THE LIGHTNESS OF TRANSPARENT SURFACES

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ABSTRACT

It is suggested that the rated lightness of an achromatic transparent surface is a function of the lightnesses of the parts that are perceived when the region of the field where transparency occurs is viewed with an analytical attitude. It has also been shown that Metelli's theory of transparency leads to a very similar suggestion. It has been found 1) that the rated lightness of a transparent surface was independent of the background; 2) that it slightly deviated from the arithmetic mean, and 3) that it coincided with the geometric mean of the rated lightnesses of the parts viewed analytically. These results confirmed the plausibility of the above suggestions, and Metelli's theory. It has also been found 4) that the rated lightness coincided with the rated average of the lightnesses of the parts viewed analytically.

THE LIGHTNESS OF TRANSPARENT SURFACES

Achromatic transparent surfaces are essentially charachterized by two properties: lightness and density. It is known that, when a transparent surface is viewed with an analytical attitude, transparency may be disrupted and their properties are no longer perceived (Fuchs, 1923). In place of the transparent surface, opaque surfaces are perceived (which corresponds to the reduction colors). In turn, these opaque surfaces give place to the transparent surface with its properties, when the normal attitude is regained. Even if, strictly, there seems to be no compelling argument in favor, the disruption of transparency with the consequent disappearance of their properties suggests that the properties of transparency depend on what remains after the disruption, that is lightnesses of opaque surfaces and lightness differences. (1)

Here, it is suggested that the rated lightness of a transparent surface depends on the lightnesses of the surfaces perceived analytically in the part of the visual field where transparency may occur. Let Figure 1 depict the contours that would be produced if a rectangular transparent surface, delimiting parts P and Q, were seen over a bicolored background made of two adjacent squares, A and B. Let a, b, p, and q be the lightnesses of parts A, B, P, and Q, when these parts are

1) In parte ~~[illegible]~~ dalla trasparenza cavati (tirati da relazione) dai colori che la determinano. Invece ci sono compelling argumenti se si parte dai colori di riduzione e si arriva alla trasparenza, invece di partire dai colori di riduzione o comunque partire dai colori visti in isolamento.

viewed with an analytical attitude. In the case of Figure 1, the above suggestion would be that the rated lightness, t, of the whole transparent surface depends on the lightnesses, p and q, of the parts viewed analytically. A general statement of this dependence would be that t is some sort of compromise between p and q. For example,

$$t = wp+(1-w)q, \tag{1}$$

where w is an unknown weight expressing the compromise.

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Figure 1 about here

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So far, only Metelli (1974 a and b) proposed a theory of the conditions for the perception of transparency in which also predictions about the lightness were made. An extension of the theory has more recently been proposed (Metelli, 1982, in press). Metelli's theory ends up with the following equation for the lightness of the transparent surface illustrated in Figure 1:

$$t = (aq-pb)/(a-p+q-b). \tag{2}$$

According to the theory, Equation 2 specifically applies to the cases where the transparent surface is homogeneous in density in all its parts. Experimental results by Masin and Gardonio (1985) seem to show clearly that homogeneity in density depends on the lightness differences $a-p$ and $q-b$. That is, if $a-p < q-b$, when $a>p>q>b$, then the transparent surface is perceived as less dense in part P. The surface is perceived as less dense in part Q when $a-p > b-q$.

It seems, therefore, that the cases of homogeneity in density -- for which Equation 2 is considered valid -- are reasonably equivalent to the cases where $a-p = q-b$, when $a>p>q>b$. One solution of the system of equations formed by the constraint $a-p = q-b$ and by Equation 2 is

$$t = (p+q)/2.$$

This result shows an impressive similarity of predictions from Equations 1 and 2. Equation 1 is only more general in that it is considered applicable also to cases of non-homogeneous density. The following experiment was made in order to check these equations.

1) 2 conseguenza di 1

METHOD

The models assert that the lightness of the transparent surface is independent of the background. A test comes from a comparison of estimates of the lightness, t, of transparent surfaces on two different backgrounds. An important question for which to search an answer is also whether or not t concides with the judged average of p and q.

Observers

The observers were 40 unpaid university students who were recruited as they entered the Intitute. A forty-first observer declared that she did not perceive anything transparent in the experimental patterns and was therefore excluded.

Stimuli

Nine patterns as that outlined in Figure 1 were used. The side length of squares A and B was 40 mm, and that of squares P and Q was 22 mm. Each pattern was stuck at the center of a 200 X 200 mm gray square with reflectance .23. Table 1 lists the reflectances of A, B, P and Q for each pattern. Gray papers from the set of 19 supplied by the NCS Institute (Sweden) were used.

As may be seen, Patterns 1 to 4, and Patterns 5 to 9, share the same reflectance for surfaces A and B. The retinal stimulation produced by an episcotister rotating at fusion speed in front of surfaces A and B may be simulated by choosing appropriate reflectances for surfaces P and Q. These reflectances were chosen to simulate an episcotister with transmittance .5 and with reflectance increasing from Pattern to 4, and from Pattern 5 to 9. Table 1 also lists these simulated transmittances and reflectances. Perceptually, the transparent rectangle in a pattern became progressively darker in passing from Pattern 1 to 4, and from Pattern 5 to 9.

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Table 1 about here

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The observer sat at a table provided with a head-and chinrest to keep the eyes level with the pattern. On the same table, the pattern was placed at 1.3 m on the frontoparallel plane. The pattern, which was viewed binocularly, was shown by removing a white screen. The illumination level was of about 30 lx.

Procedure

The observer had to rate the lightness of parts A, B, P, and Q (Figure 1). The rating had to be performed using the numbers in the range of 0-100. Zero represented the whitest white ever experienced in observer's life, and 100 the blackest black. Numbers lower than 50 had to be attributed in proportion to light grays, and numbers higher than 50 in proportion to dark grays. The numerical response had to be called out within approximately 5 sec.

Before starting the experiment, observers were shown all the nine patterns in the order 1 to 9 so that they realized which was the range of variation of grays. It was stressed that, of course, the whitest white or the blackest black were not necessarily present in that range of grays because the presence depended on their own past experience.

This procedure was common to all 40 observers, which were subdivided into two groups of 20, X and Y.

Group X. Besides rating the lightness of A, B, P, and Q, these observers had to rate also the lightness, t, of the whole transparent rectangle. They were instructed to rate the lightness of the transparent rectangle while they perceived it as a unitary transparent strip or rectangular veil. They were told not to heed surfaces P and Q, and were urged not to make any sort of valuation of the lightnesses of P and Q, under this task. Observers rated the lightness of the transparent rectangle with no special hesitation and, when asked, most of them declared that they found no special difficulty in following the instruction.

Observers had to rate a, b, p, q, and t in intermixed order, to ward off possible changes in unit (Anderson, 1982, p. 282).) ?

There were two sequences of 31 presentations of the patterns. A sequence consisted of three presentations of each of the nine 27 patterns. For each of these presentations of a pattern, the observer had to rate the lightness of P, of Q, or of the whole transparent rectangle. Interspersed, there were four more presentations, for each of which the observer was asked to rate the lightness of A or B in one of Patterns 1 to 4, or the lightness of A or B in one of Patterns 5 to 9. (The choice of one of Patterns 1 to 4, or one from 5 to 9, was at random.) The order of presentation of Patterns 1 to 9 -- and the choice for the rating of A, B, P, Q, or of the whole transparent rectangle, for a given pattern -- were predetermined at random by a microcomputer and were different for each sequence and for each observer. The number of the pattern and the name of the surface was output by the microcomputer, and the experimenter called out the name of the surface (A, B, P, Q, or "the whole transparent rectangle"). The observer interpreted the name of a surface by referring to a copy of Figure 1 displayed right below the experimental pattern.

Group Y. The procedure for Group Y was exactly the same as that for Group X, except for the following changes. In place of the instruction to rate the lightness of the whole transparent rectangle, observers were asked to rate the average lightness of surfaces P and Q. Observers were given the instruction -- which was followed by all of them -- to produce a single numerical response when the task was to rate the average lightness of surfaces P and Q, instead of "mentally" computing the arithmetic mean of two numerical responses, one for surface P and one for surface Q. In place of calling out "the whole transparent rectangle", the experimenter called out "the average of p and q". The random orders of the sequences of presentations were different from those used for Group X.

A session lasted about 25 min.

RESULTS

The results for Groups X and Y are reported in Tables 2 and 3 respectively. The number of the experimental pattern is reported in Column 1 of either Table 2 and 3. Each table reports the mean ratings of a, b, p, and q in Columns 2, 3, 4, and 5 respectively. Each value in Column 6 of Table 2 is the mean rating of the lightness, t, of the transparent rectangle in the experimental pattern, and each value in the same column of Table 3 is the mean rating of the average, m, of p and q.

The arithmetic mean of the individual differences t-[(p+q)/2], and m-[(p+q)/2], are reported in Column 7 of Tables 2 and 3, respectively. Multiple z tests showed that the

Se $(a-p) \neq (b-q)$, l'uso di $\frac{p+q}{2}$ non ha fondamento mean differences marked by asterisks were statistically different from zero, evidencing that t and m barely deviated from (p+q)/2.

The arithmetic mean of the individual differences of t, and m, from the geometric mean of p and q are reported in Column 8 of Tables 2 and 3, respectively. Multiple z tests showd that none of these mean differences in Table 2 was statistically different from zero. An asterisk marks the only one of these differences in Table 3 that was statistically different from zero.

Table 3 has a ninth column where the mean differences t-m are reported. Multiple z tests showed that none of these mean differences statistically deviated from zero.

CONCLUSION

A simple inspection of Table 2 shows that in all cases the mean ratings of t fall in between the mean ratings of p and q. This result shows that Equation 1 is descriptive of the processes underlying the observer's rating of t. The mean rating of t very slightly deviates from (p+q)/2. In consideration of the marked variation of the differences a-p and b-q (see Tables 2 and 3) from one experimental pattern to another, the above result seems therefore to provide, a

Se (a-p) ≠ (b-q), l'uso di $\frac{p+q}{2}$ non ha fondamento fortiori, notable support also to Equation 2 which inplies that t=(p+q)/2.

Moreover, it resulted that t concided with the geometric mean of p and q both for Patterns 1 to 4 and for Patterns 5 to 9. Since the background lighntnesses a and b were markedly different for these two sets of patterns, it may be concluded that the rated t is independent of the background. This conclusion also supports Equations 1 and 2, which expressly state, or imply, that the background is ineffective.

It is important to note, however, that Equation 1 is not proved to be true. As the statistical coincidence of t with the geometric mean of p and q suggests, a multiplying model could predict the same results as well. Both an averaging model (Equation 1), or a multiplying model, would imply that t is a compromise between p and q. It is this compromise -- apart from its nature -- which seems to have been experimentally proved by the independence of the rated t from the background

The results reported in Column 8 of Table 3 show that there was no difference between the mean rating of t and the mean rating of the average of p and q. Pessimistically, this could mean 1) that observers rated t even if they were instructed to rate the average of p and q; or 2) that they rated the average of p and q when they were instructed to rate t. The first possibility means that, when observers heeded separately p and q in order to follow the instruction to average them, they assumed instead a normal attitude and valuated the lightness of the transparent rectangle. The second possibility means on the contrary that, when the observer was instructed to assume a normal attitude and view the rectangle as transparent, they were not able to do so and heeded p and q arriving at an average. Either possibility implies an observer's transgression of the instructions. Another, more optimistic, interpretation of these results is that both tasks (rating t and evraging p and q) involved the same result, and that observers did not transgress the instructions. At the present stage of research, there seems to be no certain way of determining whether or not observers transgress, when they declare to follow the instructions. If the optimistic interpretation should turn out correct, it would allow for the interesting speculation that the information-integration processes implied by the averaging task could coincide -- or, at least, have something in common -- with those perceptual processes that produce t.

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NOTES

1. This hypothesis entails percept-percept couplings (Epstein, 1982) within the domain of gray colors. Beck, Prazdny, and Ivry (1984) proposed that density is a function of lightness differences. Masin (1984) and Masin and Gardonio (1985) found that, when observers rate density, their response is a function of lightness differences between the surfaces in the region of the field where transparency occurs and between these surfaces and contiguous regions of the background. Metelli (1982, in press) proposed a theory of transparency where density is predicted from lighntesses in the region of the field where transparency occurs and in the contiguous regions of the background.

In realtà Beck e Co concludono il loro articolo dicendo che non c'è modo di prevedere la trasparenza dalle condizioni cromatiche e che sono le condizioni figurali a determinare se si percepisce o no la trasparenza

Table 1

Reflectances for Surfaces A, B, P, and Q (Figure 1), and Reflectance (R) and Transmittance (T) of the Episcotister Simulated in the Experimental Pattern

Pattern Number	A	B	P	Q	R	T
1	.40	.11	.67	.52	.96	.52
2	.40	.11	.46	.31	.52	.52
3	.40	.11	.31	.16	.21	.52
4	.40	.11	.23	.08	.05	.51
5	.87	.02	.76	.31	.64	.53
6	.87	.02	.67	.23	.45	.52
7	.87	.02	.59	.16	.30	.51
8	.87	.02	.52	.08	.15	.51
9	.87	.02	.46	.04	.06	.50

Table 2

Mean Ratings of a, b, p, q, and t
from Group X

Pattern Number	a	b	p	q	t	$t - \frac{p+q}{2}$	$t-\sqrt{pq}$
1	37.6	84.6	22.4	27.3	25.7	0.9	1.1
2	37.6	84.6	31.1	45.0	38.7	0.6	1.5
3	37.6	84.6	46.0	62.7	55.3	0.9	1.8
4	37.6	84.6	55.3	85.8	63.9	-6.7 *	-4.6
5	4.2	98.2	18.5	41.4	25.4	-4.9 **	-2.4
6	4.2	98.2	24.3	43.6	34.0	0.0	1.8
7	4.2	98.2	27.1	57.2	39.0	-3.1 *	.0
8	4.2	98.2	34.0	74.4	48.3	-5.9 *	-1.4
9	4.2	98.2	37.5	89.4	58.7	-4.8	1.5

* Signifcant at the .05 level.

** Significant at the .01 level.

Note -- The symbols a, b, p, and q represent the lightnesses of parts A, B, P, and Q in Figure 1; and t represents the lightness of the whole transparent rectangle.

Table 3

Mean Ratings of a, b, p, q, and m

from Group Y

Pattern Number	a	b	p	q	m	$m - \frac{p+q}{2}$	m−/pq	t−m
1	35.9	79.8	19.6	24.1	20.0	−1.8	−1.5	2.7
2	35.9	79.8	30.4	37.6	33.2	−0.8	− .2	1.4
3	35.9	79.8	42.4	60.9	50.6	−1.0	.2	1.9
4	35.9	79.8	50.7	81.8	61.4	−4.9 *	−2.6	−1.8
5	7.2	97.6	14.6	35.5	21.7	−3.3 *	− .6	−1.6
6	7.2	97.6	19.9	40.7	27.2	−3.1	− .7	3.1
7	7.2	97.6	22.8	49.0	33.2	−2.7	.3	−0.4
8	7.2	97.6	30.1	68.8	43.8	−5.6 *	−1.3	−0.3
9	7.2	97.6	34.2	87.0	60.4	−0.2	6.5 **	4.6

* *Significant at the .05 level.*

** *Significant at the .001 level.*

Note -- *The symbols a, b, p, and q represent the lightnesses of parts A, B, P, and Q in Figure 1; and m represents the average lightness of p and q as estimated by the observer.*

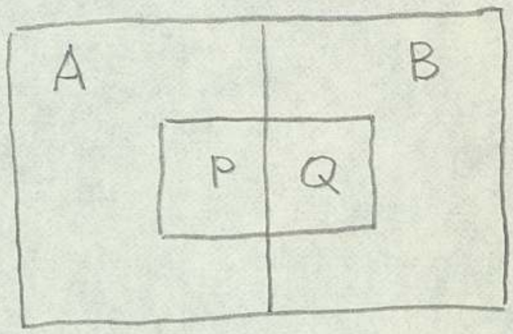

Fig. 1