Jameson and Hurvich's theory of brightness contrast¹

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Jameson and Hurvich's theoretical model, formulated to account for perceived brightness under conditions of simultaneous brightness contrast, was shown to predict linear brightness functions with (1) slopes of .33, -.33, or 0 on a log-log plot, where apparent brightness is plotted against illuminance, contrast ratio is the parameter, and spatial arrangements are constant; and (2) y-intercepts that shift monotonically as contrast ratio is increased. Predicting the value of a y-intercept and which of the three possible slopes of a function would occur was shown to depend on empirically evaluating a constant k. Because k was found unsolvable, the model as presently defined was rejected. The evidence for a general class of similar models was found to be fragmentary.

An enduring and exciting enterprise for investigators of vision has been to generate a theoretical model that would account for perceived brightness under conditions of simultaneous brightness contrast. One of the more recent candidates in this continuing inquiry has been a model proposed by Jameson and Hurvich (1964). Their model is consistent with the belief that contrast data are the output from opponent physiological processes.

Jameson and Hurvich's (1964) model, in the form of a theoretical equation, describes the net visual response in a focal region for conditions of achromatic simultaneous contrast. This equation was held by them to describe the contrast data of Hess and Pretori (1894), Diamond (1953, 1955), Leibowitz et al (1953), and Jameson and Hurvich (1961a). In addition, Brown and Mueller (1965) have cited Heinemann (1955) as support for the model.

Because of the importance of the area as well as the widespread interest in it and in view of the fact that this model has not been reviewed heretofore, it is the purpose of this paper to examine the properties of Jameson and Hurvich's (1964) equation, the theoretical predictions that can be generated from it, and the fit of the model to the experiments cited in its support.

I. THE BASIC EQUATION

Jameson and Hurvich's basic equation is:

$$R_f = \frac{c(S_f^n - k S_s^n)}{(1 - k^2)} \quad (1)$$

Equation 1³ states that in a focal area f the net visual response R_f is equal to the luminance S_f of the focal area raised to the power n less the product of an induction coefficient k and the luminance S_s of a surround area s also raised to the same power n , that difference modified by the product of a constant c and the reciprocal of the expression $(1 - k^2)$. The constant c was unexplained by Jameson and Hurvich (1964), but was arbitrarily evaluated as 1.0.

The constant k was defined as a proportionality factor related to the strength of the induction process for the given conditions of size and location of the focal and surround areas. It (k) is said to remain constant over changes in the focal and surround luminances so long as the spatial arrangements of the contrast configuration and the visual fixation remain constant. Hence, when the sizes, shapes, locations, and separations of the surround and focal fields remain constant and when the same retinal tissue is stimulated, k will remain constant. When the spatial arrangements or the retinal locus are varied, then k may vary. Presumably, k refers to visual anatomy, to numbers of pathways involved, to electrochemical events, and, it would seem, according to its use by Jameson and Hurvich (1964), may take values from 0 to 1 as sizes and locations of focal and surround areas are varied. This restriction on k is discussed below.

The exponent n in Eq. 1 was evaluated as .33 by Jameson and Hurvich (1964) for all possible contrast conditions. The net visual response R_f is postulated, apparently, as a neurophysiological response. It is said, moreover, to be isomorphic with visual phenomena.

II. LIGHT, DARK, AND NULL PROCESSES

The sign of R_f in Eq. 1 is determined by the relative magnitudes of S_f^n and $k S_s^n$. When $S_f^n \leq k S_s^n$, then $R_f \leq 0$. In these three cases, the sign of R_f indicates one of three net processes. A negative sign means

a net dark process; a positive sign, a net light process; and equality, a net of neither dark nor light process but what I will call a null process. The use of a signed R_f to indicate the type of process can be misleading unless the meaning of the sign is remembered. To avoid confusion, a net dark process will be indicated by R_{df} , a net light process by R_{lf} , and a null process by R_{0f} . A general reference to the visual response will be indicated by R_f .

III. THE FIRST RULE OF INVARIANCE

If the luminances S_f and S_s are both changed proportionately by a factor F , then they would become $F S_f$ and $F S_s$. When raised to the power n , they would become $(F S_f)^n$ and $(F S_s)^n$ or the equivalent expressions $F^n S_f^n$ and $F^n S_s^n$. Hence:

(A) When $S_f^n > k S_s^n$,

then $F^n S_f^n > k F^n S_s^n$, and $R_f = R_{lf}$

(B) When $S_f^n = k S_s^n$,

then $F^n S_f^n = k F^n S_s^n$, and $R_f = R_{0f}$

(C) When $S_f^n < k S_s^n$,

then $F^n S_f^n < k F^n S_s^n$, and $R_f = R_{df}$

The invariance expressed by Propositions A to C asserts that if a particular configuration of surround and focal luminances elicits a particular net process, then for any change in F , the same net process will occur. But a change in F is a change in relative illuminance. Hence, the net process, whether light, dark, or null, is invariant over illumination.

IV. VISUAL ACTIVITY WITH CHANGES IN ILLUMINANCE

The underlying visual activity R_f is specified for a particular configuration of surround and focal luminances by Eq. 1. Correspondingly, the visual activity $R_{f'}$ is specified for a change F of illumination by:

$$R_{f'} = \frac{c F^n S_f^n - c k F^n S_s^n}{(1 - k^2)}$$

Fig. 1. Sampling of outcomes for contrast experiments, with log contrast ratio as the parameter.

$$= F^n \frac{c(S_f^n - k S_s^n)}{1 - k^2} = F^n R_f. \quad (2)$$

In log form this becomes:

$$\log R_f' = \log R_f + n \log F, \quad (3)$$

where $\log F$ may be taken to be equal to $\log S_f' - \log S_f$, or alternatively to $\log S_s' - \log S_s$ or $\log E'$ (illuminance) - $\log E$.

Equation 3 describes a linear function with y-intercept of $\log R_f$, a variable F , and slope of $n = .33$ when $R_f \neq R_{0f}$ and slope of $n = 0$ when $R_f = R_{0f}$. It must be remembered that the contrast ratio (CR), the ratio of surround to focal luminance, and k are constant over such a function.

It should be noted that $\log R_f'$ may take negative values when R_f and/or F are less than 1, but this occurrence of negative signs would give no indication of the type of net process.

Equation 3, taken in conjunction with Eq. 1 and Propositions A to C, sets forth all possible outcomes of any contrast situation. A sampling of these outcomes is graphically shown in Fig. 1, where $\log CR$ is the parameter of each function.

The abscissa in Fig. 1 was labeled log illuminance and the distance between any two points on it would give a value for $\log F$. The ordinate was scaled separately for the light, dark, and null processes in order to maintain a clear distinction among them.

V. THE SLOPE OF A BRIGHTNESS FUNCTION AND THE SECOND RULE OF INVARIANCE

Rearranging the terms in Eq. 3 and substituting BR' (brightness response) and

BR for R_f' and R_f , respectively, which they directly measure, then:

$$\frac{\log BR' - \log BR}{\log S_f' - \log S_f} = n \quad (4)$$

where $\log S_f' - \log S_f = \log F$, and k and $CR (S_s/S_f)$ are constant.

Because brightness responses would be expressed, presumably, in positive numbers, the type of net-process would be indicated by the sign of n . Hence, n could take values $-.33$, 0 , or $+.33$.

If the ordinate in Fig. 1 were replaced by a continuous arithmetic scale called log brightness response, the descending functions in the lower part of the figure would have slopes with "−" signs instead of "+" signs.

Equation 4 demonstrates that the slope n of any brightness function is simply equal to the ratio of the difference between two log brightness responses and the difference between the log luminances of the two focal regions. The truth of the expression is conditional upon CR and k remaining constant.

It should be noted, finally, that Eq. 4 does not require the evaluation of k .

Equation 4 asserts a second rule of invariance: When CR and the spatial arrangements of a contrast situation are constant, the rate of change in brightness ($\log BR' - \log BR$) is invariant over changes in illuminance and is always equal either to one-third the change in illuminance on a log-log plot or to zero for changes in illuminance. From this it follows that changes in the brightness responses can be predicted from the focal luminances, are solely dependent on illuminance, are not dependent on the evaluation of k , and therefore are also independent of induction effects. It would also be correct to say that the induction effects are invariant over changes in illuminance.

VI. THE FORM AND DISTRIBUTION OF BRIGHTNESS FUNCTIONS WHEN k IS UNKNOWN

Following from the first and second rules of invariance, a number of tests of the model can be made even though k is unevaluated but is known to be constant. Whenever a contrast experiment can be organized with brightness responses as the dependent variable, illuminance or focal luminance as the independent variable, and CR as a parameter, then the predicted outcomes on a log-log plot like Fig. 1 would be:

(A) When k is constant over a function:

(1) The function will be linear.

(2) The slope of the function will be $.33$, $-.33$, or 0 .

(B) In addition, when k is constant over a set of functions:

(3) Only one of the functions may have a slope of 0 .

(4) There will be a perfect negative ordinal correlation between sign and CR . In Fig. 1 note that CR s in the light process or "+" region have comparatively small values, whereas CR s in the dark process or "−" region have comparatively large values. In the null process or "0" region, the value of CR is intermediate.

(5) There will be a perfect negative ordinal correlation between the y-intercepts of the functions and CR . This is readily apparent in Fig. 1. Starting at the top of the figure, CR is relatively small. Moving downward, CR increases. At the same time, the y-intercepts of the downwardly displaced functions necessarily decrease in value.

The five predicted outcomes listed in this section require the dependent variable to be a brightness response or to be transformed to a brightness response. In experiments requiring S_s to give magnitude estimates of the brightness of a focal region, those responses are usually considered to measure brightness responses and are so considered by Jameson and Hurvich (1961a).

When S_s are required to adjust a focal luminance in accordance with some criterion, however, that adjusted focal luminance S_f is not to be confused with the brightness response R_f . When data are in the form of adjusted focal luminances, k must usually be evaluated in order to test Jameson and Hurvich's (1964) model.

VII. k AND THE y-INTERCEPT $\log R_f$

The correct placement of a contrast function in a space like that of Fig. 1 depends on the evaluation of k . With k evaluated, the y-intercept $\log R_f$ may be determined. In other words, unlike its slope, the y-intercept of a brightness function depends on k .

In constructing Fig. 1, k was given the value of $.606$. That value of k determined the exact location and spacing of the lines found in the space of the figure. Had k been given a larger value, each of the lines in Fig. 1 would have been displaced downward by different distances. Had k been given the value of $.09$, for example,

all of the lines in Fig. 1 would have been displaced upward into the light-process region. With $k = .09$, it would have taken a $\log CR > 3.1$ to generate a function falling into the dark-process region. With k unknown, it would not be possible to predict where in the space of Fig. 1 a set of brightness functions should fall.

(1) k as a Symmetrical Constant

The model gives k the same value for the direction focal to surround as for surround to focal. The basis for this assumption of symmetrical effects is not self-evident. (For example, it would mean that a small focal region would have the same induction effect on a large surround region as the large surround had on the focal region.) Were the two constants to be different, then Eq. 1 would become:

$$R_f = \frac{c(S_f^n - k_{s \cdot f} S_s^n)}{1 - k_{s \cdot f} k_{f \cdot s}}, \quad (5)$$

where $k_{s \cdot f}$ is the induction coefficient for the surround on the focal region and $k_{f \cdot s}$ is the induction coefficient for the focal on the surround region.

Despite this difficulty, as a first approximation for experiments where surround and focal areas are similar it might be true that k could be evaluated, following the assumption that $k_{s \cdot f} = k_{f \cdot s} = k$.

(2) The Evaluation of k for Class I Experiments

Since no a priori method of evaluating k was suggested, it must be evaluated from contrast data. Jameson and Hurvich (1964) evaluated k for two classes of experiments. In this section, Class I experiments will be described. In Section XII, Class II experiments will be described.

In Class I experiments, a focal and surround region were presented to one eye and a second configuration composed of a focal and surround region was presented to the second eye. One of the four different luminous regions was then varied until the O reported that the two focal regions were equal in brightness. (One variation of this paradigm places both configurations in a single eye.)

When the two focal regions appeared equal in brightness, it was assumed that the corresponding net underlying physiological responses in the two eyes were also equal. If, for example, given a focal and surround luminance in the left eye, the O adjusted the surround region in the right eye until the two focal regions appeared equal in brightness, then $R_{f\ell} = R_{fr}$, where ℓ and r refer to left and right eyes (or left and right sides, as in Hess and Pretori).

It would then be true that:

$$R_{f\ell} = \frac{S_{f\ell}^n - k_{\ell} S_{s\ell}^n}{1 - k_{\ell}^2} = \frac{S_{fr}^n - k_r S_{sr}^n}{1 - k_r^2} = R_{fr} \quad (6)$$

On the assumption that $k_{\ell} = k_r = k$, the equation can be solved for k . Thus,

$$k = \frac{S_{f\ell}^n - S_{fr}^n}{S_{s\ell}^n - S_{sr}^n} \quad (7)$$

Jameson and Hurvich (1964) cited two Class I experiments as evidence for their model: Hess and Pretori (1894) and Jameson and Hurvich (1961a).

VIII. HESS AND PRETORI'S⁴ EXPERIMENTS

In most of Hess and Pretori's (1894) experiments, the O was presented with two adjacent squares, each surrounding a smaller square. The display was viewed *monocularly* for 1 sec, with a fixation point at the middle of the boundary between the two surround fields. Each infield was 1.12 deg, each surround, 11.3 deg; the distance from the fixation point to the nearest edge of a focal region was probably 5.15 deg; and the total angular distance of the display from side to side was 22.6 deg. The O's task was to adjust the surround on the right side until the two focal regions were equal in brightness. An experimental series consisted of a number of match responses for a constant pair of surround and focal luminances on the left side and for a number of different focal luminances on the right side. The experiment was then repeated for a different combination of surround and focal luminances on the left side. With this procedure, 17 series were run in one experiment and 13 series in a second. The results were reported in Hess and Pretori (1894, Tables 1 and 2).

Table 1 below is a frequency distribution of k values for the 17 series from Hess and Pretori's Table 1. Each column is labeled with the series number and with the constant left side $\log CR$ for that series. These CRs varied over the 17 series from high CR (high surround to low focal luminance) in Series 1 to low CR (low surround to high focal luminance) in Series 17. The starred columns were the series probably used by Jameson and Hurvich (1964) in the test of their model. The k s were evaluated from Eq. 7 above.

Because the spatial arrangements were the same throughout Hess and Pretori's

(1894) experiment, Jameson and Hurvich's (1964) model requires k to have a single fixed value over the entire experiment. The k s in Table 1 do not take a single fixed value. Within each column, there is considerable variation and over the table the k s vary from values less than 0 to greater than 1.

It has been assumed here that the model does not allow k to take values less than 0 or greater than 1.⁵ Of the 141 k s in Table 1, 55, or nearly 40%, fall into that category and therefore are presumed inappropriate.

The model requires k to be independent of the level of the surround and focal luminances. In Table 1, the distribution of numbers indicates a probable positive correlation between the CRs and k , the value of k being large when the value of CR was large and small when the value of CR was small. This correlation can also be observed in the tendency for the medians to decrease from Series 5 to 17. (Inappropriate values of k were excluded from the calculation of the medians.)

In addition to a probable correlation between the CRs and the k s over the columns of Table 1, there also seemed to be a correlation between CR and k within the columns of the table. These rank-order correlations are given at the bottom of the columns. (These correlations were formed between k and those right-side CRs where the focal luminance was greater than the left-side focal luminance. When the right-side focal luminance was smaller than the left-side luminance, the correlations seemed to be of a different order. But there were not enough cases to report them.) It may be that these correlations are not reliable. Nevertheless, the tendency for k to vary with CR is striking.

Finally, there is one other difficulty. The ratio of surround to focal areas used by Hess and Pretori (1894) was approximately 99:1. For those conditions, can it be assumed that $k_{s \cdot f} = k_{f \cdot s} = k$? Without that assumption, k and therefore R_f cannot be evaluated. (See Section VII-1 above.)

If the variability of k is disregarded, if the improper values of k are overlooked, if the tendency for k to be correlated to CR is not disturbing, and if the assumption that $k_{f \cdot s} = k_{s \cdot f} = k$ is tolerated, then the median k for the entire table is .58. The value of .58 is similar to the value of .60 cited by Jameson and Hurvich (1964) and used by them to evaluate Hess and Pretori's five series of data. Nevertheless, had Hess and Pretori only reported Series 1 through 8, k would have been evaluated from Table 1 as .95. The same data would then have been analyzed with $k = .95$ instead of $k = .60$. Correspondingly, had only Series

Table 1
Observed Values of k (After Hess and Pretori, 1894, Table 1) for Log Contrast Ratios on the Left Side

k Values	1	2*	3	4	5*	6	7	8*	9	10*	11	12	13*	14	15	16	17	Sum
<0		2	2		1													5
0	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	16
.13-.17															2	2		4
.18-.22													1	1	1			3
.23-.27						1	1						1	1	1		2	7
.28-.32												1		2		1		4
.33-.37												1				1		5
.38-.42															1	1	2	5
.43-.47						1		1	2		1		2	1	1	1		10
.48-.52									1		1		1	1				4
.53-.57									3	3	1							7
.58-.62						2		1		2	1	1						7
.63-.67								4			1	2						7
.68-.72								1	2	1								4
.73-.77									1			1						2
.78-.82						1	2	2			1							6
.83-.87					1							1						2
.88-.92					1	2	1				1							5
.93-.99								1	1		1							3
1.00					1													1
1.01-1.49				2	5	4	3		1									15
>1.50	2	6	4	2	3		2											19
Median	-	-	-	-	.90	.61	.80	.66	.56	.58	.62	.64	.40	.31	.25	.32	.32	.58
n					3	7	4	10	10	6	8	7	7	7	7	6	4	141
r					-1.		-1.	-1.	-.03	-.31	-.39	-.72	+.93	+.96	+.1.	+.1.	-.5	
n					2		3	7	6	6	8	7	7	7	7	7	3	

10 through 17 been reported, then that data would have been analyzed with $k = .38$.

Using Eq. 1 and Jameson and Hurvich's (1964) $k = .60$, I calculated and tabulated R_f (see Table A⁶) for each of Hess and Pretori's (1894, Table 1) experimental conditions over the 17 series. In Table A, the columns were labeled as in Table 1 above, but the rows were labeled with the right-side log focal luminance. Hence the calculated R_f s in each column represented equal net visual responses and consequently should have had the same value and the same sign. In fact, R_f s became increasingly positive from the top to the bottom of Columns 1-8 and were U-shaped from the top to the bottom of Columns 12-17. Moreover, in Columns 5, 6, 8, and 9 there were a small number of shifts in sign.

Hess and Pretori (1894, Table 2) replicated part of their first experiment, but only the part corresponding to Columns 9-17 in Table 1. For those conditions, the CRs were small and therefore do not test the matter of "+," "0," and "-" brightness functions.

IX. COMPATIBILITY OF THE MODEL WITH HESS AND PRETORI'S DATA

In view of the failure of the model to predict Hess and Pretori's k s and R_f s, it might seem that the model and Hess and Pretori's data are wholly incompatible. That is not the case.

Jameson and Hurvich (1964, Fig. 1) replotted Hess and Pretori's (1894,

Table 1, Series 2, 5, 8, 10, 13) data, plotting the right-side log CRs within a series on the ordinate and the right-side log focal illuminances on the abscissa. These data points generated a curve that was an equally-appearing brightness function. Replotting these curves, I found that two of them were negatively and three of them positively decelerating. The former corresponded to curves with large CRs, the latter to curves with small CRs.

With k arbitrarily given some value from .20 to .90, Jameson and Hurvich's model would also generate both positively and negatively decelerating curves on the same plot. (See, for example, Jameson & Hurvich, 1964, Fig. 2, where $k = .60$.) In that limited sense, therefore, Hess and Pretori's data do confirm by implication the major prediction of the model: that raising the luminance of the surround and focal regions by the same factor may *decrease* the brightness of the focal region when CR is relatively large in value, and may *increase* the brightness of the focal region when CR is relatively small in value. These opposite effects, occurring by implication in Hess and Pretori's data, give support, if not to Jameson and Hurvich's specific model, then at least to a class of similar models. It should be noted, however, that Hess and Pretori (1894, p. 14) questioned some of the data points on which the finding of clearly positive and negative functions depended.

X. JAMESON AND HURVICH'S EXPERIMENT

Jameson and Hurvich (1964) tested their

model against data of their own (Jameson & Hurvich, 1961a. For more details of the experiment see also 1961b, in particular, and 1964). In their experiment, they constructed a cross on a mid-gray background. The cross was composed of five gray squares: a white square in the center and around the center a light-gray square on the right, a mid-gray square at the top, a dark-gray square on the left, and a black square on the bottom. A transparency was made and back-projected on a milk-glass screen. Neutral density filters placed in front of the lens allowed the illumination to be changed over 1.1 log units in three steps. The test-field (TF) squares were each 3 deg on a side. Removed from the space of the TF was a second space with a comparison (CO) rectangle that was 1.75 x 2.4 deg. The surround luminance of the CO was always 1.78 log mL, and its luminance was .5 log mL greater than the highest luminance of any TF square. The CO surround was 145 deg in diam at the eyes. Three Os were required to look back and forth from the bright CO field to the test field and to adjust the CO rectangle to an equal brightness match with the TF square.

For this experiment, Jameson and Hurvich (1964, Fig. 9) published theoretical curves based on Eq. 1 above. They reported using k s between .2 and .4 (Jameson & Hurvich, 1964, p. 153).

The Evaluation of k

In this experiment, each TF square considered as a focal area had a complex

background composed of the larger mid-gray background and four other TF squares. Thus, the display was spatially subdivided into six regions, five of which served as focal regions. In order to evaluate R_f for a TF square, induction coefficients between all possible pairs of regions would enter the equation. That could be a total of $N^2 - 6$ or 30 coefficients, where N is the number of regions. Presumably, k for the induction of the mid-gray background on a TF square would differ from k for the induction of a TF square on the background. k for the induction of the top on the bottom TF square would differ, no doubt, from k for the induction of the top on the center TF square, etc. By some simplifying assumptions due to the symmetry of the display, the 30 possible k s could be reduced to 7 but probably not to less.⁷

Since there are six regions, R_f for one region requires solving six simultaneous linear equations. The general form of this solution would be

$$R_f = A_f S_f^N - \sum_{\substack{i=2 \\ i \neq f}}^N A_{i(f)} S_i^N, \quad (8)$$

where f is one of N (in this case, 6) spatial subdivisions and is arbitrarily valued as 1; i is any subdivision other than f and except that i cannot take the same value as f ($i \neq f$) i takes values from 2 to N ; A_f and A_i are fractions with summed products of induction coefficients in the numerator and denominator; S_i^N is as before the n^{th} or one-third root of the luminance of the i^{th} region.

The expansion of the right side of Eq. 8, even with the simplifying assumption of 7 instead of 30 coefficients, would yield numerators and denominators containing nearly 100 terms. For a set of appropriate constants A_f and A_i , Eq. 8 could be used to solve for the center square. For a second set of constants, it could be used to solve for the remaining four squares. Even with this last simplification, the evaluation of R_f for the five TF squares would be a considerable task.

The extent to which Jameson and Hurvich (1964) approximated the requirements of Eq. 8 in evaluating the five R_f s is not clear to me. Moreover, given the difficulty of evaluating k in simpler situations, one might choose to avoid the problem altogether for complex displays like Jameson and Hurvich's (1961a) cross.

Tests of the Model with k Unknown

For a change F in illumination, Eq. 8 would have the form of Eqs. 2 and 3. The two principles of invariance and the

Fig. 2. Brightness functions for five test-field squares, with log contrast ratio as the parameter (after Jameson & Hurvich, 1961a).

predicted outcomes described in Section VI would also apply.

In an extension of their experiment, Jameson and Hurvich (1961a) transposed their match responses into brightness responses (magnitude estimates). Hence, their data can be tested against the predicted outcomes listed in Section VI. It should be noted, however, that though the CRs remained constant as illuminance was raised, CR itself cannot be evaluated for the five TF squares. It is probably true, however, that the CRs were negatively correlated to the luminances of the TF squares at each level of illuminance. Finally, although k s were not evaluated, they would have remained constant over the experiment.

In Fig. 2, Jameson and Hurvich's (1961a) data transformed to log magnitude estimates are plotted against log TF-square luminance. First, the trends of the data points in Fig. 2 do seem to be linear. Second, the best-fit straight lines have slopes of .24, .21, .34, .06, and -.66. Whether these are or are not chance deviations from $\pm .33$ or 0 cannot be determined because the relevant error terms were not available. Third, if it is assumed that the k s are the same for each of the four TF squares surrounding the white square, then for these four TF squares the remaining predictions in Section VI can be tested. And the data do reasonably satisfy those remaining predictions. In summary, although R_f s and k s could not be examined, the data give some measure of support if not to Jameson and Hurvich's specific model then at least to a class of similar models.

XI. HEINEMANN'S EXPERIMENT

Brown and Mueller's (1965, pp. 231-233) citation of some of Heinemann's data as supporting Jameson and Hurvich's (1964) model is simply

mistaken. In some of Heinemann's experiments, a test disk and test annulus surrounded by darkness were presented to one eye and a match disk surrounded by darkness was presented to the second eye. The O adjusted the match disk until it equalled the test disk brightness. When the E gave the test surround the same luminance as the test disk, the test stimulus was, in effect, a large disk surrounded by darkness. Under those conditions, as the "large" disk luminance was increased, some match responses decreased. This occurred at two places in the data of one but not of a second O. Neither Jameson and Hurvich's nor any other model, I would think, would predict this curious but probable error fluctuation cited by Brown and Mueller.

In the same paper, however, Heinemann did report an experiment that does test some aspects of Jameson and Hurvich's model. In that experiment, Heinemann (1955, Fig. 4, and ADI Document No. 4548, Table 3) approximated a number of Hess and Pretori's (1894, Table 1) experimental conditions. Heinemann presented one disk-annulus configuration to the left eye and a second of the same size and shape to the right eye of two Os. Fixation was maintained between the two configurations. The O's task was to adjust the surround luminance in the right eye until the two focal regions were equal in brightness. The other three luminance levels were set by the E.

When Heinemann's data were replotted as Jameson and Hurvich (1964, Fig. 1) replotted Hess and Pretori's (1894) data, all of the curves took U shapes.⁸ These data, therefore, supported neither Jameson and Hurvich's model nor the general class of which Jameson and Hurvich's might be considered an instance. Moreover, when k s were calculated from Heinemann's data and given tabular form⁹ as in Table 1 above, the k s again varied widely, rather than taking a single value. Again, a correlation was found between CR and k . This time, however, the k s became systematically larger instead of smaller as log CR was decreased. Within each column, log CR for the right eye was positively correlated to k , although the magnitude of the correlation decreased as log CR for the left eye was decreased. All of these seemingly systematic tendencies again made the evaluation of k a dubious enterprise.

The evaluations of R_f ¹⁰ also departed systematically from the model's predictions. The R_f s in each column (as in Table A described above) were not the same, had different signs, and seemed to exhibit systematic variations.

XII. CLASS II EXPERIMENTS

Heretofore, experiments were

considered in which different focal-surround configurations were presented to each eye (or a pair to the same eye, as in Hess and Pretori). What characterizes Class II experiments is the presentation of a focal-surround configuration to one eye and a focal region surrounded by darkness to the second eye. The O then adjusts one of the three luminances until the two focal regions appear equally bright. In Diamond's (1953, 1955) experiments, for which Jameson and Hurvich (1964) evaluated k and R_f , the Os adjusted the left-eye focal luminance, the surround of which was always darkness. This arrangement creates an insuperable difficulty in evaluating k and R_f .

Consider again Eq. 6. The right side of the expression could be positive (light process), zero (null process), or negative (dark process) as when $S_{f_r}^n \leq k_r S_{s_r}^n$. On the other hand, the left side of the expression could only be positive or zero, never negative, because the focal region was surrounded by darkness (k_l , $S_{s_l}^n$, and $k_l S_{s_l}^n$ equaling zero). In Diamond's experiments, if the experimentally fixed surround-focal combination in the right eye did give a net dark process, then on the match side, where only a light or null process could occur, any adjusted focal luminance would constitute a nonsense response. If one knew, even after the fact, which experimentally fixed surround-focal combinations had given net dark processes, then the nonsense responses could be discarded. The trouble is that this knowledge depends on the empirical evaluation of k and the evaluation of k depends on the very data that may be nonsense.

R_f and k might be evaluated for some of Diamond's data, i.e., for those cases where CR was relatively small because $S_{s_r} \leq S_{f_r}$ and where, therefore, only null or light processes could occur. But because k may be systematically correlated to the CRs, an evaluation of k for a limited set of CRs might bias its value.

There is another reason why Diamond's data are not useful. In selecting only those data for which $S_{s_r} \leq S_{f_r}$, it would not be possible to test the unique character of the model: All of the functions would necessarily be "+" or "0." No "-" functions could occur.

In Leibowitz et al (1953), the third of the Class II experiments cited by Jameson and Hurvich (1964), the E fixed the left-side focal luminance S_{f_l} , and it was surrounded by darkness ($S_{s_l} = 0$). Hence, only light processes could occur in the left eye. The O then adjusted to a match the luminance of the focal region S_{f_r} in the right eye, which was surrounded by some other experimentally fixed luminance S_{s_r} .

Many of the objections cited above to the use of Diamond's experiments apply also to this arrangement: (1) Because no dark processes could occur, the data could not test for the uniqueness of the model. (2) Evaluations of k might be biased by the limitations on CR.

It might be useful, nevertheless, to examine a limited test of these data. For a given value of S_{f_l} , the ratio of S_{s_r} and adjusted S_{f_r} yield a CR. If these CRs are plotted against S_{f_r} , then the derived curve is an equal-appearing brightness function. Since S_{f_l} was held constant and spatial separation between f_r and s_r was the independent variable, there would be as many of these equal-appearing brightness functions as there were different separations. According to the model, all of these functions should be positively decelerating curves on a log-log plot. The data do fluctuate in that manner. But the fact of the fluctuation is not very interesting. The fluctuation simply means that if the data could have been arranged as in the top half of Fig. 1, then the functions would have been monotonically positive but would not necessarily have been linear or have had the same slopes.

A similar test can be made with some of Diamond's (1953) data. As mentioned above, these would be the data for which the experimentally fixed CRs were ≤ 1.0 . Because the Os adjusted the region surrounded by darkness, the cube-root of that adjusted luminance would be equivalent to the brightness response (k and S_s being zero in Eq. 1). A set of brightness responses could be plotted, for example, against S_{f_r} on the abscissa. Those experimental conditions generating a common CR would form the parameter of each log-log plot. Since k was constant, though unevaluated, for all of those conditions, these functions should be positive and linear and should have a slope +.33 as in the top half of Fig. 1.

Diamond's (1953) data do tend to fluctuate in this manner. That fact has some interest, although it hardly pertains to the affair of "-" functions.

XIII. GENERAL DISCUSSION

Jameson and Hurvich (1964) have described a model that generates a family of linear functions when CR (the ratio of surround to focal luminance) is the parameter of the function and when brightness responses are plotted against illuminance on a log-log plot. The expectation of linearity depends on keeping the spatial arrangements of the contrasting regions constant over the changes in illuminance. In the model, the slopes of the functions may take one of only three values, .33, -.33, and 0.

What sign a function will have in an experiment would depend on CR and on the magnitude of an empirically derived constant k . Moreover, within the coordinate space defined by apparent brightness on the ordinate and by illuminance on the abscissa, the expected location of a brightness function would depend on CR and on the appropriate evaluation of k .

In this paper, it has been shown that k could not be evaluated using the terms of reference of Jameson and Hurvich's (1964) model. Without k , presumably the present form of Jameson and Hurvich's (1964) model must be said to be invalidated. Nevertheless, even if the evaluation of k were deemed to be improbable, that fact would not necessarily invalidate the general class of models of which Jameson and Hurvich's (1964) model is an instance.

What is unique about the general class of models under consideration is embodied in two principles of invariance. In the first, at least two different processes are described, one a light, the second a dark process. The light process is manifested by a brightness function that, because of its relatively small CR and the spatial arrangements of the contrasting regions, is monotonically positive over all possible increases of illuminance. The dark process is manifested by a brightness function that, because of its relatively large CR and the spatial arrangements, is monotonically negative over increases in illuminance. Thus, depending on CR and the spatial arrangements, a brightness function will be invariantly positive or invariantly negative over increasing illuminance.

In the second principle of invariance, the rate of change of all brightness functions on a log-log plot will be invariant over changes in illuminance when CR is the parameter of the function. This would mean that all brightness functions would be linear and except for sign would have the same slopes.

A number of contrast experiments were cited by Jameson and Hurvich (1964) and Brown and Mueller (1965) as embodying these principles. Of those, the experiments of Diamond (1953, 1955) and Leibowitz et al (1953) were not very useful for testing Jameson and Hurvich's model or even a class of models that embodied the two principles of invariance.

For two other experiments, however, brightness functions were observed (Jameson & Hurvich, 1961a) or implied (Hess & Pretori, 1894), which were monotonically negative as well as positive over increasing illuminance on a log-log plot with CR as the parameter and the spatial arrangements constant. Both of these experiments, therefore, supported

the first principle of invariance. Neither of these experiments, however, gave clear support to the second principle of invariance, which requires the functions to be linear and to have slopes with the same absolute value. In contrast to these two experiments, both of which gave some support to the general class of models, Heinemann's (1955) partial replication of Hess and Pretori appeared to give no support.

It would seem, therefore, that the very evidence that has been cited as supporting Jameson and Hurvich's model actually invalidates it. This same evidence gives only fragmentary support to some still-unspecified model that would embody the two principles of invariance.

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- the focal luminance was very high and the surround luminance was very low, the net visual activity for those luminances and the appropriate spatial arrangements would be that of a dark process. This would contradict the sense of k in that a minus k should mean an excitatory effect from the surround.
- Finally, if k were allowed to take values greater than 1.0, the denominator in Eq. 1 would necessarily be negative. This would mean that the net visual activity would be a dark process when surround luminance was very low with respect to focal luminance and would shift to a light process as surround luminance was increased. This expectation would run in the face of both common sense and the empirics of simultaneous contrast.
- There is nothing in Jameson and Hurvich's writings about their model to suggest that any of these three possibilities would be acceptable to them. Even if k were allowed to take values less than 0 and greater than 1.0, nevertheless, so long as spatial arrangements were constant over an experiment, k should remain fixed in value.
6. Table A, giving these R_{fs} , may be obtained free of charge from the editorial office of this *Journal*, Document No. P835-1.
7. These k s might be for the induction exerted between squares with abutting edges, squares with touching corners, squares separated by a square, center square and background; background and center square; other squares and background; background and other squares.
8. Fig. 3 showing these curves may be obtained free of charge from the editorial office of this *Journal*, Document No. P835-2.
9. Table B giving these k s may be obtained free of charge from the editorial office of this *Journal*, Document No. P835-3. The assumption that $k_{f \cdot s} = k_{s \cdot f} = k$ was perhaps more tenable in this analysis than in the analysis of Hess and Pretori because the ratio of surround to focal area used by Heinemann was closer to 1.0, being approximately 3.0.
10. Table C giving these R_{fs} may be obtained free of charge from the editorial office of this *Journal*, Document No. P835-4.

NOTES

1. This study is part of a research project which is supported by a grant from the National Research Council of Canada, Grant No. APA-143.
 2. Address: Department of Psychology, York University, Downsview, Ontario, Canada.
 3. For the derivation of this equation, see Jameson and Hurvich, 1964, p. 139.
 4. Flock et al's recent (1969) translation is available free of charge to interested investigators by writing to the Department of Psychology, York University, Downsview, Ontario, Canada.
 5. With reference to Eq. 1, if k were allowed to take values less than 0 but not less than -1.0, the numerator and denominator would necessarily be positive. Then, for the appropriate spatial arrangements, the effect of the surround on the focal region (and of the focal region on the surround) would be excitatory rather than inhibitory at all levels of surround luminance. For those conditions, no matter what the magnitude of CR, a dark process could not occur.
- If k were allowed to take values smaller than -1.0, then the denominator of Eq. 1 would necessarily be negative, the numerator necessarily positive. This would mean that the net visual activity would be a dark process for all levels of surround luminance. In other words, even though

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