BRIGHTNESS CHANGES IN A COMPLEX FIELD WITH CHANGING ILLUMINATION: A RE-EXAMINATION OF JAMESON AND HURVICH’S STUDY OF BRIGHTNESS CONSTANCY

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A configuration of 5 Munsell neutral gray squares on a gray and white background and a modulus were haploscopically presented to 12 Ss. Each S made brightness estimates for the squares, their background, and the illumination of total field when illuminance was varied in 3 steps over 1.2 log units. Linear brightness functions were obtained on a log-log plot, where brightness estimates were plotted against illuminance. Mean slopes systematically decreased as the reflectance of test region became lower, but none were negative. The failure to find negative slopes would be a difficulty for Jameson and Hurvich’s opponent-process model. Some problematic issues concerning brightness constancy and contrast were discussed.


Recently, theories of brightness constancy have been increasingly tied to the literature on brightness contrast, especially to the literature based on a simple three-element stimulus arrangement (a test-field, inducing-field, and a dark surround) (Brown & Mueller, 1965; Cornsweet, 1970; Freeman, 1967). That is probably unfortunate. As Flock and Noguchi (1970) have proposed, brightness constancy really refers to the fact that the achromatic colors of surfaces supposedly remain phenomenally invariant over changes of illumination in a complex environment. It is not clear, therefore, that a three-element situation is an appropriate situation for testing general theories of brightness constancy. In fact, much of the data based on the three-element situation may not be applied to the prevailing theories of brightness constancy. More research, therefore, should be required for brightness constancy and contrast in a complex field.

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3 This phenomenon is also referred to as lightness (or whiteness) constancy. It may be assumed that there are two different responses: (1) to lightness (black-gray-white quality); and (2) to brightness (dim-bright quality) of either surfaces or illumination. Since brightness constancy really refers to lightness, not brightness, the use of the term lightness constancy would be preferable when observers can make an explicit distinction between lightness and brightness. In the present experiment, however, there was no explicit distinction between lightness and brightness, as had been in Jameson and Hurvich’s (1961a). Although the term brightness constancy which is the customary usage will be used in this paper, brightness implies not only the dim-bright quality but also the black-gray-white quality.
An interesting experiment on brightness constancy was performed by Jameson and Hurvich (1961a) using a complex field. In their experiment a cross composed of five different gray squares from black to white was presented against a mid-gray background under three levels of illumination covering a range of 1.1 log units. Their three observers were required to adjust a comparison spot of light surrounded by a very bright and very large region until it matched an indicated square of the cross. The observers made two brightness matches for each of the 15 conditions (5 squares×3 illumination levels). In an extension of their experiment, the brightness matches were transposed into magnitude estimates of brightness. In Fig. 1, their data transformed to log magnitude estimates are replotted against log relative illuminance. Each of the five curves in Fig. 1 describes the brightness response for a test square in the cross as illuminance was varied. As is seen in Fig. 1, as the level of illuminance was raised, the curves diverged. This divergence, they emphasized, is an insuperable difficulty for the theories of Helson (1943), Wallach (1948), and Woodworth and Schlosberg (1954). In place of these theories Jameson and Hurvich (1961b, 1964) proposed a model that is consistent with opponent-process theory (For a review of this model, see Flock, 1970).

The brightness functions obtained by Jameson and Hurvich (1961a) were shown by Flock (1970) as power curves. The slopes (or the exponents) of the best-fit straight lines were .24, .21, .34, .06, and −.66 for the five successively darker squares. In other words, when illuminance was varied over 1.1 log units in three steps, the regions with highest luminance became lighter; the region with lowest luminance became darker; and the region with intermediate luminance did not change.

In their explanation of the negativity of the slope Jameson and Hurvich pointed out that illumination of an area (for example, a mid-gray background on three sides and a white square on a fourth side) surrounding a focal area (a patch of black) induces blackness in the focal area in proportion to the magnitude of the surround excitation; and the effectiveness of the brightness decrement (or blackness increment) is greater, the smaller the direct response of the focal area. The response of both the focal area and the surround area is determined in part by a transform such as the cube root of the stimulus luminance (Jameson & Hurvich, 1964, p. 147). It would then be the case for this model that as illuminance was simultaneously raised on both a higher-luminance surround and a lower-luminance focal area, the brightness decrement in the focal area would tend to be increased (Jameson & Hurvich, 1961a, pp. 178–179). As a general rule, therefore, as the level of illuminance is raised, a region sur-

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4 Jameson and Hurvich (1961a) used the language of black and bright interchangeably, where more black and less bright were synonymous as were less black and more bright.
rounded by brighter regions should appear less and less bright (or more and more black).

More recently, Flock and Noguchi (1970) have replicated the Jameson and Hurvich (1961a) study. To enhance the possibility of observing negative slopes, a number of changes in experimental arrangements and procedures were made: (1) The number of square regions in the Jameson and Hurvich cross was increased from 5 to 7. (2) A black and white background as well as the intermediate gray background were used to increase the contrast ratios between the darkest squares and their backgrounds. (3) The range of illuminance was increased from 1.1 to 1.9 log units and the number of illuminance steps was increased from 3 to 7. (4) The squares in the cross were made angularly smaller than the ones used by Jameson and Hurvich. (5) The sample was increased from 3 to 12 Ss. (6) The method of magnitude estimates was used in order to avoid possible artifact from a matching technique.

Despite such efforts to maximize the probability of observing negative slopes, none were observed for any S at any treatment level.

Masuda (unpublished study, 1969) attempted to find negative slopes under the experimental conditions similar to those in Flock and Noguchi's (1970) experiment. He also failed to observe negative slopes. In his experiment, however, a few of Ss gave a tendency that the black square appeared darker (or more black) when the levels of illuminance were very low. Saunders (1968) also showed evidence implying such an anomalous tendency: An over-all increase of illumination on both the test and surround fields would cause a brightness decrement of the test field when the test and surround fields were relatively low in luminance. These studies suggest that, in order to find negative slopes, a further replication of Jameson and Hurvich's (1961a) study should be made under conditions where the level of illuminance is relatively low and the range of illuminance is relatively narrow, as was in Jameson and Hurvich's.

Therefore, the experiment described below was designed to replicate Jameson and Hurvich's study under the conditions of illuminance mentioned above. In the previous studies (Jameson & Hurvich, 1961a; Flock & Noguchi, 1970), brightness matches or magnitude estimates were made exclusively for 'focal' regions (squares in a cross), and not for other regions. In the present experiment, the Ss were required to make judgments for the brightnesses of the background surrounding cross and the over-all illumination of total circular field as well as the brightnesses of the five squares in the cross.

**Method**

**Subjects**

Twelve Ss, ten undergraduates and two staff members, participated in the experiment. Their median age was 22, three of them being female. All Ss had normal visual acuity in each eye, although six of them wore glasses.

**Apparatus**

A cross-shaped configuration composed of five Munsell neutral (N) grays was mounted on a Munsell N gray background. (Locations of these five grays, their Munsell values, and their log relative luminances are shown in Table 1.) It was mounted frontally at a viewing distance of 172 cm and was viewed under constant illumination by the left eye through a circular aperture. Under these conditions the background luminance was .65 log nit (cd/m²). The three grays in the vertical shaft of the cross from top to bottom gave luminances of .43, 1.00, and 1.60 log nit. The luminances of the two grays to the left and right of the center gray were .04 and .80 log nit. Each patch of gray, measuring 3 cm on a side, subtended approximately 1 deg of arc and the total angular diameter of the dis-
play, including the configuration and the background, was 7 deg.

A Super Cabin II projector with a Kondo halogen lamp (AC 24-V, 150-W) and a lens with a focal length of 100 mm illuminated the display. A neutral density filter with a density of 1.6, manufactured by Hoya Glass, was placed in front of the left eye. This left eye field or reference field will be referred to as the modulus field (MF).

An identical arrangement was constructed for the right eye. By introducing neutral density filters (with densities of 2.2, 1.6, and 1.0) in front of the eye, the illumination of the right eye could be varied over three equal steps. These log steps as calibrated with a Sanso photometer (similar to a Pritchard Spectrophotometer) and expressed as luminances of the white square in the center of the cross were: .42, 1.04, and 1.64 log nit. The luminances of the gray background for the three illuminance levels were 1.98, .61, and 1.20 log nit. The range of illuminance was, therefore, approximately 1.2 log units.

In addition to the configuration of gray patches on a gray background, an identical display was made with Munsell N papers from the same dye batches but with a white background (Munsell N). The luminances of white background for the three illuminance levels were .48, 1.08, and 1.70 log nit. The right eye field is referred to below as the test field, and the individual patches of gray in the cross as the TF squares.

Although these arrangements of the apparatus produced a dichoptic viewing situation, the apparatus was arranged so that the MF squares and the TF squares could not be imaged in the fovea simultaneously. A chin- and head-rest could be adjusted to keep the S’s eyes at the level of the eye-pieces. And each eye-piece was individually adjustable.

‘Almost the same apparatus has been described in more detail elsewhere (Flock & Noguchi, 1970).

Procedure

On each trial S was asked to look at a particular square, the background, or the total field in the MF, to let its brightness equal 100, and then to indicate the apparent brightness of the corresponding area in the TF by assigning a number to it. (The corresponding TF square was identified by its location.) The S was allowed to look back and forth from MF to TF. The instructions before his initial judgment were: Remember, you are to assign numbers proportional to your impression of the brightness of each of squares, background, or total field.

The Ss were given practice in making magnitude estimates and were given example like the following: Keep in mind that each of the squares in the cross, the background, or the total field in the left eye is always assigned the number 100. If a corresponding area on the right appeared three times as bright, what number would you assign to it? If it appeared one-half as bright? One-fourth as bright?

Further the Ss were instructed not to look at any particular area until the E asked them to do so. The E indicated the particular area after the TF had appeared for about 10 sec.

At the start of the experiment the S was dark adapted for 10 min. An S was then tested for each of the seven TF areas (five squares, background and total field) on either the gray or the white background at each of the three illuminance levels. At the end of the block of 21 trials (7 TF areas × 3 illuminances), which were presented in random order with a 20-sec dark adaptation between trials, S was dark adapted for 5 min in both eyes while background was changed. The same procedure was then repeated for a different background. The order in which the backgrounds were given was counterbalanced over the Ss. The experiment was repeated three times on each S with a 60-min rest-period between experiments.

RESULTS AND DISCUSSION

The linear relations between log magnitude estimate and log illuminance

The experimental design required each S to make 126 judgments: 7 TF areas × 3
illuminances × 2 backgrounds × 3 replications. Each judgment was transformed to a log magnitude estimate and the three replications for each condition were averaged. A straight-line was fitted by the method of least-squares to the log magnitude estimates over the three levels of illuminance for each TF area on each background, a total of 14 curves for each S.

Table 1 gives the mean linear regression coefficients \( b \) for each of the TF regions under each of the background conditions. The \( b \)s in Table 1 are all positive. Had increases in illuminance produced brightness decrements for the black TF square with a large contrast ratio, as Jameson and Hurvich (1961a), Stevens (1961), and Bartleson and Breneman (1967) had predicted, then the \( b \) for the black TF square would have been negative. That was not observed as far as the mean data were concerned.

The decision to represent the data as linear was supported by the large number of very high values for \( r^2 \). \( r^2 \) describes the total variability of an S's judgments over the three illuminance levels which can be attributed to the linearity of those judgments.) For 95 percent, or 159, of the total of 168 curves (14 curves × 12 Ss), 80 percent or more of the individual variance was linear variance. This was also supported by the large number of very low values (closer to zero) for the standard error of estimate.

Table 2 gives the distribution of \( b \)s for the Ss over the 7 TF regions and 2 backgrounds. For the gray background 2 of the total of 84 slopes were negative, though slight (−.02 and −.12), when the TF region was black or the lowest in
luminance. However, for the white background none of the slopes was negative. For the both backgrounds 130 of the 168 curves or 77 percent of them had bs of less than .30 and not less than zero.

These findings in the individual and mean data revealed that for much of the responses under the conditions of this experiment a change upward of 1.2 log units in illuminance elicited an approximately linear increase in the apparent brightness of the TF region; and the rate of change in apparent brightness for 77 percent of the responses varied from 0 to 30 percent of the change in illuminance.

The mean slopes and brightness constancy

Had the judgments been unchanged with the changes in illuminance, which would be predicted if there were perfect brightness constancy, then the bs and bs in Tables 1 and 2 would have been zero. It is seen from Table 1 that the mean slopes, bs, for the five TF squares ranged from .07 to .29 for the gray background, and .09 to .25 for the white background. For the both backgrounds the bs systematically changed as the relative luminance (or reflectance) of the TF square was changed. This is more clearly seen in Fig. 2, where the bs for the five TF squares are plotted against the log relative luminance of the TF squares. Fig. 2 indicates that there is a linear relationship between \( \hat{b} \) (reversely related to the degree of brightness constancy) and the log TF relative luminance. The linear regression coefficients for the gray and white background were .15 (\( r^2 = .989 \)) and .10 (\( r^2 = .941 \)), respectively.

The previous investigators (Helson, 1943; Leibowitz, Myers & Chinetti, 1955; Hano, 1955) reported data showing that brightness constancy would be greater when a white rather than a gray or black background was used. In contradiction to this finding, Flock and Noguchi (1970) found that brightness constancy was greater when the background was gray than when the background was white. Examination of bs in Table 1 and two curves in Fig. 2 indicates the following: brightness constancy was greater with the white background when the luminance of TF square was relatively high; and the constancy was slightly greater with the gray background when the luminance of TF square was relatively low. It was not necessarily true, therefore, that brightness constancy was improved when TF squares were placed on a white background, as compared with those on a gray background. That was dependent on the relative luminance of the TF square.

Fig. 2 also indicates that brightness constancy was better, the darker the TF region, regardless of background. This tendency is consistent with the previous findings by Flock and Noguchi (1970) in a complex field and by Hsia (1943), Kozaki (1963), and Oyama (1968) in a simple field. Such systematic tendency, however, seems to be inconsistent with Cornsweet's (1970) description on the limit of brightness constancy. On the basis of Heinemann's (1955) data on brightness contrast, Cornsweet argued as follows: So
long as the luminances of the test area and its surround did not differ by more than about five-fold, the observers showed very good constancy, even when illuminance was varied over a ranged of 3 log units; on the other hand, if the luminance of the test area was much more or much less than the luminance of the surround, then constancy began to break down. That is, the greater the ratio of luminance of test area to surround, the poorer the constancy (p. 283, see also Fig. 13.4, p. 378). That did not happen in this experiment.

Kozaki (1965) reported data showing that brightness constancy was enhanced when the luminances of co-existent stimuli were higher than the TF luminance. It should be remembered that in the present experiment the five TF squares with different luminances were simultaneously presented, and constancy was greater, the lower the luminance of the TF square. From Kozaki's data it can be predicted that, if the luminance of an indicated TF square is lower than the luminances of the remaining TF squares, constancy will be relatively high, and vice versa. This prediction was verified by the present experiment.

The y-intercepts and brightness contrast

The placements of the brightness functions could have been specified by the mean judgment for a TF region when the illuminance of the TF region was the same as that of the MF. Those y-intercepts (Ŷₘ's) are given in Table 1 (Rows 2 and 4).

Ŷₘ fluctuated around 2.0 for the gray background (Row 2, Table 1). It should be noted that the log modular value of each MF region was 2.0, the background of the MF was gray, the changes in TF-illuminance were symmetrical to either side of the level of the MF-illuminance, and the brightness functions were basically linear. Hence, the mean responses for TF regions on the gray background would fluctuate at or near a value of 2.0, as they in fact did. When the white background was substituted for the gray, however, Ŷₘ for the TF regions fluctuated at somewhat lower values than 2.0 (Row 4, Table 1). It might seem, therefore, that the white background had an inhibitory effect on the TF squares and shifted the brightness functions downward from the log modular value of 2.0.

It has been generally shown that as surround or inducing luminance (IF) is increased over that of a contiguous TF, the apparent brightness of the TF is monotonically decreased; and, therefore, the greater the luminance-difference between the brighter IF and the dimmer TF, the greater the decrement (For a review of contrast literature, see Brown & Mueller, 1965; Freeman, 1967; Kozaki, T., 1969). In accordance with this contrast principle the change from the gray to white background should have produced a decrement in apparent brightness of all of the TF squares. And the decrements are expected to be smaller as the TF squares become lighter.

In this experiment, decrements in apparent brightness did occur for all the TF squares. The decrements, however, did not become smaller and smaller as the TF square became lighter. Instead, the decrements became larger and larger (Compare Rows 2 and 4 in Table 1. The difference in Ŷₘ between the gray and white background were .03, .11, .14, .15, and .15 for the successively higher TF squares.). This seems to be discrepant with the contrast principle mentioned above.

The perception of background

As is seen in Table 1, the bs for the TF backgrounds (gray and white) gave higher values (.28 and .31 for the gray and white backgrounds, respectively) as compared with those for the TF squares. It should be remembered that the luminance of the gray background was an intermediate between the luminance of the upper
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... (middle gray) square and the luminance of the right (light gray) square. Therefore, the $b$ for the gray background was expected to be an intermediate value between the $b(=.20)$ for the upper square and the $b(=.23)$ for the right square. The obtained value of $b$, however, was much higher than those for these two squares. Since the value of $b$ is reversely related with the amount of brightness constancy, the backgrounds yielded less constancy than did the squares. And there was a slight difference between the gray and white background; the latter gave less constancy.

It should be pointed out that the background appeared differently from the squares. The appearance of the background could be called film color while the appearance of the squares could be called surface color. Therefore, it would probably be true that an area perceived as film color yields lower constancy than does an area perceived as surface color (Katz, 1935).

The perception of illumination

As shown in Table 1, the $b$s for the TF total fields gave values of .29 on the gray background and .33 on the white. These values are slightly higher than the $b$s for the TF backgrounds, and much higher than the $b$s for the TF squares except the center one. The $b$ for the TF total field with the gray background equals the one for the center (white) TF square and is very close to the one for the TF background (mid-gray); the $b$ for the TF total field with the white background is nearly the same as the one for the TF background (white). Since the luminance of the white TF square on the gray background and the luminance of the white TF background are highest in their respective total fields, the highest-luminance region would probably determine the brightness of the illumination of the TF total field. This conclusion seems to be consistent with Oyama's (1968) suggestion that the highest luminance or some weighted average of luminances is the most probable stimulus correlate for the perception of illumination.

The failure to observe negative slopes

There remains the question of why the data reported from this experiment differed from those of Jameson and Hurvich (1961a). The conditions of the present experiment were very similar to those of Jameson and Hurvich: the configurations and their luminance distributions were similar; the range and steps of illuminance were similar; even the method of magnitude estimation used in this experiment was indirectly used by them. There were some differences, of course. First, Jameson and Hurvich allowed free-viewing, whereas in this experiment the MF and TF were placed in different eyes. That could not have been a sole factor of difference, however, because the two Ss even under the conditions of the present experiment showed a tendency that the brightness of the black TF square decreased with increased illuminance.

Secondly, the Ss in this experiment set the task of judging brightness using the modulus; the MF had the same configuration as that of the TF; the reflectances of the five MF squares in the cross were the same as those of the TF squares; the exactly same MF was used for different conditions in the TF. The use of such MF seemed to facilitate the task of judging brightness. It may be that the task in Jameson and Hurvich's experiment was different. Their Ss might have been self-instructed themselves to make lightness instead of brightness judgments, perhaps that was a factor of difference. Whether this is the case, however, must be tested by a further experiment where a distinction between brightness and lightness could be clearly made. (That experiment is being performed.)

Thirdly, the sampling procedure used in this experiment was more extensive as
Jameson and Hurvich applied to observers. Their use of only three Ss, each of whom made only two judgments, meant that a total of only six judgments determined the negative slope for their black TF square. The finding of a negative slope could have simply been due to sampling error.

Finally, in Jameson and Hurvich's experiment, there was an anomalous asymmetry between preadaptation and TF luminances. The background for the matching region had a very high luminance (much higher than the highest luminance TF region) and subtended a very large angle at the eyes (about 145 deg). These facts offer a possible explanation of their results: Since S looked with his two eyes back and forth between the matching field and the TF, his eyes were always light adapted to that very high luminance when he looked at the TF. When the black TF square was at the low illumination, it would have hardly been detectable and, therefore, assimilated to the gray background. On the other hand, at the high illumination, the black TF square was discriminable from the background and so would then be judged darker (more black) than the background. That would yield a negative slope. (For more detailed explanation, see Flock & Noguchi, 1970, pp. 134–135).

References


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