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ABSTRACT

Luminance- or color-defined ±45° line elements were arranged so as to yield *double-conjunction texture-pairs, DCj_TP*. In such pairs, the two textures to be segregated differ in the *conjunction* of the 2×2 attribute-values of which they are built, i.e., luminance-polarity (dark and bright) and orientation (+45° and −45°), or color (red and green) and orientation. Observers were required to discriminate the orientation of their separating edge (vertical or horizontal). Chromatic and luminance contrasts were matched to yield equal performances as measured with *single conjunction texture-pairs*, i.e. textures whose constituent elements differed along one single dimension (luminance, color or orientation). Orientation contrast (90°) could not be matched to the remaining two contrasts and it yielded thresholds about twice as high as the color or luminance contrasts.

DCj_TP segregation was measured with two groups of naive observers. Observers in the *test* group were explained after four initial sessions the construction principle of the stimuli and were cued (asked to "pay attention") to one of their attribute-values (a given color, luminance-polarity or orientation). The *control* group ran through the same total number of sessions as the test group but the observers were not instructed in any way.

Non-cued observers typically yielded performances near chance level under the present experimental conditions. Feature cueing was effective for both color- and luminance-defined stimuli but less so for the latter, despite the equivalence of the chromatic and luminance contrasts. Within each stimulus category (color- and luminance-defined), attending to either of its two defining dimensions (color/luminance or orientation) yielded equivalent performance enhancements, despite a significant difference between the available contrasts along these dimensions. A global performance improvement occurred over time even without cueing. The test group showed such a trend in the post-cue phase for both the color- and luminance-defined stimuli, while the control group yielded similar practice effects only for the color-defined ones. These attentional and practice effects with texture stimuli are discussed in the context of one- vs. two-stage segregation theories, on the one hand, and by reference to signal enhancement vs. noise suppression proposals, on the other hand. It is concluded that, similarly to the visual search tasks, texture segregation can be improved by means of attentional strategies aimed to isolate specific stimulus features such as color, luminance-polarity and orientation.

INTRODUCTION

The improvement of our visual performance through priming one of the attributes (color, luminance, size, shape, location, etc.) characterizing a target stimulus embedded in a multidimensional "distracting" field has been documented for decades (e.g. Green & Andersen, 1956; Smith, 1962). Most of the literature assessed this priming effect in terms of a reduction in the reaction time for the cued trials, but sensitivity enhancement has also been claimed (e.g. Humphreys, 1981; Tsal & Lavie, 1988; Bravo & Nakayama, 1994; Maljkovic & Nakayama, 1994; Raymond, O'Donnell & Tipper, 1997). Generally, attribute-priming experimental designs involve an odd-man-out task. It is less clear whether or not attribute priming is equally efficient in texture discrimination tasks.

One way or another, the role of attribute priming is to reduce the size of the relevant attribute space within which the target is to be found. Phrased differently, attribute priming decreases the uncertainty characterizing search in a multiattribute space. Manipulating uncertainty has been the preferred method in assessing attentional effects in early-vision experiments (see Pelli, 1985 for a review). The general claim of this literature is that any uncertainty-related sensitivity effect (whose assessment does not necessarily require the use of priming) is evidence that the observer can somehow selectively *monitor* (or *attend to*) the sensory space circumscribed by the manipulated uncertainty. In a circular manner, the effectiveness of an uncertainty manipulation (explicitly—through priming—, or implicitly—through repetition; e.g. Bravo & Nakayama, 1992) was taken as evidence for the existence of distinct sensory mechanisms precisely because they could be addressed (monitored) independently (e.g. Davis, Kramer & Graham, 1983; Kramer, Graham & Yager, 1985). The main unanswered question in this literature is whether the observed effects are to be accounted for at the coding level (*signal enhancement*) or at the decision level (e.g. Palmer, 1994). Manipulation of uncertainty (through priming or otherwise) may be associated with a change in the number of noise sources to be considered at the decision level thereby affecting a sensitivity index such as d'. Recent studies favor this *noise suppression* interpretation (Shiu & Pashler, 1994a,b; Dosher & Lu, 1997), but evidence supporting the signal enhancement hypothesis also exists (Raymond, O'Donnell & Tipper, 1997).

Assessing the extent to which an observer can monitor (or attend to) an arbitrary perceptual attribute/dimension may be achieved without manipulating uncertainty. It is possible to design stimuli defined within a multi-attribute space in such a way that each of their defining features carry sufficient information for the task to be feasible, while their actual mixture renders the task difficult or even impossible. One can then inquire into the observer's capacity of extracting one such relevant feature *in the presence* of the remaining ones (whether they are relevant or not) so as to improve his/her performance.

A case in point is the double-conjunction (DCj) stimulus (Treisman & Gelade, 1980; Wolfe, Cave & Franzel, 1989) generalized to study texture segregation (Gorea & Papathomas, 1991, 1993; Wolfe, 1992). Figure 1a illustrates a DCj texture-pair (DCj$_{TP}$) whose building blocks (textels) are defined by their luminance-polarity (dark and bright) and by their orientation (+ and −45°). The reader would probably agree that finding the texture edge in this stimulus is quite a difficult task[1]. However, if he or she manages, one way or another, to mentally/visually "isolate" the bright (or dark) elements of the texture pair, the segregation task should be trivial (or "preattentive"): the vertical orientation-defined edge (between the + and −45° elements) will "pop out" (see Fig. 1c). In a symmetrical way, the observer may "focus" on, say, −45° elements and find the luminance-polarity-defined edge (Fig. 1d). This *two-stage* "attentional" strategy has been proposed as a general algorithm for resolving DCj targets (Treisman & Gelade, 1980; Treisman & Sato, 1990; Wolfe, 1994; Wolfe, Cave, & Franzel, 1989; Friedman-Hill & Wolfe, 1995).

FIG 1–The DCj$_{TP}$

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[1] One should bear in mind that a DCj$_{TP}$ discrimination task is not difficult by necessity. The difficulty of segregating the texture-pair shown in Fig. 1a, can be manipulated at will by modifying any of its two defining (luminance and orientation) contrasts: if the luminance- (or orientation-) contrast is set to zero, the task is impossible; increasing this contrast will by necessity improve discrimination at least up to some point beyond which performance may either saturate or possibly decrease again if the two attributes defining the texture-pair interact in some way (which must be the case with color and luminance). Thus, for one to speculate on the putative differences among the neural mechanisms subserving the discrimination of a variety of DCj stimuli, he or she must make sure that contrasts involved in each of these tasks are *equivalent*. Previous work differentiated between easy and difficult DCj stimuli in search tasks and arrived at conclusions about different underlying processing modes (e.g. Treisman & Gelade, 1980; Nakayama & Silverman, 1986; Quinlan & Humphreys, 1987; McLeod, Driver & Crisp, 1988; Wolfe, Cave, & Franzel, 1989; Wolfe, 1992), but did not consider such controls.

In the case of visual *search*, it is easy to imagine that detection of a DCj target can be guided by knowledge of one of its defining features, particularly if eye-movements are allowed (Egeth, Virzi, & Garbart, 1984; Friedman-Hill & Wolfe, 1995). It is less obvious, however, if and how one might select a given *feature map* in a DCj$_{TP}$ so as to transform its DCj *edge* into a single-conjunction one. It has been indeed shown that visual search and texture segmentation are not equivalent tasks (Wolfe, 1992). The literature provides no direct evidence in favor of the proposed two-stage strategy.

The advantage of an attentive map selection is less obvious than it seems. If one is to assume the existence of four visual "maps", ON$_{+45°}$, ON$_{-45°}$, OFF$_{+45°}$, OFF$_{-45°}$ (e.g. Duncan & Humphreys, 1992)[2], the implementation of such a selection for the case illustrated in Fig. 1 would consist in isolating any pair sharing one attribute, say the "ON" map, and then extracting the edge defined by the second attribute within this map, i.e. orientation. By doing so, however, edge information carried by the orientation contrast within the "OFF map" is lost. The selection process should then *decrease* rather than increase performance. To account for a performance improvement potentially yielded by such a selection technique, at least four additional maps must be considered: non-oriented ON and OFF units and polarity non-specific +45° and −45° units[3]. Because their activation is irrelevant to the texture segmentation task in the DCj$_{TP}$ of Fig. 1, it will play the role of noise. As a consequence, while "attending" to two of the four relevant maps will entail a reduction of the signal strength, it will also discard the four "noise maps". The interpretation of an increase in overall sensitivity should then require that the suppression of a number of signal sources be overcompensated by the concomitant suppression of the noise sources.

It should be noted that, although described here as a two-stage process, the selection scheme above is equivalent to a one-stage process whereby ON$_{+45°}$ (or ON$_{-45°}$) maps are selected from the very start. Such units will signal the DCj$_{TP}$ edge on their own. In all events, the putative increase in discriminability of a DCj$_{TP}$ due to "focusing" on one of its constituent features remains

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[2]Other mapping segmentations have also been proposed [see the Discussion section and Wolfe (1994) for a review].
[3]For the chromatic DCj, the relevant maps should be Red and Green. Physiological evidence of significant proportions of cells in V1 and beyond that are non-specific to a certain stimulus attribute (such as orientation, color and/or luminance-polarity) has been repeatedly reported (e.g. Livingstone & Hubel, 1984; De Valois & De Valois, 1988; Edwards, Purpura & Kaplan, 1995; Leventhal, Thompson, Liu, Zhou & Ault, 1995).

to be confirmed experimentally. In the affirmative, the next question to be answered is whether or not some attributes (or dimensions) can be isolated (or monitored) more readily than others.

The dimensions under focus in the present study are color, luminance and orientation. Observers were asked to discriminate DCj_{TP} prior to and after being explained the building principle of the stimuli and being instructed to "pay attention" to only one value of their constituent elements, i.e. red, green, dark, bright, + or −45°, and extract the edge within that subpopulation of textels. In order to present meaningful comparisons between potential performance gains yielded by cueing any of these features, intra-attribute contrasts must be set at an equivalent, or at least at a known discriminability level. This should insure a fair attribute-priming comparison insofar as any performance difference could not be attributed to a difference in observers' capacity of grouping the elements sharing a given primed value (say, dark elements in Fig. 1a), nor to a better segregation between the two values of the non-primed attribute (+45° from −45°). With a very few recent exceptions (e.g. Palmer, 1994; Palmer, Ames & Lundsey, 1993; Verghese & Nakayama, 1994), the previous endeavors of comparing priming efficiencies across attributes failed to achieve this basic criterion (e.g. Duncan & Humphreys, 1989, 1992). Obviously, the assessment of equivalent contrasts across stimulus dimensions is of main concern in any study trying to compare processing their efficiencies for any psychophysical task [such as direction discrimination (Gorea & Papathomas, 1989; Agonie & Gorea, 1993), texture segregation (Gorea & Papathomas, 1991; Kingdom, Moulden & Collyer, 1992); stereo (Papathomas, Kovacs, Gorea & Julesz, 1995), or depth perception in general (Landy, Maloney, Johnston & Young, 1995)].

METHODS

Stimuli

They were displayed on a Sony GDM-17E11 RGB monitor, 1280 pixels wide and 1024 pixels high under the control of an Indy Silicon Graphics workstation. The screen subtended 21.8×17.1 deg at a distance of 76 cm in all experiments. All experiments were run in a dimly illuminated room.

Main and Equivalent contrast experiments. The stimuli consisted of +45° and/or −45° textels, 5.4' (5 pixels) wide and 35.4' (33 pixels) long, presented on a yellow background (chromatic coordinates averaged across observers: 0.413, 0.451) of 27 cd/m^2. Luminance-defined textels were isochromatic to the background and yielded either variable or fixed (at $\pm\approx40\%$) luminance contrasts in the *Equivalent contrast* or *Main* experiments, respectively. Chromatic-defined textels were equiluminant to the background and differed from it in chromaticity (Red: 0.554, 0.357; Green: 0.277, 0.542). Inter-textel distance (computed from their centers) was 46.2' in average. In the Main experiment, textels were arranged so as to yield DCj$_{TP}$ with vertical or horizontal edges defined by the conjunction of color and orientation or of luminance and orientation (Fig. 1). In the Equivalent contrast experiments, they were arranged so as to yield texture pairs of the type "Color *across* Orientation" (C×O), "Luminance *across* Orientation" (L×O; see Fig. 2a), O×C and O×L (Fig. 2c; see Gorea & Papathomas, 1989, 1991, 1993). The vertical or horizontal edges of these texture pairs are defined by one attribute only with the two values of the remaining attribute being randomized over the whole texture pair (Figure 2). In the terminology used in the search literature, these stimuli are of the *single conjunction* type (SCj$_{TP}$). The horizontal or vertical edge of both the DCj and SCj texture-pairs was randomly jagged within a spatial range of 2 textels and its mean position was also randomized about the center of the screen within a range of 2 textels. Such a randomization (4 textels, i.e. 1.54° overall) was meant to minimize the chances that observers infer the orientation of the edge by means of systematic eye movements (see more in the Discussion section). To this same effect, observers were repeatedly reminded to maintain fixation on a central, conspicuous cross. SCj and DCj stimuli were presented for only 417 and 694 ms, respectively (shorter durations yielded performances close to chance level).

FIG 2–The SCJ$_{TP}$

Equiluminance stimuli. The stimuli were 16.1'×2.8° periodically displayed red, green and/or yellow bars on a red, green or yellow background. They were animated at a 18 Hz rate. A detailed account of their spatiotemporal configuration can be found in Gorea, Papathomas & Kovacs (1993).

Unique yellow stimuli consisted of equiluminant red and green square textels 8.6' of side, regularly arranged along opposite 45° diagonals on an equiluminant yellow background (see Figure 3). They were displayed repeatedly for 111 ms.

FIG 3–Unique Yellow Stimuli

Observers

They were 28 (from high-school to university graduate) students with normal or corrected-to-normal vision. They were dispatched in an experimental (n=16; 5 male; age: 18-26) and a control (n=12; 8 male; age: 19-25) group. They were all screened for normal chromatic vision with Ishihara plates. In addition, three of the four authors were run through the equivalent luminance contrast procedure.

Procedure

Preliminary experiments. If performances obtained with DCj_{TP} stimuli defined by color and orientation and by luminance-polarity and orientation are to be compared, one needs to make sure that: (1) the hues defining the texture elements (Red and Green) are *equiluminant*; (2) the Red and Green elements yield equal chromatic contrasts relative to the background so that they be equally salient (i.e. the hue of the equiluminant background must be *unique yellow*); (3) the three types of contrast (Red/Green, Dark/Bright and +45°/–45°) defining the chromatic and luminance DCj_{TP} are *equivalent* to each other. As the results will show, a ±45° orientation contrast is less salient than the maximum obtainable Red/Green contrast. Given that a ±45° contrast is the largest achievable in the orientation domain, the only way of boosting its efficiency relative to the chromatic and/or luminance contrast would be to decrease the latter. However, lowering

luminance or chromatic contrast should also reduce the perceived orientation contrast, so that the latter could not be equated to the former. As a consequence, the third requirement was satisfied for the chromatic and luminance contrasts only. The equivalent contrast procedure was run with three of the four authors. Because their luminance contrasts equivalent to the red/green chromatic contrast were very similar (i.e., 38.5%, 36.4%, 43.6%), their average was used for all 28 observers. Equiluminant and unique yellow points were assessed for each observer.

Equiluminance. The equiluminance assessment procedure involved a reverse-phi motion technique originally described by Gorea et al. (1993). Equiluminance was achieved for each observer in two steps. *Step 1a,b.* The background was yellow and the animated bars were (a) yellow and red or (b) yellow and green. The yellow bars were set + or −5% luminance contrast with respect to the background. The luminance of the red or green bars was variable. The yellow background and bars were obtained by mixing the outputs of the red and green phosphors in equal proportions (in luminance units). When the luminance contrasts of the yellow and red (or green) bars are of the *same* sign, the spatiotemporal configuration of the stimulus is such that it yields the same perceived direction as the physical displacement over time. Luminance contrasts of *opposite* signs for the yellow and red (or green) bars yield reverse-phi motion and hence a perceived direction of motion opposite to the physical one. Thus, when the variable luminance of the red or green bars is strictly equal to the luminance of the yellow background, the stimulus should yield 50% leftward and rightward directional reports. The average of these values, yielding 50% performances with yellow bars of +5% and -5% contrast, was taken to be the red-yellow and the green-yellow equiluminance point. Previous measurements (see Gorea et al., 1993) show that this procedure insures (through transitivity) the equiluminance between the red and green bars. *Step 2a,b.* The same procedure was repeated after having assessed the unique yellow (see below).

Unique yellow. This procedure was meant to make sure that the equiluminant red and green elements yielded equal chromatic contrasts with respect to the yellow background (see Figure 3 for the illustration of the achromatic case). The yellow background was originally obtained by using the red-to-green phosphor output ratio derived from the equiluminance settings. Both textels and background were set at their equiluminant point as assessed above. Observers

were asked to report the most salient perceived diagonal by pressing one of two response keys ("red" vs. "green" diagonal). The chromaticity of the background was varied along the red-green (L-M) chromatic axis so as to achieve 50% saliency for the red- and green-defined diagonals. This was achieved by means of a staircase which increased the output of the red phosphor relative to the output of the green phosphor subsequent to a "red" response and decreased it after a "green" response. The manipulation of the red/green output ratio was such as to keep the sum of the two outputs constant. The red/green output values obtained for the last 10 reversals (out of 15) were averaged to obtain the unique yellow. This new yellow was used in to reassess equiluminance red and green values, and was used in all subsequent experiments.

Equivalent luminance contrast was measured in three steps for only three observers (three authors). *Step 1.* % Signal threshold (see next section) was first assessed for the equiluminant C×O stimulus. *Step 2.* The obtained % Signal threshold for a given observer (hereafter referred to as θ) was kept constant for the P×O stimulus and discrimination performance for this latter was measured in terms of its luminance contrast required to achieve the same % correct criterion as for the C×O stimulus. This luminance contrast threshold was the luminance contrast *equivalent* to the red/green chromatic contrast. *Step 3.* θ was also measured for the O×C stimulus. It was typically higher than the one obtained in step 1. Because the orientation contrast was already maximal (i.e. 90°), it could not be increased even more to achieve the same performance level as for the C×O stimulus. *Step 4.* θ was finally measured with O×P stimuli set at the equivalent luminance contrast obtained in step 2. The obtained thresholds were practically identical to those obtained in step 3 (i.e., larger than those obtained in step 1), thus offering an additional validation of the equivalent luminance contrast procedure.

Given that the three observers having been run through this procedure displayed very similar equivalent luminance contrasts, their mean value was used for the 28 naive observers for all the achromatic stimuli.

% Signal thresholds (θ) were measured for both DCj$_{TP}$ and SCj$_{TP}$ stimuli. The orientation of the texture pair edge (vertical or horizontal) was randomized across trials and observers had to specify it by pressing one of two response keys. For any texture-pair type, the textels defining the

contrast of the texture edge were intermixed in variable proportions (noise, N) so that the saliency of the edge was decreased. Take as an example the LxO texture pair of Fig. 2. A 0% N condition is the one where all the bright/+45° and bright/-45° textels are on its left-hand side and all the dark/+45° and dark/-45° are on its right side (Fig. 2a). A 25% N configuration is the one where one fourth of the left-hand textels at random locations are exchanged with one fourth of the right-hand textels, also selected at random locations (Fig. 2b). A 50% N stimulus is a purely random one, i.e. it yields no edge whatsoever. All data will be presented in terms of signal, S (rather than noise) on a 0 to 100% scale so that $S=1-2N$. % S was under the control of a staircase which increased it by 2 percentage points after three correct responses in a row and decreased it by the same amount after every wrong response. This rule yields an average of 79% correct. One session was completed after 20 reversals and θ was computed as the average of the last 12 ones.

Experimental design. **A.** Following the preliminary experiments, % S thresholds were obtained from all 28 observers for the four SCj conditions (i.e. CxO, OxC, LxO and OxL). Each condition was repeated twice in a sequence randomized across observers. In addition to checking the reliability of the equivalent contrasts assessed for only three of the four authors, this first experimental series was meant to familiarize the observers with the texture edge segregation task. **B.** Observers were subsequently run through the DCj conditions in two distinct groups, the *test* group (which ran in two stages, B1$_{TEST}$ and B2$_{TEST}$), and the *control* group B$_{CTR}$: **B1$_{TEST}$**. The test group was presented with the color- and with the luminance-defined DCj$_{TP}$ with no other instruction than to specify the orientation of their separating edge. This will be referred hereafter as the *pre-cue* phase. Each stimulus was run twice. The four sessions were run in a *abba* sequence for half of the observers and in a *baab* sequence for the other half. **B2$_{TEST}$**. Observers were then explained the construction principle of the DCj$_{TP}$. They were drawn attention to the fact that segregation might be much easier if they could mentally isolate or group one of the defining features of the DCj$_{TP}$ (i.e. a given color, luminance or orientation) and perform the edge orientation task based on the contrast of the second attribute. This will be referred hereafter as the *post-cue* phase. There were six possible "cues", i.e. "pay attention" to red, green, bright, dark, +45° or -45° elements. Given that the latter two occurred for both the color- and luminance-defined DCj$_{TP}$, there were eight cueing conditions overall. The cueing sequence was randomized

according to two, 8×8 Latin squares, one for each subgroup of eight observers. Including the pre-cue phase, each observer ran 12 sessions. B_{CTR}. A *control* group was also run through 12 sessions but without any cueing or instructions as to the construction principle of the DCj_{TP}. The sequence of color- and luminance-defined stimuli was randomized in such a way that each of the two stimuli was presented an equal number of times for each observer (i.e. 6) and that it appeared with the same frequency (i.e. 6 repeats) in every sequence order across observers. This control group was necessary to check for potential learning effects which could be confounded with the attentional/cueing effect. In addition, the control group was also used to test the attentional/cueing effect across groups.

Each observer ran the whole set of experiments in about five hours on two separate days.

RESULTS

Equivalent luminance contrast

The three observers who run this preliminary experiment (with SCj_{TP}) yielded equivalent luminance contrasts of 38.5, 36.4 and 43.6% at % Signal levels of 18.1, 20.3 and 18.6, for observers TVP, TEC, and AF, respectively. Once the luminance contrast of the OxL stimuli was set at this equivalent level for observer TEC, the orientation discrimination performance yielded % Signal thresholds of 63.3% for the OxL stimulus and 67.7% for the OxC stimulus. The fact that the two sets of thresholds were very similar was taken as additional evidence of the accuracy of the equivalent contrast measurement.

Figure 4 displays mean θs for the test (gray bars) and control (white bars) groups and for each of the four SCj_{TP} with the luminance contrast set at 40% (the average of the equivalent contrasts measured with three of the authors). As expected, the data show very similar thresholds for CxO and LxO stimuli, on the one hand, and for OxC and OxL stimuli, on the other hand. Thresholds for the latter two are about a factor of 2 larger than for the former two. This was also the case for the three trained observers. Overall, the data show that, for the present stimuli, chromatic and luminance contrasts were equally efficient, while the orientation contrast was substantially less efficient.

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FIG 4—$A \times B$ Results

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Cue effects

Figure 5 displays mean segregation thresholds (θ) with DCj$_{TP}$ for the control (bars with thin outline) and test (bars with thick outlines) groups. Thresholds for the color- and luminance-defined stimuli are shown as white and gray bars, respectively. The first four bars show θs obtained during the first four sessions for both groups (the pre-cue phase for the test group). The next eight θs are for the test group in the post-cue phase under all eight cueing conditions (as indicated on the abscissa; "R": cue on Red, "G": green, "B": bright, "D": dark, "/": +45°, and "\": -45°). The last two bars show θs obtained by the control group during the last eight sessions. Vertical lines are ±1 SE. The horizontal gray area indicates expected thresholds given that observers respond at chance level (and that θs are limited to 100% signal).

During the pre-cue phase (first four sessions) performances of the test group for the two types of stimuli are barely below the gray horizontal bar, i.e. slightly above chance level (14 out of 16 observers showed θs > 98%). For the luminance-defined DCj$_{TP}$, the control group also shows performances close to chance during both the first four and the last eight sessions. However, for this same group, color-defined stimuli yield significantly lower thresholds during the 12 sessions of the experiment.

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FIG 5—DCj$_{TP}$ Cueing Effects

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At inspection, the data seem to display an overall cue effect both within and across groups. Cueing the color-defined stimuli appears to be substantially more efficient than cueing the luminance-defined ones. This is so despite the accurate match of their color and luminance contrasts. Within each group of stimuli, cueing either of its two defining attributes (orientation, color or luminance) appears to yield similar effects despite the significantly lower efficiency of

the orientation contrast. At first glance, cueing "red" is more efficient than cueing "green" but this difference is not significant (see below).

Statistical analysis of the pre-/post-cue effect. The design of the present experiments was by necessity unbalanced: the stimulus factor had two modalities (color and luminance) in the pre-cue phase, and eight modalities (cue on red, green, dark, bright and on +45° and −45° elements in both chromatic and achromatic stimuli) in the post-cue phase. To circumvent this difficulty, two distinct ANOVA tests were run independently. In the first ANOVA (**A1**) the eight cueing conditions were collapsed into two modalities, i.e. cueing the chromatic and cueing the achromatic stimulus, so that the analysis was of the 2 [stimuli] × 2 [pre-/post-cue] type. It was meant to assess the global cue and stimulus type effects. A1 was performed both within the test group (**A1$_W$**) and across the test and control groups (**A1$_A$**). A1$_A$ compared performances of the test group for the last 8 sessions (i.e. post-cue phase) with those of the control group also during the last 8 sessions. This ensured that the two groups had the same exposure to the stimuli. In order to avoid interference between the effects under test and a potential overall performance difference between the two groups, A1$_A$ was run with both raw and normalized data. Normalization was achieved for each observer by reference to his/her mean threshold during the first four sessions. Normalization was performed independently for the color- and luminance-defined stimuli.

To analyze the specific cue effects, a second 2 [stimuli] × 2 [cue type] ANOVA (**A2**) involved only performances of the test group in the post-cue phase. Cue type referred to orientation (±45°) and "polarity", each with two modalities. To achieve this format, color and luminance polarity cueing conditions were lumped together, "red" with "bright" and "green" with "dark" cueing, as well as "red" with "dark" and "green" with "bright" cueing. A2 was performed for each of these two grouping conditions. Because this grouping procedure precludes the comparison between the effects of cueing red vs. green and of cueing dark vs. bright elements, two independent one-way ANOVA were run to this effect.

Global cue and stimulus effects. The within-group analysis (A1$_W$) confirms all the observations made on mere inspection of Fig. 5. It yields significant effects of both the pre-/post-

cue manipulation [F(1,15)=33.05, p < .00001] and stimulus type [F(1,15)=6.47, p < .0225], as well as a strong interaction between the two factors [F(1,15)=17.65, p < .0008]. The significant interaction strengthens the conclusion that the stimulus type modulates sensitivity only in the post-cue phase. The across-groups analysis (A1$_A$) *on the raw data* yields the following effects: pre-/post-cue [F(1,26)=3.59, p < .069], stimulus type [F(1,26)=15.73, p < .0005], interaction [F(1,26)=0.30, ns.]. The overall decrease of the pre-/post-cue effect and of the interaction would be expected if, by chance, the control group happened to perform better than the test group during the first four sessions. This difference is visible in Fig. 5 (first four sessions) for the color stimuli. The same analysis performed on the normalized data (see above) confirms this hypothesis: pre-/post-cue [F(1,26)=13.04, p < .001], stimulus type [F(1,26)=11.88, p < .002], interaction [F(1,26)=5.20, p < .031]. Thus, once the level of performance across groups is taken into account, both within- and across-groups analyses confirm the significance of the cue and stimulus effects as well as their interaction.

Specific cue effects (A2). As noted above, this analysis was performed twice, once by pairing red-bright and green-dark performances and a second time by using red-dark and green-bright pairing. The two variants yielded practically identical results (those of the second one are given in parentheses); the only significant effect was that of stimulus type [F(1,15)=12.30 (12.30), p < .0032]. The two analyses showed no significant effect for either cue type (i.e., orientation vs. color or polarity), cue and stimulus type interaction, or the cued orientation (+ vs. −45°). As noted above, the format of the analysis did not allow to assess the effects of "polarity" (i.e., red vs. green and bright vs. dark cueing). The two one-way ANOVA showed no such effect.

In conclusion, the statistical analysis shows (1) an overall pre-/post-cue effect (2) larger for the color than for the luminance stimuli; (3) no effect of the cue type for a given stimulus type, (4) no interaction between stimulus and cue-type factors, and (5) no effect between cueing bright vs. dark or between cueing red vs. green elements.

Practice effects

Figure 6 displays % Signal thresholds as a function of the session order for both the test (a) and control (b) groups. Gray and crosshatched columns show θs for luminance- and color-

defined stimuli, respectively. Open and closed squares are mean θs (averaged over color and luminance conditions) for each of the first four and for each of the last eight sessions, respectively. Vertical bars show ± 1 SE computed over all observers. At inspection, mean θs appear to slightly, but systematically decrease with session order for both groups. To assess the significance of this effect linear regressions were independently fit to performances obtained with luminance- and color-defined stimuli (continuous and dashed lines in Fig. 6) for each group. To avoid confounding the potential practice effect with the cue effect in the test group, only the last eight sessions (post-cue phase) for this group were considered. For the control group, a session-order effect was obtained only for the color-defined stimuli (slope $= -0.63$, p $< .0004$). The test group showed performance improvement over the last eight sessions for both color- (slope $= -0.30$) and luminance-defined (slope $= -0.18$) stimuli but this decrease in threshold did not reach statistical significance. This observation suggests that, once the observers have benefited from the cueing effect, they cannot improve significantly beyond that level. Moreover, inspection of Fig. 6 reveals that, for the last two sessions, performances with color-defined stimuli are practically identical across groups. This is not the case for the luminance-defined stimuli. We speculate that, even without explicit knowledge on the construction principle of the DCj_{TP}, naive observers manage to apply, for color stimuli, segregation strategies similar to the one suggested to the test group. For some unknown reason, however, such strategies appear to be difficult to implement with luminance-defined stimuli (see the Discussion section).

FIG 6–PRACTICE

DISCUSSION

The present experiments on DCj texture segregation yielded two main effects: a feature-cueing and a practice effect. Feature cueing was effective for both color- and luminance-defined stimuli but less so for the latter. This cueing efficiency difference was obtained despite the equivalence of the chromatic and luminance contrasts. Within each stimulus category (color- and