Psychol Res (1983) 45:117–134

Psychological Research

The Role of Colours in the Formation of Subjective Contours

Charles M.M. de Weert

Psychological Laboratory, Catholic University, Montessorilaan 3, Postbus 9104, 6500 HE Nijmegen, The Netherlands

Summary. A computer-driven colour television monitor with separate red, green and blue input channels is employed to measure the luminance-difference thresholds for the occurrence of subjective contours, when induction fields and background are of unequal colour. These thresholds are strongly dependent upon the size of the colour difference between the two fields. With increasing difference in colour between induction fields and background, the luminance-difference thresholds necessary to just obtain the subjective contour-effect increase. Various explanations are discussed. Chromatic aberration is not likely to be the main cause for this colour effect, although it has some detrimental influence. At the level of colour-coding mechanisms, lateral interactions between cones or Pi-mechanisms of the same type and interactions between opponent colour codes of the same type are considered. Finally, attention is given to possible psychological factors.

Introduction

Interest in subjective contours has revived in the last few years, partly because it has turned out to be a tool in the continuous debate over which processes are central and which processes take place peripherally in visual perception. This discussion is not continued in any detail here; suffice it to remark that this issue is still far from settled. There is a strong resemblance between the process of subjective contour formation and that of simultaneous brightness contrast (Brigner and Gallagher 1974; Jory and Day 1979; Frisby and Clatworthy 1975). Despite reported differences (Dumais and Bradley 1976; Coren and Theodor 1975), we agree with many others that the two processes have basic data in common. In our view, the two processes differ in the way in which the basic available data are used. By "basic available data" we mean receptive or perceptive fields of different sizes and/or

---

Offprint requests to: C.M.M. de Weert

organization. Both in simultaneous brightness contrast and in subjective (brightness) contour formation, peripheral and central factors play a role, even if only that the relative weights are different. It may be stressed here that Helmholtz (1924) held a purely cognitive theory of contrast.

Both the study of subjective contour formation and the study of simultaneous brightness contrast give us the means to study spatial interaction within and between photopic mechanisms. Because of the fact that in subjective contours no barriers are present between induced field and background (comparison) field, it could even be that more subtle measurements can be made under these conditions than in a classic simultaneous-contrast condition where closed contours are generally used. Data on brightness contrast under heterochromatic conditions are amply available (Alpern 1964; Kerr 1974, 1976; Bender 1973; Kinnear 1979; Mitsuboshi 1980; Oyama et al. 1980). Data on the colour dependence of subjective contour formation are scarce. There are some quantitative studies showing that no subjective contours occur under isoluminance (Brussell et al. 1977; De Weert 1980). Gregory (1977) reported an absence of subjective contours under isoluminance in informal experiments.

As can be seen in Fig. 1, which gives a recording of part of the data from De Weert (1980), the luminance-difference thresholds for the occurrence of subjective contours are strongly dependent upon the wavelengths of induction fields and background.

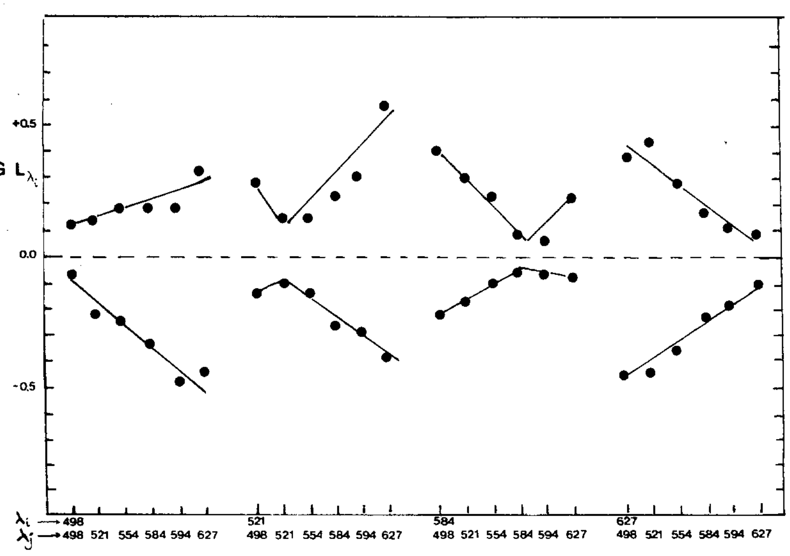

Fig. 1. Along the ordinate the log of the ratio of the luminance of induction fields (L_i) and background (L_j) necessary to obtain a subjective contour are represented. At $\log(L_i/L_j) = 0.0$ the luminance values for induction fields and background are 300 trolands. The luminance of the background remains constant. For simplicity L_j is taken as 1 here. Along the abscissa, the pairs of wave-lengths used in induction fields (upper number) and background (lower number) are given

We interpreted this wavelength dependence of the luminance thresholds as an indication that luminance, as determined by the flicker-photometric procedure, could not be the only relevant signal for the formation of subjective brightness contours. In fact, an alternative luminance measure (L′) which was related to the colour-dependent luminance measure as proposed by Guth et al. (1969), was used to explain the results. In particular, the systematic asymmetry in the data when wavelengths of background and induction fields were interchanged could be reasonably explained under the assumption that L′, and not L, was the relevant signal. However, what was not well explained by this concept is the fact that the difference thresholds grow with increasing difference in wavelength between induction fields and background. This aspect will be dealt with in the study to be presented here, in which additional data will be given on the influence of chromatic differences on the luminance-difference thresholds.

Apparatus

A colour television monitor with red (R), green (G), and blue (B) inputs (bandwidth 9 MHz, high resolution screen) is used for the presentation of the test stimuli. The test stimuli are generated by computer (PDP MINC-11). The colour-stimulus generator is described in detail in Wittebrood et al. (1981). Briefly, a logical value i ($i = 0, 1, ..., 7$) can be assigned to each point in a system of video memories with 512 × 512 points. Each of these eight values, in turn, corresponds to one of 256 × 256 × 256 possible combinations of R, G or B values. The R, G and B values are controlled by the subject either by pushing buttons, or by a computer program. Calibration of the luminances for all values of the three primaries was performed with a Spectra Pritchard Photometer. The maximal luminance values for the R, G and B channels were 51, 100 and 21 cd/m^2, respectively. The chromaticity coordinates of the television primaries as specified by the manufacturer (BARCO) are:

Red primary	$x = 0.654$	$y = 0.341$
Green primary	$x = 0.285$	$y = 0.606$
Blue primary	$x = 0.154$	$y = 0.061$

Knowing the x,y values and the luminance values of the primaries allows for computation of any desired transformation in the colour domain. See Appendix for calculations.

Stimuli

The stimulus is shown in Fig. 2.

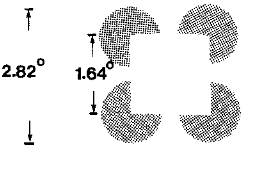

Fig. 2. Stimulus used in threshold experiments 1 and 2

Subjects

The author (W), an experienced subject in colour vision, took part in all experiments. Three inexperienced subjects (M, V, and S) participated in different parts of the experiments. All subjects had normal colour vision.

Threshold Experiment 1

Procedure

A starting configuration was chosen in which the induction fields and the background were equal in colour and luminance. At each presentation, the induction fields were changed in luminance and colour by introducing a random number of incremental or decremental steps in the luminance level of either the R-channel (Lr) or the G-channel (Lgr). The step width (in cd/m^2) and the maximum number of steps were chosen in advance. In Fig. 3b, the starting configuration belonging to the data presented in this paper is indicated with a cross. The variation in chromaticity is many times larger than the variations necessary for just-noticeable colour differences. The subject subsequently made six possible types of threshold adjustments (illustrated in more detail in Fig. 3a), by either increasing or decreasing the R-luminance, the G-luminance or the R- and G-luminances together.

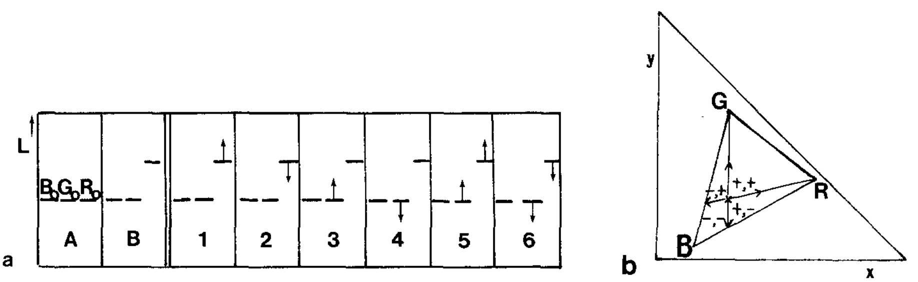

Fig. 3a,b. Luminance levels of the Red, Green and Blue channel activities in the induction fields. *State A:* Levels of the luminance values of the R (red), G (green), and B (blue) channels in the starting configuration. For simplification the levels of R, G and B are drawn as equal, although they generally are not. In this starting state, induction fields and background are equal in colour and luminance. *State B:* New figurations, randomly chosen. Only R or G changes are introduced. This new configuration is the starting stimulus for six threshold determinations. After registration of each of the six thresholds, the stimulus returns to state B. *1–6:* Arrows upwards (incremental thresholds) indicate that subjects increase the luminance of R or G (or R and G) until a subjectively seen square appears as darker than the surround. Arrows downwards (decremental thresholds) point to a decrease in the respective luminance values until a subjective square just appears as lighter than the surround. **b** In **b** the variations in chromaticity, corresponding to the changes in the luminance of Lr, Lgr or both are indicated. The signs in the four quadrants indicate the changes in Lr and Lgr, respectively

In each series of six threshold determinations, the isoluminance-isocolour state (starting configuration) is passed at least once (see case two in the example of Fig. 3a). In this case, the threshold can very easily be detected because the resulting colour difference is small. The two cases in which the subjects altered Lr and Lgr simultaneously, were introduced to get a larger variety in chromaticity differences between induction fields and background. Subjects were asked explicitly to move their gaze smoothly over the area where the subjective contour is supposed to arise because it is known that subjective contours easily fade with fixation. No time limit was imposed. Subjects needed, in general, less than about 5 s to reach a threshold. It is clear that with these relatively long presentation times and with the freedom to move the eyes, complex after-effects can occur. There is, however, no a priori reason to assume that these effects exert a differential influence on luminance differences when induction fields and background are of different colour.

Results and Discussion

Some typical results are represented in Fig. 4 for the experienced subject W for one starting position. Along the abscissa, the luminance of the R-channel is represented;

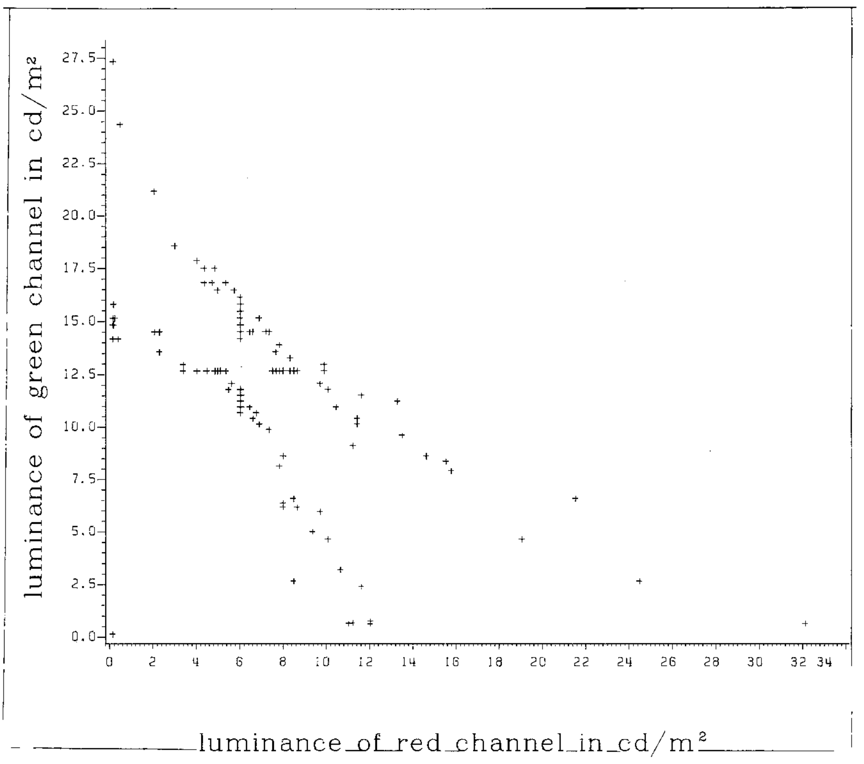

Fig. 4a. Explanation see Fig. 4c

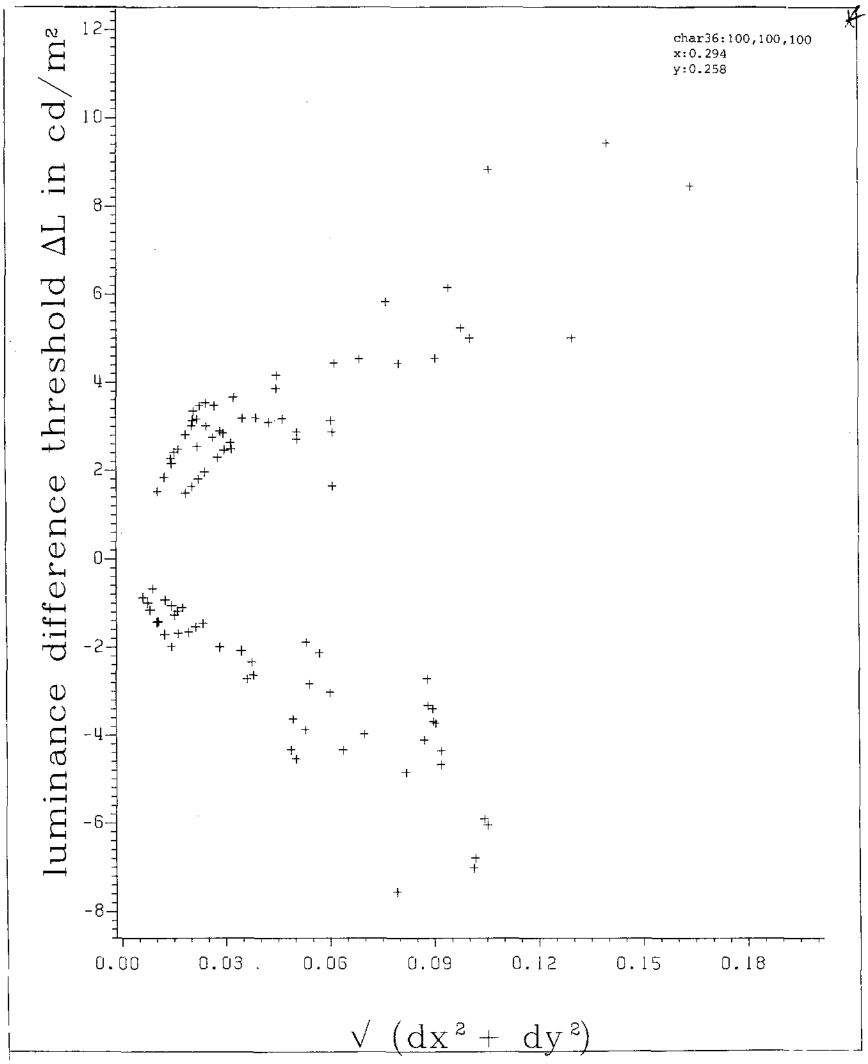

Fig. 4b. Explanation see Fig. 4c

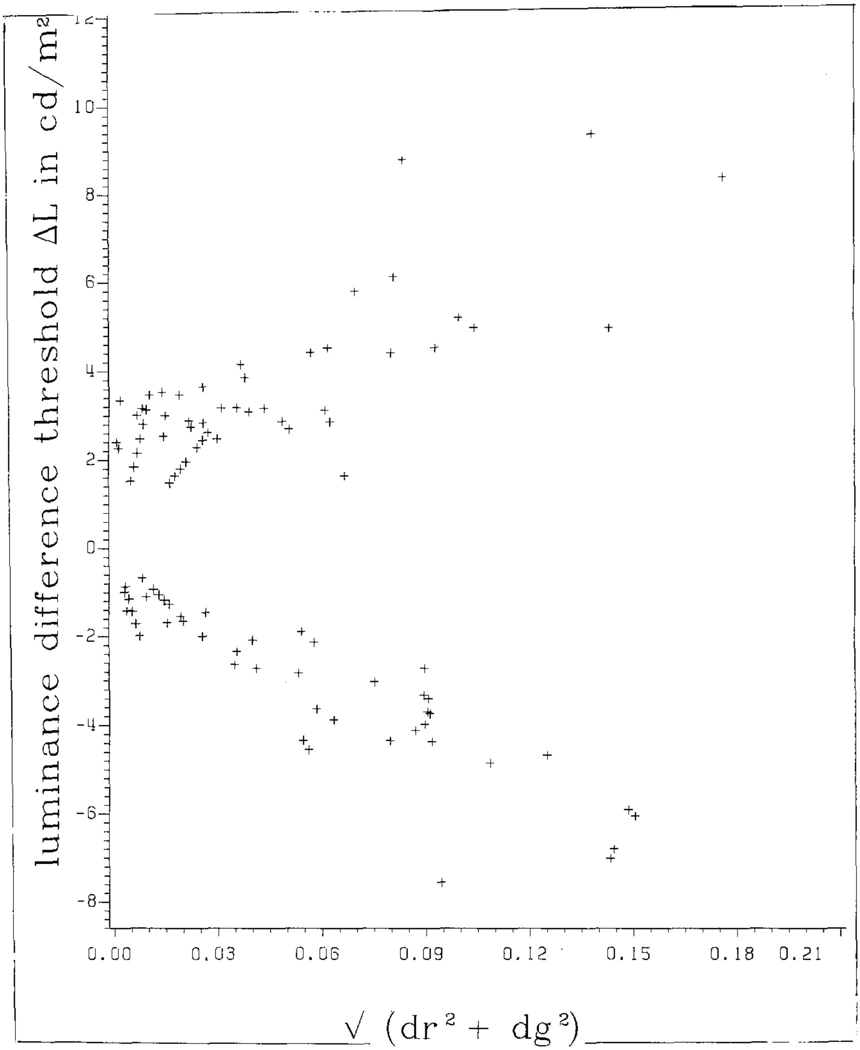

Fig. 4c

Fig. 4a. Luminance values of R and G television primaries for the induction fields at incremental and decremental thresholds for the occurrence of the subjective square. At the —0— symbol, colour and luminance of induction fields and background are identical. **b** Dependence of luminance threshold upon colour difference between induction fields and background. For the distance function a rather arbitrary choice has been made. **c** Similar to 4b, but now a different system of chromaticity coordinates has been used, based upon the Vos-Walraven primaries

along the ordinate the luminance of the G-channel is given. The open symbol indicates the equilibrium position where there is only a homogeneous field because induction fields and background are identical in colour and luminance. Global inspection of these types of curves already gives some idea of the colour dependence of the luminance thresholds.

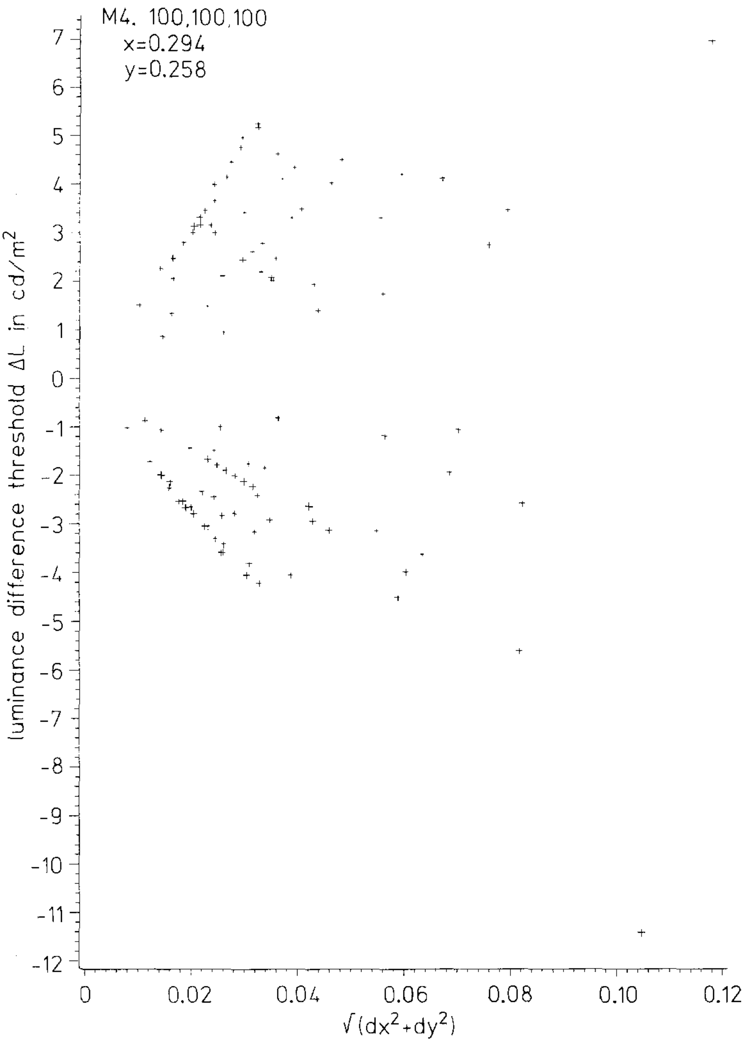

Fig. 5a. Data for subject M. See legend of Fig. 4b

For the equally signed quadrants, where Lr and Lgr are both positive or both negative, the shifts in colour are relatively small because the shifts of R and G are in the same direction. For the unequal quadrants, the colour differences are always larger. Within (+,+) and (–,–) quadrants a simple linear combination of the R and G incremental or decremental luminance values seems to give an adequate description of the threshold relationship: $a\Delta\mathrm{Lr} + b\Delta\mathrm{Lgr} = C$. For the (–,+) and the (+,–) areas, however, the absolute value of the sum of the luminance differences in R and G channels is not constant, but increases.

Without relying in any respect on this linear description, it can safely be stated that as soon as considerable colour differences exist, there is an enlargement of the

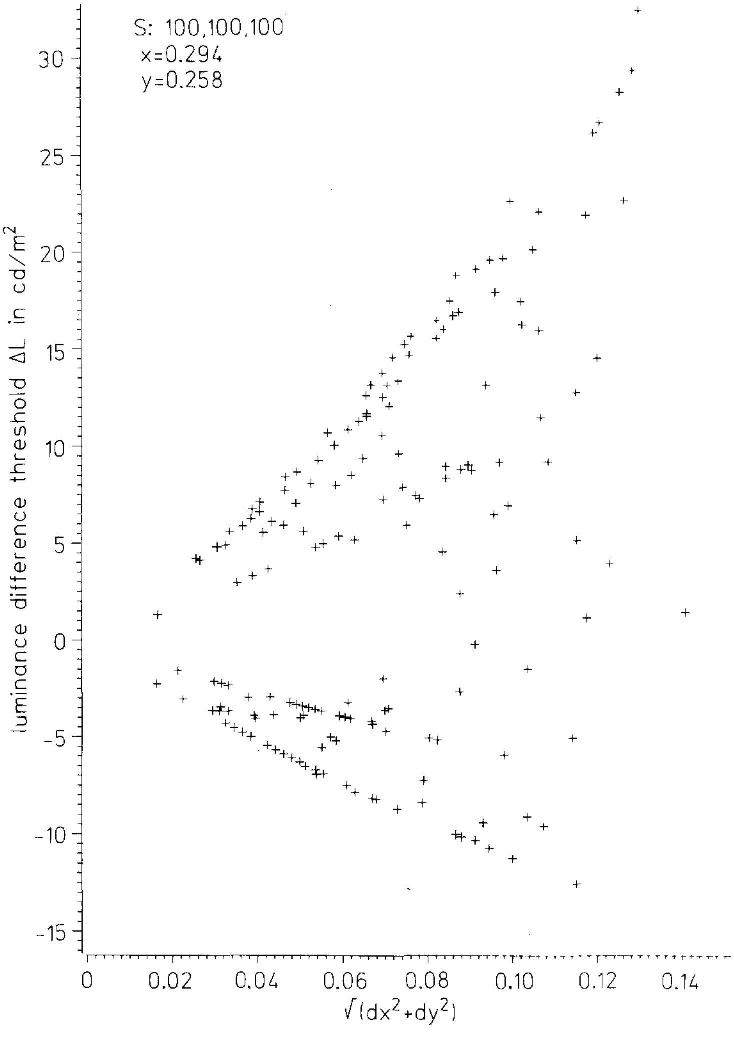

Fig. 5b. Data for subject S. See legend of Fig. 4b

thresholds, both in the decremental and in the incremental case. In this respect, the results strongly resemble the earlier results obtained with spectral stimuli for the same subject (De Weert 1980). As a measure of the distance in the chromaticity diagram we take a quadratic function $d = (dx^2 + dy^2)^{0.5}$, with dx and dy indicating differences in chromaticity coordinates of the induction fields in relation to the background. This function, or an equivalent one, in the (r, g) chromaticity space as derived from Vos and Walraven (1971) primaries, serves as a first-order approximation of the perceptual colour difference between induction fields and background. In Figure 4b and c the ΔL values (the sum of the changes in Lr and Lgr values) are plotted against the proposed distance function in the chromaticity diagram.

It is quite clear that with increasing distance in the chromaticity space, larger luminance thresholds are required to obtain subjective contours. As a matter of fact, results like those of Fig. 4, etc. were reproduced by the experienced subject W over a period of months.

In Fig.5a and b, plots of ΔL versus distance in the (x,y) chromaticity plane are given for subjects S and M. The results for the unexperienced subjects are more noisy, just as they were for W at the beginning of the experiments. Finding a stable criterion for the occurrence of the subjective contours is quite difficult. A conclusion similar to that derived for W can also be made for the inexperienced subjects: an increase in thresholds with increasing colour differences seems to be valid. For the two less-experienced subjects there seems to be a tendency towards finding subjective contours for purely chromatic contours. In view of the fact that for smaller differences in colour, the tendency towards an increase in luminance threshold with increasing chromatic difference is quite clear. We do think that the reports of subjective contours at zero-luminance differences, with higher chromatic differences, are false alarms due to the perception of amodal contours.[1]

In the experiment described above, variations in colour and luminance were interrelated. A change in luminance of the R-channel, the Gr-channel, or in both, brought in most cases a change in chromaticity with it. Independent variation of the two was not possible. It is a disadvantage that it was not possible to make repeated threshold measurements at a fixed position in the induction fields in the chromaticity diagram, and it is also a disadvantage that we could not spread in advance the measurements uniformly over the available chromaticity space. In the next section, an experiment will be described in which variation of luminance of the induction fields was made possible while keeping the chromaticity level fixed.

Threshold Experiment 2

For a number of points in the colour triangle we monitored the luminance thresholds for the occurrence of subjective contours, altering only the luminance of the induction fields. We chose the stimuli at the three primary positions and at positions in between, as can be seen in Fig. 6b. Stimuli were equated in luminance by means of the flicker-photometric procedure. A number of combinations of these stimuli in induction and background field were used. Two subjects took part in this experiment: the author (W) and an inexperienced subject (V).

The results are represented in Fig. 6. The homochromatic pairs clearly need the least luminance differences. Generally, one can say that the larger the perceived

1 As a matter of fact, both for subject M and for W more data are available from experiments in which induction fields and background already differed in colour in the starting configuration. The reason for not presenting these data in the same way as those of Figs. 4 and 5 is that the measure for perceptual distance $[(dx)^2 + (dy)^2)^{0.5}]$ used for not too large distances in the chromaticity domain, is too simple a measure for large distances. However, these data strongly suggest that the difference thresholds are greater for larger differences in colour, as well as for the less experienced subject

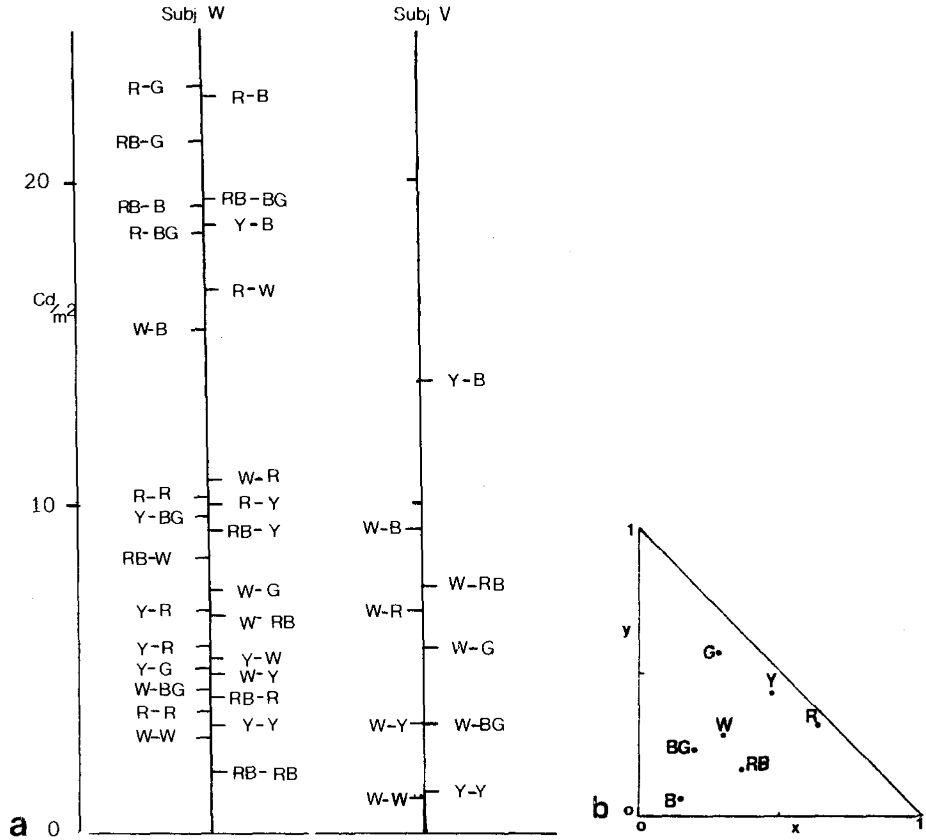

Fig. 6a,b. The different colour pairs, used in induction fields and background are positioned along a scale indicating the sum of the incremental and decremental luminance differences of the induction fields with respect to the background, necessary to obtain subjective contours. The first symbol indicates the colour of the induction fields. The luminance of the background is 21 cd/m^2. The stimuli in the (x,y) chromaticity diagram are represented in **b**

colour difference between induction field and background, the larger the luminance difference threshold.

Model Considerations

What type of explanation must be searched for for the enlargement of the luminance threshold with increasing chromatic difference? Considerations on three types of possible causes will be given here:

1. Considerations of physical causes
2. Considerations of a mechanistic nature
3. Considerations on psychological factors

Physical Causes

Let us assume that either L or L′ (achromatic or chromatic luminance) is the only relevant signal for the formation of subjective contours. Now it is conceivable that the strength of the effect is dependent upon the quality of the contours between induction fields and the background in which the induction has to take place. In the next section some data will be presented which diminish the likelihood that contour degradation due to chromatic aberration effects is the major cause for the colour-difference effect on the luminance difference thresholds.

Contour-Degradation Experiments: Two Experiments

From both the spectral measurements (De Weert 1980) and the non-spectral data presented here, one might conclude that differences in colour between the fields lead to an increase in threshold values as expressed in luminance units. One possible reason for this effect should be degradation of contours due to chromatic aberrations of the human eye lens. For several reasons we did not correct for chromatic aberration. The main reason is that the correction lens we had at our disposal introduced new distortions, which actually worsened the image. The second reason is that a better lens would also create problems concerning chromatic aberration because these lenses only correct for differences in focal lengths, not for differences in transverse magnification power. According to Noorlander et al. (1981), it is not possible to eliminate chromatic aberration effects for the TV spectrum with the help of any correction lens. Finally, from the literature it has become clear that despite the large expected differences in results, correction generally produced only marginal improvement (Cornsweet 1970). Of course, we do not exclude the possibility that contour degradation due to chromatic aberration may be the major cause of threshold enlargements with increasing difference in colour between the fields involved. It would be the simplest possible solution to ascribe the worsening effect of colour to this contour-degradation effect.

In two auxiliary experiments, we tried to find indications of the amount of chromatic aberration influence. In the first auxiliary experiment, contour degradation was introduced in order to study the possible consequence of accommodation problems. The precise form of degradation is not known to us. We still think that even a rough simulation of contour degradation, keeping colours of induction fields and background identical, can give us sufficient indication of the possible role of chromatic aberration in the effects described in the main experiment.

The type of degradation introduced was very simple. A gradient in the contour of the induction fields was simulated on the television screen by introducing fields of an intermediate luminance level between induction field and background. The number and width of the fields in between, as well as the levels of the luminance, could freely be chosen with the restriction, of course, that too-wide intermediate fields do not give the impression of a continuous gradient anymore. Determined in all of the experimental conditions indicated in Fig. 7 was the luminance difference necessary for the match of the brightness impression, both in the case of a

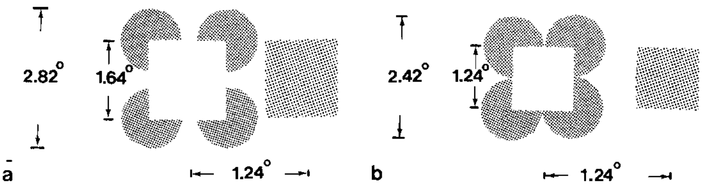

Fig. 7a. Stimulus configuration used in the matchings of the strength of the subjective contour effect with degraded contours. b Stimulus configuration used in the matchings of the strength of the simultaneous brightness induction under conditions of contour degradation. The right parts of the Figures represent the matching field which is varied in luminance and/or colour by the subject

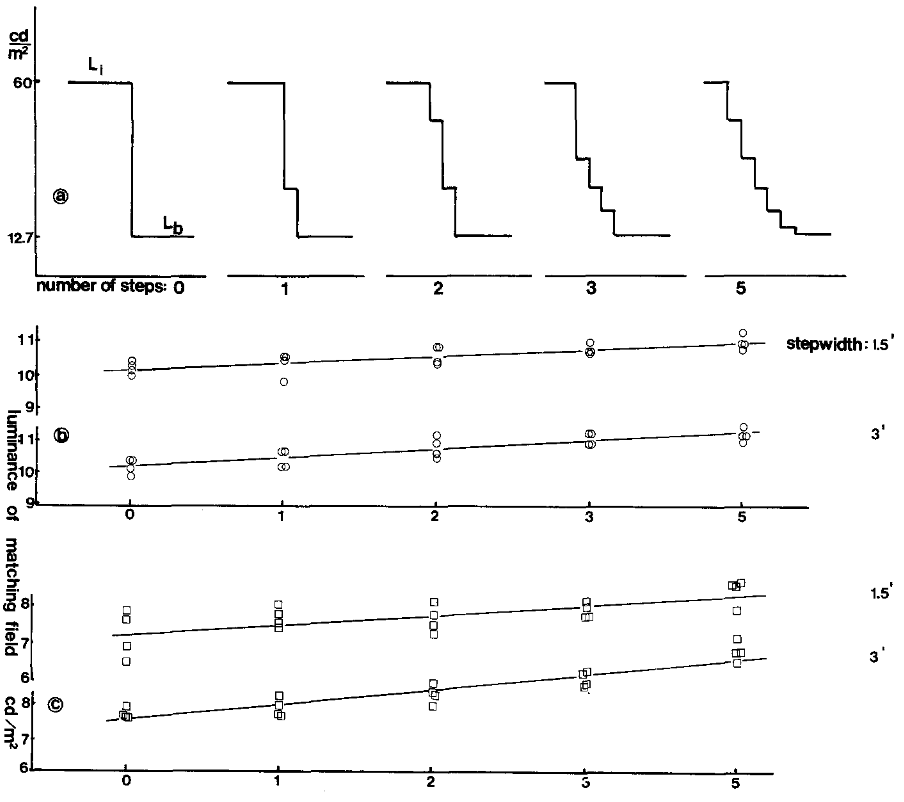

Fig. 8a. Schematic shape of the contour between induction field and background. b Matching data for the subjective contour stimuli. c Matching data for the simultaneous contrast stimuli

subjective contour stimulus and a strongly similar simultaneous-contrast stimulus. The results are presented in Fig. 8.

In the first auxiliary experiment supra-threshold measurements were made. One might object that the contour degradation could have had a more manifest influence

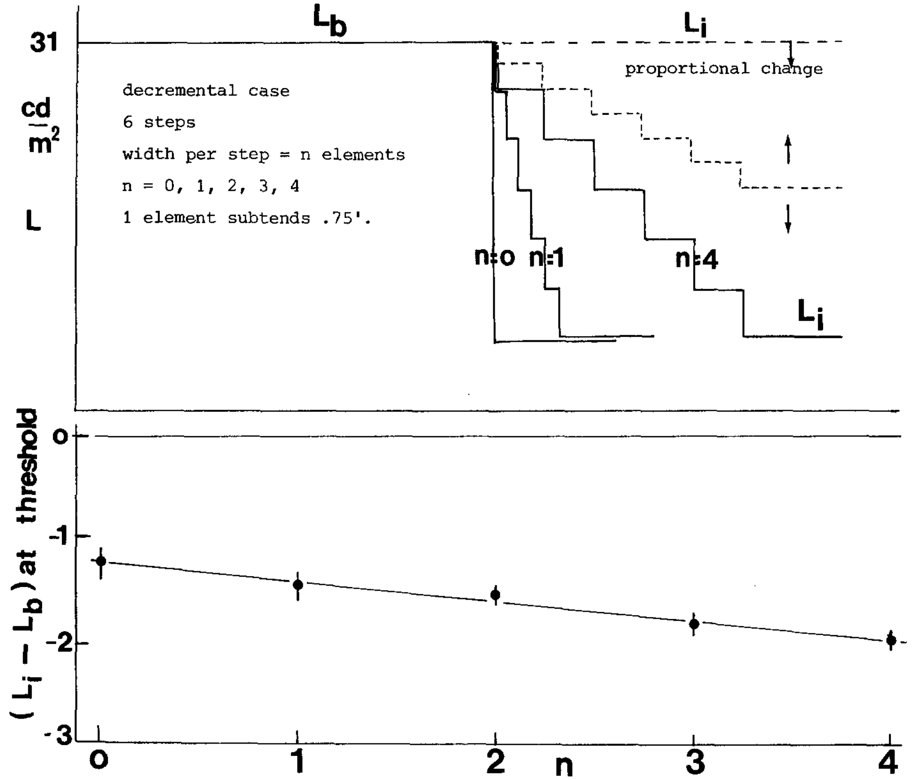

Fig. 9. Thresholds for degraded contours. Colour of induction field and background was green. By a suitable program the change in luminance of the several intermediate steps between the induction field is made linear. Measurements were made for the subjective contour stimulus and only decremental values of the induction fields were introduced

at the threshold level. We therefore devised an experiment in which thresholds for the occurrence of subjective contours could be measured with different shapes of contours between induction fields and background. The luminance between induction fields and background changed in such a way that a quasi-linear contour shape with increasing or decreasing slope is formed. Only decremental thresholds were measured. The subject changed the slope of the contour just until a subjective contour appeared.

As can be seen in Fig. 9, there is a contour-degradation effect, but it is not nearly large enough to explain the effects found in the threshold measurements. In concluding this part, we would like to state that contour degradation, as a possible consequence of chromatic aberration, certainly has an effect, but it is presumably not strong enough to explain the colour difference effect.

Mechanistic Considerations

The global similarity in colour dependence of simultaneous-brightness contrast and of the threshold for the occurrence of subjective contours strongly strengthens the idea that these effects have basic mechanisms in common. Models given to explain the colour dependence of simultaneous-brightness contrast might also apply to subjective-brightness contours. In Kerr's model (1976) and in Oyama et al. (1981), the dependence of colour difference is accounted for by cone- or π-mechanism-specific-lateral interaction. Interactions occur only within the same kind of systems. This explains why effects are less the larger the difference in colour. According to the same authors, the lateral interaction within the achromatic or luminance channel is not cone-specific. If, after several types of lateral interactions, the brightness signal is a composite of the achromatic signal and of the chromatic signals, the colour-difference dependence of the simultaneous contrast and of the formation of subjective-brightness contours can be understood – at least qualitatively. Stated in simple terms, the model says: "the smaller the number of common signal types, the smaller the amount of lateral inhibition". The fact that subjective contours were not seen under isoluminance conditions is remarkable in view of the lateral inhibition theory given above. If the lateral interaction effects occurring in the chromatic channels are solely responsible for the colour-difference effect in the luminance thresholds, one might wonder why these lateral effects are not seen as colour changes at the place of the induced figure. This shows a remarkable difference with the 'pure' simultaneous-contrast condition, in which colour induction is only easily visible under isoluminance conditions. We did not find a visible colour-induction effect in the type of subjective contour stimuli used in the experiments reported here, whereas we easily detected colour-induction effects in the 'simultaneous contrast' stimulus depicted in Fig. 7b. This difference, however, needs quantitative investigation. If established as a general effect, it would present us with the interesting question of where the colour has gone. It could be that illusory contours do not function in exactly the same way as real brightness contours do, i.e. serving as a locking boundary for colour (Gregory 1977).

Psychological Factors

Even if we assume that simultaneous contrast and the formation of subjective brightness contours are strongly related, we do not necessarily need to assume that lateral inhibition is the only relevant process. As has been mentioned before, simultaneous contrast also has central components. This has been made clear in beautiful examples like Benary's cross (Kanizsa 1979), in which two gray areas, with identical physical boundaries show quite different types of contrast, depending on their role in the pattern as either part of the figure or part of the ground. The process of assigning the role of figure and of ground is a cognitive process, probably mostly an unconscious and automatic one. Presumably this process is different insofar as the stimuli for simultaneous contrast and subjective contours are structurally different. It remains to be seen, however, how these cognitive processes would explain the colour difference effects. All three types of processes considered in this discussion are of importance for the colour-difference effect with, in my view, the larger weights on the blur effect and the lateral interaction mechanisms.

Appendix

Given the luminance values of the red, green and blue channels of the colour television monitor, and their respective CIE x,y chromaticity coordinates, the x,y values of any mixture can be computed. The following transformations were applied on the resulting x,y values:

1. A correction according to Judd was applied.

$$x' = (1.0271x - 0.000084y - 0.00009)/(0.03845x + 0.014964y + 1)$$
$$y' = (0.00376x - 1.00724y + 0.00764)/(0.03845x + 0.014964y + 1)$$

These x',y' values were computed both for the background and for those values of the induction fields where thresholds were obtained. Differences dx and dy were used in measures for the distance in the chromaticity space.

2. Transformation of x',y',z' values to chromaticity coordinates as used by Vos-Walraven (1971):

$$\begin{bmatrix} r = \\ g = \\ b = \end{bmatrix} \begin{bmatrix} 0.19112 & 0.57903 & -0.03596 \\ 0.18576 & 0.42633 & 0.03060 \\ -0.00536 & -0.00536 & 0.00536 \end{bmatrix} \begin{bmatrix} x'/y' \\ 1 \\ 1/y' \end{bmatrix}$$

dr and dg values could also be used in measures for the difference in chromaticity. It is also possible to compute the differences in receptor activities (Vos-Walraven model) between induction fields and background: (suffix i points to induction fields, suffix b to background).

$$r_i = \frac{R_{vwi}}{(R_{vwi} + G_{vwi} + B_{vwi})} = R_{vwi}/L_i \text{ on the assumption that}$$

$$R_{vwi} + G_{vwi} + B_{vwi} = L_i$$

$$r_b = \frac{R_{vwb}}{R_{vwb} + G_{vwb} + B_{vwb}} = R_{vwb}/L_b \text{ with } R_{vwb} + G_{vwb} + B_{vwb} = L_b \quad .$$

Let us further note R_{vw} as R.

$$\Delta r = r_i - r_b = (R_i L_b - L_i R_b)/L_i L_b = ((R_b + \Delta R) L_b - (L_b + \Delta L) R_b)/((L_b + \Delta L) L_b)$$

$$\Delta r = (L_b \Delta R - R_b \Delta L)/(L_b + \Delta L) L_b)$$

$$\Delta r = (\Delta R - R_b \Delta L/L_b)/(L_b + \Delta L)$$

Thus $\Delta R = \Delta r(L_b + \Delta L) + R_b \Delta L/L_b = \Delta r(L_b + \Delta L) + r_b \Delta L$

and $\Delta G = \Delta g(L_b + \Delta L) + G_b \Delta L/L_b = \Delta g(L_b + \Delta L) + g_b.\Delta L$

$$\Delta B = -(\Delta r + \Delta g)(L_b + \Delta L) + (1 - r_b - g_b)\Delta L \quad \text{with} \quad \Delta R + \Delta G + \Delta B = \Delta L$$

References

Alpern M (1964) Relation between brightness and color contrast. J Opt Soc Am 54: 1491–1492

Bender BG (1973) Spatial interaction between the red and green sensitive colour mechanisms of the human visual system. Vision Res 13:2205–2218

Brigner WL, Gallagher MB (1979) Subjective contours, apparent depth or simultaneous brightness contrast. Percept Mot Skills 38:1047–1053

Brussell EM, Stober SR, Bodinger DM (1977) Sensory information and subjective contours. Am J Psychol 90:145–156

Coren WL, Theodor LH (1975) Subjective contour: The inadequacy of brightness contrast as an explanation. Bull Psychon Soc 6:87–89

Cornsweet TW (1970) Visual perception. Academic Press, New York

Dumais ST, Bradley DR (1976) The effects of illumination level and retinal size of apparent strength of subjective contours. Percept Psychophys 4:339–345

Frisby JP, Clatworthy JL (1975) Illusory contours: curious cases of simultaneous brightness contrast. Perception 4:349–357

Gregory RL (1977) Vision with isoluminant colour contrast: I. A projection technique and observations. Perception 6:113–119

Guth SL, Donley NJ, Marocco RT (1969) On luminance additivity and related topics. Vision Res 9:537–575

Helmholtz H von (1924) in Southall. J.P.C.: Helmholtz's Treatise on Physiological Optics I and II. Dover Edition 1962

Jory MK, Day RH (1979) The relationship between brightness contrast and illusory contours. Perception 8:3–9

Kanizsa G (1979) Organisation in vision. Praeger, New York

Kinnear PR (1979) The effects of coloured surrounds on colour naming and luminosity. Vision Res 19:1381–1391

Kerr L (1974) Detection and identification of monochromatic stimuli under chromatic contrast. Vision Res 14:1095–1105

Kerr L (1976) Effect of chromatic contrast on stimulus brightness. Vision Res 16:467–468

Mitsuboshi M, Mitsuboshi T (1980) The specificity of interactions among the visual photopic mechanisms as revealed by spatial on effects. Jap Psychol Res 22:197–206

Noorlander C, Heuts MJG, Koenderink JJ (1981) Sensitivity to spatiotemporal combined luminance and chromaticity contrast. J Opt Soc Am 71:453–459

Oyama T, Mitsuboshi M, Kamoshita T (1980) Wavelength specific brightness contrast as a function of surround luminance. Vision Res 20:127–136

Vos JJ, Walraven PL (1971) On the derivation of the foveal receptor primaries. Vision Res 11:799–818

Weert ChMM de (1980) Die Bedeutung von Farbkonturen verglichen mit der Bedeutung von Helligkeitskonturen. Farbe und Design 15/16:89–93

Wittebrood JEM, Wansink MG, Weert ChMM de (1981) A versatile colour stimulus generator. Perception 10:63–69

Received February 10, 1983/June 6, 1983