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AD-A268 435

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No 0704-0188

DTIC ELECTE AUG 18 1993 S C D

1a. REPORT SECURITY CLASSIFICATION	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S) AFOSR-TR- 93 0617
6a. NAME OF PERFORMING ORGANIZATION Eye Rsch Inst & Retina Fnd; 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION AFOSR/NL
6c. ADDRESS (City, State, and ZIP Code) 20 Staniford Street Boston, MA 02114	7b. ADDRESS (City, State, and ZIP Code) Building 410 Bolling AFB, DC 20332
8a. NAME OF FUNDING/SPONSORING ORGANIZATION AFOSR; 8b. OFFICE SYMBOL (If applicable) NL	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER AFOSR-89-0377
8c. ADDRESS (City, State, and ZIP Code) Building 410 Bolling AFB, DC 20332	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
61102F	2313	A5	

11. TITLE (Include Security Classification)

Perception of Lightness and Brightness in Complex Patterns

12. PERSONAL AUTHOR(S)

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13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
~~ANNUAL~~ FINAL	FROM 01 May ~~91~~ 89 TO 30 Apr 93	93 Jun 30	23

16. SUPPLEMENTARY NOTATION

93 8 17 020

93-19125

2490

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Perception of surface color plays an important part in many everyday visual tasks. Psychophysical and neurophysiological data on early visual processes suggest a number of potential sensory limitations on the accuracy of surface-color perception. A new paradigm has been used to clarify the relationships between early visual processes and perception of achromatic surface colors (shades of gray). Psychophysical measurements of perceived surface color were made using achromatic stimulus patterns that were complex enough to support unambiguous perception of surfaces and lights. Lightness (apparent reflectance), brightness (apparent luminance) and local brightness contrasts were all measured using the same stimulus patterns. According to a number of models, lightness is closely related to local brightness contrast, but the data indicated that the relationship is more complicated than previously supposed. The brightness contrast data are well described by Stiles' threshold-vs-radiance curve, which is widely thought to be a characteristic of retinal adaptation processes. Both brightness and lightness are slightly higher on dark gray backgrounds than on white backgrounds. This perceptual error appear to be independent of illumination level.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION
22a. NAME OF RESPONSIBLE INDIVIDUAL Dr John F Tangney	22b. TELEPHONE (Include Area Code) (202) 767-5021; 22c. OFFICE SYMBOL NL

DD Form 1473, JUN 86 Previous editions are obsolete. SECURITY CLASSIFICATION OF THIS PAGE

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13 JUL 1993

FINAL TECHNICAL REPORT
5/1/91-4/30/93

GRANT AFOSR 89-0377

Lawrence E. Arend
Principal Investigator

I. OBJECTIVES

II. STATUS OF RESEARCH EFFORT

A. Experiments

1. Light., Bright., App. Contrast All of our early constancy experiments utilized displays in which the standard and test patches are surrounded by the same reflectances. While this was a necessary control in those designs, it had the disadvantage that local luminance contrast covaried with reflectance. When the test patch was set to the same reflectance as the standard patch, the local luminance ratios with surrounding patches were also identical. Some theorists (e.g., Shapley, Wallach) have argued that the excellent lightness constancy we have found is attributable to local contrast matching. While there are fairly convincing logical objections to their argument, it became clear that it was necessary to disentangle lightness and local contrast experimentally.

In the previous grant period we conducted experiments in which the test and standard patches were placed on surrounds of differing reflectance. Preliminary results were reported in a poster at ARVO in 1990. In this grant period the experiments were completed, two manuscripts were submitted to Perception and Psychophysics and are now in press.

The main conclusions are quite simple. Wallach's and Shapley's models are wrong. Lightnesses are not given by local contrast. Some form of edge integration is logically required to obtain lightness constancy, and the human visual system seems to do it. Disk-and-annulus patterns do not provide sufficient information for lightness constancy. Subjects trying to match lightnesses in disk/annulus patterns instead match local brightness contrasts, demonstrated by the magnitudes and form of our data in experiments with and without Mondrian regions.

2. Mesopic lightness, brightness, and brightness-contrast. A secondary result of the lightness/brightness/brightness-contrast experiment was the loss of contrast efficiency at low illuminations. As the illumination decreased more physical contrast was required to maintain constant brightness-contrast. The differences were fairly small but consistent within and across subjects. We extended the experiment to mesopic mean luminances, showing that this effect was related to effects observed by Whittle and Challands (1969). Preliminary data were reported at the Nov. 1990 annual

meeting of the Optical Society of America. In this grant period the experiments were completed, a manuscript was submitted to Perception and Psychophysics and is now in press.

3. Chromatic adaptation. The chromatic adaptation experiments described in the proposal were completed and reported at the November, 1991 meeting of the Optical Society of America in San Jose. A manuscript was submitted to J. Opt. Soc. Amer. A and is in press.

The data, in conjunction with our 1990 simultaneous constancy data, show that the visual system has two quite different color constancy strategies. In slightly oversimplified terms (neither of the strategies produces perfect illumination invariance), slow shifts of illumination over the entire visual field result in normalization of hues, i.e., there is a tendency for a surface to produce approximately the same hue at complete adaptation to the current illuminant. Within scenes the hues of surfaces are primarily determined by the adaptation illuminant. If there are regions in the scene with a different illuminant, the same reflectance will have a different hue, but the observer will nevertheless perceive it to be the same surface color under a different illuminant.

4. Contrast-Contrast. We completed and wrote up for publication a study of "contrast-contrast." The paper has been submitted to Vision Res. The apparent contrast of a pattern is lower when it is surrounded by patterns with high physical contrast than when surrounded by lower-contrast patterns. Chubb, Sperling and Solomon (1989) found that a test patch of random visual texture had lower apparent contrast when surrounded by a high-contrast background of similar texture than when surrounded by a uniform gray field. They called this phenomenon “contrast-contrast” in analogy with classical simultaneous brightness contrast.

Contrast-contrast has been attributed by previous investigators to neural interactions among contrast gain signals. We found several configurations that seemed to be more consistent with transparency and lightness constancy mechanisms than with pattern-specific neural interactions.

Our measurements showed that there are two components to contrast-contrast. There is a pattern-specific component in which the surrounding high contrast pattern influences the apparent contrast of test patterns that are similar in spatial frequency spectrum and phase to the inducer but has no effect on the apparent contrast of other patterns. There is also a pattern-nonspecific component in which the high contrast inducing pattern reduces the apparent contrast of any test pattern. The two components are roughly equal in magnitude.

We found that the pattern-specific component is limited only to a restricted range of the luminance relationships between the test patch and background elements, namely, to the range of luminance relationships that are compatible with a transparency appearance. In that case the display has the appearance of one large, continuous grating with a superimposed transparent veiling luminance over the region of the test patch.

5. White's Illusion. The experiment on White's Illusion was presented as a poster at the 1992 ARVO meeting, and we are preparing a manuscript.

In White's illusion gray bars replacing segments of black and white square-wave grating appear different in a direction opposite from what would be expected on the basis of simultaneous lightness contrast. The flanking bars share more contour with the gray patches and have more adjacent area than the bar segments at the ends of the gray patches, yet the brightness differences are opposite the expectation from contrast with the flanking bars.

Several explanations have been offered:

White and White (1985) suggested that this is an instance of counterphase lightness induction based on the phenomenon of grating induction. Kingdom and Moulden (1989) suggested a dual mechanism involving local and spatially extensive contrast mechanisms modeled in terms of circular-symmetrical opponent filters and filters with elongated opponent surrounds. Polichar and Brown (1991) proposed a "higher-order" contrast adjustment process related to perceptual organization or to the notion of edge "belongingness".

We proposed instead that White's Illusion is a result of occlusion relations and a process that assigns lightnesses as in phenomenal transparency. We found that White's Illusion requires two conditions to be satisfied. The first is that the apparent ordering in depth of the elements of the pattern must place the gray patches in front of the long bars. The second condition is the same luminance range constraint we found in contrast-contrast. White's Illusion occurs only when the luminance of the gray bars lies somewhere between those of the lighter and darker inducing stripes.

6. Apparent chromatic contrast.

Our achromatic experiments made useful connections between apparent contrast in side-by-side displays and matches in the Whittle and Challands paradigm. This suggests that the chromatic analog of Whittle and Challand's paradigm might be used to collect data to support modelling of the visual system's encoding of suprathreshold chromatic gradients, information that has proven very difficult to obtain with any other known paradigm (though Boynton, Kaiser, and others have tried).

During my visit to Cambridge (September, October, 1990) Paul Whittle and I collected data in a study extending his achromatic paradigm to chromatic patterns. While Whittle is till working on fully analyzing those data and related results from the thesis of one of his students, he presented a preliminary paper on the experiments at the September, 1991 European Conference on Visual Perception in Vilnius.

In this grant period I extended that work in a direction analogous to my achromatic work. The ultimate goal is to develop a predictor of apparent chromatic contrast at the level of sophistication of achromatic local band-limited contrast (Peli, 1990).

To implement a chromatic version of local band-limited contrast we must first make a number of choices.

The first concerns which variables to use in the calculation of physical chromatic contrast. Physiologically oriented modeling of color adaptation can't help us much at the moment. Recent developments have thrown the whole question of the numbers and arrangements of additive and multiplicative stages into confusion. The early time course of chromatic adaptation is so discrepant from that of achromatic adaptation as to raise questions as to whether there are any common adaptation mechanisms between the two (Hayhoe and Wenderoth, 1991). Analyses designed to reveal the locations of nonlinearities in early visual processing have also raised new questions about the earlier models (Zaidi and his colleagues, Gaudiano, 1991).

Given the problems with the chromatic version of the Arend and Spehar paradigm, the most promising source of apparent contrast data is Whittle and Challands' Haploscopically Superimposed Display (HSD) paradigm. In the HSD each eye is provided with its own large background field and small target field (fig. 1). In the combined view the background fields are fused but the target fields do not overlap. The test target is adjusted to exactly match the appearance of the standard target. Whittle and Challands' achromatic data generally support the interpretation that the match is based on equating the differential signals at the edges of the test and standard targets.

In the achromatic case, the close agreement between Whittle and Challands' matches and Arend and Spehar's brightness contrast matches suggests that the match in the HSD is based on equating local apparent contrasts. If so, then tri-dimensional color matches between test and standard patches on fused chromatic backgrounds in the HSD provide an empirical measure of equal chromatic apparent contrasts.

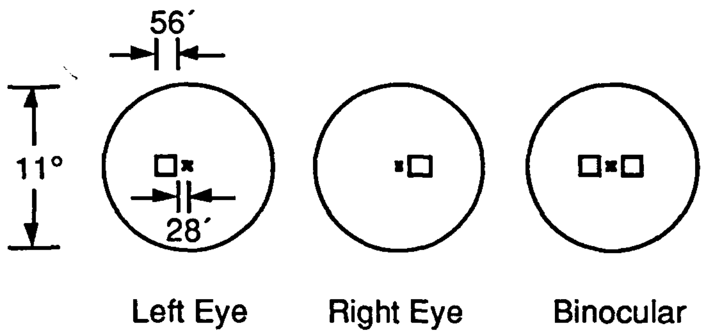

Fig. 1. Diagram of the HSD pattern.

Pilot experiments with the HSD have generated promising data.

The stimuli are illustrated in fig. 2.

Standard fields of preselected colors appeared on a neutral (D65) background in the left eye. The background in the right eye was one of four colors, Red, Green, Yellow, or Blue[1]. These backgrounds were preselected to provide enough gamut that a reasonable range of standard fields could be matched. The backgrounds lay halfway between the D65 neutral point and the (separately measured) locus of the corresponding unique hue on the edge of the monitor's gamut, in u′v′ coordinates. Their luminance was fixed at 15.0 cd/m^2.

[1]In this paper I will use the following conventions regarding two special uses of color names: Capitalized names, e.g., Red, will be used as proper nouns, the names of particular physical colors fully specified elsewhere in the paper; names in quotation marks, e.g., "red" are reports of appearance of some physical stimulus. In the latter case I will attempt to clearly indicate the scientific status of the report, e.g., casual observation by the experimenter vs. careful and constrained descriptions from subjects. Other use of color names will be infrequent and defined by context.

Fig. 2

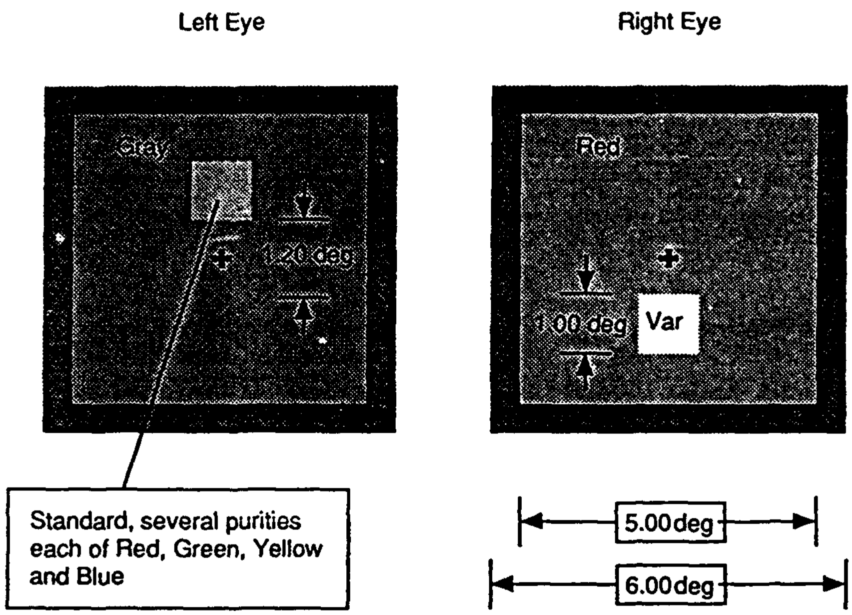

Fig. 2. Diagram of stimulus in pilot chromatic HSD experiments.

The standard patch colors also lay on the vectors from D65 to the unique points at distances of 0.01, 0.02, 0.03, 0.04, and 0.06 in u′v′ coordinates (fig. 3, filled circles), with fixed luminance of 18.0 cd/m^2. In the absence of any better guide to equal spacing, equal distances in u′v′ seemed appropriate because differential threshold ellipses are approximately circular in that space. In fact, one interpretation that is often made of this space is that two pairs of points separated by the same suprathreshold distance are equally chromatically distinct. If this were strictly true one might argue that two pairs of colors that have equal apparent chromatic contrasts should be separated by equal distances in u′v′, i.e., separation in u′v′ is one candidate statistic for physical chromatic contrast.

On each trial the observer adjusted the test patch to match its appearance (hue, saturation, and brightness) to that of the standard patch. The observer adjusted the luminance of the test patch by "up" and "down" pushbuttons and its chromaticity by moving the mouse of a bitpad. The bitpad was mapped such that horizontal position controlled primarily the red/green component and vertical controlled primarily the yellow/blue content.

The PI's matches are shown in fig. 3 in u′v′ coordinates and in Luthor space (normalized cone excitations) in fig. 4.

While the second-order details of these data are complicated, the general pattern is crudely in accord with the hypothesis that the patches match when their local chromatic contrasts are equal. Vectors from the match points to the test background are roughly equal to those from the corresponding standard points to the standard background (fig. 5). Assuming even very approximate uniformity of u′v′ coordinates, this confirms that the HSD matches are a kind of differential match.

Matches were also made to standards of several hues at a constant Δu′v′ of 0.04 (fig. 6, filled circles). The same four test background colors were used. The data are shown in Fig. 6, in u′v′ coordinates. The filled circles are the standard stimuli, and the open circles are the HSD matches. For the red test background, matches were also made in a binocular viewing paradigm, with the stimuli of fig. 2 viewed side by side rather than fused. The binocular matches are shown by gray circles in fig. 6a.

Ellipses fit by eye to the matches on the various backgrounds are clearly not the same shape. The ellipses are shown superimposed in fig. 7 along with the circle describing the standard patches. It is clear that larger vectors were required in the direction of the line between the standard and test backgrounds.

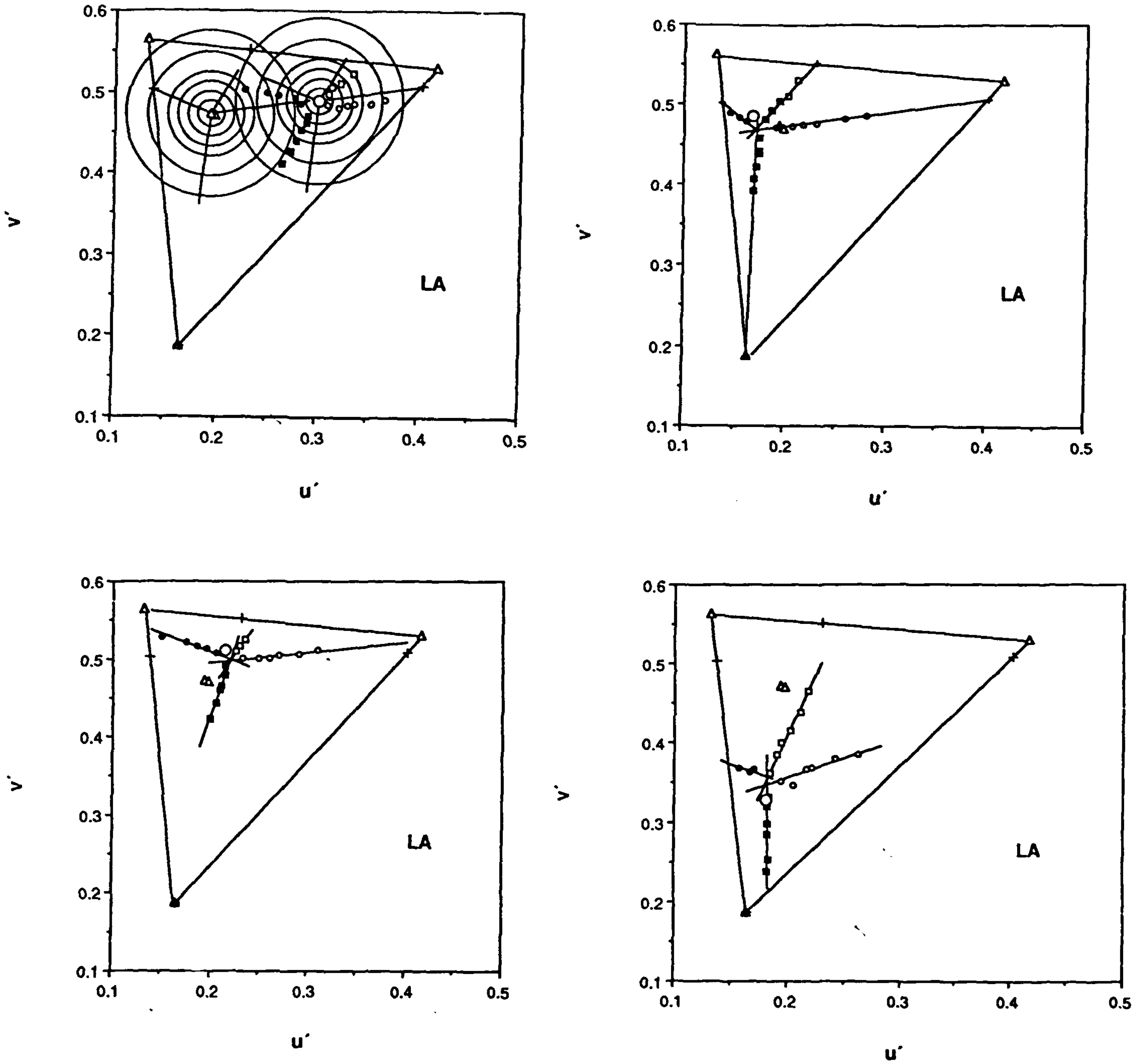

Fig. 3. Mean color matches in the HSD paradigm, plotted in u′v′. Triangles: Background$_{std}$, RGB guns. Large open circle: Background$_{test}$. Crosses: Unique hues at edge of monitor gamut. Open small circles: Matches to R stds. Filled small circles: Matches to G stds. Open squares: Matches to Y stds. Filled squares: Matches to B stds. Lines fit by eye. a: R Background$_{test}$. b: G Bk$_{test}$. c: Y Bk$_{test}$. d: B Bk$_{test}$.

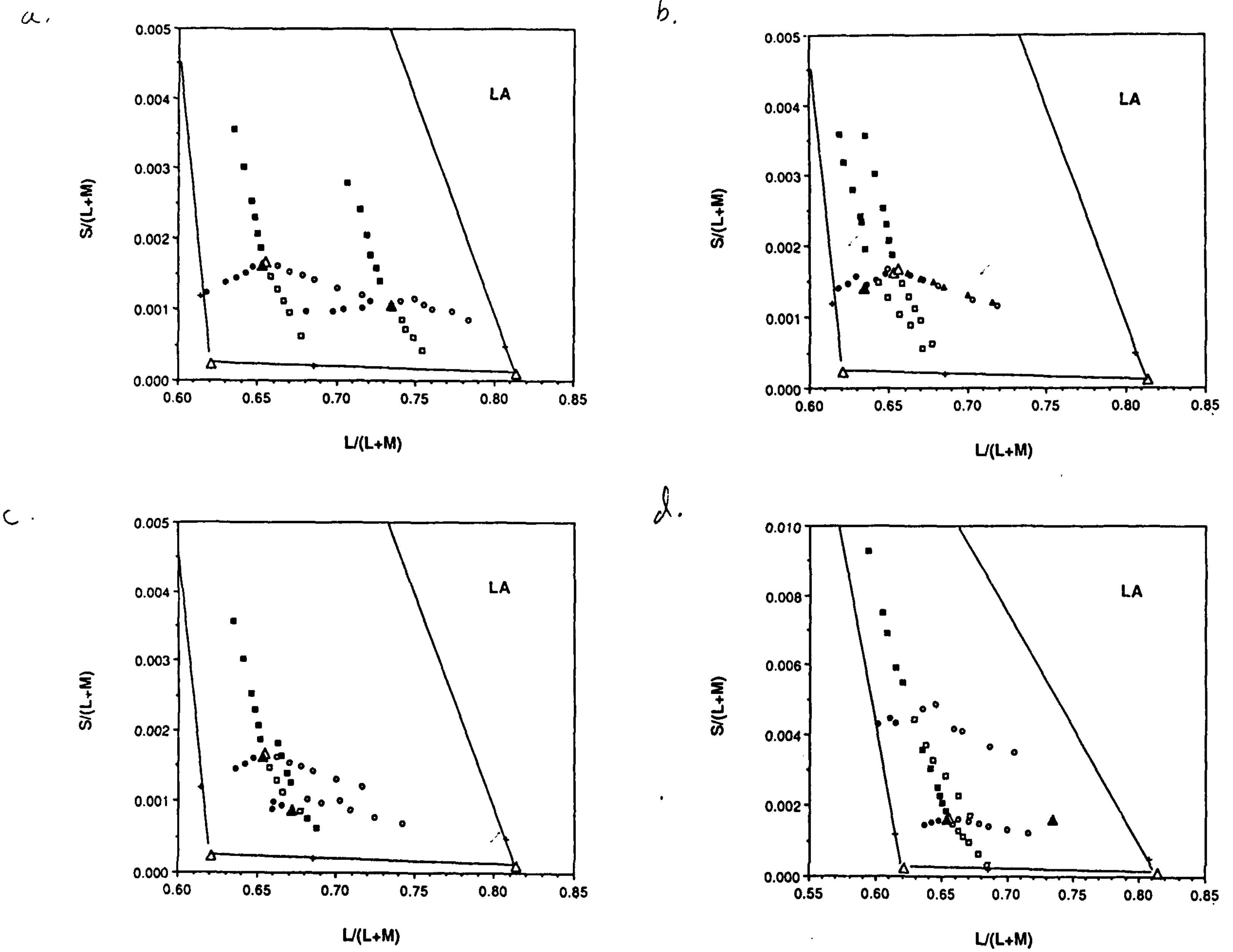

Fig. 4. Mean color matches in the HSD paradigm, plotted in Luthor coordinates. Triangles: Background$_{std}$, RGB guns. Large open circle: Background$_{test}$. Crosses: Unique hues at edge of monitor gamut. Open small circles: Matches to R stds. Filled small circles: Matches to G stds. Open squares: Matches to Y stds. Filled squares: Matches to B stds. Lines fit by eye. a: R Background$_{test}$. b: G Bk$_{test}$. c: Y Bk$_{test}$. d: B Bk$_{test}$.

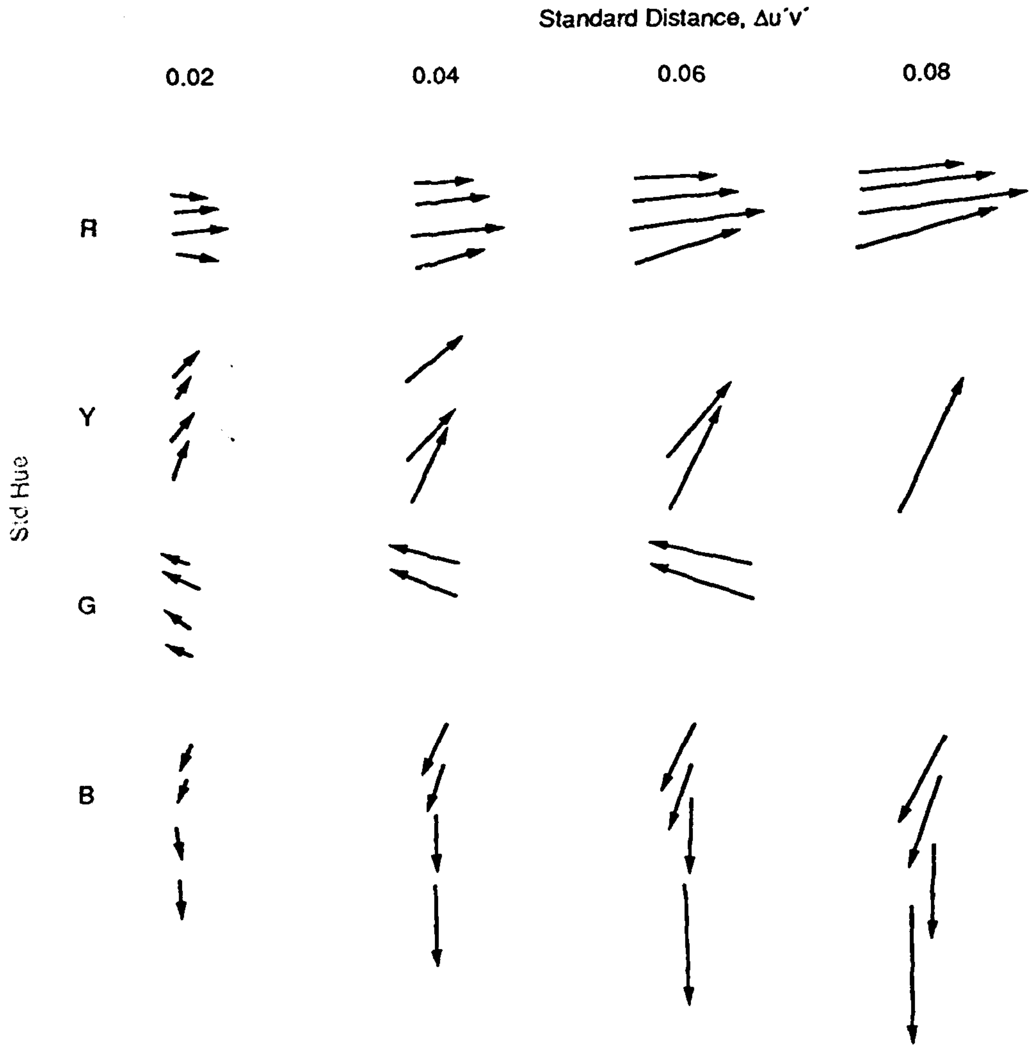

Fig. 5. Vector distances in u´v´ between HSD match points and the test backgrounds (thin arrows) and between the corresponding standard patches and the D65 standard background (thick arrows). Columns: Δu´v´ between standard patch and standard background. Rows: Hue of standard patch. Arrows within cell are, top-to-bottom, R, Y, G, and B test background.

a. b.

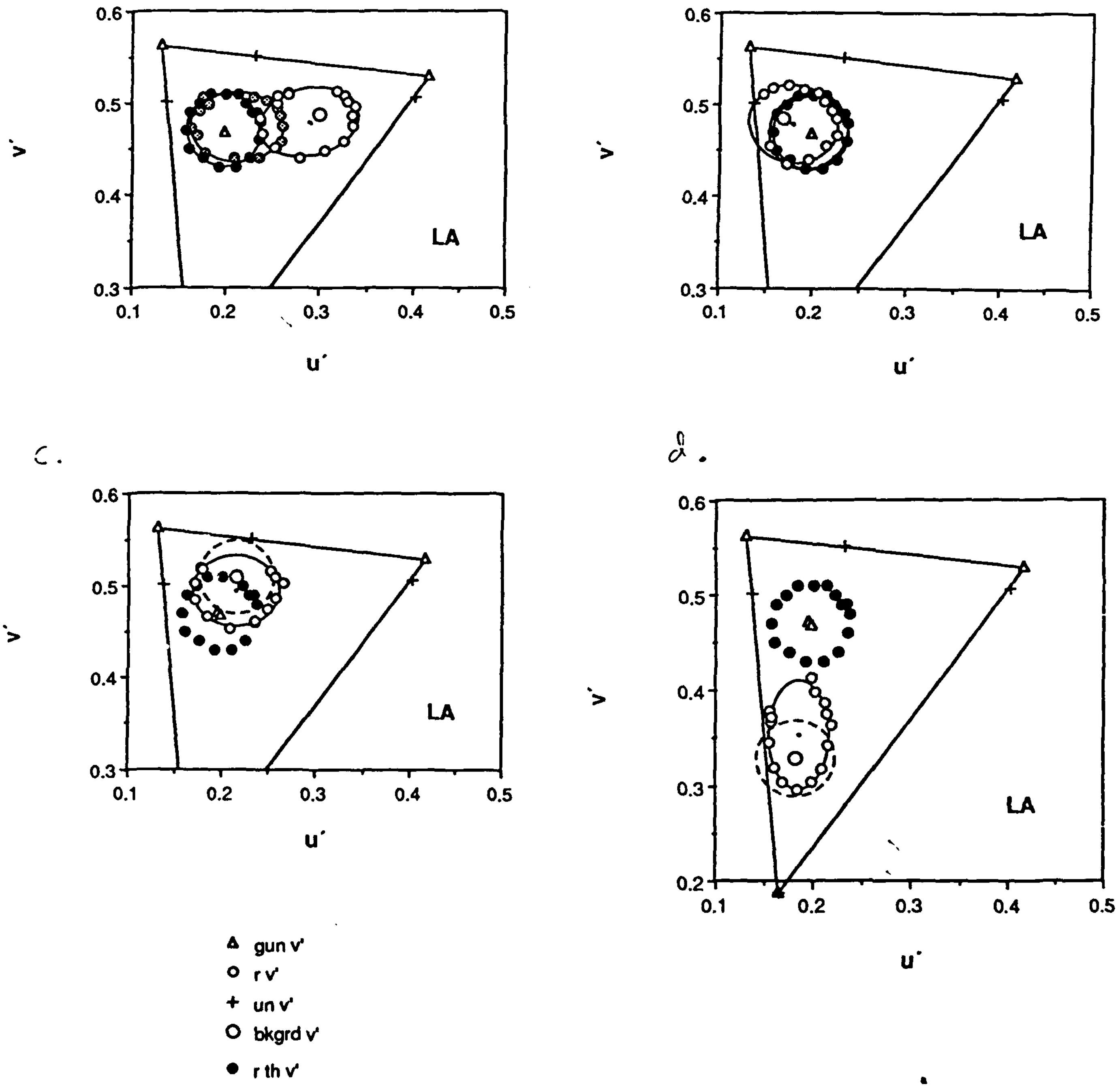

Fig. 6. Matches to standards at a constant u′v′ distance of 0.04. Triangles: Background$_{std}$, RGB guns. Large open circle: Background$_{test}$. Crosses: Unique hues at edge of monitor gamut. Filled small circles: Standards. Open small circles: Matches to stds. Dot: Center of ellipse through data. a: R Background$_{test}$. b: G Bk$_{test}$. c: Y Bk$_{test}$. d: B Bk$_{test}$.

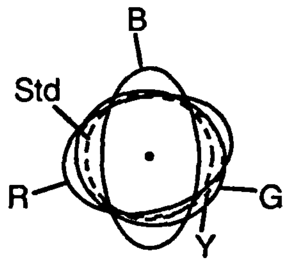

Fig. 7. Ellipses through data of fig. 6, translated to superpose their centers.

The data are too preliminary to begin trying to choose a chromatic contrast model, but their differential pattern and the tractability of the paradigm are encouraging.

3.2.2.3 Apparent chromatic contrast as a function of surround luminance

To design a chromatic contrast metric we need data that show the dependence of apparent chromatic contrast on adaptive state. Some of the most important data are apparent chromatic contrasts measured in the HSD paradigm as a function of surround luminance. While extensive data are available at contrast threshold levels there is relatively little suprathreshold contrast literature.

We collected pilot data in several HSD conditions. The 18 cd/m^2 standard fields were the red, and green patches at purity $\Delta u'v' = 0.04$ on the 15 cd/m^2 gray (D65) standard surround. The test surrounds of the pattern in fig. 5 were red, green, and gray (D65) surrounds at 11 luminances spanning the range from 1.5 cd/m^2 to the 15 cd/m^2 luminance of the standard surround. The subject made complete trichromatic matches.

It is well established in both the laboratory[2] and applied color literatures[3] that a chromatic field of fixed physical purity increases in saturation as the luminance of its gray surround increases. On a neutral-appearing surround an increase of test-field saturation is an increase of apparent chromatic contrast. This implies that the

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[2]Hunt R. W. G. (1953) The perception of color in one degree fields for different states of adaptation. *J. Opt. Soc. Am.* 43, 479. Hunt R. W. G. (1977) The specification of colour appearance. II. Effects of changes in viewing conditions. *Color Res. and Applic.* 2, 109-120.

[3]Bartleson C. J. and Witzel R. F. (1967) Illumination for color transparencies. Phot. Sci. Eng. 11, 329-335. Hunt R. W. G. (1987) The Reproduction of Color. John Wiley & Sons, New York. Hunt R. W. G. and Winter L. M. (1975) Color adaptation in picture-viewing situations. J. Phot. Sci. 23, 112-115.

physical chromatic contrast (purity) required to maintain constant saturation decreases with increasing surround luminance.

The PI's matches to fixed red and green standard patches on the neutral surrounds are plotted in fig. 8 in Luthor chromaticity coordinates. As the surround luminance was increased the chromaticities required for constant saturation (apparent chromatic contrast) moved toward the background chromaticity (filled large circle). This was true for the green standard patch (filled circles), but even more for the red standard patch (open circles).
A similar situation occurred for the red backgrounds (fig. 9), except that the changes were larger for the green standard than for the red.

Thus the apparently paradoxical result of the classical work was reproduced. Even though the level of excitation of the L-cones increased as the background luminance was increased, the required relative L-cone excitation required in the test patch for constant apparent chromatic contrast decreased.

This is markedly different from the relationship which holds with apparent luminance contrast. The luminance component of the matches for both red and gray surrounds are shown in fig. 10. As in Whittle and Challands' experiment the curves are well fit by Stiles' function, and the best fitting position (found by eye) is reasonably located on the axes. This agrees with later luminance contrast work by Whittle showing that luminance contrast in the HSD paradigm behaves similarly for achromatic and chromatic test patches.

To press the comparison further, the HSD matches for red backgrounds are plotted in fig. 11 in terms of cone excitations, in Whittle and Challands' coordinates. Separate curves are plotted for the three cone classes. As one would expect, the background produces highest excitation in the long-wavelength cones, slightly less in the medium-wavelength cones (the spectral sensitivity of which is only slightly shifted toward shorter wavelengths), and dramatically less for short-wavelength cones. For all six curves the slope is substantially less than one, indicating that the required contrasts fall much more slowly than required by Weber's Law. For all but one the slope is similar to that for the luminance contrasts (fig. 10). For red standard patches (fig. 11a) the short-wavelength and long-wavelength components of the required match contrasts are roughly in the relationship specified by Weber's Law; corresponding data points are related by lines of slope one. The middle-wavelength contrasts, on the other hand, are substantially less than specified by those lines. For green standard patches (fig. 11b) the opposite is true; the middle-wavelength contrasts are

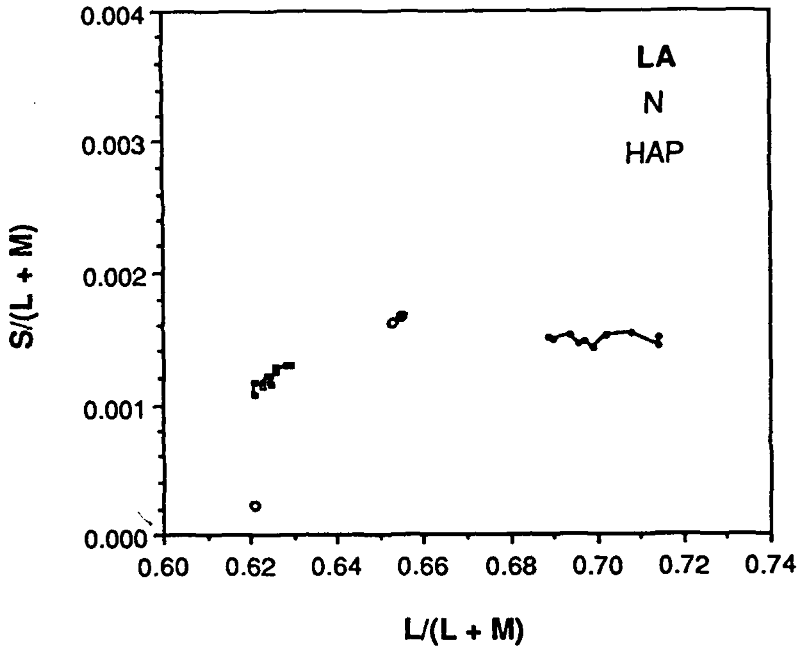


Fig. 8. The PI's mean color matches in the HSD paradigm for neutral backgrounds, plotted in Luthor coordinates. Triangles: $\text{Background}_{\text{std}}$, RGB guns. Large filled circle: $\text{Background}_{\text{test}}$. Open small circles: Matches to R std. Filled small circles: Matches to G std.

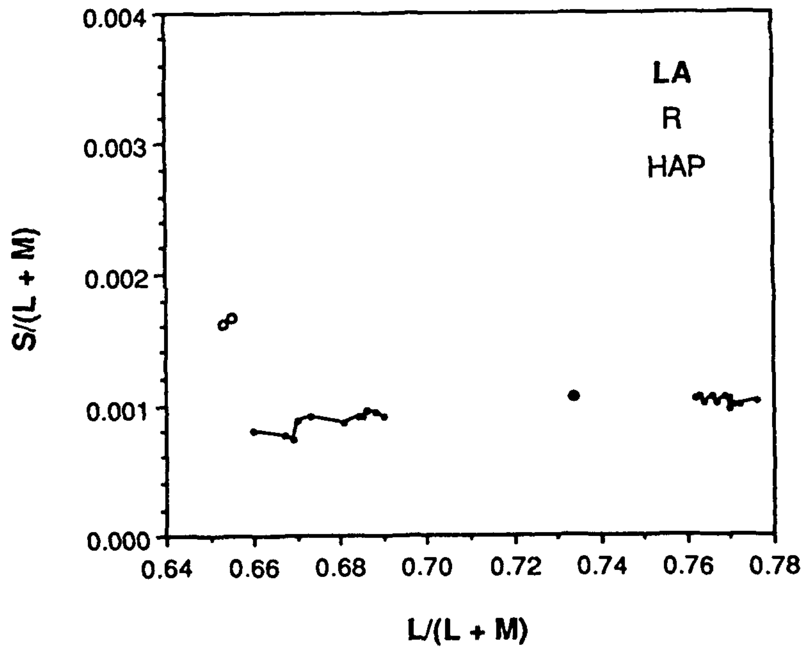


Fig. 9. The PI's mean color matches in the HSD paradigm for red backgrounds, plotted in Luthor coordinates. Triangles: $\text{Background}_{\text{std}}$, RGB guns. Large filled circle: $\text{Background}_{\text{test}}$. Open small circles: Matches to R std. Filled small circles: Matches to G std.

substantially more than specified by lines connecting corresponding long-wavelength and short-wavelength points.

For the gray surrounds the picture is more complicated (fig. 12). Three of the six curves do not fit the pattern of Stiles' template at all, the required contrasts actually decreasing as the cone excitation produced by the background increases as suggested by figs. 8 and 9. Otherwise they resemble the data for red backgrounds. This negative slope is a new addition to the very short list of psychophysical phenomena that can only be explained by opponent linkage of the signals from cone classes.

In future extensions of these pilot experiments we will consider such data to be iso-apparent-contrast functions of the backgrounds and will attempt to fit them using the various options for physical correlates of apparent chromatic contrast. The Retinex description in terms of simple cone-contrasts is ruled out on qualitative grounds by the relationships in figs. 10 and 11. Options for opponent weights will be considered in order of complexity, starting with the data where the background variation changes predominately one cone adaptation level. The expressions providing the best global description of the data should provide a good starting point for a chromatic version of the Peli band-limited contrast metric.

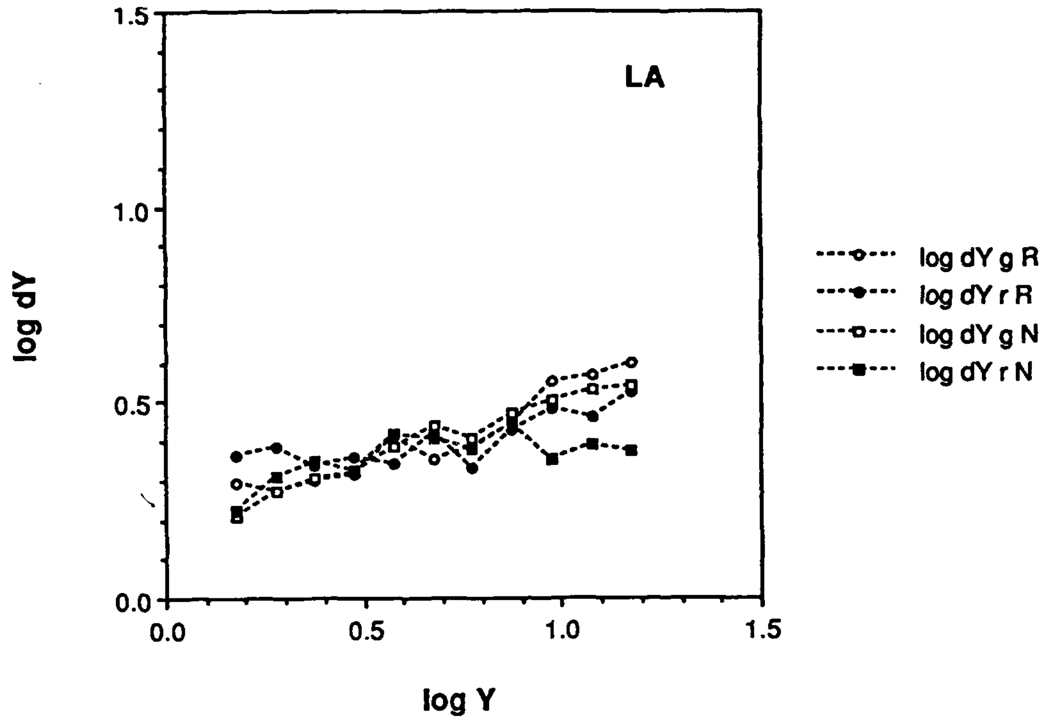


Fig. 10. Luminance components of HSD matches from subject LA. Test surrounds at 11 luminances. In Whittle and Challands' coordinates. Solid lines are Stiles' template.

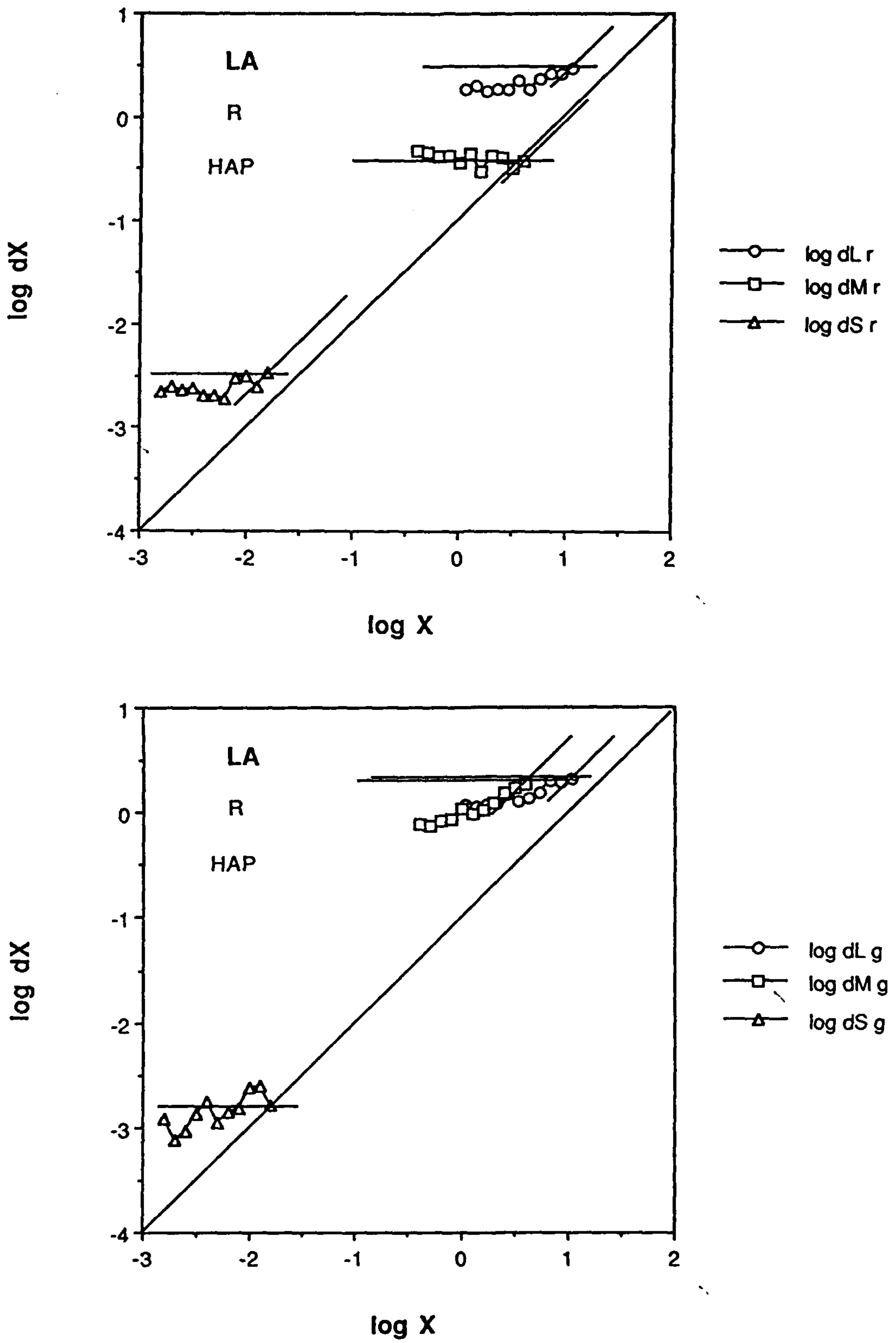
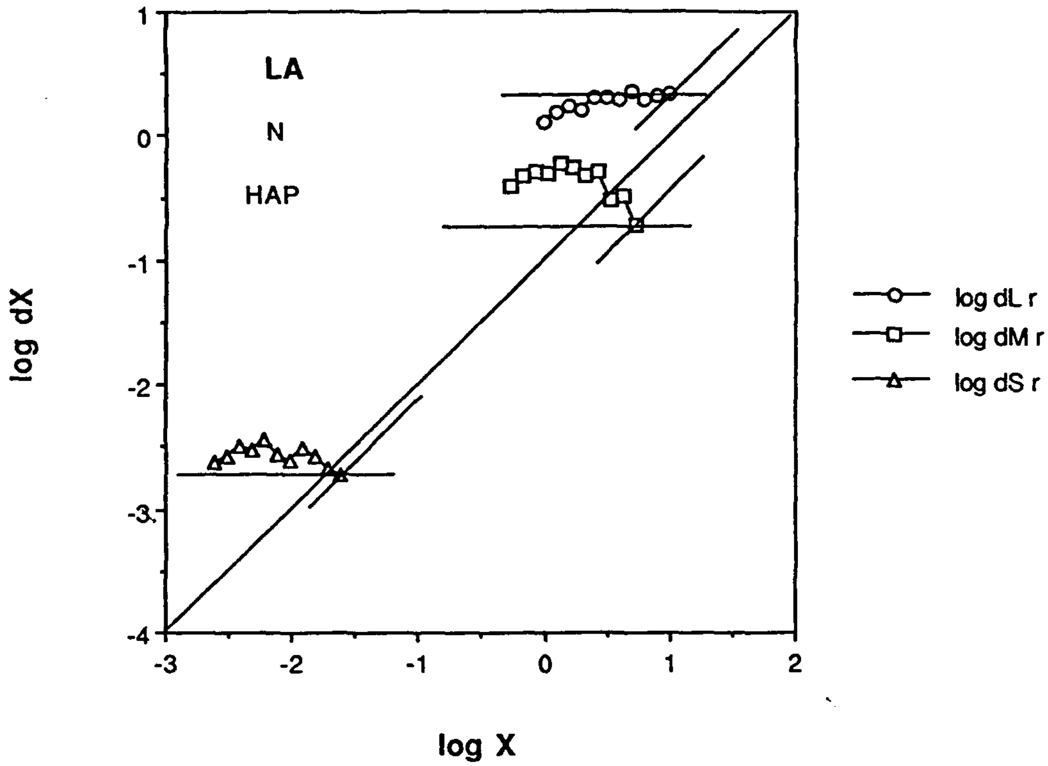


Fig. 11. HSD match data from subject LA. Red test surrounds at 11 luminances. Plotted in terms of cone excitations, in Whittle and Challands' coordinates. a. Red standard patches. b. Green standard patches.



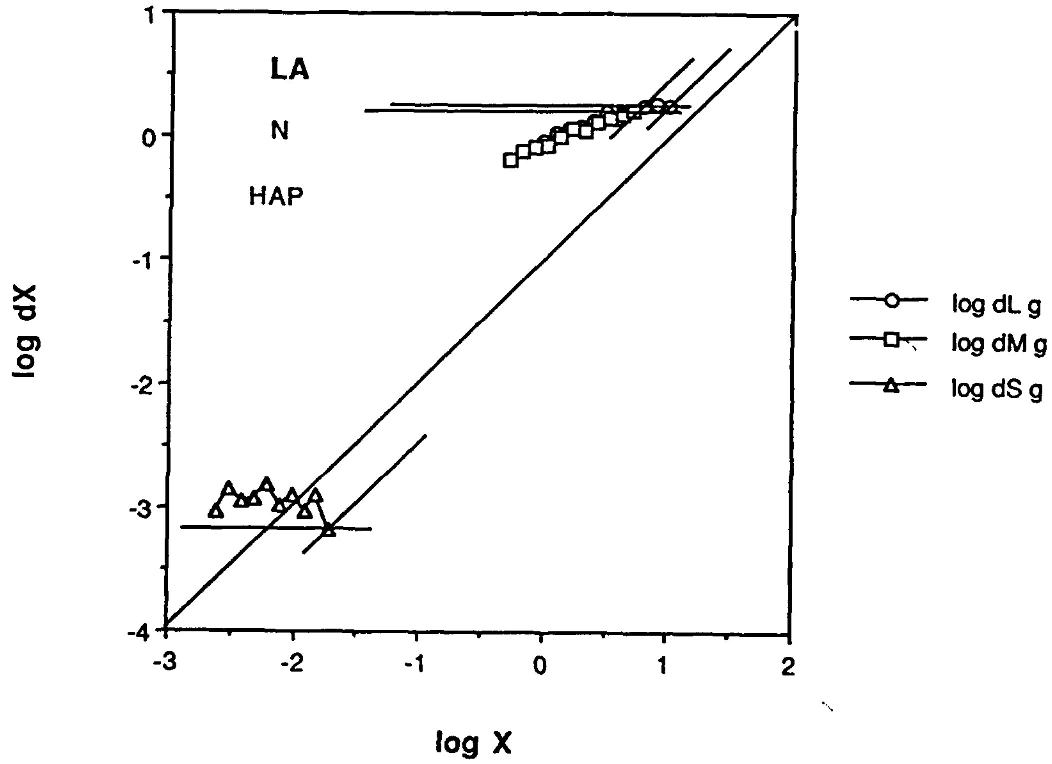


Fig. 12. HSD match data from subject LA. Neutral (D65) test surrounds at the same 11 luminances as for red surrounds. Plotted in terms of cone excitations, in Whittle and Challands' coordinates. a. Red standard patches. b. Green standard patches.

III. PAPERS

Significant time was devoted during this grant period to reporting results of the research project. In addition to submission of several articles, I gave a number of invited and contributed papers.

Arend, L. Apparent contrast and surface color in complex scenes. In Rogowitz, B.E., Brill, M.H., and Allebach, J.P. (Eds.) Human Vision, Visual Processing, and Digital Display II, Proc. SPIE 1453, 412-421, 1991.

Skon J. and Arend L. Color changes in red and white projections at low luminance. J. Opt. Soc. Am. A 9, 30-33, 1992.

Reeves, A and Arend L. Color constancy. Advances in Color Vision Technical Digest 4, 115-117, 1992.

Peli, E., Arend, L., Young, G. and Goldstein, R. Contrast sensitivity to patch stimuli: The effects of spatial bandwidth and temporal presentation. Spatial Vision, 7, 1-14, 1993.

In Press:

Arend, L. Surface colors, illumination, and surface geometry: intrinsic-image models of surface color perception. In Press, Chapter 2 of Gilchrist, A. (Ed.) Lightness, Brightness, and Transparency. Lawrence Erlbaum Assoc., Hillsdale, NJ.

Arend, L. and Spehar, B. Lightness, brightness, and brightness contrast. I. Illuminance variation. Perception and Psychophysics, In Press.

Arend, L. and Spehar, B. Lightness, brightness, and brightness contrast. II. Reflectance variation. Perception and Psychophysics, In Press.

Arend, L.E. How much does illuminant color affect unasserted colors? J. Opt. Soc. Am. A, In Press.

Arend, L. Mesopic brightness, lightness, and brightness contrast. Perception and Psychophysics, In Press.

Submitted:

Spehar, B., Arend, L., and Gilchrist, A. Luminance and spatial constraints of contrast-contrast. Submitted to Vision Research.

Review:

Arend, L.E. Review of "Perceiving, Measuring, and Using Color", 1991 SPIE/SPSE Conferences on Electronic Imaging. Color Research and Application, **16**, 347-348, 1991.

Abstracts:

Whittle, P. and Arend,L. Homochromatic Colour Induction. Perception , 1991.

Arend,L. How much does illuminant color affect unasserted colors? In OSA Annual Meeting Technical Digest 1991 , **16**, 24, 1991.

Spehar, B. and Arend,L. Perceptual factors in contrast-contrast. In OSA Annual Meeting Technical Digest 1991 , **16**, 121-122, 1991.

Spehar, B., Arend, L., and Gilchrist, A. White's illusion: A new luminance distribution constraint. Invest. Ophthalmol. Vis. Sci. **33** (ARVO Issue.), 1260, 1992.

In Preparation:

Arend, L. Providing a reference grayscale for lightness judgments.

Arend, L. and Arend, D. Effect of background reflectance on lightness.

Spehar, B., Gilchrist, A., and Arend, L. White's Illusion and grating induction: Similarities and differences.

Reeves, A. and Arend, L. Successive color constancy.

Whittle, P. and Arend,L. Homochromatic Colour Induction.

IV. PROFESSIONAL PERSONNEL

Arend, Lawrence E., Principal Investigator

Goldstein, Robert, Research Assistant

Gilchrist, Alan (Rutgers Univ.), nonsalaried part-time collaborator

Mingolla, Ennio (Boston Univ.), nonsalaried part-time collaborator

Peli, Eliezer (ERI), nonsalaried part-time collaborator

Reeves, Adam (Northeastern Univ.), nonsalaried part-time collaborator

Schirillo, James (Univ. of Chicago), nonsalaried part-time collaborator

Skon, Joy, nonsalaried part-time collaborator

Spehar, Branka (Rutgers Univ.), nonsalaried part-time collaborator

Whittle, Paul (Cambridge Univ.), nonsalaried part-time collaborator

V. PROFESSIONAL INTERACTIONS

Papers presented:

Arend, L. "Lightness, brightness and apparent contrast," Invited talk, I.P. Pavlov Institute of Physiology, Academy of Sciences of the Soviet Union, St. Petersburg, USSR, September, 1991.

Arend,L. "Constancy of unasserted colors", Annual Meeting of the Optical Society of America, San Jose, November, 1991.

Spehar, B. and Arend,L. Perceptual factors in contrast-contrast. Poster, Optical Society of America Annual Meeting, San Jose, 1991.

Arend,L. "Perception of unnatural images", Invited talk, US Army Night Vision Laboratory, Ft Belvoir, VA, 1991.

Arend,L. "Intrinsic images in human perception: The apparent color of the light vs. the apparent color of the surface", Invited talk, Center for Visual Science, University of Rochester, Rochester, NY, December, 1991.

Arend, L. Visual intrinsics and subjective physics. "Cognitive Aspects of Vision", Internat. School for Advanced Studies, Trieste, Italy, 1992.

Spehar, B., Arend, L., and Gilchrist, A. White's illusion: A new luminance distribution constraint. Poster, ARVO annual meeting, Sarasota, 1992.

Arend, L. Visual intrinsics and subjective physics. Sarnoff Laboratories, Princeton, NJ, March, 1993.

Other interactions:

September, 1991--I attended the Int. Conf. Event Percept. and Action in Amsterdam and continued on to the Pavlov Institute, St. Petersburg, Russia, where I presented a talk to area vision researchers.

November, 1991--I attended the annual meeting of the Opt. Soc. of Amer., in San Jose, CA, where Branka Spehar and I presented a poster on "contrast-contrast" which was well received.

December, 1991--I gave a talk at the Institute of Optics, Rochester, on the differences between color appearance and apparent surface color.

August, 1992--I met in Umbria, IT with the Trieste Group (P. Whittle, Cambridge U.; A. Gilchrist, Rutgers U.; W. Gerbino, U. of Trieste; S.S. Bergstrom, U. of Umea) for several days finishing our joint book and discussing the members' recent lightness research) and continued to Pisa, IT where Branka Spehar and I presented a poster on White's Illusion at the Eur. Conf. on Vis. Percept.

October 1992--I attended the annual meeting of the Opt. Soc. of Amer., in Albuquerque, NM.

October 1992--I gave an invited talk at a small international meeting at the Internat. School for Advanced Studies, Trieste, IT. The other ten speakers were from European countries, primarily U.K., Denmark, Sweden, and Italy.

VI. INVENTIONS

There were no patentable inventions under this project.