What is Controlling Chromatic Contrast in a Complex Scene?

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Abstract

This study deals with the regulation of colour simultaneous contrast. We have proceeded to the measurement of the regulation effect of a scene in a situation where a strong induction generated by a large peripheral field is counterbalanced by a complex colour surround in the neighbouring. Results show that every neighbouring scene considerably reduces the chromatic contrast induced by the large peripheral colour field. Although every neighbouring scene has the same average chromatic content, the resulting colour appearance of the target seems to differ between scenes, and this may be ascribed to the spatio-chromatic organisation of the scene.

Introduction

Chromatic induction is an omnipresent phenomenon in customary environments. Practically, a strong effect of contrast is observed when the target is embedded in a larger chromatic surround.

A well-accepted definition of chromatic induction is that the chromaticity of adjacent patches affects the colour appearance of a test patch.[1] For chromatic contrast, a more accurate statement proposed by Miyahara, Smith and Pokorny[2] is that a chromatic surround of a given hue removes the shade of hue of the target.

Explanations for chromatic contrast are many. Most authors propose models that comprise at least two processes: a multiplicative receptoral sensitivity change followed by a subtractive chromatic opponent action. Recent studies focus on complex scenes. They investigate the influence of chromatic variability[6] and the influence of scene articulation[7] on colour appearance. Shevell and Wei[3] have demonstrated the importance of variation within the surrounding field, in supplement to the effect of chromaticity. McCann[4] has identified situations where increasing the complexity of the surround can shut off an achromatic contrast. The statement from Miyahara, Smith and Pokorny[2], as well as the fact that not only colour appearance is subject to contrast but contrast itself is subject to contrast[5], are consistent with a third post-receptoral cortical process. In consequence the appearance of a patch of colour is usually not easily derived from its colour specification because it is strongly dependent upon the context.

The question arises how colour appearance can change so easily depending upon the context and object identification remains so stable in the real world. Our study deals with the regulation of colour simultaneous contrast. We hypothesise that it is the spatio-chromatic content of the surrounding scene that is effective on inducing contrast rather than the chromatic content only.

Methods

We have proceeded to the measurement of the regulation effect of a scene in a situation where a strong induction on a target generated by a large peripheral coloured field is counterbalanced, or opposed, by a complex colour surround in the neighbouring of the target (Fig. 1).

In such an equilibrium situation, we expect a higher induction sensitivity of the visual system to chromatic induction than when its state of adaptation is merely shifted by the inducing field alone and we hope that small variations of the induction effect could be recorded.

*Figure 1. Spatial configuration of stimuli and set up. The large uniform peripheral inducing field (55°H*53°V) consists of a white diffusing panel illuminated by a retro projector equipped with a colour filter. Light is blocked at the centre of the field. Four square targets (1,8°H*1,8°V) are imbedded in a surrounding image (18°H*14°V) which is displayed on a calibrated CRT monitor. Original set up is in colour.*

All stimuli are specified in terms of cone excitation signals (L-cone, M-cone and S-cone signals) in order to obtain a clear definition of the visual input.

In the experimental set-up:

- The peripheral inducing field (55°H*53°V) is uniform and highly colourful, either green ([lms] =

[0,60 0,40 0,02]) or red ([lms] = [0,75 0,25 0,00]), or neutral ([lms] = [0,66 0,34 0,01]).

- Several neighbouring surrounds (18°H*14°V) differing in terms of spatial contrast but identical in terms of average chromaticity and luminance have been prepared (Fig. 2) and imbedded in the peripheral inducing field.
  A. "Natural": The image of a natural scene.
  B. "Beach": All pixels of "Natural" scene are reorganised along the vertical axis depending upon the S-cone signal, and along the horizontal axis depending upon the L-cone signal.
  C. "Pixelised": All pixels of "Natural" scene are randomly distributed.
  D. "Black": The case with no surround (the display is black) serves as the reference.

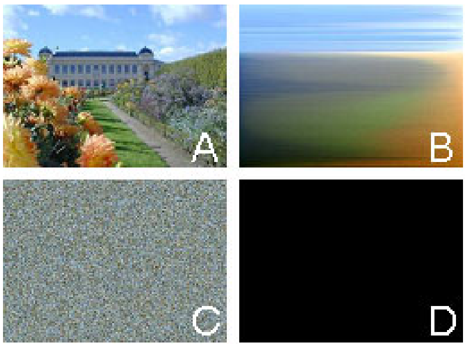

Figure 2. Images of the four surrounding scenes shown in the experiment. A: "Natural"; B: "Beach"; C: "Pixelised"; D: "Black". Original set up is in colour.

- The targets consist of 4 coloured squares (1,8°H*1,8°V), the colour of which varies along the *l*- chromatic axis of the MacLeod-Boynton diagram[8] which represents in an equiluminant plane the signal in a channel comparing L- and M- cone signals. Chromaticity co-ordinate *s* and luminance are respectively equal to the average *s*-value and to the average luminance of the natural image. A narrow 10' black line fringes each square in order to minimise local contrast that would severely disturb the observer.

The luminance of the peripheral field is 30 cd.m^{-2}. The luminance of targets is equal to the average luminance of the surrounding image about 13 cd.m^{-2}.

The intensity of chromatic induction is measured using a modified hue cancellation technique. The observer assesses the least chromatic target among the 4 squares. An adaptive procedure allows to approach each individual observer's preferred choice. It is immediately followed by a constant stimuli procedure, where the four concurring squares close to the final choice are presented and repeated 4 times along a constant stimuli procedure. Only data collected with the constant stimuli procedure enter the computation of the final result.

A session is made of one trial run followed by 4 runs corresponding to every neighbouring surround. The observer performs 6 sessions with every adaptation field.

In order to avoid any temporal bias, the sequence of runs during all sessions conforms to a Latin square organisation, with the first run serving as probationary, having all the properties of the subsequent trials, and being repeated at the end of the sequence for results.

5 observers have participated in the experiment. All had normal colour vision as assessed with Ishihara plates, Panel D-15, desaturated DD15 from Lanthony and the Nagel anomaloscope. Finally each observer has made 24 trials for every neighbouring scene and peripheral field combination.

Results

The method has proved to be effective to quantify chromatic induction. The observer can easily identify the square that appears the least chromatic. The observer's choice can be transformed in order to build a psychometric curve and to assess a figure to the mean and to the variance of his response.

Let us first consider results collected with each peripheral inducing field. With the neutral inducing field the achromatic point is close to *l* = 0.64 for all neighbouring scenes. Also, all observers have chosen as apparently achromatic a target with a much higher *l* value (more reddish) with the red inducing field and with a much lower *l* value (more greenish) with the green inducing field (Fig. 3). This is expected from a contrast phenomenon.

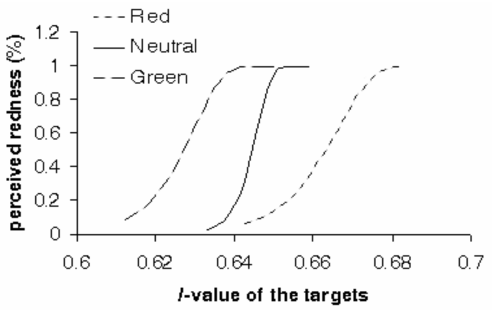

Figure 3. Perceived redness versus l-*values of the target when it is presented in red, neutral or green periphery with black surround. The distribution of the responses of 5 observers is adjusted with a Weibull function.*

We note that the setting obtained with the "Black" surround (no surrounding scene) in the two colour adaptation states is further away from the setting obtained in the neutral adaptation state than with any surrounding image (Fig. 4). This shows that in such a configuration the presence of an image between the large peripheral field and the test is effective to reduce chromatic induction from the periphery.

Considering that the average Δ*l*-value corresponding to the difference between achromatic assessments with the colourful and the neutral adaptation field indicates the amount of induction undergone by the target, we have tested whether every scene has yielded a different amount of induction. We have treated the red peripheral inducing field and the green one separately, and we have pooled the results of all observers together. Then we have ranked the induction regulation obtained with each scene and tested whether one was different from the next using a ε statistics (Table 1) with

$$\varepsilon = (m_A - m_B) / ((s^2_A / n_A) + (s^2_B / n_B))^{1/2}$$

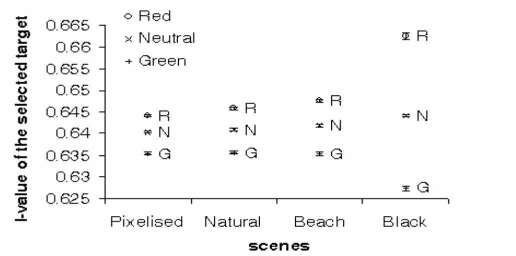

Figure 4. Average l-*value and standard error corresponding to the achromatic assessments made by 5 observers when the target is presented in various periphery and surrounding configurations.*

Table 1. Indication of significant differences of induction with the surrounding scenes. ε: statistic variable; p: risk factor.

Comparison of the averages of the Δ*l*-values	Green peripheral inducing field		Red peripheral inducing field	
	ε	p	ε	p
Pixelised-Natural	0.746	0.228	**5.139**	**0.000**
Natural-Beach	**3.652**	**0.000**	**2.490**	**0.006**
Beach-Black	**23.982**	**0.000**	**29.899**	**0.000**

With the green peripheral surround, ranking the average Δ*l*-value along the *l*-axis yields

Pixelised = Natural < Beach < Black

and with the red peripheral surround, ranking the average Δ*l*-value along the inverse of *l*-axis yields

Pixelised < Natural < Beach < Black

Where the "<" symbol indicates significant differences at the risk factor p=0,05 and means "results in less induction than" i.e. "regulates more than".

Considering that the variance of the *l*-value corresponding to the achromatic assessment indicates the amount of dispersion of the judgements given by the observers, we have tested whether every scene has yielded a different dispersion in the amount of induction. Again, we have treated the red peripheral inducing field and the green one separately, and we have pooled the results of all observers together. Then we have ranked the variance obtained with each scene and tested whether one was different from the next using a *F* statistics (Table 2) with

$$F = s^2_A / s^2_B$$

Table 2. Indication of significant differences of variance of induction. F: statistic variable; p: risk factor.

Comparison of the variances of the *l*-value	Green peripheral inducing field		Red peripheral inducing field	
	F	p	*F*	p
Pixelised-Natural	**0.779**	**0.027**	0.914	0.244
Natural-Beach	**0.659**	**0.001**	**0.468**	**0.000**
Beach-Black	0.835	0.081	**0.661**	**0.001**

With the green peripheral surround, ranking the variance of the *l*-value yields

Pixelised < Natural < Beach = Black

and with the red peripheral surround, it yields

Pixelised = Natural < Beach < Black

We note that the ranking is the same with the green and the red peripheral fields. The "Black" surround in a peripheral colourful field is always ranked further away from the neutral condition than any surround.

Discussion

Our results have shown that every neighbouring scene considerably reduces the chromatic contrast induced by the large peripheral colour field. Moreover not all scenes have yielded identical reduction of chromatic induction. The "Pixelised" image is the most effective one in controlling chromatic induction. Then come the "Natural" image and the "Beach". More precisely, the image "Beach" is ranked, for averages as for variance, as significantly less regulating than the other two.

The three images created with the same original pixels differ through their spatial distribution.

- Image "Natural" comprises all achromatic and chromatic spatial frequencies with a major representation of low frequencies.
- Image "Beach", in which pixels have been monotonically organised along the S-axis in the vertical direction, and along the L-axis in every horizontal line comprises only the lowest chromatic spatial frequency in the horizontal direction. The frequency distribution in the vertical direction is only slightly modified compared to the natural image.
- Image "Pixelised" in which pixels have been randomised yields a random FFT. High as well as middle and low spatial frequencies are presented.

The question arises whether a neighbouring surround with high spatial frequencies in the L and M direction, which is precisely the direction of chromatic induction under test, could be responsible for acting as a barrier against chromatic induction from the periphery.

A "spatial tuning" has been demonstrated by Singer and D'Zmura[9] and by Werner[10]. Their experiments show that when the targets and the surrounds are in register, chromatic contrast is tuned for spatial frequency. Although the purpose of our experiment differs from theirs in the sense that we test for the regulation rather than for the generation of chromatic induction and that our scenes have not been constructed to address directly the tuning for spatial frequency, our results seem to be in contradiction with theirs.

If there was a spatial tuning, we would expect the scene "Beach" which is rich in low spatial frequency to be more efficient than the scene "Pixelised" which is rich in high spatial frequency for regulating chromatic induction on a uniform test which is rich in low spatial frequencies. Why is the pixelised scene the most efficient? One possibility is that the chromatic high spatial frequencies that are present in the pixelised scene are too high to be visible according to the cut-off frequency of the chromatic mechanisms[11]. This is strengthened by the fact that the observers have reported that the pixelised scene looked uniform in colour although textured in luminance. If so, this would be in favour of regulation for induction located at a cortical site.

Besides, we note that in our configuration, the "Natural" image is not the most efficient to regulate chromatic induction. This excludes the prevalence of some cognitive cue as control of colour appearance. This might be due to the fact that the target we used was deprived of cognitive cue, or, possibly, that bottom-up processes could be sufficient to explain chromatic induction in a complex scene.

Finally, our results have also shown that when a peripheral highly saturated colour field induces colour contrast onto a central target, the colour variegated neighbouring surround regulates the contrast effect not only by opposing it but also by reducing the variance of the visual responses. Indeed, we may expect that a better balance of the sensitivity improve the accuracy of the response.

Conclusion

In an experiment where complex scenes have been shown to considerably reduce a strong induction generated by a large peripheral field, not all scenes yield identical reduction of chromatic induction.

Although every neighbouring scene has the same average chromatic content, the resulting colour appearance of the target seems to differ between scenes, and this may be ascribed to the spatio-chromatic organisation of the scene.

The ultimate control of chromatic induction would be located at a cortical site where many visual signals are integrated.

References

1. Chevreul M-E., *The principles of harmony and contrast of colors*. Translated from the French. Introduction and Notes by Faber Birren, New York: Van Nostrand Reinhold Company; 1981, 224 p. (1839).
2. Miyahara, E., Smith, V. C., Pokorny, J., The consequences of opponent rectification : the effect of surround size and luminance on color appearance, *Vision Research, 41,* 859-871. (2001).
3. Shevell, S. K., & Wei, J., Chromatic induction: border contrast or adaptation to surrounding light ? *Vision Research, 38,* 1561-1566. (1998).
4. McCann J. J., Image processing analysis of traditional Gestalt vision experiments, *Proc. of SPIE, 4421,* 375-378. (2002).
5. D'Zmura, M. & Singer, B., Contrast gain control, in K. R. Gegenfurtner & L. T. Sharpe (Eds.), *Color Vision, from genes to perception* (pp. 369-385), Cambridge : Cambridge University Press. (1999).
6. Brenner, E., Ruiz, J. S., Herráiz, E. M., Cornelissen, F. W., Smeets, J. B. J., Chromatic induction and the layout of colours within a complex scene, *Vision Research, 43,* 1413-1421. (2003).
7. Linnell, K. J., & Foster, D. H., Scene articulation: dependence of illuminant estimates on number of surfaces, *Perception, 31,* 151-159. (2002).
8. MacLeod, D. I. A., & Boynton, R. M., Chromaticity diagram showing cone excitation by stimuli of equal luminance, *J. Opt. Soc. Am., 69,* 1183, 1186. (1979).
9. Singer, B., & D'Zmura, M., Color contrast induction, *Vision Research, 34,* 3111-3126. (1994).
10. Werner, A., The spatial tuning of chromatic adaptation, *Vision Research, 43,* 1611-1623. (2003).
11. Mullen, K. T., The contrast sensitivity of human colour vision to red-green and blue-yellow chromatic gratings, *J. Physiol., 359,* 381-400. (1985).

Biographies

Margalith Harrar is an optometrist and has received her Master Degree in Cognitive Psychology at Université René Descartes - Paris 5. Her previous work deals with the chromatic dimension of glare. harrar@mnhn.fr.

Françoise Viénot is a physicist. She is conducting research and supervising graduate and postgraduate studies at Museum National d'Histoire Naturelle in colorimetry, photometry and color vision and visual metrics. She is teaching color vision and colorimetry at the University Paris XI. She is President of the Centre National Français de l'Eclairage and serves as Associated Director for Vision for Division 1 of the CIE, and on the editorial board of *Color Research and Application.*