Lightness of grays: Effects of background reflectance¹

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The influence of background reflectance was determined for lightness judgments relative to white of small gray patches. The effect of prior stimulus-context was avoided by considering only first judgments. It was found that lightness was proportional to the square root of reflectance when the background was a gray darker than the stimulus, but not when the background was lighter gray or white. In general, a small difference in reflectance between the stimulus and background produced the same effect as a larger difference.

The quantitative relation between subjective lightness of grays and reflectance has a long history. The first experimental attempt to measure any sensation intensity directly involved judgments of the lightness of gray along the continuum extending from white to black (Plateau, 1872). Since then, many experiments have been reported on lightness, which are not always in agreement with each other. Two factors seem to be responsible for a great deal of this disagreement: (1) lightness judgments can be influenced by the choice of background chosen for viewing the stimuli (Godlove, 1933); and (2) quantitative judgments of the lightness of one gray depend to a great extent upon previous judgments of other grays (Warren & Poulton, 1960; Poulton et al, 1965). Recent experiments have found it possible to eliminate both these biasing effects: (1) changes in background reflectance were without influence upon lightness judgments when large contiguous white and gray rectangles were used as stimuli; and (2) prior context was eliminated by use of only first judgments from large groups of Ss (Warren & Poulton, 1960; Warren & Warren, 1966). It is of some theoretical interest that these two studies found lightness proportional to the square root of reflectance for grays near the middle of the range, in agreement with the physical correlate theory of sensory intensity (Warren, 1958).

This square root relation between reflectance and lightness has appeared several times in the literature when no precautions were taken to eliminate either prior context or background effects. The original Munsell Neutral Value Scale (1915) had numerical values given to grays which were equal to the square root of their reflectance, according to a photometric analysis of the stimuli of the Munsell Atlas (Priest et al, 1920). A report by a subcommittee appointed by the Optical Society of America (Newhall et al, 1943) indicated that lightness of single small gray patches was affected markedly by background reflectance and was proportional to the square root of the reflectance only when viewed against

a white background. However, in a recent study in which prior context was eliminated, the lightness of a small mid-gray patch viewed against a white background deviated considerably from the square root rule (Warren & Poulton, 1962).

The present series of experiments were undertaken to investigate systematically the influence of background reflectance upon lightness of small gray patches in the absence of prior context effects. Since an earlier study had demonstrated that "partition" judgments of lightness along a continuum extending from white to black, and "ratio" judgments of lightness relative to white are equivalent when differences in prior context are eliminated (Warren & Poulton, 1962) the present study employs the simpler ratio procedure; Ss are instructed to give a numerical value for the lightness of a gray stimulus relative to white which is called 100. In Part I, a range of gray stimuli are viewed against a white background. In Part II, a single middle gray comparison patch is viewed, together with a white standard patch, against a variety of backgrounds. Part III was designed to test the generality of observations made in Part II.

METHOD

Part I

Subjects. The 250 Ss were students at Cambridge University, mainly undergraduates. All had no previous experience with, or knowledge of, sensory scaling.

Materials. Sheets of paper ranging from white (reflectance=83%) through a series of neutral grays to black (reflectance=3.3%) were purchased from the Mitchell Colour Card Co., London. These papers had a dull finish with low specular reflection. By cementing sheets of two different grays together back to back and then cutting to the desired size (1.5 x 2 in.), pairs of comparison stimuli were produced which could be changed simply by turning over. The gray papers were viewed with their longer edges parallel to, and at the center of, a large sheet of white paper (17.5 x 11.3 in.) placed with a longer side closest to S. This sheet of white paper in turn was resting on a dark oak table (reflectance=20%). The reflectances of all these materials were measured using both a MacBeth Illuminometer and a Salford Electric Instruments Ltd. Illuminometer.

Procedure. The Ss were tested one at a time in the Junior Combination Rooms of several Cambridge colleges. S read the following typewritten instructions: "You will see a gray patch of paper lying on a white blotter. If the lightness of the white blotter is called 100, what (smaller) number describes the lightness of the

gray patch? Please write down your answer on the slip of paper provided." S was then taken to another part of the room and seated before the stimulus-display. The ambient illumination was always at a level adequate for comfortable reading. After S made his judgment of the lightness of the gray paper (thinking that only this one judgment was required), a different gray was substituted, and S made a second lightness judgment. If S did not give a higher number to the lighter gray, his data were rejected. S was then requested not to discuss the experiment with anyone who had not already served in it. The first gray paper again was placed in position, and the next S brought over. Data from 50 different Ss were recorded for each of the experimental conditions, as listed in Table I.

Part II

Subjects. The 200 Ss were students at Cambridge University, mainly undergraduates. All had no previous experience with, or knowledge of, sensory scaling.

Materials. The gray and white papers employed were described in Part I. In addition, a black cotton velvet (reflectance=0.50%) was used. A single pair of gray papers 2.0 x 1.5 in. cemented back to back served as comparison stimuli throughout Part II. A white patch 2.0 x 1.5 in. was present along with the gray comparison patch, both lying on one of a series of gray background papers, each 17.5 x 11.3 in. with a reflectance different from comparison stimuli. The small white and gray patches were oriented with their long sides parallel to the long side of the background sheet, and were separated from each other by the same distance separating each from the nearer short side of the background paper, and both were equidistant from the long sides of the background sheet. This large background sheet rested on a dark oak table (reflectance=20%). Reflectances of all these materials were measured as in Part I, and are listed in Table II.

Procedure. The Ss were tested one at a time in the Junior Combination Rooms of several Cambridge colleges. S read the following typewritten instructions: "You will see two paper patches, one white and one gray, lying on a blotter. If the lightness of the white paper is called 100, what (smaller) number describes the lightness of the gray patch? Please write down your answer on the slip of paper provided." After reading these instructions, the procedure was the same as that described for Part I.

Part III

Subjects. The 60 Ss were students in the introductory psychology course at The University of Wisconsin at Milwaukee. All had no previous experience with, or knowledge of, sensory scaling.

Materials. A white paper (reflectance=89.1%) and several neutral gray papers with a dull finish and low specular reflection were purchased from the Munsell Color Co., Baltimore. A single pair of gray papers 2.0 x

1.5 in. cemented back to back served as comparison-stimuli for Part III. A white patch 2.0 x 1.5 in. was presented along with the gray comparison. In one group the white and gray stimulus-patches were viewed with their 1.5 in. edges contiguous (actually, the white paper extended for a short distance under the gray), in the center of a 17.7 x 11.7 in. sheet of gray background paper having a reflectance different from the comparison-stimuli. The small white and gray patches were oriented with their long side parallel to the background sheet. The large background sheet rested on a light oak finish table (reflectance=55%). For the second group in Part III, the small white and gray patches were oriented with their long sides parallel to a longer side of a background rectangle of white satin velvet (32 x 30 in.; reflectance=79%). The satin was arranged with a longer side closest to S, and each small patch was 9 in. from the closest side of the satin, 4 in. from the other patch, and 16 in. from the nearer shorter edge. Reflectances for all materials are listed in Table II, and were measured with a MacBeth Illuminometer and a Spectra Light Meter. The values for the papers checked with those furnished by Munsell Co.

Procedure. The Ss were tested one at a time in a classroom empty but for S and E. Otherwise the procedure was the same and the instructions were the same as described for Part II.

RESULTS

Lightness judgments for small gray patches of different reflectances viewed against a white background are summarized in Table I. It can be seen that the relation between first lightness judgments (uncontaminated by prior judgments) and reflectance differs significantly from the square root rule for each of these different grays viewed against the same white background.

The influence of different background reflectances upon the apparent lightness of a single gray patch having a reflectance of 22% is shown in Table II. As before, we are interested primarily in the first lightness judgments, uncontaminated by prior judgments. For all five backgrounds lighter than the Co, judgments are less than the

Table 1. Lightness of Gray Patches Relative to White Background Called 100

Percent Reflectance(R)*	First Judgment					Second Judgment			
	10 $\sqrt{R}$	Median	Mean	SE		Percent Reflectance(R)*	Median	Mean	SE
82	91	75	70.6**	2.2	22	35.5	35.7	2.1	
70	84	70	64.2**	2.1	53	55	50.9	2.2	
53	73	50	50.3**	2.4	22	30	29.6	1.9	
22	47	39.5	38.0**	2.6	53	70	64.6	2.7	
9.4	31	25	24.2**	1.9	22	45	46.0	2.5	

* Reflectance (R) is expressed as percentage of the reflectance of the standard white paper.

** Significantly different (t-test, $p < .001$) from value $19\sqrt{R}$ derived from the square root rule.

Table 2. Effect of the Reflectance* of the Background Upon Lightness of Gray Relative to a White Called 100

Back- ground	First Judgment				Second Judgment			
	Stimulus R*	Median	Mean	SE	Stimulus R*	Median	Mean	SE
79 ^b	22	37.5	37.0 ^d	2.9	48	67.5	62.2	2.8
64 ^a	22	40	42.8	2.9	53	74	70.3	2.4
53 ^a	22	38.5	38.9 ^d	2.5	9.4	15	20.4	1.9
48 ^b	22	35	37.6 ^d	3.5	7.6	10	12.5	2.9
29 ^a	22	42.5	42.0 ^c	2.5	53	75	72.9	2.4
16 ^a	22	52.5	47.9	2.9	53	75	71.6	2.4
4.1 ^a	22	50	48.7	2.1	53	80	73.9	1.8
0.49 ^a	22	55	51.5 ^c	2.4	53	77.5	74.7	1.9

* Reflectance (R) is expressed as percentage of the reflectance of the standard white paper.

a Data from Part II, see Method Section for details.

b Data from Part III, see Method Section for details.

c Significantly different (*t*-test, $p < .05$) from value of 47 calculated from the square root rule.

d Significantly different (*t*-test, $p < .01$) from value of 47 calculated from the square root rule.

value of 47 calculated from the square root rule, and this difference is significant in four cases. For both background papers darker than the Co gray, lightness judgments are in excellent agreement with the calculated value of 47. However, use of black velvet as a background increases the lightness of the gray Co significantly above that corresponding to the square root rule.

It can be seen from Table II, the results obtained in Part III are in agreement with those of Part II, despite differences in the populations from which Ss were drawn and differences in experimental procedure.

DISCUSSION

It should be emphasized that the primary interest of the present study is with the first lightness judgments. The judgments of the second grays insured that S followed instructions in giving a higher number to the lighter gray. These second judgments were, of course, subject to the biasing effects of the first in a manner discussed by Warren & Poulton (1960) and in greater detail by Poulton et al (1965).

The rule that lightness is proportional to the square root of reflectance for a gray patch viewed against a white background, suggested by Godlove (1933) and supported by Newhall et al (1943), is not in agreement with data from Part I of the present experiment. Table I shows that lightness judgments for a wide range of gray patches were all significantly lower than would be predicted from the square root rule when the patches were viewed against a white background. The difference between the results in the present study and the square root rule reported in the literature may be attributable in part to the differences in experimental procedure, the data in the earlier studies being subject to the influence of prior context occasioned by judgments of different grays by the same S.

It is of interest that the square root rule is followed in the absence of prior context when the background con-

sists of a paper darker than the gray stimulus, as can be seen in Table II. "Black" papers generally have a reflectance of 2 to 4%, but use of black velvet provided a background of 0.49%, far below that of any paper. It can be seen that the lightness of the gray stimulus was significantly higher than that of the square root rule when viewed against this velvet.

If we examine all of the data from this study, it appears that the effect of background upon first lightness judgments is determined simply by whether it is lighter or darker than the gray stimulus; the degree by which background and stimulus differ does not have any statistically significant effect. The only exception to this generalization seems to be the black velvet background. With all other backgrounds, there is no systematic change in lightness with increasing difference between the reflectance of the sample and the background. This is reminiscent of the observation made some time ago by Bezold (1876) that for a single gray viewed against a variety of backgrounds, "... the smallest perceivable difference ... produces almost the same effect of contrast as that produced by the greatest contrast that can be conceived."

Part III represents an attempt to replicate the relations observed in Parts I and II, using slightly different experimental procedures and Ss drawn from a different population. In Part III, rather than groups of 50 English university students, two groups of 30 American university students were employed for determining first lightness judgments. One group viewed gray and white paper patches against a white satin background, and lightness judgments (mean = 37.0) were not significantly different (two-tailed *t*-tests) from those obtained for a gray of the same reflectance viewed either (1) against a large sheet of white paper (Part I) or (2) together with white patch against a gray background lighter than the comparison-gray stimulus (Part II). The other group in Part III viewed contiguous middle gray and white patches against a light gray background. Although the stimulus patches were directly alongside each other and not separated spatially as was the case for the same patches in Part II, no significant differences in lightness judgments were observed.

The agreement of Part III with the observations of the main parts of this study supports the validity and indicates the generality of the observations made concerning the effect of background upon lightness of small gray patches.

If we consider the results of the present study together with other experiments in this series investigating the lightness of gray relative to white in the absence of prior context, we find lightness of grays near the middle of the range are proportional to the square root of their reflectance when: (1) the influence of background reflectance is eliminated (Warren & Poulton, 1960; Warren & Warren, 1966); (2) a small white St patch is viewed against a large gray Co field (Warren, 1965); and (3) the gray Co and the white St are both viewed against

a background darker than the Co (present study). The square root rule does not apply for grays near the white or black limits of the range of grays in the absence of background effects (Warren & Warren, 1966), or for small gray patches subject to the influence of a lighter gray or white background (present study).²

References

- Bezold, W. v. *The theory of color and its relation to art and industry* (S. R. Koehler, Transl.). Boston: L. Prang, 1876. P. 146.
- Godlove, I. H. Neutral value scales: II. A comparison of results and equations describing value scales. *J. Opt. Soc. Amer.*, 1933, 23, 419-425.
- Munsell, A. H. *The atlas of the Munsell color system*. Boston: Wadsworth, Howland, 1915.
- Newhall, S. M., Nickerson, D., & Judd, D. B. Final report of the O. S. A. subcommittee on the spacing of the Munsell Colors. *J. Opt. Soc. Amer.*, 1943, 33, 385-418.
- Plateau, J. A. F. Sur la mesure des sensations physiques, et sur la loi qui lie l'intensité de ces sensations à l'intensité de la cause excitante. *Bull. Acad. Roy. Belg.*, 1872, 33, 376-388.
- Poulton, E. C., Simmonds, D. C. V., Warren, R. M., & Webster, J. C. Prior context and fractional versus multiple estimates of the reflectance of grays against a fixed standard. *J. exp. Psychol.*, 1965, 69, 496-502.
- Priest, I. G., Gibson, K. S., & McNicholas, H. J. An examination of the Munsell Color System. *Tech. Papers Bur. Standards*, 1920, No. 167.
- Warren, R. M. A basis for judgments of sensory intensity. *Amer. J. Psychol.*, 1958, 71, 675-687.
- Warren, R. M. Are loudness judgments based on distance estimates? *J. Acoust. Soc. Amer.*, 1963, 35, 613-614.
- Warren, R. M. Lightness of gray in the presence of white. *Percept. mot. Skills*, 1965, 21, 925-926.
- Warren, R. M., & Poulton, E. C. Basis for lightness-judgments of grays. *Amer. J. Psychol.*, 1960, 73, 380-387.
- Warren, R. M., & Poulton, E. C. Ratio- and partition-judgments. *Amer. J. Psychol.*, 1962, 75, 109-114.
- Warren, R. M., & Warren, R. P. Basis for judgments of relative brightness. *J. Opt. Soc. Amer.*, 1958, 48, 445-450.
- Warren, R. M., & Warren, R. P. Lightness, brightness, and distance. In *Tagungsbericht Internationale Farbtagung Luzern*, 1965, Goettingen: Musterschmidt-Verlag, in press.

Notes

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2. A discussion of the square root rule in terms of the physical correlate theory is given for vision by Warren & Warren (1958) and Warren & Poulton (1960), and for hearing by Warren (1963).