (0%) or luminance (100%); curves refer to the different line rasters tested. There was virtually no difference between rasters. With an increasing luminance difference between the line texture fields, observers strongly preferred the same luminance over the same orientation. There was no clear transition between preferences in the tested luminance range; even the smallest luminance variation produced only indifferent mean responses and no reliable preference for orientation. For control, also patterns with no luminance difference were included, in which only orientation could be used for similarity estimates (black circle). The transition in preference (orientation over luminance) should fall in the range of the dotted connection line.

Details and Discussion

In this test series, all patches of a given test pattern displayed lines in the same raster. The 5x5 and 7x7 raster conditions were intermingled in one test run; the larger 3x3 raster was tested separately in later sessions. For control, also test conditions without luminance variations were added to the series. All nine observers served as subjects in this test.

A strong preference for orientation (Fig. 7, ratings near 0%) was only seen in the control condition without luminance variations (single data point in Fig. 7) but has already disappeared at the smallest luminance difference tested (~10 cd/m²).

Statistics. All ratings with luminance variations (filled data points in Fig. 7) differed significantly from the control condition with no luminance variations (open data point) (Wilcoxon signed-rank test; n=9; T=0, T_{crit}<1; p<0.01); the differences were highly significant when pooled across all data points within each raster (n=18; T=0, T_{crit}<14; p<0.001). Since some observers preferred luminance in all ratings (except the control condition), the rating variations between the smallest and largest luminance differences tested with each raster were only just about significant (n=7; T=0, T_{crit}<2; p<0.05) but highly significant when pooled over all raster variants (all curves in Fig. 7; n=21; T=0, T_{crit}<25; p<0.001).

Test series D. Luminance and Line Size

In test series D, all lines of a given test pattern had the same orientation (orientation varied randomly between subsequent patterns) but lines in different texture patches varied in size and eventually luminance (see examples in Fig. 8). Luminance settings were different to those in test series C.

Overview

Although the tested range of luminance variations was larger than in test series C (cf. abscissas in Figs. 7 and 9), the overall grouping preference for luminance over size (Fig. 9) was less pronounced than that for luminance over orientation (Fig. 7). No observer grouped size differences for luminance when luminance variations were small (but

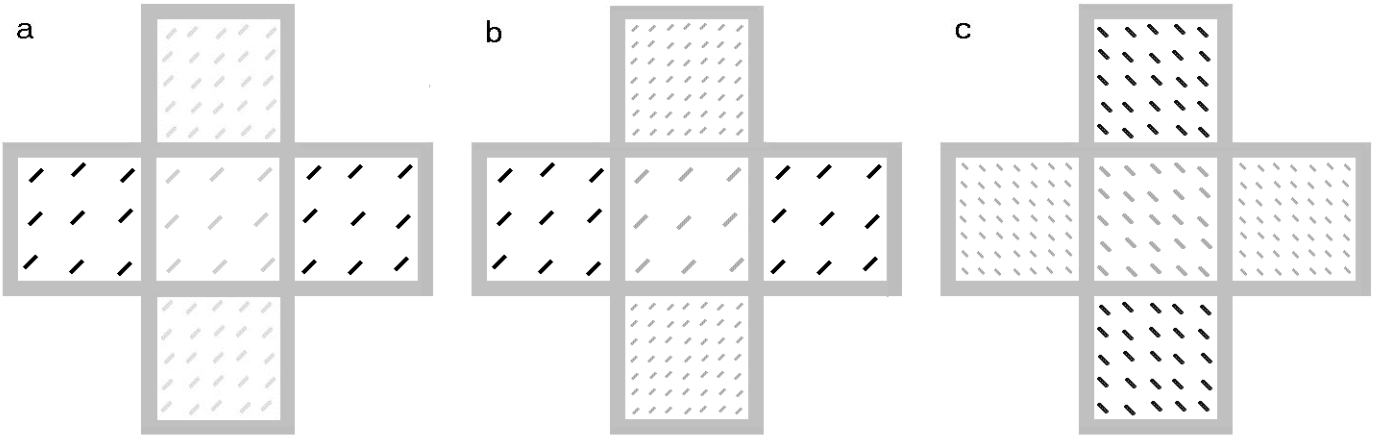

Figure 8. *Test series D: Luminance and Size.* Observers saw patterns with lines of different size at different orientations. Size variations were achieved by the combination of different line rasters, 3x3, 5x5, and 7x7. **a.-c.** Sketches of test pattern examples; lines in experiment were white on dark background. Strong luminance differences between texture fields could dominate the similarity ratings, but this depended also on the line rasters combined (size differences). The strongest grouping for luminance, despite different line sizes, is obtained in combinations of the two finest line rasters *(c)*, whereas in other combinations lines in the coarser raster were sometimes seen as individual items which could be better grouped for similar size despite the different contrast *(b)* - unless luminance contrast was strong *(a)*.

several observers did that with orientation differences), and even with the strongest luminance variations tested (larger than the maximal difference tested with orientation), four observers showed only a small preference for luminance and had instead grouped several patterns for the same line size. This is reflected in the means (Fig. 9) which do not reach 100% ratings for luminance. For most observers, the luminance-preferred grouping was strongest with fine line raster combinations (5x5 and 7x7; red curve in Fig. 9) and less strong when the coarse 3x3 raster was included (blue and green curves). This can be visualized in Figure 8. In patterns with small luminance variations (Fig. 8b and c), the patches with many small lines (Fig. 8c; combinations of the 5x5 and 7x7 raster) tend to group better for equal luminance than the patches with lines of strongly different sizes (Fig. 8b). The larger lines of the 3x3 raster were often seen as single items which then looked similar to other, identical items at slightly reduced contrast. Thus, the similarity grouping for luminance is less strong in Figure 8b than in Figure 8c and would require stronger luminance differences to become perceptually dominant (e.g., Fig. 8a).

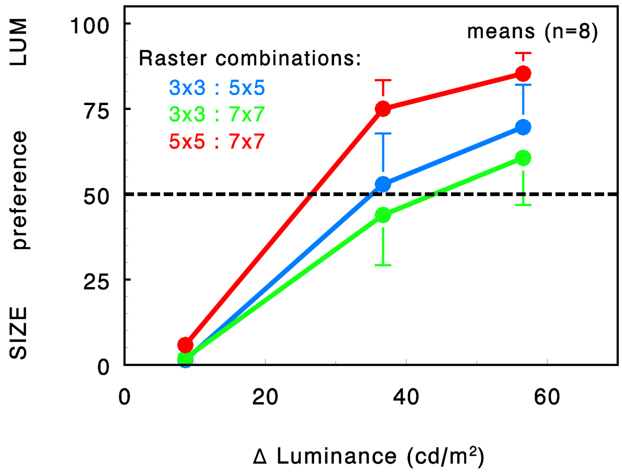

Figure 9. *Test series D: Luminance and Size.* Mean rating data, and s.e.m., of eight observers. Data plot the grouping preferences for similarities in line size (0%) or luminance (100%); curves refer to the different combinations of line rasters tested. With an increasing luminance difference between lines in different texture fields, there was an increasing preference to group texture fields for luminance rather than line size. But this preference shift depended on the raster combination tested. Only with the finest line arrays (red curve) there was a strong transition of preferences from size to luminance. In the other combinations, which both included the coarse line raster, the transitions were incomplete. Note that in comparison with Fig. 7 (test series C, luminance and orientation) the overall preference for luminance is here reduced.

Details and Discussion

Test conditions were split in three runs, each with the same raster variations (i.e., all raster combinations were intermingled) but only one luminance difference. Eight observers participated in this test.

Like in test series C, luminance variations were measured as the difference between lines in the two rasters of a given test pattern; background luminance was constant over all tests. The *mean luminance* of line texture patches varied only little between the three rasters tested. The larger size of lines in the 3x3 raster was compensated by the larger number of (smaller) lines in the 5x5 and 7x7 rasters.

Statistics. Most rating differences along the data curves in Figure 9 are significant (Wilcoxon signed-rank test; $n \geq 7$; $T \leq 1$, $T_{crit} < 2$; $p < 0.05$); exceptions were two data pairs on the green curve (3x3 vs. 7x7 rasters) and the last data pair on the red curve (5x5 and 7x7 rasters). When the data from all three curves are pooled, the rating differences between data pairs become highly significant (Δlum=8.6 cd/m² versus Δlum=36.7 cd/m²; $n=22$; $T=0$, $T_{crit}<30$; $p<0.001$; Δlum=8.6 cd/m² versus Δlum=56.6 cd/m²; $n=24$; $T=0$, $T_{crit}<40$; $p<0.001$; and Δlum=36.7 cd/m² versus Δlum=56.6 cd/m²; $n=21$; $T=25$, $T_{crit}<37$; $p<0.005$). This indicates that the transitions from size to luminance preferences with increasing luminance variations were statistically significant, for all raster variations.

Test series E. Color and Orientation

An early data analysis of part of this test series has recently been published (Nothdurft, 2024).

Given the strong preference for luminance when compared with orientation (test series C) and the strong bias for color when matched against not too large luminance differences (test series A) we should expect that color differences should strongly predominate the grouping for color vs. orientation in line raster patches.

Overview

This was indeed the case (as likely already seen in Fig. 1). Almost all observers grouped colored line patterns for similar colors, not for similar orientations. To see whether the predominance of color would deteriorate with decreasing saturation, also patterns with less saturated colors were tested (cf. Fig. 10). But even when color saturation was reduced to 10% (90% white light) and colored lines looked only faintly red or green (cf. Fig. 10b), observers still preferred color over orientation when grouping line patches for similarity (Fig. 11). Note, however, that the orientation information was not ignored. When saturation was set to zero and colors were absent (Fig. 10c), all observers reliably grouped these patterns for line orientation (Fig. 11, "no color" condition). Only one observer frequently preferred orientation over color in his

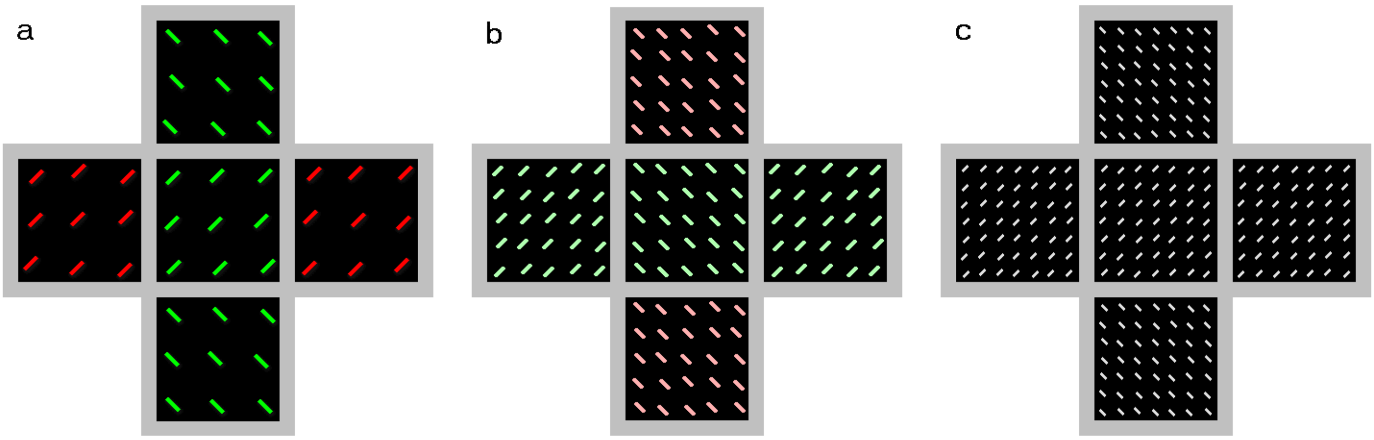

Figure 10. *Test series E: Color and Orientation.* Observers saw texture fields with lines in different colors and orientations. All lines in a test pattern had the same size, but the size (and raster) was varied between runs. **a.-c.** Examples of test patterns. Color differences were varied over several saturation levels, from full saturation *(a)* over less saturated color patterns *(b)* to 0% saturation added for control *(c)*. All line rasters were tested. Almost all observers grouped line patterns for similar colors, not orientation. When colors were removed (0% saturation), grouping was always made for orientation.

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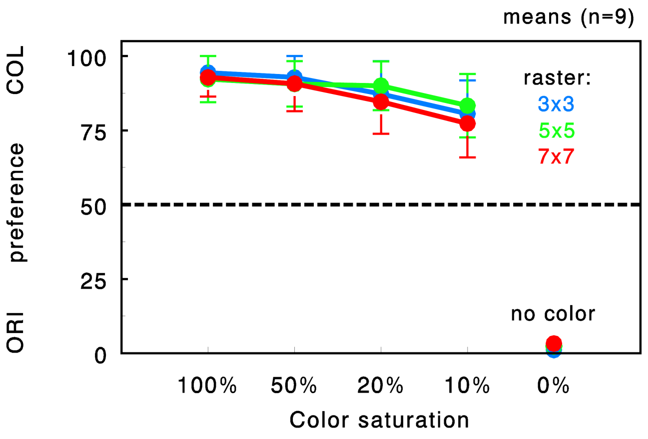

Figure 11. *Test series E: Color and Orientation.* Mean rating data, with s.e.m., of nine observers. Data plot the mean preferences in similarity grouping between line orientation (0%) and color (100%); different curves refer to different line rasters. Ratings were obtained at four levels of color saturation, from 100% to 10%, plus a control condition without color (saturation 0%). In all patterns with color information, color grouping was generally preferred over orientation grouping, but preferences slightly diminished with decreasing saturation. In the "no color" control condition, all observers grouped texture fields for line orientation.

rankings. He produced intermediate ratings (30-50%) with fully saturated patterns (which indicates that he could not completely ignore the color in these patterns) and quickly reached ratings near 0% (preference for orientation) when saturation was decreased. His color sensitivity was normal (Ishihara test plates). All other observers showed a strong preference for color over orientation with fully saturated colors, and many of them only a small reduction when color saturation was diminished. Even at 10% saturation, however, quite a few observers still selected the same line color more often than the same line orientation when grouping texture patches for similarity. There was no systematic difference between the three line rasters tested (Fig. 11).

Details and Discussion

Test conditions included color and orientation differences in various combinations and configurations. Color saturation was varied from full to 10% saturation (100%, 50%, 20%, 10%), plus a no-color condition (0% saturation) that was included for control. All test conditions for a given raster were intermingled in the same run. The test was originally performed only on the 7x7 line raster. This part has been published (Nothdurft, 2024). For aesthetic reasons, however, the test was later expanded to all rasters used in the study, and the missing test conditions were performed in separate runs. At this time, a new observer was included and performed all tests, so that altogether nine observers had participated in this test series.

Statistics. The rating differences between color and no-color patches (connected versus single data points in Fig. 11) were statistically significant both for individual comparisons (Wilcoxon signed-rank test; n=9; T=0, T_{crit}<1; p<0.01) and when pooled over all comparisons with a given line raster (n=36; T=0, T_{crit}<130; p<0.001). Only with the coarse 3x3 raster, one observer gave same ratings for the 20% and 10% saturation levels as for the "no color" condition, which reduced the significance level for these two conditions (n=8; T=0, T_{crit}<3; p<0.05).

Figure 11.

Test series F. Color and Size

With the different rankings of orientation and size against luminance (test series C and D; size was less frequently overridden by luminance than was orientation) but the very strong preference for color when compared with orientation (test series E) we cannot reliably predict which feature dimension will predominate when color and size are compared. But with the very strong preference for color in text series E we expect that color might also predominate similarity grouping in line patterns with different line sizes.

Overview

This can be visualized in Figure 12. In some patterns, texture fields are indeed immediately grouped for color, across different line sizes and line densities. This is quite obvious in Figure 12c. With the coarse 3x3 raster (Fig. 12a and b), however, in particular in combination with texture patches of a much finer raster (Fig. 12b), one may treat the large lines as individual items and group them for their identical form despite their different colors. This is exactly what is seen in the data (Fig. 13). In combinations of the finest line rasters 2 and 3, with 5x5 and 7x7 line patterns, all observers grouped patterns for color similarities (right-hand bar in the main histogram of Fig. 13). But when the coarse 3x3 line raster (raster "1") was involved (left-hand and middle histogram bars), the preference for color was reduced, in particular, when the 3x3 raster was combined

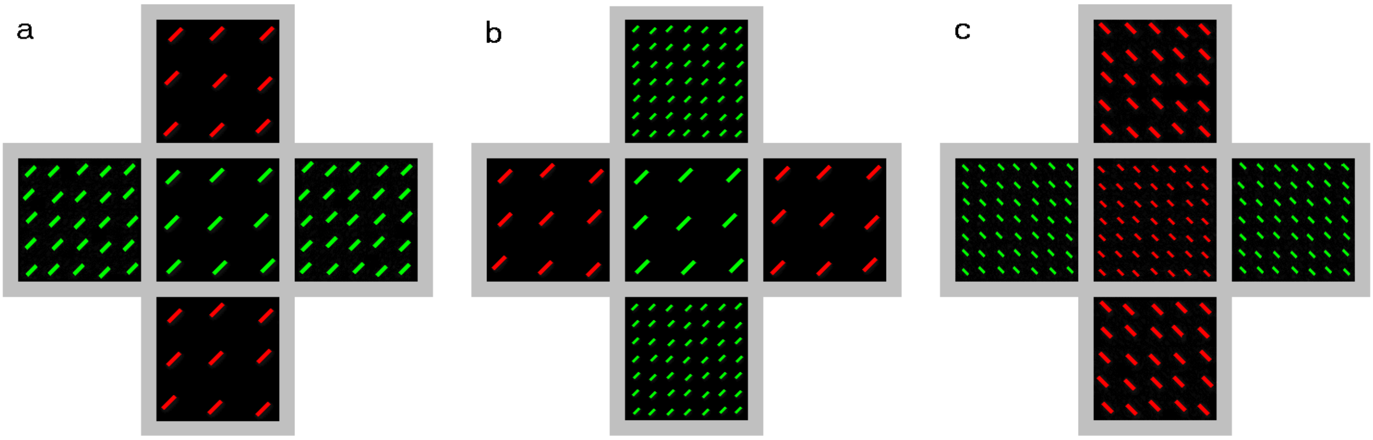

Figure 12. *Test series F: Color and Size.* Texture fields differed in line size and line color. All lines in a test pattern had the same orientation, which was, however, randomly varied between presentations. **a.-c.** Examples of test patterns. Which texture fields look more similar, the three vertical or the three horizontal ones? In the fine raster combinations *(c)*, most observers grouped texture fields for the same color, not the same size. But when the coarse 3x3 line raster was included *(a, b)*, similarity grouping was sometimes also seen for the same line size.

with the finest 7x7 raster (raster combination 1:3). For comparison, also patterns without any color differences (in similar raster combinations) were included in the test series. The ratings indicate that all observers detected the patches with similar line sizes and reliably grouped them for similarity ("Size only" condition).

Figure 12.

Details and Discussion

Only fully saturated colors were tested in this series, plus the white control conditions. All raster combinations were randomly intermingled in a single run. Eight observers participated in the test.

Ratings varied between observers. Two of them preferred color over size in all raster combinations, the remaining six observers showed rating variations with the different raster pairs, which were similar to the variations seen in the mean data (Fig. 13). All but one observer were strictly biased to color when the two fine raster patterns were compared (raster combination 2:3); the one exceptional observer behaved indifferently in this condition but still generated far more color ratings than in combinations with the coarse raster. When the coarse 3x3 line raster was included in a pattern, most observers were less strongly biased to color; this was particularly so when coarse (3x3) and fine (7x7) raster patches were combined (raster combinations 1:3; middle histogram bar). Overall, rating preferences were slightly more indifferent with the

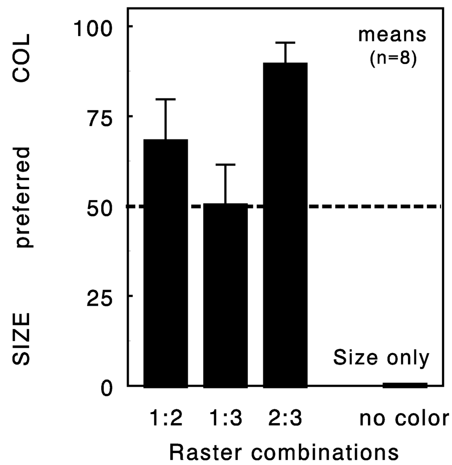

Figure 13. *Test series F: Color and Size.* Mean rating data plus s.e.m., of eight observers. Data plot the mean preferences in similarity grouping for line size (0%) or color (100%), with three raster combinations (cf. Fig. 12) as indicated under the histogram. Raster "1" refers to the 3x3 line raster, "2" to the 5x5 raster, and "3" to the 7x7 raster. For control, additional test patterns without color and only size differences were also tested. Overall, color grouping was preferred over size grouping, but this preference was strong only in combinations of the finest line rasters (combination 2:3). In combinations with the coarse 3x3 raster, the mean preference for color was less pronounced (combination 1:2) or even indifferent (combination 1:3). Similarity ratings in the "size only" control patterns were all correct.

coarse rasters and clearly biased for color with the two finest rasters 5x5 and 7x7 (Fig. 13).

Statistics. All color ratings differed significantly from the "no color" condition (Wilcoxon signed-rank test; n=8; T=0, T_{crit}<3; p<0.05); the differences are highly significant when ratings are pooled (n=24; T=0, T_{crit}<40; p<0.001). The rating differences between raster combinations (i.e., between the three left-hand histogram bars in Fig. 13) were individually just about significant (n≥7; T=0, T_{crit}≤2; p<0.05), the pooled differences between coarse and finer raster combinations (1:2 and 1:3 vs. 2:3; i.e., the two left-hand histogram bars vs. the third bar in Fig. 13) were highly significant (n=16; T=3, T_{crit}<8; p<0.001).

Test series G. Orientation and Size

In the final test series, line orientation and line size (and density) were directly compared to see if there is a ranking between the two spatial parameters (Fig. 14). Since in test series C - F luminance and color variations had dominated orientation variations more strongly than size variations, we expect that size may generally be given more weight in similarity estimates than orientation.

Overview

The ranking is, in fact, quite obvious in the examples of Figure 14. When looking for similar texture properties, all observers rated patches with the same raster and line size as more important than patches with the same line orientation (Fig. 15). This was valid for all raster combinations and suggests that orientation was almost ignored in this task. But this was not the case. In two control conditions intermingled in the tests, in which patterns displayed only size variations (all lines had the same orientation) or only orientation differences (all lines had the same size), observers could perfectly discriminate between these two conditions (right-hand histogram bars in Fig. 15) and always selected orientation as the key parameter for similarity grouping in the pure orientation conditions.

Details and Discussion

All test conditions were intermingled in one single run. Nine observers participated in the test. The preference for size was generally very high. Only one observer, and only in the fine raster combination 2:3, preferred orientation over size in a number of presentations (rating 32%). Apparently, the size difference between the 5x5 and the 7x7 raster was not strong enough for him.

Statistics. The rating differences between raster combinations (left-hand histogram bars in Fig. 15) and the "noSIZE" control condition (right-most histogram bar) were all significant (Wilcoxon signed-rank test; n=9; T=0, T_{crit}≤1; p<0.01) and even highly significant when pooled across all raster combinations (n=24; T=0, T_{crit}≤40; p<0.001). Performance variations between the different raster combinations were not significant.

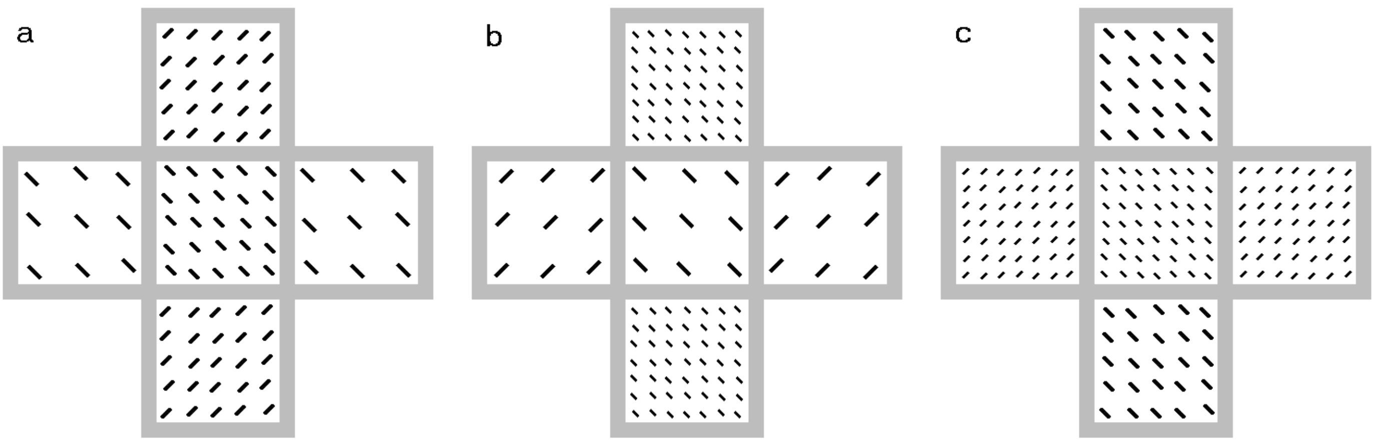

Figure 14. *Test series G: Orientation and Size.* Texture fields differed in line size and orientation. **a.-c.** Sketches of test pattern examples. In experiment, lines were white on dark background. All lines had the same luminance contrast. Size variations were obtained with different raster combinations, 3x3 with 5x5 *(a)*, 3x3 with 7x7 *(b)* and 5x5 with 7x7 *(c)*. In all combinations, the similarity grouping of line size (density) over orientation is obvious.

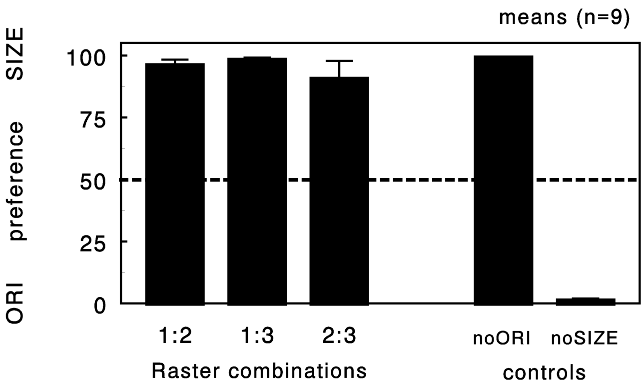

Figure 15. *Test series G: Orientation and Size.* Mean rating data, and s.e.m., of nine observers. Data plot the mean preferences in similarity grouping for orientation (0%) or size (100%), for raster combinations as sketched in Fig. 14 and indicated under the histogram. Raster "1" refers to the 3x3 line raster, "2" to the 5x5 raster, and "3" to the 7x7 raster. For control, test patterns without orientation differences ("noORI") or without size variations ("noSIZE") were also included. The grouping preference for size similarities over orientation was strong in all raster combinations. Only in the "noSIZE" control condition, all similarity ratings were (correctly) made for orientation.

Conclusions of section II

Similarity grouping was studied in five test series with different combinations of feature dimensions. Both color and luminance could override spatial properties like orientation or line size and density; effects from color grouping then were stronger than effects from luminance grouping. In the comparisons with color or luminance and also in the direct comparison, line size and density were rated as more important than orientation.he study reports five series of experiments with four different target types (Fig.1). The test sequence was not the same in all observers and is here sorted for the clarity of presentation. Experiment 1 (oriented lines) tested performance with relatively simple target features and is here also used to introduce the major steps of analysis. Experiments 2 (Vernier's) and 3 (T's) present data obtained with more complicated targets which are commonly reported to require focal attention for identification and discrimination. Experiments 4 and 5 (conjunctions) transfer the task to targets with feature combinations of orientation and color, and also add a final test with new target locations which allowed for a better distinction of distance and hemifield effects.

DISCUSSION

Altogether, the data show a clear ranking of feature dimensions in texture identification. Color was the most dominant feature dimension and provided the strongest grouping for similarity. Luminance was strong, too, but could override color only when luminance differences were strong and affected the appearance of color. Generally lower levels in ranking were seen with spatial feature dimensions, and here variations in line size and raster were rated more strongly than variations in orientation. Thus, it was mainly orientation that contributed only little to texture identification in the presence of other features. The strong ranking of line size and line orientation was confirmed with (continuous) noise patterns (Nothdurft, 2024). When noise patterns varied in spatial frequency and orientation, different patches were better grouped for similar spatial frequency bands (even across orthogonal orientations) than for similar orientations at different spatial frequencies.

This finding is surprising, after so many texture studies have spent so much effort to establish the role of orientation in texture discrimination and segmentation (e.g., Beck, 1966, 1982; Olson & Attneave, 1970; Mayhew & Frisby, 1978; Caelli, 1980, 1982; Bergen & Julesz, 1983; Julesz, 1984; Nothdurft, 1985, 1991a, 1992, 1993, 1994; Nothdurft & Li, 1985; Landy & Bergen, 1991; Knierim & Van Essen, 1992; Nothdurft, Gallant, & Van Essen, 2000; Li, 2000). Orientation and spatial frequency filters were considered as powerful sensors to discriminate almost all segregating texture variations (Turner, 1986; Caelli, 1982, 1988; Caelli & Moraglia, 1985; Voorhees & Poggio, 1988; Fogel & Sagi, 1989). Contrary to the early texton model (Julesz, 1981, 1984; see also Treisman, 1985), however, the segmentation of texture regions with different orientations has been reported to depend on the orientation *gradient* across texture borders, not on the identity of certain orientation features within a texture region (Nothdurft, 1985, 1991a, 1992, 1993; Landy & Bergen, 1991). This suggests that orientation itself may not be the best descriptor to characterize texture regions (for further discussion, see Nothdurft, 2024).

The low ranking does, however, not imply that orientation was ignored in the rating task. It simply was weighed less strongly than other features and feature dimensions when texture fields had to be rated for similarity. Upon request, all observers could deliberately ignore color and luminance variations and reliably identify texture fields with lines of the same size or same orientation (as the reader will also be able to do in the figures). But when asked to rate texture fields for their similarity, observers (and likely the reader, too) tended to ignore orientation and eventually line size differences.

Limits of findings

Note that I have used the "classical" parameters color, luminance (contrast), spatial frequency (SF), and orientation, rather than more texture-based descriptors like coarseness, directionality, regularity, or contrast (Kim, Bair, Pasupathy, 2022; cf. Sun, St-Amand, Baker, & Kingdom, 2021). This might not always have been optimal. In Test Series B, for example, I had to describe some preferences in similarity grouping with "faintness", a parameter that is not part of the classical list of physical parameters above but represents a subjective impression of color sensation. However, the observed ranking of feature dimensions should not be affected by the use of different terminologies, and most of the new and perhaps more texture-based descriptors are fully covered by the classical feature dimensions even though perhaps not in a direct one-to-one relationship.

Another limit of the study is the use of plain patches in the comparison of non-spatial parameters, color and luminance (Test series A and B). This was adequate for color and luminance variations but may diminish the overall validity of the study since these two rankings were not tested with texture-like stimuli. In principle, one should not expect different rankings when line textures instead of plain color fields were used. But to confirm this assumption, test series A and B were later informally repeated with line patterns (7x7 raster) and the main findings qualitatively reproduced. In combinations of color and luminance variations (test series A), color grouping is preferred except when luminance variations are large (cf. Fig. 3a). Transitions curves are superimposed when ratings are plotted against the luminance of darker lines (cf. Fig.3c), indicating that the preference for color is overridden by the darkness of lines, not by an absolute luminance contrast. The bias between dark and bright center fields (cf. Figs. 3a vs. 3b) can, in principle, be reproduced if observers refuse to rate patches of bright but differently colored lines as similar (bright colors appear less similar than very dark colors). In ratings of color hue vs. saturation (test series B), similar rankings as with plain color patches are obtained with texture lines.

Forest and trees

The deliberate bias to either look at global similarities or to identify fine details in the patterns was a principle experimental difficulty in the tests. The aim of the study was to evaluate the perceived similarity of *textures*, not to analyze structural details like the number or the thickness of lines. Like we may distinguish the trees from the forest, observers could look at each line individually. But to perform the experiments correctly, it was important that they looked at the test patterns as a collection of textures (forest), not of single lines, and decided about the similarity of texture patches, not about the form and identity of individual items inside the patches (trees). This was usually the case, but in particular with coarse lines as in the 3x3 raster their spontaneous interest in trees, not the forest, might have been emphasized.

This difference has been perfectly described by Kimchi & Palmer (1982). When studying the perceived organization of hierarchically constructed patterns, using similarity judgments, they noticed that "...in patterns composed of a few relatively large elements, the elements were perceived as individual parts of the overall form and were perceptually salient. Increasing the number of elements and/or decreasing their size resulted in a perceived unified form associated with texture, representing the structural properties of the elements as a group. In the latter case, the perceptual salience of the individual element decreased, and the global form (or sometimes the texture) dominated perception" (cited from their Abstract). This is exactly what was sometimes also observed in the present study and may explain the preference variations between ratings with either 3x3 or 7x7 raster patches.

Previous studies

Some studies have explicitly looked at the combination of different texture parameters, mostly under the aspect whether coincident ("redundant") variations in different parameters would increase or diminish the strength of perceived segregation and whether the segmentation from one parameter might be disturbed by conflicting or independent ("irrelevant") variations in the second parameter (for combinations of color and orientation see, for example, Morgan, Adam, & Mollon, 1992; Pearson & Kingdom, 2001; Saarela & Landy, 2012).

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Callaghan and colleagues addressed this question by measuring the reaction times in simple segmentation tasks. When comparing hue and brightness effects (comparable to test series A of the present study), Callaghan (1984) found interactions that depended on the strength of color and brightness differences tested (and on the presentation of test conditions in blocked or unblocked conditions). With sufficiently strong differences, both irrelevant hue and irrelevant brightness variations could affect the speed of segregation in the other parameter. This would be in agreement with the observations in test series A that texture patches could be grouped for either color or luminance depending on the strength of the luminance contrast (Fig. 3); color contrast has not been varied in my experiments. In a later study (Callaghan, Lasaga, & Garner, 1986), the authors measured interactions between color and orientation, and again found symmetrical interference of both parameters when using oblique line orientations as in the present study. This is contrary to my observations (test series E; Figs. 10 and 11) where color strongly dominated the similarity ratings and orientation differences merely ignored (cf. Fig. 1). From this ranking we should expect that irrelevant color variations would disturb the segregation of orientation differences more strongly than would irrelevant orientation variations disturb the segregation of color differences. Interference should be strongly asymmetrical. One reason for the discrepancy between studies might be that the items in the Callaghan *et al.* study were too few (3x3 in the segmenting field) and perhaps too large to be recognized as a texture field. As seen with the 3x3 raster in the present study, large lines were sometimes seen as individual items and might then have been rated more by their form than by their color (see the discussion above; Kimchi & Palmer, 1982). It also may be difficult to conclude from an observer's reaction time upon the percept of segregating fields; detection of a segmenting quadrant in a figure may be indistinguishable from the detection of one or two particular items in that quadrant. In a third paper, Callaghan (1989) measured interactions between the parameters hue, geometric form, and line orientation. In "ambiguous" arrays in which two segmentation parameters were superimposed, she found clear transitions from preferences to one or the other parameter, which I have seen with luminance and line orientation (Fig. 7) or line size (Fig. 9) but not with color (Figs. 11 and 13). But particularly for hue and orientation (comparable to test series E), the preference for hue-defined segments in Callaghan's experiments quickly grew over that for orientation-defined segments, when hue differences were increased. This would be consistent with the more or less overall preference for color in my study (Figs. 11 and 13) where hue differences were maximum. The point of transition from orientation to color in Callaghan's experiments was found at a much smaller hue difference than that for other form variations (squares vs. circles). This, again, would be consistent with the present data where other form variations like line size and density were less strongly dominated by color (test series F; Figs. 12 and 13) than orientation (test series E, Figs. 10 and 11). And size (i.e., "form") was generally rated as more important than orientation in similarity comparisons (test series G, Figs. 14 and 15).

In the mid eighties of the last century, when vision research had been challenged by the proposal of textons (Julesz, 1981, 1984) and several new textons were described that seemed to provide spontaneous segregation (e.g., Enns, 1986), a number of papers underlined the importance of early filters in the visual system (Bergen & Adelson, 1988; Caelli, 1988; Voorhees & Poggio, 1988; Fogel & Sagi, 1989). Many supposed textons generated response differences in these filters (cf. Nothdurft, 1990, 1991b) so that the segmentation of spatial form variations could, in principle, also be explained by the different activation of (oriented) spatial frequency filters in the early visual system (Turner, 1986; Caelli, 1982, 1988; Caelli & Moraglia, 1985; Fogel & Sagi, 1989). Orientation and spatial frequency were established as independent parameters (Caelli, Brettel, Rentschler, & Hilz, 1983; Caelli & Moraglia, 1985) that seemed to interfere only little, and likely symmetrically, in texture segmentation. The observation that they, in fact, may interfere strongly and not symmetrically (as also seen in test series F; Fig. 14) was recently reported and discussed (Nothdurft, 2024).

Feature ranking or variations in perceived salience?

An important question in the interpretation of similarity rankings in texture identification is whether textures might not be simply grouped against the strongest perceived texture differences, or along the most salient feature dimensions? These two proposals of potential saliency effects are opposite: Two clearly segregating texture fields would unlikely be grouped together (like, e.g., red and green line patches), whereas it seems plausible to group salient over less salient feature dimensions (e.g., color

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over orientation). In either proposal, however, the link to perceived salience would imply that grouping preferences might change, and perhaps even reverse, when the salience of one feature dimension or the perceived strength of texture variations between two patches is varied. This was apparently the case in test series A (color vs. luminance); when the luminance was strongly varied (and hue sensation between dark patches was reduced), dark patches of different colors were more often grouped than dark and bright patches of same colors or even bright patches of different colors (Fig. 3). Ranking variations were also seen in test series D (size vs. luminance); with increasing luminance contrast, preferences in similarity ratings switched from size to luminance (Fig. 9). In all comparisons with orientation, however (series C, E, and G), such transitions were absent or outside the tested parameter range, since variations in the second feature had to be extremely small to let orientation win (small luminance variations, very low color saturation, or small variations in line size). With luminance (test series C), even the smallest difference tested (Δlum=11.5cd/m²) did not generate a reliable preference for orientation (Fig. 7). With color (and the strong color contrast used in the tests; test series E), no preference shift was seen, not even when color saturation was reduced down to 10% (Fig. 11). And also with line size (test series G), all observers weighed size over orientation (Fig. 15); only one observer gradually changed his preference with the finest raster pair tested. Since all these tests were made with orthogonal lines at maximal orientation contrast (90°), it shows that orientation is an apparently little salient texture feature when combined with other texture variations.

Similar rankings in texture segmentation?

Is texture *segregation* similarly affected by superimposed parameter variations? If segmentation and

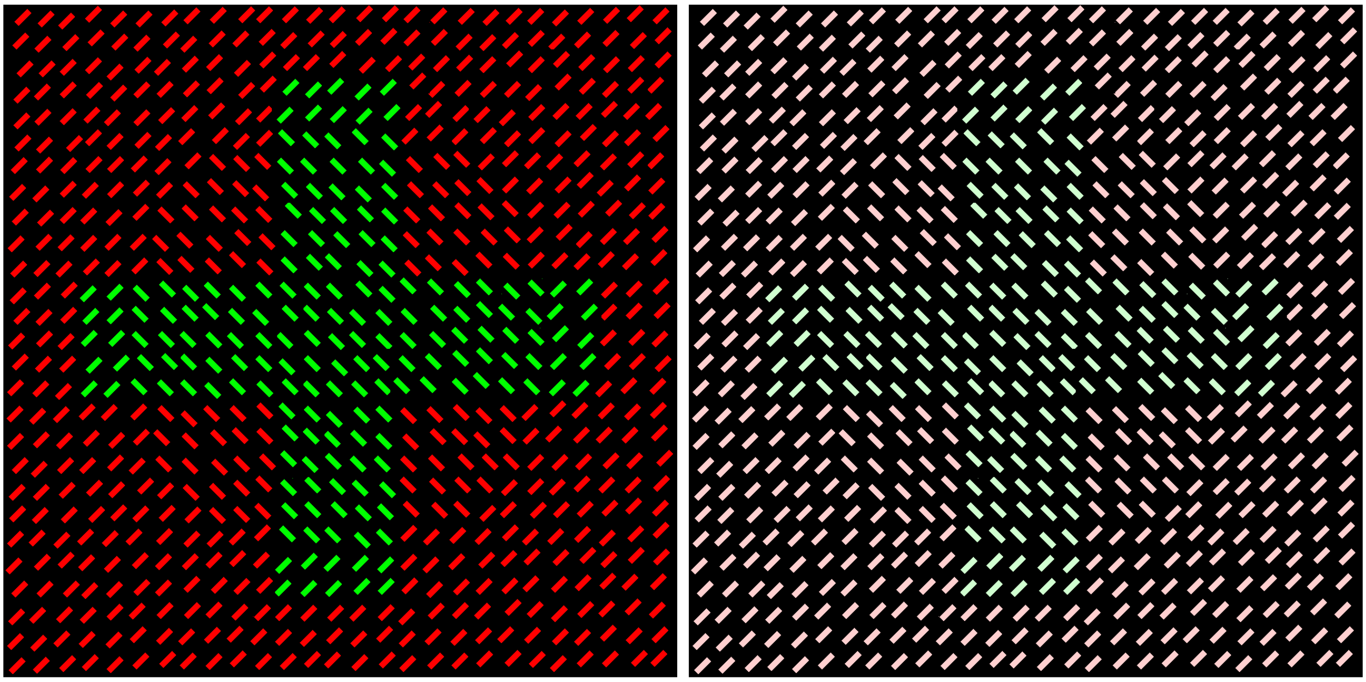

Figure 16. *Similarities between texture identification and texture segmentation?* The compelling dominance of color over orientation found in similarity grouping, a texture *identification* task, is here transferred to texture *segmentation*. **a.** Two segmentation keys, color and orientation, are superimposed to generate two relatively simple texture regions. While dominant color differences make the cross stand out, despite partly different line orientations (grouping for color over orientation), the orientation-defined textured disk is not well seen, in particular not across different colors and near color borders. **b.** When the color contrast is strongly reduced and the cross begins to disappear, the full disk of similarly oriented lines becomes better visible (grouping for orientation over color). Thus, preference variations in texture identification and similarity grouping do also show up in texture segmentation.

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similarity ratings were perceptually linked, we might expect similar rankings between feature dimensions in segmentation. While orientation differences alone are known to segregate well, the segregation should be strongly disturbed when other feature dimensions, like color or luminance, are varied across the texture fields. For color, this has been shown (Morgan, Adam, & Mollon, 1992; Pearson & Kingdom, 2001); interestingly (but not surprisingly), the disturbances are reduced when an observer cannot distinguish the implemented colors—one of the few advantages of dichromates in visual perception. According to the data from the present study, however, such disturbances should be notably smaller when orientation is varied across well segregating color or luminance fields. For spatial frequency and orientation, that was indeed shown (Nothdurft, 2024). The segmentation of texture fields at different spatial frequencies is only little affected by random orientation variations, but the segmentation of fields with different orientations is strongly disturbed by random variations of spatial frequency.

A similar interaction between feature dimensions in texture segmentation is illustrated in Figure 16. Two texture regions from different feature variations are superimposed. When the color contrast is large (Fig. 16a) primarily the green cross is seen; the superimposed disk of orthogonal lines is hard to identify, in particular across the different color regions and near the color borders. The disk is better seen when the color contrast is reduced and segmentation from color becomes less dominant (Fig. 16b). But to reach this level and make the orientation-defined disk fully visible, color contrast must be weakened dramatically—the ranking is similarly strong as in grouping (Fig. 11). In Figure 16a, all sections of the green cross are grouped as similar (despite the different line orientations they display), but the various disk sections with same line orientation cannot be grouped together. In Figure 16b, the grouping preferences are reversed. Disk regions with the same line orientation can now be grouped together (across different colors) but not so easily the various regions of the cross in the same color.

Thus, the observed ranking in texture grouping is also seen in the perceived strength of texture segmentation when different feature dimensions are superimposed. Strongest differences predominate both percepts. In this aspect, texture discrimination and texture identification may be more similar than intuitively assumed.

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