Improvable, yes; insoluble, no: A reply to Flock

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The brightness constancy problem is placed in perspective with a brief restatement of the main theoretical issue. Flock's use of our theoretical formulation with the Hess and Pretori empirical data to demonstrate that the k values fluctuate merely restates the fact that our own theoretical approximations to these and other data using a fixed value of k were not perfect fits, a fact we thought clear from graphs included in our original work. The reality of the observation that perceived brightness may increase, stay constant, or decrease with an increase in illumination is affirmed by replotting Hess and Pretori's 17 series of experiments. The basis on which interactive effects for complex fields were calculated appears to have been missed by our critic and is here retold, and his mistaken criticism of Brown and Mueller's citation of Heinemann's data is corrected. Attention is called to an elemental analysis derived from our integrated theory as a constructive alternative approach.

We appreciate the Editor's invitation to reply to Flock's (1970) rejection of our theoretical ideas about the mechanisms of brightness and color contrast and their role in the perceived "constancies." Before turning to any of the specifics of Flock's critique, most of which misses the primary target, we should first like to restate our general view of the main theoretical issue and place the constancy problem in perspective.

If brightness constancy were *perfect* rather than *approximate* then the phenomenon could be readily subsumed by (1) a view that assumes simply that the visual system adjusts its *sensitivity* to light in a compensatory fashion as the average level of illumination is varied, or alternatively (2) a view that assumes that the visual system responds to ratios of light stimuli (e.g., Wallach, 1948) without specifying the nature of the 'ratio-response' mechanism. Our net impression from a survey of the relevant literature as well as from our own everyday experience is, however, that perceived brightness is not perfectly constant with changes in illumination, but only approximately so. If we substitute a 15-W bulb for each of the 150-W ones that provide the illumination in the room in which we are writing, the perceived contrast is *not* unchanged, although the

stimulus ratios remain the same with the overall change in illumination level.

There are various ways in which this change in apparent contrast or departure from general brightness constancy might come about. We might, for example, try to apply Stevens's (Stevens & Stevens, 1963) conclusion that the gain of the brightness response mechanism varies with the degree of bright adaptation (and threshold) that is presumably controlled by the level of general illumination. A variable gain mechanism tied to the general level of bright adaptation says nothing, however, about local contrast effects of the familiar sort, such as the obvious change in the appearance of a "gray" surface under constant illumination when it is moved from a "white" background to a darker "gray" or "black" one. If we were to limit our thinking to the primitive concept of a retinal mosaic of shielded "private lines" from retinal receptor to optic nerve fiber to higher order neurons in the visual centers of the brain, we might be forced to an assumption of a corresponding mosaic of locally different adaptation levels, etc., to try to subsume the contrast and constancy phenomena. There is, however, abundant evidence from histological studies of synaptic organization and from electrophysiological studies of receptive field organization that runs counter to the primitive "private-line" concept, but that does seem consistent with a different view of the visual system as an organized tissue of functionally interacting elements, the functional organization of which depends on both excitatory and inhibitory neural events.

The theoretical view that we have sought to explore, then, is one based on the concept of opponent interactions, and our aim was to see if such an opponent functional organization could give rise to the kinds of "approximate constancy" and contrast phenomena mentioned above. In so doing, we explicitly ignored variations in general level of brightness sensitivity, because, as we said in our 1964 paper (Jameson & Hurvich), overall sensitivity changes *alone* do not predict the kinds of phenomena to which our inquiry was addressed. This is not, of course, to deny that sensitivity changes occur or to imply that a complete theory of brightness vision need not consider such changes.

We turn now to specifics. In our 1964

paper, we explored the opponent induction hypothesis, first, by setting up a symmetrical formal relation between two reciprocally interacting "elements" of a visual response field, then, using a particular fixed value for the term k in this relation that represents the strength or degree of the opponent induction, we computed a set of stimulus relations to be expected from this particular formulation of the induction hypothesis. The theoretical value of the induction coefficient, k , was taken to be "of the order of 0.6 [Jameson & Hurvich, 1964, p. 139]." This value was based on the one set of matches made by Hess and Pretori (1894) that implied nearly perfect brightness constancy, as we stated in our paper (p. 139ff.), and was not, as Flock implies, a median solution for all of Hess and Pretori's individual match data. The calculated theoretical curves showing ratios of surround-to-test luminance as functions of test luminance for equal apparent brightness of the test (i.e., for a match to a given comparison stimulus in a fixed surround) were plotted (in log-log coordinates) as Fig. 2 of our 1964 paper, for comparison with Fig. 1 of the same paper in which we had plotted comparable measures computed from a sample of five series of Hess and Pretori's experimental results. These figures are reproduced here as Figs. 1 and 2.

The theoretical treatment generated a family of curves that exhibit what we consider to be the main finding of the Hess and Pretori experiments, namely, (1) that for some ratio of surround-to-test luminance, the brightness of the test field can be maintained constant by keeping the surround-to-test luminance ratio constant, (2) that for ratios of surround-to-test luminance greater than this, the surround luminance cannot be increased as fast as the test luminance for constant test brightness, and (3) that for ratios of surround-to-test luminance smaller than this, the surround luminance must be increased relatively more than the test for constant test brightness. Result 1 implies brightness constancy, Result 2 implies test field darkening with increase in illumination, Result 3 implies test field brightening with increase in illumination. The theoretical functions do not duplicate precisely the curvatures of the smoothed ratio functions fitted to the Hess and

Pretori data, nor do they, of course, duplicate the nonsystematic irregularities of Hess and Pretori's individual experimental measures. These nonduplications of experiment by theory can be seen from Figs. 1 and 2; Flock's Table 1 (variations in k) and Table A (variations in R) present the same facts in numerical form. The nonsystematic irregularities of the individual data points would, of course, require nonsystematic, wildly fluctuating values of k in our equation to predict uniform responses. These nonsystematic irregularities do not

concern us. The systematic curvature differences between the theoretical and experimental functions would require systematic variations in the value of k in our equation to predict uniform responses, or, preferably, inclusion of other relevant variables, such as pupil size, sensitivity, and induction between the surrounds. These systematic deviations do concern us, and we would welcome an improved theoretical account that would handle not only the essential characteristics of the departures from brightness constancy, but also their precise forms. We anticipated, when we

Fig. 1. Hess and Pretori (1894) experimental data replotted. At the various test luminance values, the plotted points (o) represent the ratio of surround luminance/test luminance necessary to match standard fields (●) at values specified on the same ordinate and abscissa scales. (From Jameson & Hurvich, 1964)

had read this far in Flock's paper, that he was about to present such an improved theoretical treatment.

He does not do this, however, but says, rather, that (1) "In that limited sense, therefore, Hess and Pretori's data do confirm by implication the major prediction of the model . . ." but (2), "It should be noted, however, that Hess and Pretori questioned some of the data points on which the finding of clearly positive and negative functions depended [Flock, p. 126]."

Here we move to a different kettle of fish, for in raising this point Flock is calling into question, not the precision of our theoretical model, but the reality of the phenomena whose main features the model is intended to describe and that show departures in two directions from perfect brightness constancy. Were we biased in selecting the sample functions we did and do the sample functions show trends contradicted by the remainder of the Hess and Pretori data from the same experiment? To let the reader answer this question for himself, in Fig. 3 we plot luminance ratios computed for all 17 series of Hess and Pretori's matching data. Although there are many irregular data points, we believe there is a systematic trend in the overall picture. Unfortunately, Hess and Pretori themselves did not analyze their data in this way, but simply plotted the arithmetic test and surround luminance values in linear (rather than logarithmic) coordinates, which, given the luminance range involved, failed, understandably, to reveal the systematic variations present in their data. Although Hess and Pretori did report that the matches in their experiment were difficult to make when the test fields appeared either extremely bright or extremely dark, we cannot agree with Flock's implication that they would have rejected all of the "clearly positive and negative" functions of Fig. 3 and accepted only those data that can be described by a straight line with zero slope!

Fig. 2. Solid lines are theoretical functions derived from opponent induction hypothesis to account for data of Fig. 1. Circles represent same parametric values of standard as in Fig. 1. (From Jameson & Hurvich, 1964)

Fig. 3. Experimental data obtained by Hess and Pretori (1894) replotted for 17 series. Single datum for zero test luminance not shown.

Flock, having first dismissed our theory because it does not precisely duplicate the Hess and Pretori data, and then having questioned in the data the essence of the phenomena for which the theory does account, goes on to point out the computational difficulty of applying the theory as stated for the symmetrical, two-element situation, to a complex field of many different reflectances. We did not make this jump directly in our 1964 paper, but rather, went on to show the way in which the induction strength depends on area and on separation between stimulated areas. We did this by applying the theoretical model to results reported by Diamond (1953, 1955) for two different experiments and by Leibowitz, Mote, and Thurlow (1953) for a third. Flock dismisses our treatment of such experiments because the matching stimulus was viewed in a nonilluminated surround and hence was not subject to induction effects of an adjacent stimulated area, and only the test field was subjected to such influence. Although he concludes, nevertheless, that the model and the experiments are consistent with each other, he dismisses that consistency, too, as either "not very interesting [p. 123]," or of "some interest, although it hardly pertains to the affair of '-' functions [p. 123]."

Our next step in the 1964 paper was to consider the effects of opponent induction processes on chromatic contrast, and of particular relevance here, measures obtained (Jameson & Hurvich, 1961a) for a pattern of stimuli in which appearance changes were determined for single "elements" of the pattern when paired with one or more other elements. These

experimental measures enabled us to assess the effects of contiguity between pattern elements, and to develop empirical weighting factors for average effects of a complex surround. We applied the same empirically based, weighted average procedure to predict complex brightness induction effects in a spatially similar pattern, and presented the theoretical functions as Fig. 9 of our paper for comparison with Fig. 8, which reproduced the brightness matching data (Jameson & Hurvich, 1961b) for such a pattern. Again, the theoretical curves hardly duplicated the experimental ones, there are "obvious differences in the precise forms of the function," but they do show "the general characteristics of the measured effects [1964, p. 147]." Without the empirical generalizations based on the chromatic contrast experiments, which Flock seems to have missed, theoretical treatment of brightness induction in a complex field is indeed, as he says, "a considerable task." It is not, however, an insuperable one, and has been carried out by computer solution of r simultaneous equations for a visual field made up of r elements by Marsden (1969) for an elemental theory of induction derived from what he calls our "integrated theory." Although we would modify some of Marsden's specific assumptions, we do consider the elemental approach a fruitful advance.²

Finally, we come to Flock's discussion of the Heinemann data in relation to our theoretical model. When Flock says "In addition, Brown and Mueller (1965) have cited Heinemann (1955) as support for the model [p. 118]," and "Brown and Mueller's (1965, pp. 231-233) citation of some of

Heinemann's data as supporting Jameson and Hurvich's model is simply mistaken [p. 122]," it is, rather, Flock who is simply mistaken. Brown and Mueller make no reference to our 1964 model, nor was it likely to have been in print at the time their chapter was prepared. They do make reference to the phenomenal observation that under some circumstances, an area of the visual field may become perceptually darker as the illumination is increased, and they cite our 1961 paper and Stevens's paper of 1961 as documentation for the phenomenon. They also refer to their own "construction" superimposed on a graph of Heinemann's (1955) results that implies the same "darkening" effect of increased illumination. In fact, when one looks at Fig. 4 of Heinemann's 1955 paper, the complete data, which include the three conditions that Flock plots in his Fig. 3 and three others that Flock omits but that are approximate mirror images of those he plots, the general finding is not greatly dissimilar from the Hess and Pretori finding even though there are obvious differences in the two sets of data. Brown and Mueller's citation of Heinemann for the darkening phenomenon is hardly mistaken, since Heinemann himself discusses the fact that when the inducing field luminance is strong relative to the test field, the latter "always had an apparent brightness lower than the lowest apparent brightness that a comparison field which is not surrounded by an inducing field can show [Heinemann, 1955, p. 93, italics in original]."

Despite all his emphasis on k values, which expresses his scorn for what Marsden (1969, p. 660) has called "a tolerable description of experimental data," it is the "darkening" effect that Flock seems most intent in challenging in the brightness contrast theory. We should be happy to see him develop an improved theoretical account of all of the available contrast and constancy data. We do not think he can do so by shutting his eyes to the darkening phenomenon.

REFERENCES

- BROWN, J. L., & MUELLER, C. G. Brightness discrimination and brightness contrast. In C. H. Graham (Ed.), *Vision and visual perception*. New York: Wiley, 1965. Pp. 208-250.
- DIAMOND, A. L. Foveal simultaneous brightness contrast as a function of inducing- and test-field luminances. *Journal of Experimental Psychology*, 1953, 45, 304-314.
- DIAMOND, A. L. Foveal simultaneous contrast as a function of inducing-field area. *Journal of*

- Experimental Psychology, 1955, 50, 144-152.
- FLOCK, H. R. Jameson and Hurvich's theory of brightness contrast. *Perception & Psychophysics*, 1970, 8, 118-124.
- HEINEMANN, E. G. Simultaneous brightness induction as a function of inducing and test field luminances. *Journal of Experimental Psychology*, 1955, 50, 89-96.
- HESS, C., & PRETORI, H. Messende Untersuchungen über die Gesetzmässigkeit des simultanen Helligkeits-contrastes. *Archives of Ophthalmology*, 1894, 40, 1-24. (Translated by H. R. Flock and J. H. Tenny. Technical Report FPL-1, York University).
- JAMESON, D., & HURVICH, L. M. Opponent chromatic induction: Experimental evaluation and theoretical account. *Journal of the Optical Society of America*, 1961a, 51, 46-53.
- JAMESON, D. & HURVICH, L. M. Complexities of perceived brightness. *Science*, 1961b, 133, 174-179.
- JAMESON, D., & HURVICH, L. M. Theory of brightness and color contrast in human vision. *Vision Research*, 1964, 4, 135-154.
- LEIBOWITZ, H., MOTE, F. A., & THURLOW, W. R. Simultaneous contrast as a function of separation between test and inducing fields. *Journal of Experimental Psychology*, 1953, 46, 453-456.
- MARSDEN, A. M. An elemental theory of induction. *Vision Research*, 1969, 9, 653-663.
- STEVENS, S. S. To honor Fechner and repeal his law. *Science*, 1961, 133, 80-86.
- STEVENS, J. C., & STEVENS, S. S. Brightness function: Effects of adaptation. *Journal of the Optical Society of America*, 1963, 53, 375-385.
- WALLACH, H. Brightness constancy and the nature of achromatic colors. *Journal of Experimental Psychology*, 1948, 38, 310-324.

NOTES

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2. The veto on negative values imposed by Marsden in his computer program is an important theoretical weakness, but is not a necessary feature of this otherwise fruitful approach.

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