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Classification of colours presented against different coloured backgrounds

S McFadden, R Kaufmann* and M Janzen

In complex colour-coded displays, similar colours may be presented against different coloured backgrounds. Shifts in colour appearance as a function of surround colours could impair the accurate interpretation of information. Using a colour-naming task, a study was carried out to evaluate the appearance of chromaticities presented against different coloured backgrounds on a CRT. The results identified chromaticities that can be reliably named and those that are most susceptible to the effects of chromatic induction. Recommendations for decreasing the effect of chromatic induction are discussed.

Keywords: chromatic induction, colour naming, classification, CRT, colour-coded displays

Visual display units are used widely for displaying complex information such as navigational charts and medical, radar and satellite imagery. All of these applications make considerable use of colour coding. In using colour to code information, it is important that the appearance of a colour assigned to a particular class of information be the same, independent of its location on the display, and be different from the colours assigned to other classes of information. Under certain conditions, it may be difficult to meet this criterion. These conditions include using a relatively large number of colours (more than four or five), juxtaposing of different coloured areas, and varying the size of the coloured areas from a few minutes of arc up to a few degrees. Unfortunately, these are precisely the characteristics of the above types of applications.

The main reason that chromatic discrimination and classification may be degraded is that the appearance of a coloured area is affected by its surround. Two areas with the same spectral power distribution, or in computer terms two areas for which the relative voltage applied to the three guns is the same, may appear to be different colours if they are presented against different coloured surrounds. Conversely, two areas coded different colours may appear to be the same colour. This situation is due primarily to chromatic induction. It refers to the shifts in colour appearance of a specified area as a function of the chromaticities of surrounding areas. Most studies on chromatic induction find that the appearance of a test area is shifted away from the chromaticity of the surround or towards the complementary colour of the surround. A stimulus on a red background will tend to appear greener than it will against a grey background and vice versa, and a stimulus on a yellow background will tend to appear bluer and vice versa. Recent data on the precise directions, in the CIE 1931 chromaticity diagram, of the shifts in colour appearance under carefully controlled conditions can be found in studies by Ware and Cowan[1], and Krauskopf *et al.*[2].

Other factors have been shown to influence the appearance of a test stimulus as well. If the surround and test differ in luminance as well as chromaticity, brightness contrast may cause the brightness of the test to shift away from that of the surround[3]. If the test stimulus is relatively small, spread of physical light from the surround into the test area may influence colour appearance as well[4]. Under such conditions, the surround and test chromaticities seem to add, resulting in the test chromaticity appearing more like that of the surround as happens with assimilation.

Accurate interpretation of information on a colour-coded electronic display requires selecting colours that do not

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alter significantly the appearance of other colours on the display. The effects of chromatic induction and assimilation on colour appearance is reasonably well understood for simple stimulus configurations and carefully controlled conditions, and should provide at least general guidelines for the selection of colours. However, it may be that these studies will overestimate the shifts in appearance that will be found in complex displays. In most applications using colour coding, it is important that the different chromaticities be labelled reliably. Trained and untrained users should be able to associate a unique label with each chromaticity used. Small shifts in colour appearance that do not cross colour-naming boundaries are unlikely to be of critical importance.

In studies on the effect of chromatic adaptation (the effect of ambient illumination on colour appearance), it has been found that with a complex stimulus configuration, where multiple colours are present, stimulus areas tend to maintain their appearance independent of their illumination[5–7]. With simpler stimulus configurations, changes in illumination result in shifts in appearance[8,9]. Part of the reason for this difference may be that the studies cited above that showed colour constancy used a colour-naming task while those that showed shifts in appearance used colour matching, a method that allows more accurate measurement of small changes.

CURRENT STUDY

Based on the results of the research referenced above on chromatic induction and chromatic adaptation, it was felt that more data were needed on the effects of surround on colour appearance in more complex display configurations. The current study was an initial effort to collect these data in order to provide better colour selection guidelines for complex displays. The specific aim of the study was to determine chromaticities, at a specified luminance on a CRT, that could be reliably labelled, independent of the background against which they were presented.

The labels were ten common colour names (white, pink, yellow, orange, red, purple, blue, green, aqua, grey) that have been used in other studies on colour naming of chromaticities on CRTs[10,11]. Other possible names were black and brown. Black would not be expected because all the colours were equal in luminance. Similarly, the perception of brown usually occurs on a CRT when a colour in the appropriate part of the chromaticity diagram is presented against a higher luminance background[12]. Subjects were required to assign one of the names to each of a large set of stimuli whose chromaticity coordinates covered the total gamut available on our CRT. Each of the stimuli was presented against six different coloured backgrounds. To simulate a complex multicoloured display, the six different backgrounds were presented on the screen at the same time.

By using a large set of stimuli, we hoped to determine the chromaticity or chromaticities on the CRT that are most closely associated with population stereotypes for each of the colour names used. The chromaticities were kept equal in luminance so that we could look at the effects of chromatic induction independent of the effect of luminance induction. In order to cover the whole gamut of chromaticities potentially available on our CRT, it was necessary to limit the luminance to 10 cd/m^2. However, an earlier study by Post and Greene[13] found that the colour names listed above were used as modal responses when they presented chromaticities at 10 cd/m^2. In that study, subjects were not restricted in terms of the colour names they used.

METHOD

Subjects

Twenty-four subjects, 12 men and 12 women with normal or corrected-to-normal visual acuity, participated in the study. All participants had normal colour vision as assessed by the Farnsworth–Munsell 100-hue test. The mean age was 30 (range 21–48) years.

Apparatus

A *sun* 3/110 workstation attached to a *sun* file server running the UNIX operating system was used to control the experiment and display the stimuli on a 19in diagonal, high-resolution Hitachi colour monitor (model 4619-AA-2). The subjects indicated their responses via a mouse-controlled cursor.

Colour calibration[14] of the stimuli was carried out using a calibrated EG&G Gamma Scientific GS-4100 Intelligent Radiometer, NM-3H Monochromator and a GS 2110 Telemicroscope. The calibration was carried out at the centre of the screen. The luminance and chromaticity varied somewhat across the screen. However, no effort was made to correct for this variation. We wanted the effect of this variation on colour naming to be reflected in variability in the data. This decision was based on the expectation that correction of the chromaticities across the surface of the display is not likely or even practical with most applications using multichromatic displays. Thus, if the changes in the chromaticity coordinates for a given set of DAC values shifted across the surface of the screen to the extent that a stimulus was labelled differently, that chromaticity was probably not a good choice for a display application. The chromaticity coordinates of the test and background stimuli were checked at regular intervals to ensure that they fell within ± 0.005 of the specified u',v' values on the 1976 CIE UCS (Commission Internationale de l'Eclairage Uniform Colour Space) chromaticity diagram. With the exceptions noted below, the luminance of the stimuli were within 10% of the specified value of 10 cd/m^2.

Stimuli

The stimulus set was composed of 210 chromaticities evenly spaced on the 1976 CIE UCS diagram within the gamut available on the CRT as shown in *Figure 1*. Each of these

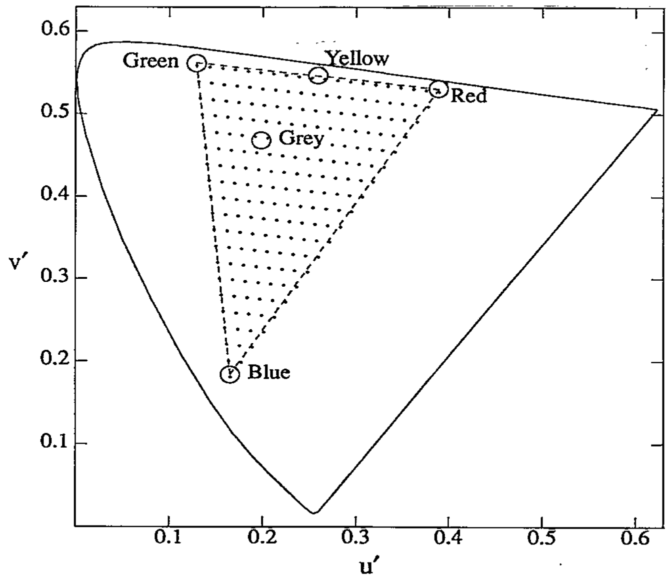


Figure 1 Locations of 210 foreground chromaticities (dots) and background chromaticities (circles) on the 1976 CIE UCS diagram

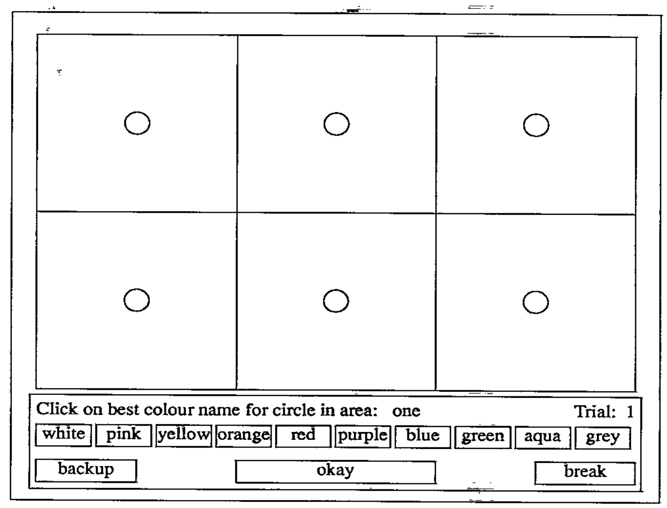


Figure 2 Stimulus configuration. Squares are background-colour filled and circles are foreground-colour filled. Instructions and response buttons are displayed at the bottom of the screen against a grey background

test stimuli was presented against a black, grey (0.198, 0.468), red (0.389, 0.531), green (0.129, 0.562), blue (0.165, 0.184) and yellow (0.259, 0.547) background (marked by circles in *Figure 1*).

The backgrounds were chosen on the basis of existing data on chromatic induction[1,15] with the aim of producing clearly defined shifts in the appearance of the test stimuli. The highest purity chromaticities available on the CRT were used because there is evidence that chromatic induction increases with increasing purity[16,17] and we wanted to determine the worst case. Also, some guidelines for selecting chromaticities for CRTs recommend saturated colours for coding information because they maintain their hue under high levels of ambient illumination[18].

Both black and grey backgrounds were included as controls since both have been used in previous studies on chromatic induction in which a comparison stimulus is matched to the test[1,16,17]. In addition, the grey background may provide some evidence on the effect of a low purity or desaturated background on colour appearance.

All of the test stimuli and five of the backgrounds were nominally equal in luminance. This was done to avoid luminance-induced shifts in brightness along with shifts in chromaticity. The specified luminance was 10 cd/m^2. The actual luminances with a few exceptions ranged from 9 to 11 cd/m^2 at the centre of the screen. Because of limitations of the CRT, the blue background and a few of the blue test stimuli were lower in luminance. The maximum output of the blue gun was 5.6 cd/m^2. The black background was approximately 0.001 cd/m^2.

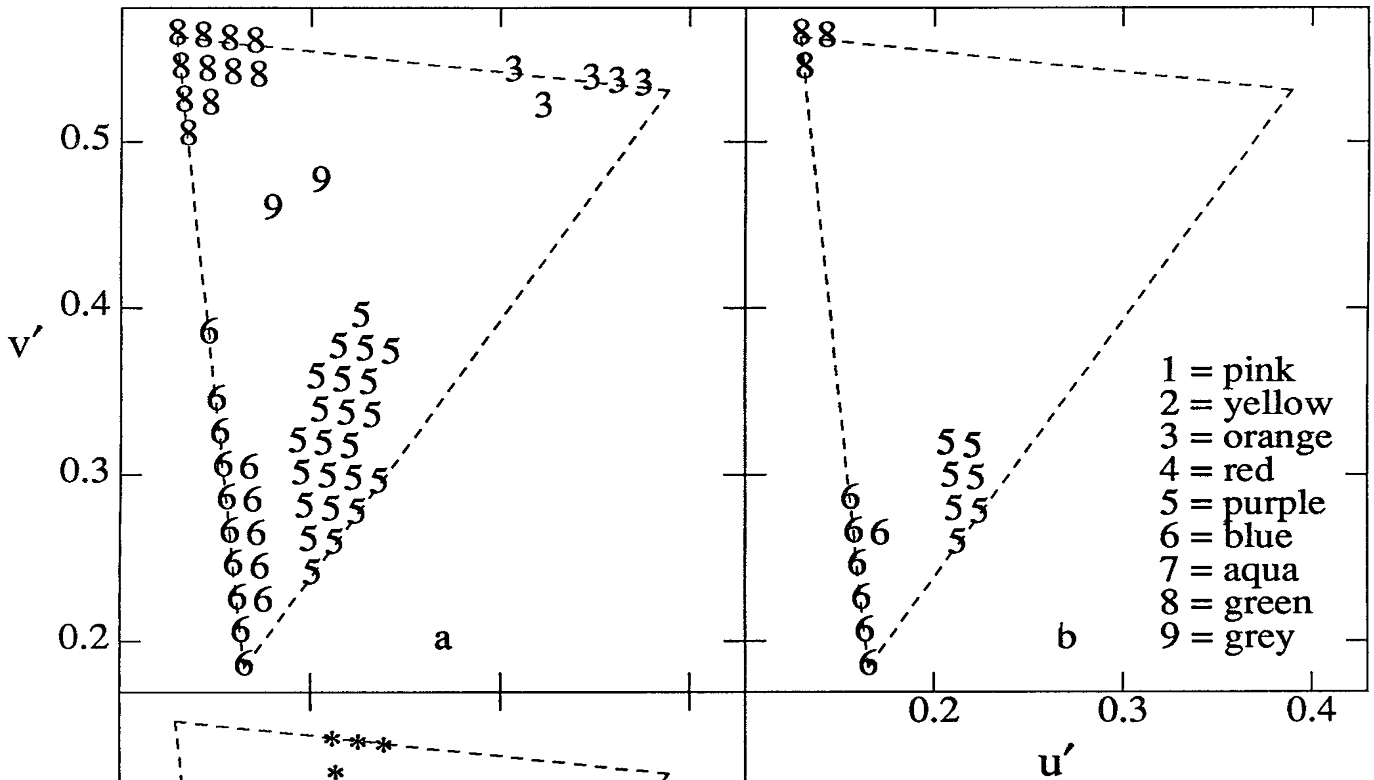
Display configuration

The display configuration is shown in *Figure 2*. Multiple stimuli and backgrounds were presented on the display simultaneously to simulate the chromatic complexity that might be found in a multichromatic display. For each of 210 trials, the six surround colours were randomly assigned to six equally sized squares, arranged in a 2 × 3 grid to cover the entire screen (except for the response panel). Each square subtended a visual angle of 10.8° horizontally and vertically. On each background, one of the foreground colours was displayed in a 30 minute of arc circle. The size and shape were chosen to simulate a typical symbol on a complex display. The order of the backgrounds was varied randomly from trial to trial. Each test chromaticity appeared once against each surround. The order that the chromaticities were presented in was randomly varied for each background and subject.

The panel at the bottom of the display, coded grey with black text, provided the subject with instructions, two counters indicating the current stimulus to label and the current trial, and a set of response buttons. The buttons with colour names were for the subject to indicate the label they wished to associate with each stimulus. The buttons at the bottom of the response panel allowed the subject to repeat a response if the wrong label button was accidentally pushed (backup), to indicate when all six responses had been completed (okay), and to interrupt the experiment if bored or fatigued (break).

Procedure

The subjects' task was to classify the appearance of each test stimulus against each background using one of the ten colour names. Subjects were seated approximately 60 cm from the screen in a dark room (the only illumination came from the CRT). Initially, they received ten practice trials to become familiar with the procedure and to adapt to the dark



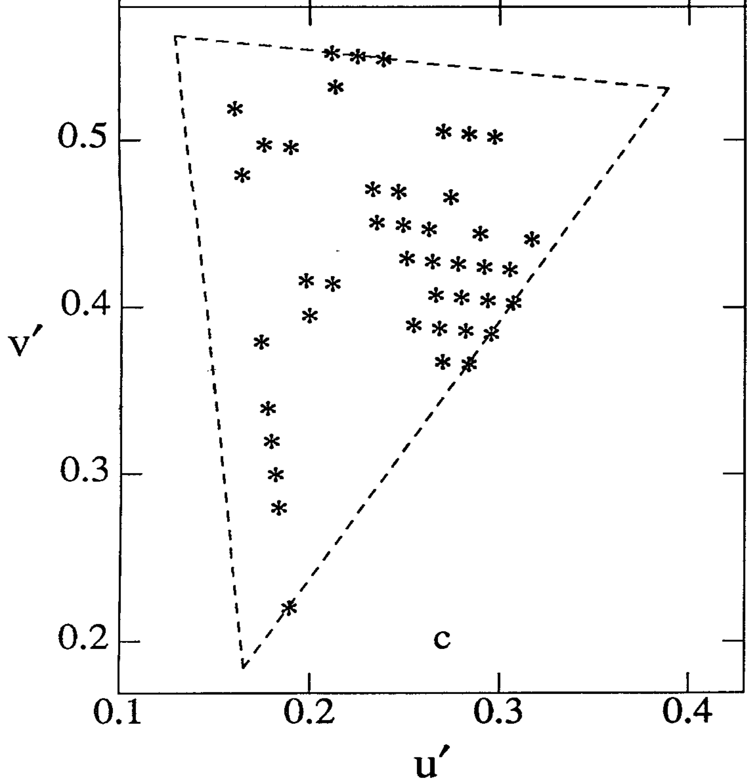


Figure 3 Chromaticities that (a) had the same modal response across all backgrounds and (b) were given the same label across all backgrounds by 75% or more of the subjects and (c) were given the same label by 75% or more of the subjects against one background and a different label by 75% or more of the subjects against a second background

room. On these trials, one of the ten colour names appeared in the centre of each square instead of circles. Following this practice period, 210 experimental trials were completed. On each experimental trial, subjects selected the six colour names they believed best described the appearance of the six stimuli, one against each background, that were presented. The subject labelled each circle in order from left to right and top to bottom by clicking a mouse on the appropriate name button. After a 2 s screen blank, in which a grey square the same colour as the response panel filled the screen to avoid afterimages, a different set of six test stimuli were presented against a different random order of the six backgrounds. Each participant labelled a total of 1260 stimuli.

RESULTS

Most of the analysis of the data was based on the modal responses for each chromaticity. The modal response is the response or label most frequently applied to a chromaticity. Since each subject labelled each chromaticity against each background once, the modal response is also the label used most consistently across subjects. *Figure 3a* shows those chromaticities that had the same modal response across all backgrounds. As can be seen, only five colour name labels were applied to specific chromaticities independent of background.

One problem with using a simple modal response is that it could reflect the response that as few as one-third of the subjects made to a particular chromaticity. Since we were concerned with finding those chromaticities that were consistently labelled, we next looked at those chromaticities for which 75% of the subjects used the same label. These chromaticities are shown in *Figure 3b*. Using a 75% criterion, only 17 chromaticities were given the same label consistently across all backgrounds. They fell into three regions – blue, purple and green.

Another method for assessing the effect of chromatic induction is to determine those chromaticities that were labelled consistently one way against one background and another against a different background. *Figure 3c* shows the chromaticities that were given one label by at least 75% of the subjects against one background and a different label by at least 75% of the subjects against a second background. As might be expected, these chromaticities are near the boundaries of colour regions. The highest degree of confusion was between the colour labels pink and purple. With a red surround, these chromaticities were labelled purple, whereas with a blue surround they were labelled pink.

Having determined which colours maintained their appearance across the backgrounds used in this study, the next step was to find out when and why the appearance of the remaining colours changed. *Figures 4* and *5* show the chromaticities to which at least 75% of the subjects applied the same label for each surround. The actual numbers are shown in *Table 1*. Even against the black background, only eight labels were applied consistently to different chromaticities. White was selected only seven times during the entire experiment. Red did appear as a modal response, but it was never associated with a particular chromaticity by as many as 75% of the subjects. The results for the grey background (*Figure 4b*) were similar to those for the black with the exception that the label grey was no longer used consistently.

Table 1 Number of chromaticities for which 75% of the subjects applied the same label for each colour label and background

Label	Background					
	Grey	Black	Red	Green	Blue	Yellow
Pink	32	33	0	21	12	29
Yellow	3	6	0	0	1	0
Orange	18	15	0	10	5	7
Red	0	0	0	0	0	0
Purple	34	32	45	51	11	44
Blue	24	22	29	16	7	22
Aqua	3	1	0	0	0	2
Green	21	15	25	3	11	16
Grey	0	5	5	5	9	4
Total	135	129	104	106	56	124

An examination of the chromatic backgrounds (*Figure 5*) indicated an effect similar to that found for the grey background. For each background, there was a decrease in the use of the label or labels associated with the hue of the background. As well, there was usually a concomitant increase in the use of the label associated with the colour complementary to the background. Thus, the number of chromaticities labelled green increased with the red

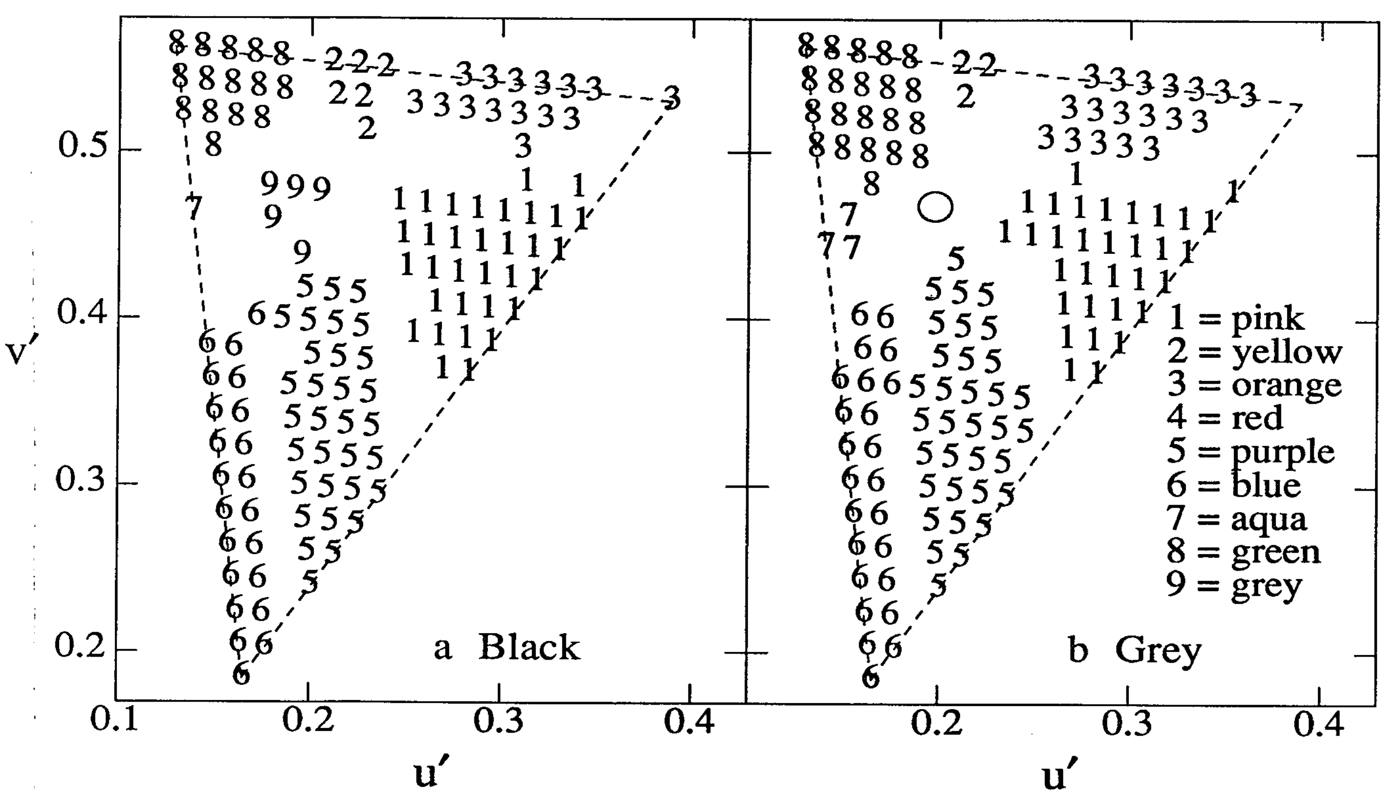


Figure 4 Chromaticities that were given the same label by 75% or more of the subjects for the (a) black and (b) grey backgrounds. The numbers show the labels applied consistently to those chromaticities

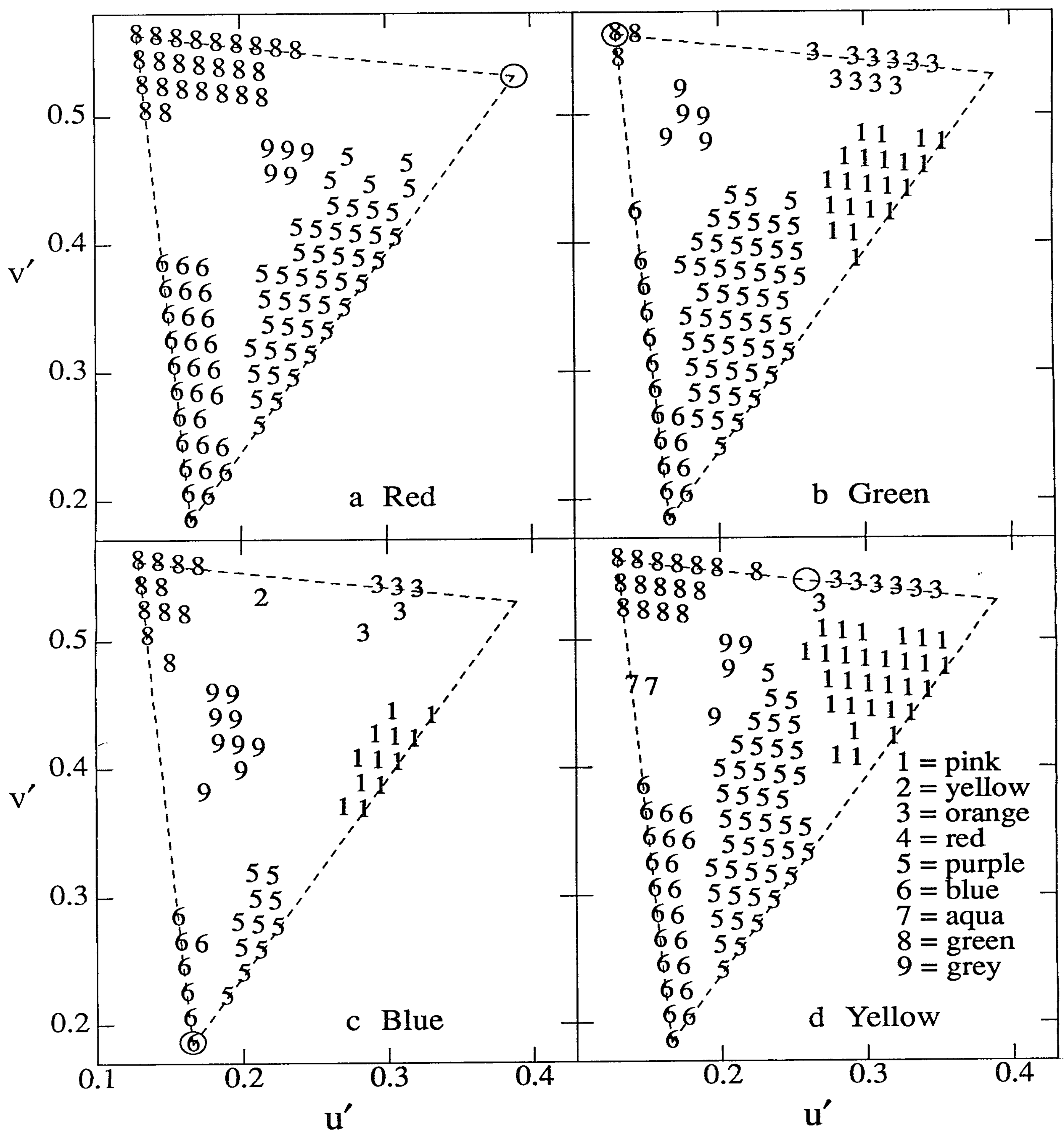


Figure 5 Chromaticities that were given the same label by 75% or more of the subjects for each of the chromatic backgrounds. The numbers show the labels applied consistently to those chromaticities

surround, and the region for pink and orange disappeared. On a green surround, fewer chromaticities were selected as green and blue, whereas pink, and orange were well represented. Similar effects were found with the blue and yellow backgrounds.

A Pearson χ^2 test of association was carried out using the data in *Table 1*. It supported the observation of differences in the pattern of responses across the six backgrounds and differences in the frequency with which each label was applied consistently against each background ($\chi^2 = 129$, $p < 0.01$ for 35 degrees of freedom). For this test, the expected value for each cell is the product of the column frequency and the row frequency divided by the overall N (654). The largest deviations from the expected frequencies were found for the label/background combinations in which the label corresponded to the hue of the background. Across all the backgrounds, the largest deviations were found with the red background on average.

A χ^2 test was also carried out for each label separately. If the backgrounds had no effect then one would expect the same number of chromaticities to be labelled with each colour name against each background. The data were normalized to correct for the differences in the absolute number of chromaticities labelled consistently against each background. Variation in the frequency with which each label was used across the different backgrounds was significant for the pink, $\chi^2 = 24.0$, yellow, $\chi^2 = 10.8$, orange, $\chi^2 = 13.0$, purple, $\chi^2 = 19.1$, green, $\chi^2 = 17.9$, and grey, $\chi^2 = 27.2$, labels ($p < 0.01$ for 5 degrees of freedom in each case). These results support the observation that the frequency with which each label was used varied across the backgrounds.

The chromatic backgrounds differed also in terms of the number of chromaticities labelled consistently and the number of colour names used overall (*Table 1*). The blue background had the smallest number of chromaticities labelled consistently. The red and green backgrounds were next, with the largest number of consistently labelled chromaticities occurring with the yellow, grey and black backgrounds. Again a χ^2 test supported the differences in number of chromaticities labelled consistently ($\chi^2 = 38.02$, $p < 0.01$ for 5 degrees of freedom). In terms of the number of different labels applied consistently, the red background was poorest with only four as compared to six or seven labels for the remaining backgrounds (*Figures 4* and *5*).

To compare our data with existing data on chromatic induction, we examined the shifts in the average chromaticity associated with each colour name between the control backgrounds and each of the chromatic backgrounds. For each background, the chromaticities having the same modal response were averaged. The average u',v' value for each label was determined by averaging separately the u' and v' values for each chromaticity to which 50% or more of the subjects applied that label. The 50% point was used so that we could measure shifts in the use of as many labels as possible. The u' and v' values were weighted by the percentage of subjects applying the modal label to that chromaticity.

An initial comparison of the black and grey backgrounds indicated that the average chromaticity associated with each label was similar for the two control backgrounds (see *Table 2*). Thus, the changes in appearance are shown relative to the black control background only (*Figure 6*). The arrows show the shift in the location of the average u',v' coordinates for the modal responses for each label. The origin of the arrows indicates the average u',v' for the black background, whereas the points of the arrows show the average u', v' with the specified chromatic background.

The pattern of the shifts in appearance was similar for all four chromatic backgrounds although the actual directions and extent of the shifts varied. For each label used in each of the chromatic backgrounds, the difference between the average u',v' for that label and the average u',v' for the same label against the black background was determined (i.e. the length of the vectors in *Figure 6*). These differences are shown in *Table 2*. An analysis of variance of these means showed that the difference in the size of the shifts across the backgrounds was significant ($F(4,30) = 4.65$, $p < 0.01$). The results of a Duncan Multiple Range Test indicated that this difference was due primarily to the red background. Within each background, the size of the shifts tended to be larger for those labels that were similar to the hue of the background.

The directions of the shifts in *Figure 6* tend to be towards the background. This seems to be contrary to the statement that the effect of chromatic induction is to shift the appearance of the test stimulus away from the background hue. In fact that is what happened. It appears reversed because what is shown is the shift in the chromaticities associated with a given colour name rather than the shift in the appearance of specific chromaticities. For example, in *Figure 6a*, the chromaticities labelled pink against a black background are centred around the bottom of the arrow labelled 1. Against a red background those chromaticities no longer appear pink. As shown in *Figure 5a*, they are labelled purple indicating that their appearance has shifted away from red. The colours labelled pink are those that were labelled orange or red against a black background.

Table 2 Vector length between the average u',v' value for each label against the black background and the corresponding average u',v' value against each of the other backgrounds

Label	Background				
	Grey	Red	Green	Blue	Yellow
Pink	0.006	0.087	0.019	0.028	0.030
Yellow	0.004	0.074	0.013	0.002	0.032
Orange	0.005	0.016	0.010	0.009	0.010
Purple	0.013	0.066	0.019	0.038	0.030
Blue	0.002	0.006	0.006	0.046	0.002
Green	0.006	0.018	0.024	0.015	0.011
Grey	0.006	0.046	0.027	0.050	0.014
Average	0.006	0.045	0.017	0.027	0.019

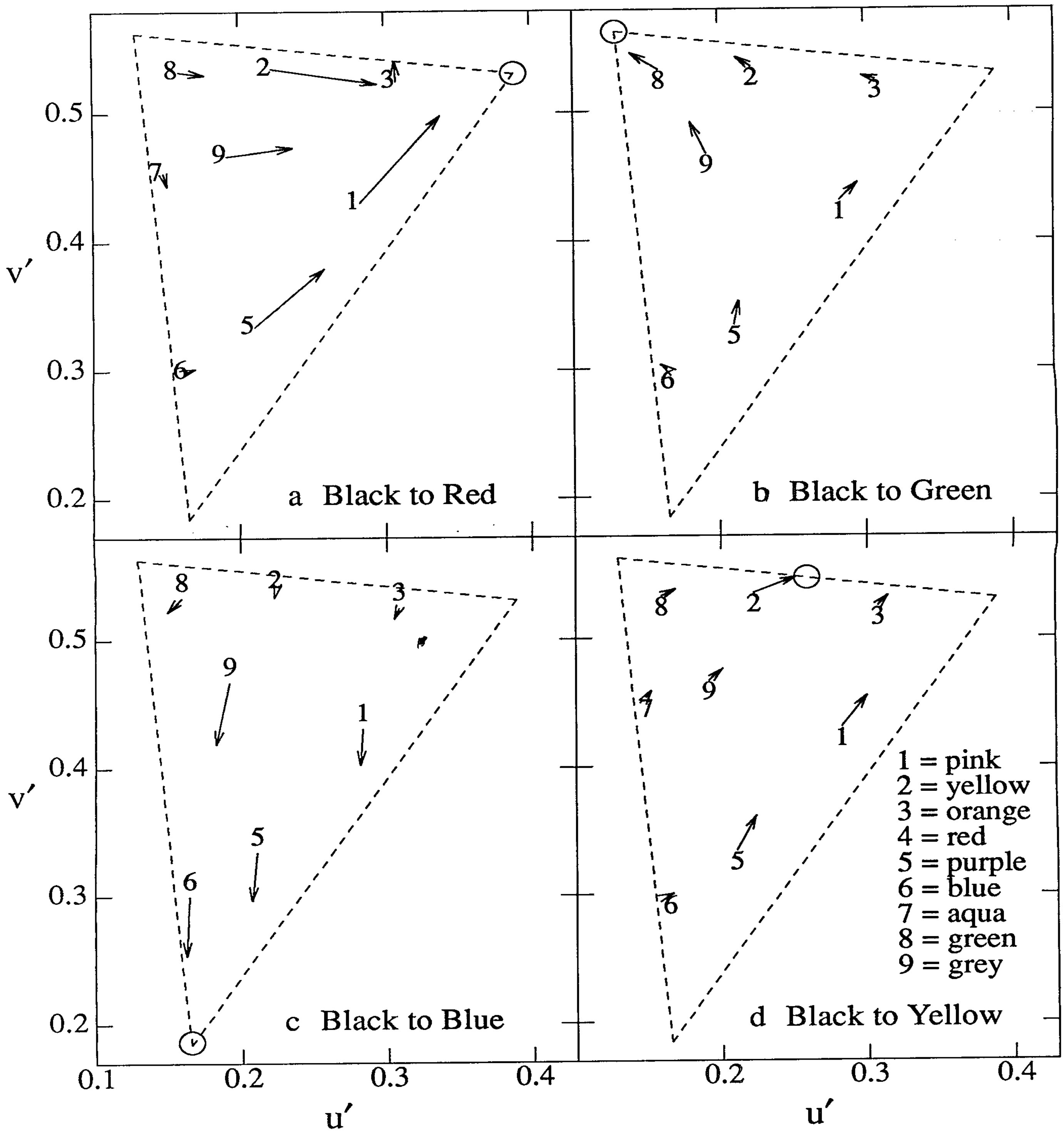


Figure 6 The average u',v' coordinates for modal responses above 50% for each colour name on the chromatic backgrounds as compared to the average u',v' coordinates against a black background

DISCUSSION

Effect of chromatic induction

Overall, the results indicated that chromatic induction could be a problem on a CRT-based complex display. Despite using a colour-naming task with a display that showed several background and foreground chromaticities simultaneously, there were clear shifts in the appearance of some of the test stimuli as a function of background. In some cases, a chromaticity was given one label consistently against one background and a second label against another. Moreover, the chromaticities whose appearance changed varied from background to background. Thus, several chromaticities that were labelled pink against the yellow, green and neutral backgrounds were labelled purple against the red background.

On the other hand, the results were not consistent with previous studies that used a colour-matching task and a simpler stimulus configuration. The average modal response for each label did not shift substantially between a grey and black surround. This differs from a study by Ware and Cowan[1] that looked at the effect of five different backgrounds on the appearance of chromaticities in various parts of the chromaticity diagram. They found noticeable differences in the appearance of a chromaticity against a grey and a black background. One possible reason for this difference may be that the shifts in appearance in going from black to grey are ones of saturation rather than hue. The set of labels used in this study would not necessarily reflect differences in saturation.

A second difference was a lack of strong chromatic induction effects when the test and background chromaticities were widely separated in the chromaticity diagram. In the study by Ware and Cowan[1], the extent of the shifts in appearance was similar for all test chromaticities against a given background. As in the previous discussion, the shifts in appearance for chromaticities remote from the background chromaticity may have been due to changes in saturation to which this colour-naming task was not sensitive. In addition, the limited range of chromaticities available on the CRT may have affected the results by artificially limiting the size of the set of chromaticities to which a label was applied for certain backgrounds. This would have affected the selection of the average modal response and, in turn, the size of the shifts shown in *Figure 6*.

Another possibility is that the shifts in appearance from chromatic induction were counteracted by the spread of physical light from the surround into the test area. Shevell and Wesner[4] found that the appearance of small stimuli can be affected by the spread of physical light from factors such as diffraction, imperfections in the eye and scattered light. The effect is a shift in appearance towards that of the surround rather than a shift towards the complementary colour of the surround. However, it is difficult to see how the combined effects of induction and spread of physical light would predict the pattern of results in *Figure 6*.

The shifts in appearance may also have been modified because of the stimulus configuration used in this study. The presence of multiple backgrounds may have provided the subjects with anchors which biased their responses. The multiple backgrounds could also have produced some chromatic adaptation effects as the gaze of the subject moved from background to background throughout the trial. Since the backgrounds were randomly ordered from trial to trial and a unique order was used for each subject, it is unlikely that systematic chromatic adaptation effects occurred. However, the overall effect might have been a reduction in chromatic induction. One would expect similar effects with a display in an application employing similar chromaticities. Thus, the effects are probably consistent with those that might occur in complex scenes.

Other factors affecting colour naming

The small number of chromaticities that were consistently associated with each of the labels cannot be attributed entirely to chromatic induction. Even against the black background only eight names were associated consistently with specific chromaticities. The labels red and white were not used. The failure to use the label red is usually attributed to the orange appearance of the red phosphor on CRTs as found in previous colour naming studies carried out in this[11] and other[10] laboratories. An examination of the names associated with the chromaticities in the red part of the chromaticity diagram indicates almost equal use of the names red and orange. For CRT colour-coding applications, it appears that many people are reluctant to label chromaticities as red unless they are predefined as such. Designers of colour displays should be aware of this limitation since red is often used to code important information. If an orange or pink is also used with red, and absolute identification is required, confusion may result.

The limited use of the label white was probably due to the use of equal luminance stimuli and a relatively low luminance. Low luminance may also have contributed to the small number of stimuli labelled yellow. The labels white and yellow tend to be associated with relatively high luminances. On the other hand, the label pink was applied to a large number of chromaticities and pink is also associated with relatively high luminance stimuli. In addition, yellow was a modal response in a study by Post and Greene[13] that used chromaticities at 10 cd/m^2 and that allowed an unrestricted vocabulary of colour names. Thus, the limited use of the label yellow may be as much a reflection of the limited gamut available on the CRT as the luminance. Certainly any 10 cd/m^2 chromaticity labelled yellow should be labelled similarly at a higher luminance.

The small number of distinct colour areas could also have resulted from limiting the response set to ten names. However, it is unlikely that using a larger set of colour names would have increased the number of differentially labelled areas. Post and Greene[10], who used the same set of labels, reported that those labels accounted for 88% of

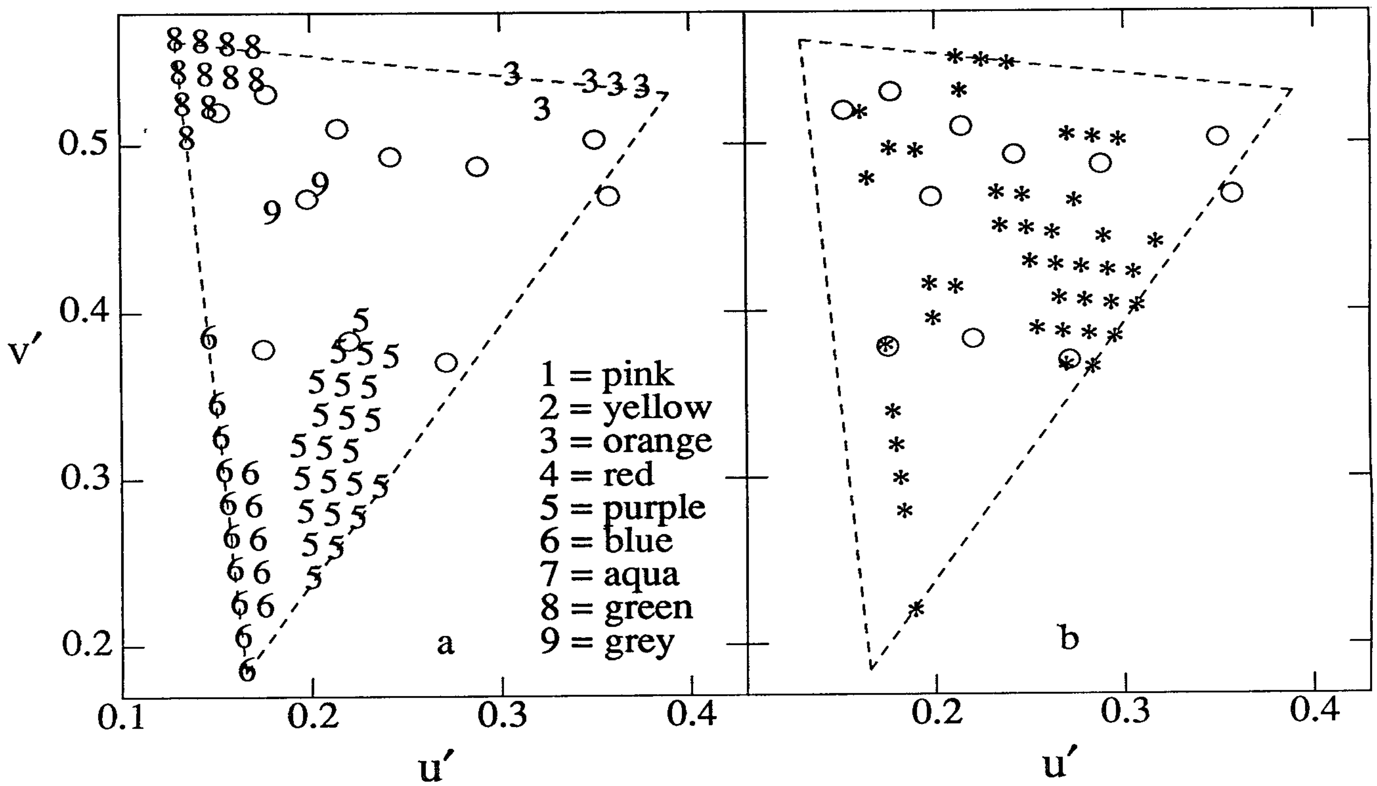


Figure 7 (a) Chromaticities recommended by McFadden[20] shown as circles compared with consistent colour name areas. (b) The same chromaticities compared with inconsistent areas of colour naming

the responses in their earlier study with an unrestricted vocabulary[13].

Selecting chromaticities for complex displays

In this study, only five colour names were used consistently in labelling chromaticities across all backgrounds. This is obviously an inadequate number for many colour coding applications. Thus it would appear to be impossible to use the current data by themselves to specify a large colour set. However, based on the results, we can suggest guidelines for selecting chromaticities for complex displays. The largest shifts in appearance and the largest deviations in the response patterns occurred with the red and blue backgrounds. Thus, it is probably advisable to avoid these types of chromaticities especially when the displays are being used in low ambient illumination. Within each background, the largest shifts in appearance occurred when the test stimuli were presented against a background similar in hue but higher in excitation purity. Such a combination can be avoided by ensuring that the background stimuli are lower in purity (subjectively lower in saturation) than foreground colours. For applications where it is not possible to discriminate between background and foreground colours, chromaticities should vary in hue rather than in purity. In addition, it is probably best to avoid the chromaticities identified in *Figure 3c*.

Our study also suggests limitations in previous guidelines that recommend using an algorithmic approach to select colours that are maximally discriminable in the CRT colour gamut[19]. Although this may ensure maximum discrimination between colours, it does not ensure consistent colour appearance across different coloured backgrounds. Empirically derived colours based on maximum distances on the u',v' 1976 UCS chromaticity diagram are usually chromaticities along the edge of the CRT gamut. Some of these chromaticities would be similar to the backgrounds used in this study. If those colours were used as backgrounds, especially the red and blue, they could alter the appearance of other chromaticities. Other chromaticities, especially those in the region between purple and red, would be colours whose appearance changed drastically from background to background in our study.

The current results could be used with previous findings on colour discrimination to specify larger colour sets. McFadden[20] looked at the effect of chromatic induction on colour discrimination with the aim of identifying chromaticities that were likely to be discriminable on a complex display even when they were juxtaposed. Based on those results, a set of 11 chromaticities were identified. *Figure 7* compares the location of these stimuli with the results shown in *Figure 3b* and *c*. As might be expected, many of the chromaticities do not fall into areas associated consistently with a given colour name. However, this is to be expected since 11 unique colour names were not available in the current study. The critical factor is whether the chromaticities fall in areas where the label applied to a stimulus is likely to change. On this basis, the set scores well, with only two chromaticities falling directly within a space that is easily confused. A small modification in these two chromaticities towards the purple and the blue would improve on the original set.

Limitations of the study

One limitation of the current study was the use of equal luminance chromaticities. As discussed earlier, this decision may have affected the use of the label yellow and even orange. It would seem useful to examine the effect of equating the stimuli in brightness on colour naming of stimuli presented against different backgrounds. Given the low luminance of the blue gun this would best be accomplished by matching the brightness of the other colours to the brightness of the blue gun either empirically[21] or algorithmically[10]. Alternatively, one might carry out the study with two or three sets of chromaticities each at a specified luminance level, including in each set only those chromaticities that could be reproduced at the specified luminance. The best examples of each label could then be used in a further study to examine the combined effects of chromatic and luminance induction.

The fact that it was only possible to achieve a luminance of 5.6 cd/m^2 with the blue gun may have affected our results as well. A study by Takahashi and Ejima[22] found that chromatic induction increased as the ratio of surround luminance to stimulus luminance increased, reaching a maximum when the ratio was unity and then levelling off. Based on this finding, one would expect the blue surround to have produced greater shifts in colour appearance if its luminance had been equal to that of the other surrounds. Those stimuli with lower luminances than their surrounds probably appeared less bright than they would have done if the surround and stimulus were equal in luminance. Based on the work of Boynton and Olson[23], this probably had little effect on colour naming. They found that the label blue was used over a wide range of lightnesses.

Another possible limitation of the current study was the large stimulus set. While this allowed us to determine more precisely which areas of the CRT gamut were reliably labelled, it may have affected the subjects' ability to maintain a consistent definition of what they meant by the various labels. This would apply especially to the labels that could not be associated with one of the background colours. More consistent labelling might occur if one used a more limited stimulus set or gave the subjects more experience with the stimulus set. Another possible way of improving response consistency would be to change the task into a matching task by providing reference colours. This mimics many colour-coding applications where sample colours are provided in a coding legend. It is hypothesized that these refinements would increase the consistency with which subjects labelled the chromaticities, but would not change the modal responses of most of the chromaticities.

CONCLUSIONS

A colour-naming task was used to determine the consistency with which specific chromaticities are labelled across a set of chromatic and achromatic backgrounds. Out of the large set of test chromaticities presented, only a few were labelled reliably. Only five of the ten colour names available were associated with specific chromaticities consistently across all backgrounds. The limited number of colour names used was attributed to chromatic induction and to other factors specific to the experimental paradigm, such as the use of equal luminance stimuli and limitations in the CRT gamut of colours.

Chromatic induction caused significant shifts in the frequency of use of specific labels across the different backgrounds and in the choice of labels for specific chromaticities. To prevent these shifts, it was recommended that stimuli on complex displays should differ in hue rather than purity and that high-purity chromaticities and those falling on colour-naming boundaries be avoided. Further research is planned to investigate the effect of chromatic induction with a higher luminance stimulus set and with a stimulus set that varies in both chromaticity and luminance.

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