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Luminance and chromatic cues in a spatial integration task

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Abstract

These experiments explore the way in which cues provided by luminance and chromatic contrast interact in the spatial integration of elements. The stimuli were composed of bidimensional and isotropic Gauss functions. The elements were placed so that when experimentally manipulating the separations between the lines, subjects could generate an oriented percept from the elements sharing luminance or chromaticity. Results showed that, in most cases, grouping elements that share chromatic content is possible, in spite of variations in luminance content. Grouping elements as a function of luminance is more difficult when chromaticity alternates from one element to another. Lastly, if competing groupings are generated, the stimulus is structured as a function of chromatic content and not of luminance content. © 2001 Elsevier Science Ltd. All rights reserved.

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1. Introduction

The luminance and the chromaticity of a stimulus are inseparably joined in the retina. This is because, in photopic vision, both types of information are extracted from the responses of the same photoreceptors. However, there is increasing evidence that, during visual processing, separation of the luminance and chromaticity of a stimulus is produced. Indications of this separation have even been observed in the first stages of physiological processing (for references, see Livingstone & Hubel, 1984; Hubel & Livingstone, 1990; Lee, Pokorny, Smith, Martin, & Valberg, 1990; Dacey, 1996). Many studies have been carried out, especially after the works of Livingstone and Hubel (1984, 1987, 1988), to analyze whether the separation is plausibly maintained during higher processing stages and even whether information from chromatic and luminance contrast subserve different perceptual functions.

Most of the experimental results reveal the predominant role of luminance in tasks related to depth perception (for example, see Simmons & Kingdom, 1994, 1995, 1997; Kingdom & Simmons, 1996) and movement perception (for a review, see Farell, 1999), although perception of both is possible with chromatic information. However, the role of chromatic contrast has been traditionally related to form perception.

According to Jacobs (1981), color contributes fundamentally to object detection and recognition, and to the observation of signal properties of color. Mollon (1989) added two more aspects where chromaticity is a primary source of information: detection of targets against dappled backgrounds and perceptual segregation when patches vary in lightness, that is, color is a fundamental attribute when there are random changes in the luminance pattern. Subsequently, Mullen and Kingdom (1991) incorporated a final property to this list: enhancement of object localization.

Therefore, two types of tasks, in which chromaticity is relevant, can be established. A first task type is related to the processes of object perception, independently of background, such as identification, localization, or extraction of object properties by means of color (ripe fruit). The second type of perceptual task is related to separating the object from the background in which it is immersed, in conditions of random luminance pattern. These tasks are performed in two condi-

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tions: when the object is among a group of objects with a random luminance pattern (detecting a flower among branches), or when the random luminance pattern is produced within the object itself (perceiving a bush).

In this second type of task, the visual system is faced with a fundamental problem: the treatment of the variations in the luminance pattern. For this purpose, chromatic information is of vital importance, as is revealed in the difficulty encountered by people who have chromatic alterations when performing these tasks (some cases are reviewed in Mollon, 1989).

Therefore, the first problem to be solved by the perceptual system is that of differentiating changes due to the properties of objects as compared with changes due to the illuminant. Mullen and Kingdom (1991) proposed that the low-pass characteristics of the chromatic contrast sensitivity function (Van der Horst & Bouman, 1969; Granger & Heurtley, 1973; Kelly, 1983; Mullen, 1985) make it especially appropriate for differentiating changes in the spectral composition of a scene when the illuminant changes. This would facilitate perceiving an object when, due to the illuminant, many luminance changes occur simultaneously, as in the case of dappling. In fact, some classical color-perception tests make use of this kind of skill of the visual system (for example, the Ishihara test).

McIlhagga and Mullen (1996) analyze in detail the implications of this concept (which they call 'ecological' hypotheses): changes in luminance are fundamentally due to changes in the illuminant, whereas changes in chromatic information are fundamentally due to changes in the stimulus reflectance. Therefore, elements that vary in luminance, but not in chromaticity, would be more easily grouped as part of the same surface. One version of this hypothesis states that spatial integration should not be greatly affected when chromatic information is fixed and luminance changes. In an edge-integration task, these same authors were not able to confirm this claim definitely, observing high variability among subjects.

The purpose of this study is to analyze the role of chromatic contrast and luminance in a classical spatial integration task. In keeping with Kingdom, Moulden, and Collyer (1992), spatial integration was generically defined as any process in which structured information is obtained from multi-element stimulus patterns. If the role of chromatic information is fundamental to detect the global structure, in those circumstances in which chromatic information generates consistent information, chromatic information should predominate over luminance information. In order to verify this, three conditions are introduced that will allow evaluation of some aspects that have not been taken into account in other research.

In the first place, participation of the edge system, based exclusively on luminance information, was to be avoided. In previous research, to analyze grouping perception by chromatic and luminance contrast, the elements used are the so-called 'hard-edged' elements (test de Ishihara, Kingdom et al., 1992). The problem with them is that one cannot be certain that the luminance transitions of the stimulus edges are eliminated (because of the fact that points R, G, and B of each pixel are not perfectly aligned in the monitor). Therefore, in this study, a different type of stimulus, bidimensional Gaussian functions, was used. Thus, an edge of perceptible luminance is avoided, and the effects of chromatic axial aberration are reduced.

In the second place, our task would not require grouping oriented stimuli. The Gabor functions are more appropriate to study edge integration with chromatic information, as in the study by McIlhagga and Mullen (1996). However, in this study, the aim was to study perceptual grouping without interference from edge detection and alignment.

Lastly, the primary aim is to determine the importance of chromatic content both when luminance pattern varies randomly and when it produces a structured pattern that is, however, incompatible with the chromatic pattern.

To achieve our goals, we attempt to obtain luminance and chromatic contrasts that are perceptually equivalent (comparable), that is, performance of the experimental task should be the same when each of the stimuli is presented independently. This is the aim of Experiments 1 and 2. Subsequently, we attempt to combine these contrast levels to see which of the two systems, chromatic or luminance, is stronger when presented simultaneously. This is one of the differences between our procedure and that employed by other authors, who use configurations similar to ours to study grouping as a function of similarity and proximity (Ben-Av & Sagi, 1995; Regan & Mollon, 1997), because they manipulate the level in the different dimensions within the same stimulus pattern. Thus, in experiments 3, 4, and 5, the possibility of spatial integration was evaluated when either luminance or chromaticity varied from one element to another, with the other remaining constant, or when both of them varied. Finally, in experiment 6, the way in which spatial integration was carried out was studied when competing groupings were generated: one from chromatic information and the other from luminance.

2. Method

2.1. Subjects

Four subjects participated in these experiments. Three of them (MHLL, MVH, and ALB) discriminated color normally, and the third (FZ) showed low discrim-

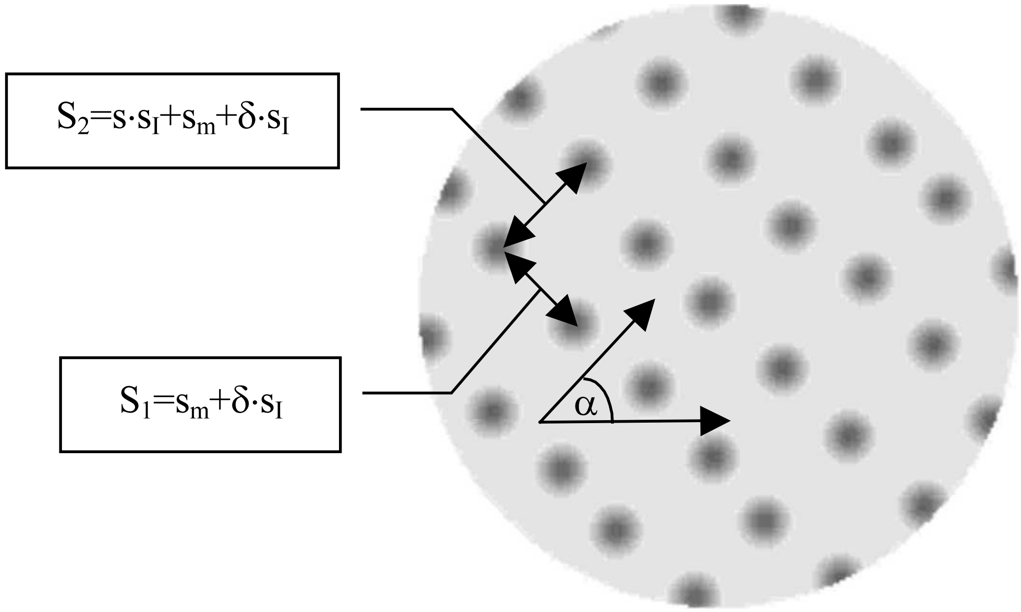

Fig. 1. Definition of relevant parameters of the complete stimuli, where s_1 defines the separation between elements on the same line and s_2 defines the separation between lines of elements, s_m refers to the minimum separation between simple elements, s_I is the separation increment for each separation unit s, and δ represents a random displacement factor that can equiprobably take on the values of -1, 0, or 1 (it was treated independently for x and y).

ination according to Farnsworth–Munsell's 100 hue test. This subject was used as a source of additional information about the possible interference of luminance artifacts in the isoluminant stimuli.

2.2. Apparatus

Stimuli were presented on a graphic color monitor (SONY Multiscan Trinitron 20 Se-v), controlled by a VSG 2/3 graphics generation card (Cambridge Research Systems Ltd.) connected to a Pentium at 100 Mhz. Digital–analog calibration (DAC) of the monitor and gamma correction were carried out using the OptiCal automatic correction system (Cambridge Research Systems, Ltd.). The CIE coordinates were obtained by means of a colorimeter (Minolta CS-100).

2.3. Stimuli

Each stimulus was made up of a grid of elements (bidimensional Gaussian functions) and was presented within a circular window of 2.57 deg (Fig. 1). Three kinds of stimuli were created: isochromatic, isoluminant, and with variations of both luminance and chromaticity. First, the generation of individual (Gaussian) elements will be analyzed and, later, the construction of the complete stimulus.

In the isoluminant stimuli, the chromaticity of each of the elements varied according to an isotropic bidimensional Gaussian function between two specific CIE coordinates (Fig. 2). In the isochromatic stimuli, the luminance of each of the elements varied according to the same function, and in the stimuli with both kinds of variation, both luminance and chromaticity varied together according to the corresponding bidimensional Gaussian function.

Eq. (1) shows how the chromaticity (x_c, y_c) and/or the luminance (l_c) for each of the individual elements and for each pixel (x, y) was obtained, with (x_1, y_1) being the CIE background coordinates, (x_2, y_2) being those of the center of the stimulus, l_1 being the background luminance, l_2 the luminance of the stimulus center, $g(x, y)$ the bidimensional isotropic Gaussian function, normalized at the [0, 1] range, and r_x, r_y, the

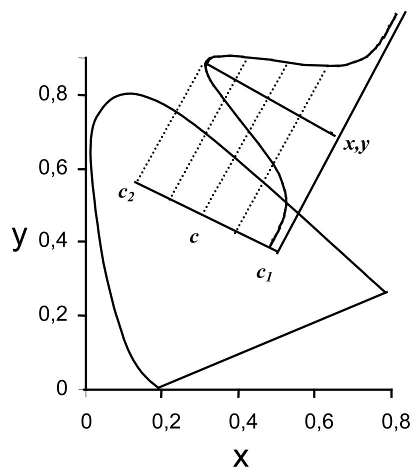

Fig. 2. Projection on the CIE coordinates of the function that defines the color variation of the stimuli elements.

spatial coordinates of the center of the Gaussian function. In the isochromatic case, $x_1 = x_2$ and $y_1 = y_2$. Each one of the bidimensional Gaussians had a standard deviation of 0.117 deg and occupied a 0.24 deg extension.

$$x_c = x_1 + (x_2 - x_1)g(x,y,r_x,r_y)$$
$$y_c = y_1 + (y_2 - y_1)g(x,y,r_x,r_y)$$
$$l_c = l_1 + (l_2 - l_1)g(x,y,r_x,r_y). \quad (1)$$

The spatial coordinates of each one of the elements were obtained by means of Eq. (2). It defines the position (r_x, r_y) of the center of the elements before rotating the Gaussian grids, where s refers to the separation of the elements of each particular stimulus (one of the experimental conditions), s_m refers to the minimum separation between simple elements, s_I is the separation increment for each separation unit s, and δ represents a random displacement factor that can equiprobably take on the values of -1, 0, or 1 (it was treated independently for x and y).

$$r_x = i(ss_I + s_m) + \delta s_I$$
$$r_y = js_m + \delta s_I$$
$$i, j = -n,\ldots,0,\ldots,n. \quad (2)$$

Then, a series of Gaussians were distributed along an axis. These lines could appear in four orientations: horizontal (0°), vertical (90°), oblique $-45°$, and oblique $+45°$. These four orientations were grouped into pairs, so that there were only two experimental conditions: vertical/horizontal (0°/90°) and oblique ($-45°/+45°$). The Gaussians were placed along each line with a separation between them of 0.351deg, measured from center-to-center of the Gaussians (see s_1 in Fig. 1) for the vertical/horizontal orientation, and of 0.486 deg, for the oblique orientation. The separation within each line was always maintained fixed, and a small random displacement factor (δ) was added.

In each stimulus, various Gaussian lines were presented simultaneously, all having the same orientation and with six separations between the lines (see s_2 in Fig. 1). The separation was considered 0 deg when the separation (s_1) between the Gaussians within one line and the separation between Gaussian lines (s_2) was the same, that is, when the physical distance between all the Gaussians present in the stimulus was the same in the two orientations in which it could be perceived. In each of the experiments, for each contrast level (explained in detail in each experiment), the stimulus was presented in all four possible orientations, with all six separation levels. This kind of stimulus pattern is the same as that employed by Hochberg and Silverstein (1956), Ben-Av and Sagi (1995), and Regan and Mollon (1997).

2.4. Experimental procedure

In all the experiments, the aim was to determine the way grouping is performed as a function of element proximity. For this purpose, in all the experiments, the separation value (or threshold) between the different Gaussian lines at which the stimulus was perceived as oriented was calculated for each condition. Some researchers (Hochberg & Silverstein, 1956; Gillam, 1981) have proposed that integration processes are sensitive to the distance between elements and that grouping is based on the separation ratio between elements. Therefore, any mechanism responsible for perceptual grouping must be sensitive to these variations. In all the experiments, except for the cues provided by each experimental condition, the only available grouping cue was element proximity, because all the remaining relevant cues that could interfere (alignment, symmetry, etc.) were the same for all conditions. The subject was informed that on the monitor would appear a stimulus that could be oriented and that the task consisted of specifying in which direction its orientation was perceived: vertical, horizontal, or $+45°/-45°$. The constant stimulus method was used.

For each condition, the two possible orientations (horizontal/vertical and oblique) were randomly presented. Five blocks of 120 trials each were generated, obtaining a total of 50 responses for each of the six separations between lines that were randomly presented within the same block. For each of the two orientation conditions, there were two possible responses: $+45°$ or $-45°$, for the oblique orientation, and (0° or 90°), for the vertical/horizontal orientation. Before beginning the first experimental session, the subject performed 20 training trials.

The experiment started with a noise mask, of the same size as the stimulus, consisting of random dots with the same luminance and/or chromatic values as the stimulus that subsequently appeared. In the center of the mask was a small fixation point. When the subject pressed a key, the stimulus appeared during 350 ms, immediately followed by the mask. The subject was requested to respond by pressing one key if the stimulus was perceived with an orientation of 90° or $-45°$ and another key if the stimulus was perceived with an orientation of 0° or $+45°$ (the keys were unified in the two orientation conditions to facilitate the task). Each block lasted approximately 7 min and each experimental session, made up of five blocks, lasted 35 min. The contrast levels were randomized. The subject's chin was supported by a chin-rest, and the stimulus was perceived through a transparent viewfinder in a dark room. The viewing distance was 136 cm.

For each subject and separation, the number of times that the subject responded in the orthogonal direction to that of the separation between lines was registered.

Later, the separation value corresponding to 80% of the subject's responses was calculated and, in order to estimate this value, a bootstrap procedure was used (an evaluation of this method can be seen in Maloney, 1990). For each of 1000 samples and for each separation level, 50 points were randomly generated with a response probability proportional to the percentage of responses obtained in the experiment. The separation value corresponding to 80% of the responses was calculated by linear interpolation. As final values, the separation value and the standard deviation of the 1000 samples were obtained. No separation value was taken into account if the separation value corresponding to 80% was impossible to obtain, in at least 95% of the samples.

3. Preliminary experiments

3.1. Spatial integration with luminance/chromatic contrast

The main goal of Experiments 1 and 2 was to obtain comparable chromatic and luminance contrast levels for each of the subjects. The notion of comparable was defined operationally. Two levels of chromatic and luminance contrast are said to be comparable when the distance (between lines) needed to perceive an oriented stimulus is about the same. These levels would be used in the remaining experiments. By means of the heterochromatic flicker procedure, a range of luminance values was determined that corresponded to red (CIE 0.605,0.357) and green (CIE 0.29, 0.60) and was isoluminant for the different subjects. For this range of luminance values, the experimental stimuli were generated and, by means of a staircase procedure, the luminance values of R and G were selected as isoluminance points at which the subject perceived the Gaussians and the background as being equally bright. This procedure ensured that the values obtained by the heterochromatic flicker method were also perceptually valid for the specific experimental stimuli.

In Experiment 1, five luminance contrasts were used (based on Michelson's definition): 5%, 10%, 20%, 30%, and 50%. For each subject, the maximum and minimum luminance were calculated so that the mean luminance was the same as in the chromatic contrast condition of Experiments 2.

In Experiment 2, four isoluminant chromatic contrasts were used. A definition of chromatic contrast from the R and G of the monitor and based on the CIE diagram (1931) was employed. Chromatic contrast corresponding to the contrast of the R and G coordinates of the monitor was considered the maximum. Readers are reminded that the goal of these experiments was not to carry out a complete study of grouping as a function of chromatic contrast, but rather to obtain equivalent levels of chromatic and luminance contrast. The first value of chromatic contrast employed was considered maximum. Starting at this maximum distance, tracing the line that joined the two coordinates in the CIE diagram, equidistant pairs of values from maximum red and green were selected so that the distance between each pair, on the CIE diagram axis was, respectively, 10%, 20%, and 30% of the distance that was considered maximum.

The results of Experiments 1 and 2 (see Figs. 3 and 4) allowed the use of chromatic and luminance contrast values that guaranteed that the strength of the grouping with both kinds of information would be sufficient and comparable. For this purpose, the values of chromatic and luminance contrasts that produced comparable performance levels for each subject were selected. Thus, the separation value necessary in the chromatic contrast condition between 30% and the maximum was generally equivalent to that of a 10% to 30% luminance contrast. Therefore, values within these ranges were used in the following experiments, adjusting them for each subject.

FZ, who had low color discrimination, was not evaluated in the 10% chromatic contrast condition because he could not distinguish the Gaussians from the stimulus background, perceiving only a uniform field. These data lend support to the hypothesis that task performance is not due to luminance artifacts, because this subject was capable of grouping with a 5% luminance contrast in the horizontal/vertical condition and 10% in both conditions.

3.1.1. Spatial integration with conflicting chromatic and luminance information

The goal of the four experiments described hereunder was to study spatial integration when cues provided by chromatic and luminance information did not covary spatially. Before describing the stimuli, it is useful to make clear that, in all four experiments, the elements were not isoluminant with the background. The Gaussians were generated the same way as in the previous experiments. In all these experiments, the chromaticity of the stimulus background corresponded to the mean value of the CIE coordinates (0.3127, 0.329) of the R and G of the monitor and Gaussians were generated from red and green to this mean point (this was because, in some of the experiments, it was necessary to use Gaussians with two different chromaticities but isoluminant with respect to each other). Thus, there was a 50% chromatic contrast of the Gaussians with respect to the background, a value falling between the 30% chromatic contrast and the maximum, adequate for all the subjects (except for subject FZ), as can be seen from the results of Experiments 1 and 2.

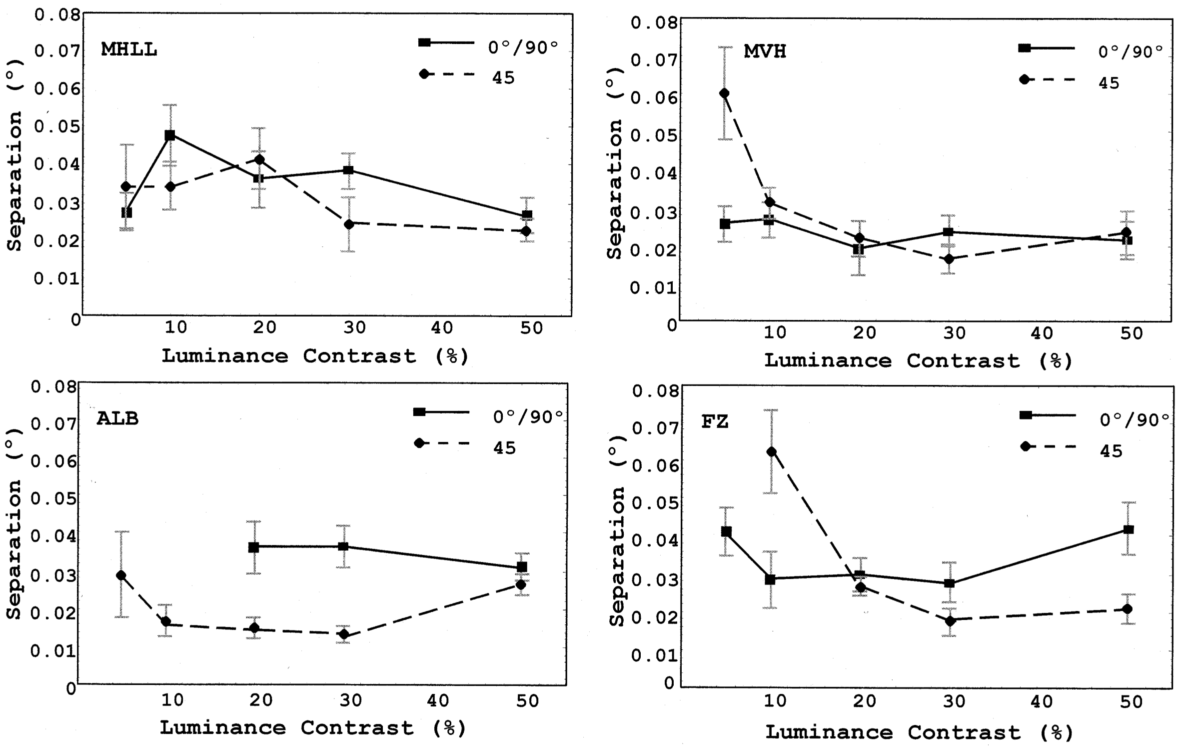

Fig. 3. Separation values at which the subject responds 80% of the time in the orthogonal direction to that of the separation between lines, as a function of luminance contrast. The solid line shows the results for the horizontal/vertical condition and the dashed line for the oblique condition (45°). The separation value and the standard deviation were obtained by a bootstrap procedure, assuming a binomial distribution of the responses.

In Experiment 3 (see 'A' in Fig. 5), chromatic information was maintained fixed and luminance information varied from one element to another. For this experiment, each stimulus consisted of two kinds of Gaussians: light green and dark green. The former had luminance values corresponding to the isoluminance point G for each subject, and the latter, a lower value (to adjust this value, for each subject, there had to be sufficient luminance contrast with the background value to guarantee adequate task performance according to the results of Experiment 1). Both Gaussians had green monitor CIE coordinates. The background luminance was such that luminance contrast with regard to the Gaussians guaranteed task performance in conditions similar to those of the luminance experiment (the values were adjusted for each subject). The Gaussians were placed so that, within the elements of one line, luminance varied from one to another and chromatic information remained constant (see 'A' in Fig. 5).

In Experiment 4 (see 'B' in Fig. 5), spatial integration as a function of luminance information when chromatic information varied was examined. Each stimulus consisted of two types of Gaussians: light red and light green (with the same luminance values corresponding to those considered isoluminant for each subject and with the CIE red and green monitor values). The background was the same as in the previous experiment. The Gaussians were placed so that, within the lines, luminance value was the same, but chromatic information varied.

Experiment 5 (see 'C' in Fig. 5) was designed as an attempt to explain the results obtained by some subjects in Experiment 4. In this experiment, both chromatic and luminance information varied. Each stimulus consisted of two kinds of Gaussians: light green (the same as in the previous experiment) and dark red (generated the same way as the light red ones described previously, but with a lower luminance value, following the same conditions already described in Experiment 3 for the dark green Gaussians). The Gaussians were placed so that, within the lines, the elements did not share either chromatic or luminance information.

In Experiment 6 (see 'D' and 'E' in Fig. 5), the chromatic and luminance content of the elements was placed so that competing groups were generated as a function of chromatic and luminance information. Each stimulus consisted of four kinds of Gaussians (already described in the previous experiments): light red, light green, dark red, and dark green. Two experimental conditions were designed. Both conditions were established so that, in one case, the experimentally manipulated separations were chromatic lines, and, in the other, luminance lines. In the first condition ('A'), the elements of a same line shared chromatic information, but not luminance, and the corresponding elements (placed in the same position) of different lines shared luminance, but not chromatic information (see 'D' in Fig. 5). In the second condition ('B'), the elements of one line shared luminance information and the corresponding elements of different lines shared chromatic information (see 'E' in Fig. 5). In this experiment, it was always possible to group the Gaussians in the two directions: in one condition, by chromatic information, and, in the other, by luminance information.

4. Results and comments

Separation values at which the subject responds 80% of the times in the orthogonal direction to that of the separation between lines for these four experiments are presented in Fig. 6.

The results of Experiment 3 (see 'A' in Fig. 6) show how, for all subjects except for MHLL in the oblique condition, separation values were found at which perceptual grouping of chromatic elements was possible, despite alternating luminance values. In general, the separation values were similar to those obtained by the subjects in the conditions of isoluminant chromatic contrast between 30% and the maximum. The greatest differences observed corresponded to subject MHLL in the oblique condition, and to subject FZ in both conditions.

When subjects were required to perform grouping as a function of common luminance, in Experiment 4 (see 'B' in Fig. 6), for two of the subjects (ALB and FZ), of the separation values employed, none was found at which the elements could be grouped by luminance when chromatic information alternated. For a third subject (MVH), the separation values found were similar to those in the condition where luminance contrast alternated (Experiment 3). For another subject (MHLL), the separation values required in this condition were lower than those obtained in the previous experiment.

Experiment 5 was designed in order to test whether subjects MHLL and MVH were using only element proximity cues in Experiment 4, without taking their content into account. In this experiment, the elements of the same line did not share either chromatic or luminance information.

For subject MVH in both orientations, and for subject MHLL in the vertical/horizontal orientation of Experiment 4, the results were compatible with the hypotheses that grouping when chromatic contrast alternates is comparable to grouping as a function of element proximity, without taking the content of the elements into account (see 'A', 'B' and 'C' in Fig. 6).

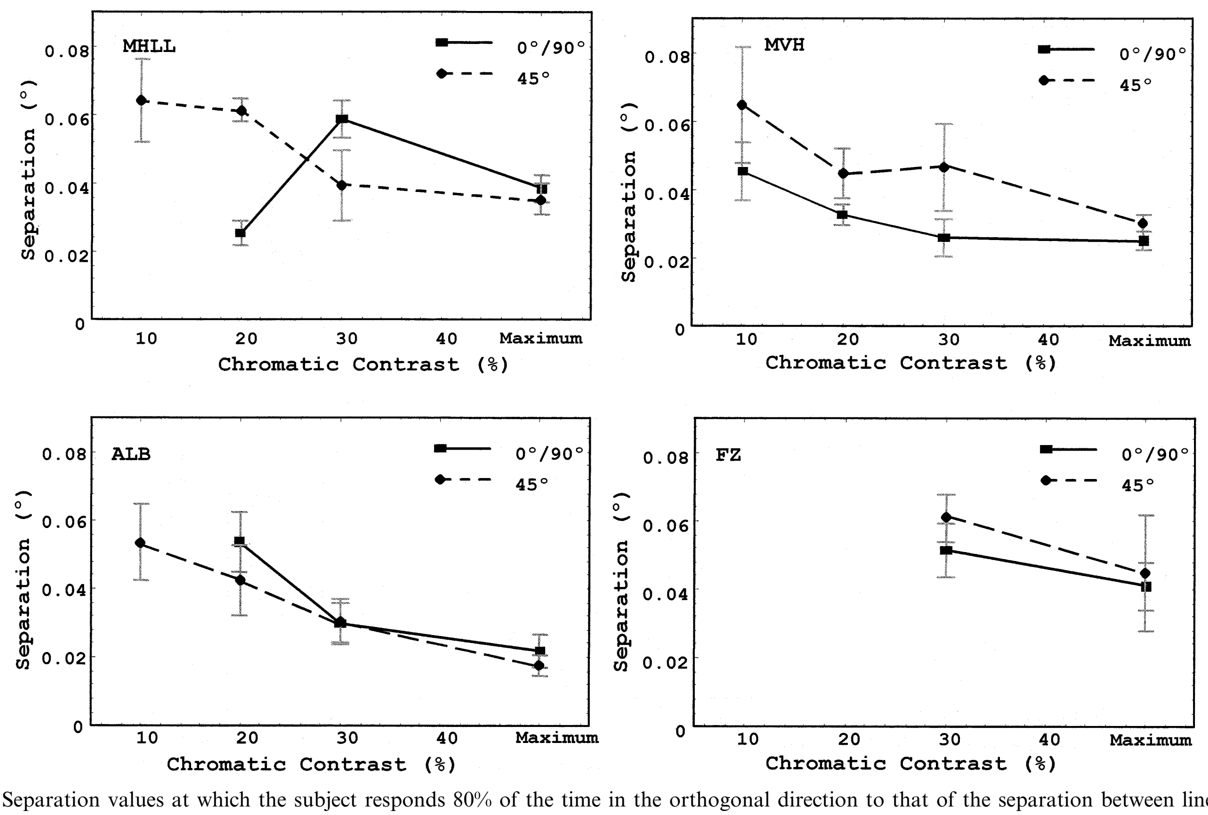

Fig. 4. Separation values at which the subject responds 80% of the time in the orthogonal direction to that of the separation between lines, as a function of chromatic contrast. The solid line shows the results for the horizontal/vertical condition and the dashed line for the oblique condition (45°). The separation value and the standard deviation were obtained by a bootstrap procedure, assuming a binomial distribution of the responses.

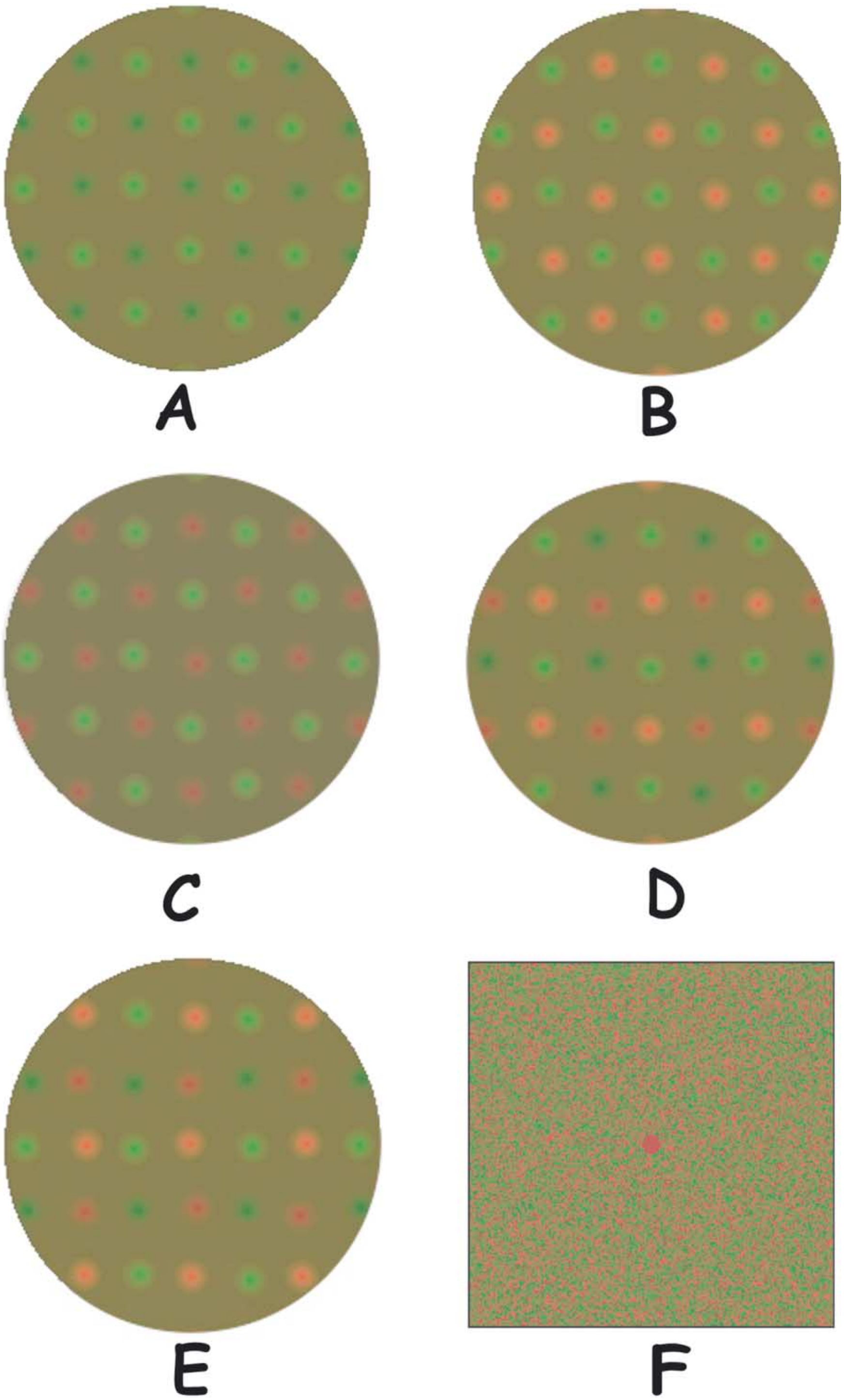

Fig. 5. Examples of stimuli used to measure the grouping effect. For Experiment 3, the Gaussians of a same line shared chromaticity but not luminance (a). For Experiment 4, the Gaussians of a same line shared luminance but not chromaticity (b). For Experiment 5, the Gaussians of a same line did not share either chromaticity or luminance (c). In Experiment 6, there are two conditions, the Gaussians of a same line shared chromatic information, but not luminance, and the corresponding elements of different lines (in the orthogonal direction) shared luminance, but not chromatic information (d); and the elements of one line shared luminance information and the corresponding elements of different lines (in the orthogonal direction) shared chromatic information (e). In Experiment 6, it was always possible to group the Gaussians in the two directions: in one, by chromatic information, and, in the other, by luminance information. The figure also shows an example of the mask used in the experiments (f).

This occurred because, when both chromatic and luminance information alternated, the separation values required for grouping were very similar to those obtained in the conditions in which only one of them alternated. The remaining separation values obtained for subject MHLL were lower (thus, easier grouping) when both chromatic and luminance information alternated than when only one of the two alternated (Experiments 3 and 4). This may indicate that alternating chromatic or luminance information caused interference and that grouping was not performed solely as a function of element proximity. For this subject, luminance variations interfered with task performance more than chromatic variations.

As for Experiment 6, values corresponding to the separation at which the subjects responded 80% of the times in an orthogonal direction to that of the separation between lines are presented in Figs. 7 and 8. Separation values at which the subject responds 80% of the times in the orthogonal direction to that of the separation between lines are presented in condition 'D' and 'E' of Fig. 6.

For this experiment, the results were conclusive for all subjects. Element integration, when there were competing cues, that is, when in one direction, elements could be grouped by luminance, and in the other direction by chromatic information, grouping was always performed as a function of chromatic, and not of luminance, information. Therefore, for condition A, in which the elements of one line shared chromatic information (and luminance information alternated) and the elements corresponding to the same direction between different lines shared luminance information (chromatic information alternated), perceptual grouping was performed as a function of chromatic information. This was the case even for separations between lines that were equal or close to the separation within a line. Whereas, in condition B, in which the elements of a line shared luminance information (chromatic information alternated), the elements corresponding to the same direction between different lines shared chromatic information (luminance alternated), grouping by luminance was not obtained for any of the subjects with the separation values employed. This is the most important result derived from these experiments. When two structured percepts with the same perceptual strength are generated, chromatic information predominates to produce a global percept.

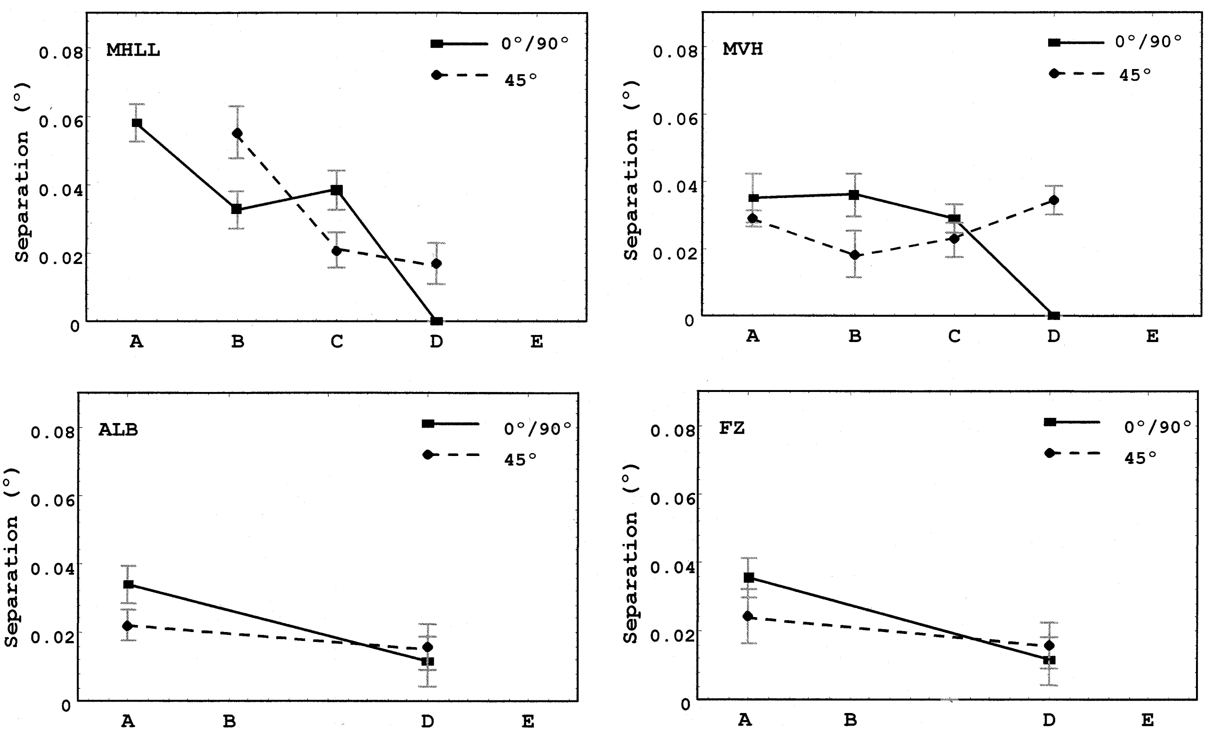

Fig. 6. Separation values at which the subject responds 80% of the time in the orthogonal direction to that of the separation between lines for the following conditions: (A) luminance information changes; (B) chromatic information changes; (C) both chromatic and luminance information change; (D) chromatic and luminance information compete, grouping the lines by chromaticity; (E) chromatic and luminance information compete, grouping the lines by luminance. The separation value and the standard deviation were obtained by a bootstrap method, assuming a binomial distribution of the responses.

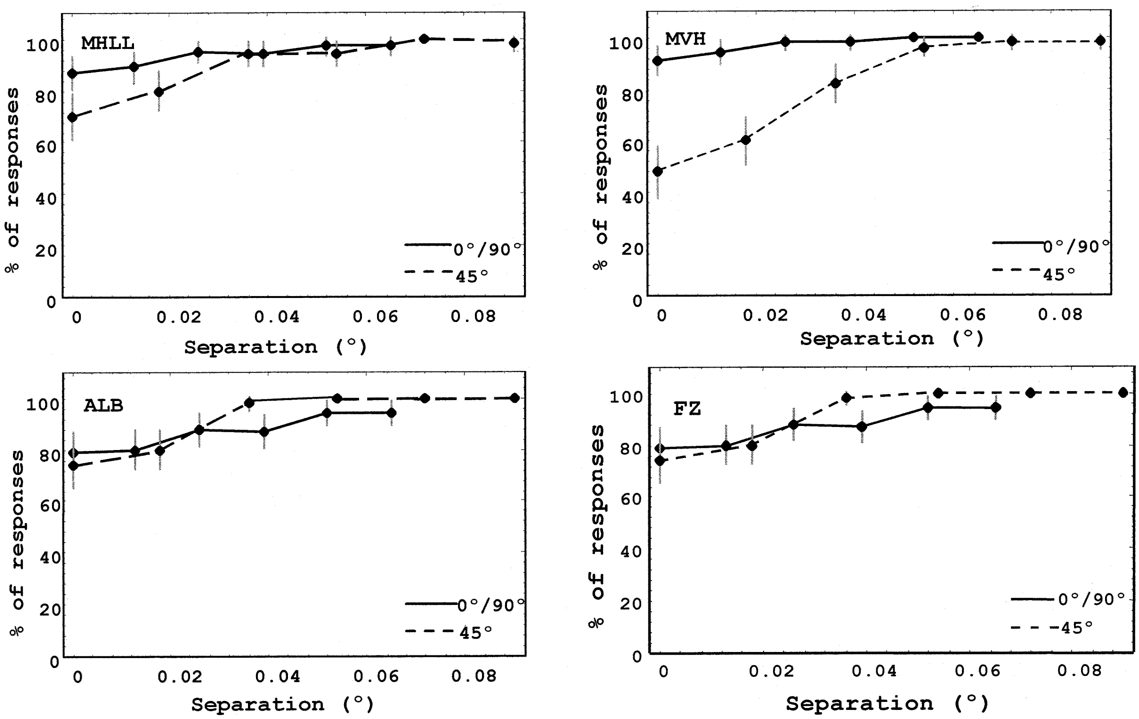

Fig. 7. Results obtained for the four subjects in the condition in which the elements of one line shared chromatic information (and luminance information alternated) and the corresponding elements of differnt lines, in the orthogonal direction, shared luminance (and chromatic information alternated). The percentage of responses in the orthogonal direction to that of the separation between lines as a function of the different separations is shown. The solid line shows the results for the horizontal/vertical condition and the dashed line for the oblique condition (45°). The standard deviation for each point was calculated assuming a binomial distribution of the responses.

5. General discussion

5.1. Role of chromatic contrast when luminance varies randomly

In the first place, we shall analyze our results within the role that has been classically assigned to chromatic contrast: imposing structure when luminance information varies randomly (Mollon, 1989). A conclusion derived from this hypothesis is that spatial integration should not be affected when chromatic information is fixed and luminance varies. In an edge-integration task with Gabor stimuli, McIlhagga and Mullen (1996) could not definitely confirm this hypothesis. The results of the current work are more consistent. In general, spatial integration with chromatic information was not affected when luminance information varied. This result is compatible with the hypothesis positing that variations in luminance are attributed to changes in the illuminant and not to changes in the object. The difference between these results and those of the former authors could be due to the different tasks evaluated. The task used by McIlhagga and Mullen consisted of border integration, that is, variations of the luminance contrast were produced at the edge of the image. In this study, the integration of elements was evaluated without first having to integrate their edges. Two alternative explanations could account for the difference in the results. Firstly, as some authors defend (Grossberg & Mingolla, 1985; Livingstone & Hubel, 1987), luminance information is fundamentally used for edge integration and, although the task could also be performed with chromatic information, luminance information is decisive. The chromatic information would later help 'fill-in', and therefore, luminance variations may have less effect within the image. The second alternative is that the task employed is more similar to natural conditions where luminance variations occur, and the visual system is known to be capable of eliminating information from the illuminant. Normally, shadows do not produce variations alternating at the edges of an object unless there are variations within the object. But shadows frequently produce variations within the objects with no variations at the edges (in conditions of dappling and shading). Therefore, McIlhagga and Mullen's task may be different from those in which color constancy was observed, and in the former, the visual system may not interpret the variations as changes in the illuminant.

A second version of this ecological hypothesis sustains that luminance information is highly affected by chromatic variations. This was not definitely confirmed either by McIlhagga and Mullen's experiments on edge integration, or by the current study on element integration. In both cases, a high variability in subjects' strategies was observed.

However, these results reveal that, if competing grouping is generated as a function of both chromatic and luminance information, chromatic information always dominates. Therefore, when both cues compete, perceptual grouping is performed as a function of common chromatic information. These results are also compatible with the hypotheses, according to which the system would attribute luminance changes to changes in illumination and chromatic changes to changes in objects, confirming once more the role played by chromatic contrast when chromatic cues do not coincide with cues provided by luminance.

5.2. Spatial integration with chromatic and luminance contrast

In addition, the results allow us to analyze other aspects about the contribution of chromatic and luminance information to the spatial integration mechanism. First, the results reveal that spatial integration of elements (as defined in this work) can be performed with chromatic information (Experiment 2). Besides, spatial integration occurs with stimuli that are isoluminant in comparison with the background. This latter result confirms that reported by other authors in their research on perception of colinearity (Kingdom et al., 1992). Nevertheless, they are slightly different from those observed for texture discrimination (Gorea & Papathomas, 1991), in which discrimination occurred when the stimuli were isoluminant compared with each other but not with the background. The difference may lie in the fact that the textons are much smaller, and the chromatic mechanism, having less spatial resolution (Hilz & Cavonius, 1970; Granger & Heurtley, 1973; Kelly, 1983; Mullen, 1985), is incapable of separating the textons by itself.

The data do not lend support to the existence of two independent mechanisms, one responsible for spatial integration with chromatic information, and another that uses luminance information. In this case, two conditions should be met. In the first place, grouping should be perceived when it is produced by chromatic, but not luminance, information, and it should occur in the same way as if the information present in the stimulus were only chromatic. The second condition, which complements the first, is that grouping should be perceived when it is produced by luminance, but not chromatic, information and it should occur the same way as if the information present in the stimulus were only luminance.

In the experimental condition in which chromatic information, but not luminance, was constant, that is,

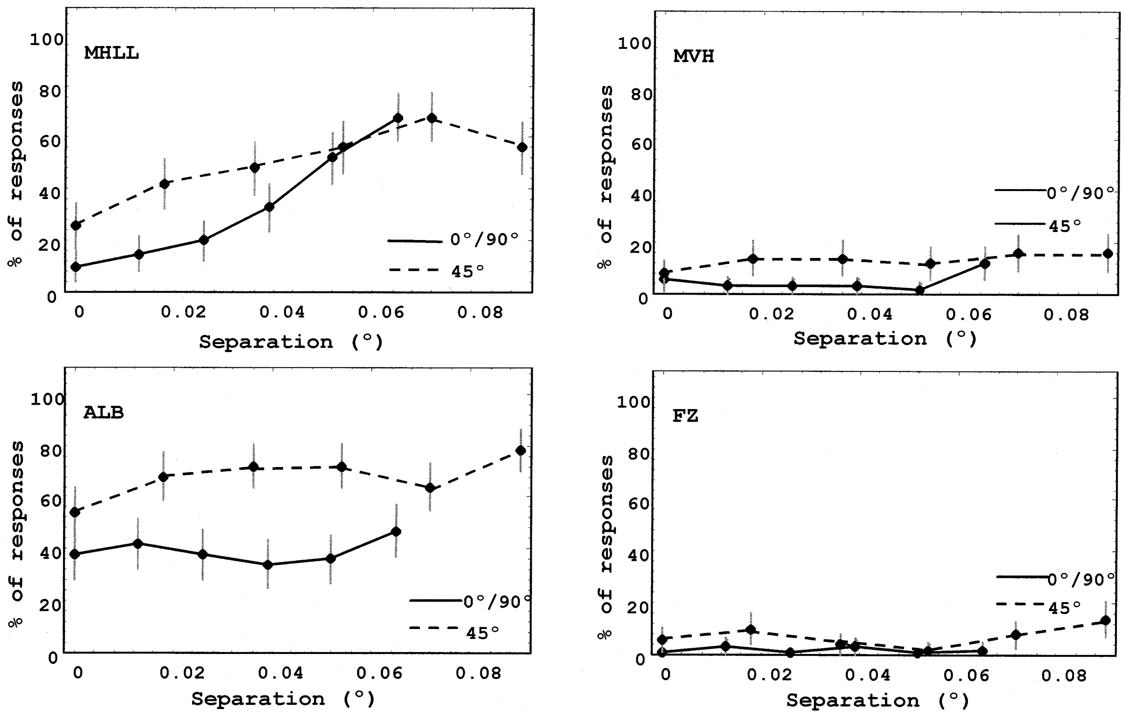

Fig. 8. Results obtained for the four subjects in the condition in which the elements of a line shared luminance information (chromatic information alternated) and the corresponding elements of different lines, in the orthogonal direction, shared chromatic information (luminance information alternated). The percentage of responses in the orthogonal direction to that of the separation between lines as a function of the different separations is shown. The solid line shows the results for the horizontal/vertical condition and the dashed line for the oblique condition (45°). The standard deviation for each point was calculated assuming a binomial distribution of the responses.

when grouping was produced by the spatial integration mechanism based on chromatic information, subjects should be able to perform the task, and similar to the way they perform it when only chromatic information is present. The results point in that direction. For all the subjects, when luminance, but not chromatic information, alternated from one element to another, spatial integration occurred, and, although with some variability, the task was performed, in most cases similarly to when only chromatic information was present. However, in the condition in which the luminance mechanism was responsible for grouping (luminance information was constant between elements and chromatic information varied), this independence hypothesis was not confirmed. Therefore, the data indicate the existence of just one mechanism in which chromatic and luminance information are processed.

This mechanism should contemplate separate, although not independent, treatment of chromatic and luminance information. A system that treats them without differentiation, could only detect color changes (simultaneous variations of luminance and chromaticity) when both luminance and chromatic information vary in the stimuli. In this case, grouping should be performed based only on proximity cues and different conditions should produce the same results. Since this does not occur, the human visual system must be capable of separating chromatic and luminance information in any of its processing stages.

A second consideration, in view of these results, is that cues provided by chromatic information dominate over those provided by luminance, when both cues are of the same strength, in the spatial integration mechanism. When both cues generate competing groupings, chromatic cues can dominate even over proximity cues. This result is consistent with those obtained by Ben-Av and Sagi (1995) by means of a prediction model based on the intensity of the autocorrelation, in which they showed that, for exposition periods over 100 ms, as in our case, grouping based on similarity predominated.

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