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A Study of the Effects of a Coloured Episcotister on Brightness Matches with Grays

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A STUDY OF THE EFFECTS OF A COLOURED
EPISCOTISTER ON BRIGHTNESS
MATCHES WITH GRAYS

By
LILLIAN-FRANCES BOWDEN

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
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VITA

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CHAPTER I

A HISTORY OF COLOUR EXPERIMENTS

Of necessity, a discussion of any topic must begin and end somewhere. The writer has deemed it advisable to start with a brief review of the theories of colour vision, from their development in the early part of the nineteenth century to the generally accepted views of our own time. A description of the experiments involved in the present thesis project and the conclusions derived from these observations will be given.

Thomas Young was born at Milverton, England, on June 13, 1773, and it was a little more than a quarter of a century later, about 1807, that his work which is of particular interest to us, and out of which has come Young's hypothesis, was undertaken. His contribution to our present knowledge of colour vision is simple and fundamental.

In 1690, Huygens had conjectured that light consisted in undulations of a delicate elastic medium; but Young's interference theory was a necessary pre-requisite to the acceptance of such a supposition. This undulatory theory of vision, which made sight more closely analagous to the other senses, implies as antecedent an ether medium through which light waves might travel. Young speaks of a luminiferous ether pervading the universe which is "rare and elastic in a high degree."¹ Whenever a body

¹ Crew, Henry, (Ed.), The Wave Theory of Light: Memoirs of Huygens, Young, and Fresnel, American Book Co., New York, 1900, 49.

becomes luminous, undulations are present in this ether, the colour of different sensations being dependent on the frequency of vibrations excited by light on the retina. The interference theory assumes that converging wave-lengths combine to form a new one. In contradistinction to the hypothesizing of Brewster, Young claims "all impulses are propagated in a homogeneous elastic medium with equable velocity."²

In explaining his theory, Young set up a conditional structural basis. The eye was believed to contain three types of light-sensitive receptors; one type of receptor was sensitive to red, another to green, and a third to blue light. The particular colour evoked in a given situation would depend upon the receptors acted upon, as well as the degree to which each was stimulated. Young did not, however, insist upon the presence of the structural plan. He merely regarded three independent types of action as necessary, stating that lack of knowledge concerning the physiology of the visual organ should not militate against an advancement of empirical investigations.

Young looked upon colour as a sensation. In so doing, he included the triple aspects of colour vision, psychical, as well as physical and physiological.

He postulated the existence of three definite and independent colours. These primary colours were red, green, and blue. All colours were composed of these initial constituents. A specific combination of

² Ibid, 54.

red and green would produce yellow; a specific combination of all three of the primary colours would yield white.

This was not unlike the findings of Sir Isaac Newton, a precursor of Thomas Young. For Newton, the primary colours were red, orange, yellow, green, blue, indigo, and violet-purple. He could never, by mixing only two fundamental colours, produce a white. Newton states--

The most surprising and wonderful composition is that of whiteness. There is no one sort of rays which alone can exhibit this. It is always compounded, and all the ... primary colours, mixed in a certain proportion, are requisite to form it.³

This heterogeneous nature of white light which Newton recognized is looked upon as the first empirical step toward recognition of the subjective significance of sense-perceptions. Goethe's artistic view had caused him to look upon all that exists directly; therefore, he bitterly disagreed with Newton's theory. Newton explained "the colour of the rays of light as being entirely the result of their action on the retina. The rays themselves were not red, but they produced the sensation of red."⁴

Much of Young's work was purely speculative; confirmation or denial of its acceptability through physiological investigations was entirely lacking, or, at best, inconclusive.

And what was the fate of this theorizing of Thomas Young? It was

³ Priestley, Joseph, The History and Present State of Discoveries Relating to Vision and Colours, J. Johnson Pub. Co., London, 1772, 258.

⁴ Helmholtz, H., Treatise on Physiological Optics, Trans. from the third edition. ed. by J. P. Southall, Optical Society of America, 1924, II, 115-116.

doomed to obscurity. It was allowed to expire as it had been born, without notice, when Young died in London in 1829.

Eventually, the fruit of Young's mental labors was re-discovered by Helmholtz and incorporated into the Young-Helmholtz Trichromatic Theory of Colour Vision.

Hermann Ludwig Ferdinand von Helmholtz studied at the University of Berlin under Johannes Müller. Helmholtz was greatly impressed by this eminent physiologist, and his theoretical assumptions, wherever possible, were substantiated by physiological investigations of the point under discussion. In 1871, Helmholtz became professor of physics at this same university, thereby having greater facilities for experimentation placed at his disposal. Berlin's laboratories were the most modern and best equipped at that time. The trend toward experimentation was so great, in fact, that textbooks were of little use, becoming outmoded with the new findings of successive lecturers.

Previous to his appointment at Berlin, in 1856, Helmholtz completed the first volume of Physiological Optics. Second and third volumes followed, and it is chiefly in the second that is found Helmholtz's view pertinent to the colour vision theory. This second volume, subtitled "Visual Sensation", deals with simple and compound colours and a criticism of other theories of colour vision. The third volume, subtitled "Visual Perception", treats of the antagonistic viewpoints of nativism and empiricism. In this profound contribution to the field of optical investigations, Helmholtz gives concreteness to Young's rather fragmentary proposition, and formulates a more complete theory of colour

vision which is still, in substance, generally accepted today. Helmholtz wrote of Young's thinking "...his theory affords an exceedingly simple and clear explanation of all phenomena of the physiological colour theory."⁵

Helmholtz's is a theory of photochemical action, with a consideration of three variables necessary for the determination of colour quality. The variables are luminosity, hue, and saturation. These Helmholtz describes simply. Luminosity is the quantity of white; hue is the quantity of some colour of the spectrum; and saturation depends on the particular wave-length of this colour. The theory consists--

1. in the recognition as a fact of the statement that all colours can be compounded of three definite and independent colours, and
2. in the recognition that this fact implies further the coexistence of three independent and mutually non-interfering activities.⁶

All known sources of light emit radiations of different frequencies. This is best analyzed prismatically. Thus, Helmholtz determined the sequence of colours as red, orange, yellow, green, blue, and violet. The actual existence of indigo seemed questionable.

In ascertaining the primary colours, those no longer definable into simpler colours, Helmholtz worked with spectral light; Young had employed pigment mixing for his observations. With the use of spectral light, Helmholtz discovered a discrepancy in the primary colours as advanced by

⁵ Ibid, II, 143.

⁶ Peddie, W., Colour Vision, Edward Arnold, London, 1922, 29.

Young. He says, "...it would rather be better to take violet, green, and red for fundamental colours."⁷ Speaking of the previous choice of fundamental constituents as given by Young, Helmholtz says, "These three colours would not have been selected, had it not been that most persons, relying on the mixture of pigments, made the mistake of thinking that a mixture of yellow and blue...gives green."⁸ They yield white with spectral light.

Helmholtz maintained the retinal fibers are arranged in three sets which give a triple quality to the brain impulse through connection to separate cortical centers. He points out that the specific sensation peculiar to each nerve follows, regardless of the mode of excitation. This is true of visual impression; for instance, pressure on the eyeball produces a sensation of light.

Black was a definite sensation, rather than the absence of colour. While black does not reflect any light to the eye, it is a definite sensation.

Helmholtz tackled the problem of the nature of the correspondence between the percept and the object, stating, "There is absolutely no one-to-one correspondence between the composition of wave-lengths in a given luminous radiation and the light sensation which will be attached to it (provided every link in the nerve chain from retina to cortex is intact.)"⁹ For Helmholtz, our sensations are signs for external things and processes

⁷ Helmholtz, II, 141.

⁸ Ibid, II, 141.

⁹ Ibid, II, 61.

which we must learn to interpret through experience and practice. Müller assumed the retina's innate possession of ability to sense itself in its space-extension. Helmholtz claims the percepts of the internal and external sense, arranged in time sequence, make it possible for us to observe and recognize the regular repetition of such sequences of homogeneous percepts. But he says it is the relations of time, space, equality, and their derivatives, such as number, magnitude, and conformity, which are common to both the outer and inner worlds. It is in these we can strive for complete correspondence between the percept and the thing perceived.

The Young-Helmholtz Trichromatic Theory of Colour Vision has been remarkably confirmed in the light of later knowledge. Writing of this fact, von Kries states--

It accounts for the behavior of the normal organ of vision and its relations to typically dichromatic vision in a simple and accurately satisfactory fashion. The somewhat more complicated conditions of anomalous trichromatic vision can be made to fit in it in an intelligible manner, although not quite so simply. And it affords us at least the simplest way of expressing the observed facts in a comprehensive system...there can hardly be any doubt as to the correctness of its fundamental conceptions.¹⁰

Helmholtz's theory, unlike Young's, did not go unnoticed. Its appearance at a time when psychology was coming into its own as a science made it an easy target for criticism. Two contradictory theories followed

¹⁰ Ibid, II, 433-434.

one another in quick succession. These were the works of Ewald Hering and Christine Ladd-Franklin.

Hering's theory, too, assumes the presence of three substances in the retina, each capable of katabolic and anabolic action. The katabolic reaction, following stimulation, is a decomposing process; anabolic reaction is a building-up process. The six-primary colours are arranged in antagonistic pairs of red-green, yellow-blue, and white-black. One substance in the retina would function upon stimulation of that given set. The first colour of each set is dependent on katabolic action; the latter involves anabolic action. A state of equilibrium in any set yields gray.

Hering followed a nativistic philosophy in explaining the perception of colours. "The power of specializing and individualizing its functions is an inborn quality of living substance, and bears its richest and most wonderful fruit in the nervous system.... By an innate faculty the optic nerve of the new-born babe responds to the ray of light which enters the eye with a sensation of light...."¹¹

Hering speaks of the impressionability of the brain and the spread of stimulation; each impression of the virgin brain makes it more readily impressed by later similar stimulation. In explaining the relation of the object to the percept, Hering stressed the importance of peripheral factors. The inadequacy of these was admitted, however, and Hering

¹¹ Hering, Ewald, Memory, Open Court Pub. Co., Chicago, 1913, 35.

postulated a cerebral factor, dependent on attention and past experience. This developed into Hering's conception of "memory colour." It is described by Woodworth thus:

The colour in which we have oftenest seen an external thing impresses itself indelibly on our memory and becomes a fixed characteristic of the memory image. What the layman calls the real colour of a thing is a colour which has become firmly attached to the thing in memory; I might call it the memory colour of the thing. All the things which are known to us from past experience, or which we believe to be known to us in respect to colour, are seen through the spectacles of memory colours.¹²

Christine Ladd-Franklin's theory is one of genetic development.

Colour vision is regarded as an evolutionary process, resulting from a single photochemical substance. In the beginning, only black-white vision is present. Then the mother substance, as it is called, splits, part becoming sensitive to blue light and part to yellow light. The yellow-sensitive substance again sub-divides. Part becomes sensitive to red light and part to green light. The blue-sensitive substance passes into the final stage unaltered.

Colour sensitivity zoning in the retina tends to substantiate the Ladd-Franklin theory.

At the turn of the century, a new school of thought developed as a revolt against the psychology "per se" of that time. Though not devoted exclusively to the study of colour vision, some experimentation along

¹² Woodworth, Robert, Experimental Psychology, Henry Holt and Co., New York, 1938, 597.

this line was carried on and incorporated into a larger body of knowledge that came to be known as Gestalt Psychology.

In Gestaltism, the new approach was perception; no such thing as an isolated experience was admitted. Behavior was dynamic, as opposed to mechanical.

According to Gestalt theory, behavior is dependent on the total situation at any moment, rather than upon any parts. Totality is significant in motivation and response.

An experiment of Burzlaff required subjects to compare a series of 48 gray papers arranged in irregular order and placed in diffuse daylight with a similar set of papers arranged in regular order and placed far back in a room so that the illumination was only $1/20$ th of that of the irregular set. In responding to various standard stimuli indicated by the experimenter throughout the experiment, the subjects' choices showed that the object colour tended to remain the same although the stimulus was cut to $1/20$ th through a lessening of the illumination.

Kohler experimented on young hens. After training them to pick up only grains from the darker of two papers, under the same illumination, he placed the darker paper in direct sunlight. The lighter gray was allowed to remain in the same illumination. Grains were again selected from the darker paper only, indicating a continuation of colour constancy and the significance of the total situation.

Another experiment was conducted by Heider. When part of a circle of yellow dots on a black background was viewed through a blue episcotister, the yellow dots appeared gray. But when the outfield of black

and the complete circle of yellow dots was made visible above the segment that had been viewed episcotistically, all the dots appeared yellow even though part of the circle was still seen through the episcotister.

Woodworth says that continuity was the factor which made possible a separation of the planes of the episcotister and background, as well as colour.

According to most Gestaltists, reality was believed to consist of experiences of perceptual phenomena. Emphasis was placed upon the subjective more than upon the objective aspects of this experience. From this, naturally, arose the question as to whether or not experience is one and the same for all persons.

Around this question an endless controversy has arisen, as is clear from the literature on Gestalt, on personality, and on perception in general. Many tentative answers have been given by the experimenters, but nothing final seems to have emerged. Many of the colour experiments of the Gestaltists and others seem to admit of both interpretations. Wertheimer, in investigating the phi-phenomenon with the use of coloured lights, obtained movement in which no trace of colour was seen. Some of his subjects obtained coloured movement also.

Out of this and similar experiments, which will be given later in the context in order to place them where they can be more advantageously compared with findings of the present investigation, has come the question of subjective differences in reaction to colour and coloured objects, and the assumption that some individuals respond more deeply to

colour than do others. The present thesis project purports to investigate this through a study of the effects of a coloured episcotister on brightness matches with grays.

CHAPTER II

THE PRESENT EXPERIMENT

The subject is seated at a table in front of a revolving episcotister, behind which is a small window containing a constant stimulus patch. Slightly to the right is another window of the same size, in which comparison patches are exposed by the experimenter. The subject is asked merely to report whether each comparison patch, as given, is "brighter than", "equal to", or "darker than" the constant stimulus patch on the left. (See Fig. 1)

The present experiment involves a comparison of the subjects' responses in two equated situations, the differentiating independent variable being the presence of colour in one part of the experiment and the absence of colour in the other part. In one half of the experiment, the light interrupter, or episcotister, is constructed of a Hering gray #13, and the constant stimulus patch exposed in the window to the left, and to the rear, to be viewed episcotistically, is a Hering gray #3. In the other half of the experiment, the gray on the episcotister is replaced by a Hering blue, and a Hering yellow is used for the constant stimulus patch.

Preliminary to the actual experiment, the controlled factors were set up. The Hering gray #3 constant stimulus patch for one half of the experiment and the Hering yellow constant stimulus patch for the other half were matched for brightness by the flicker method. The Hering gray #13

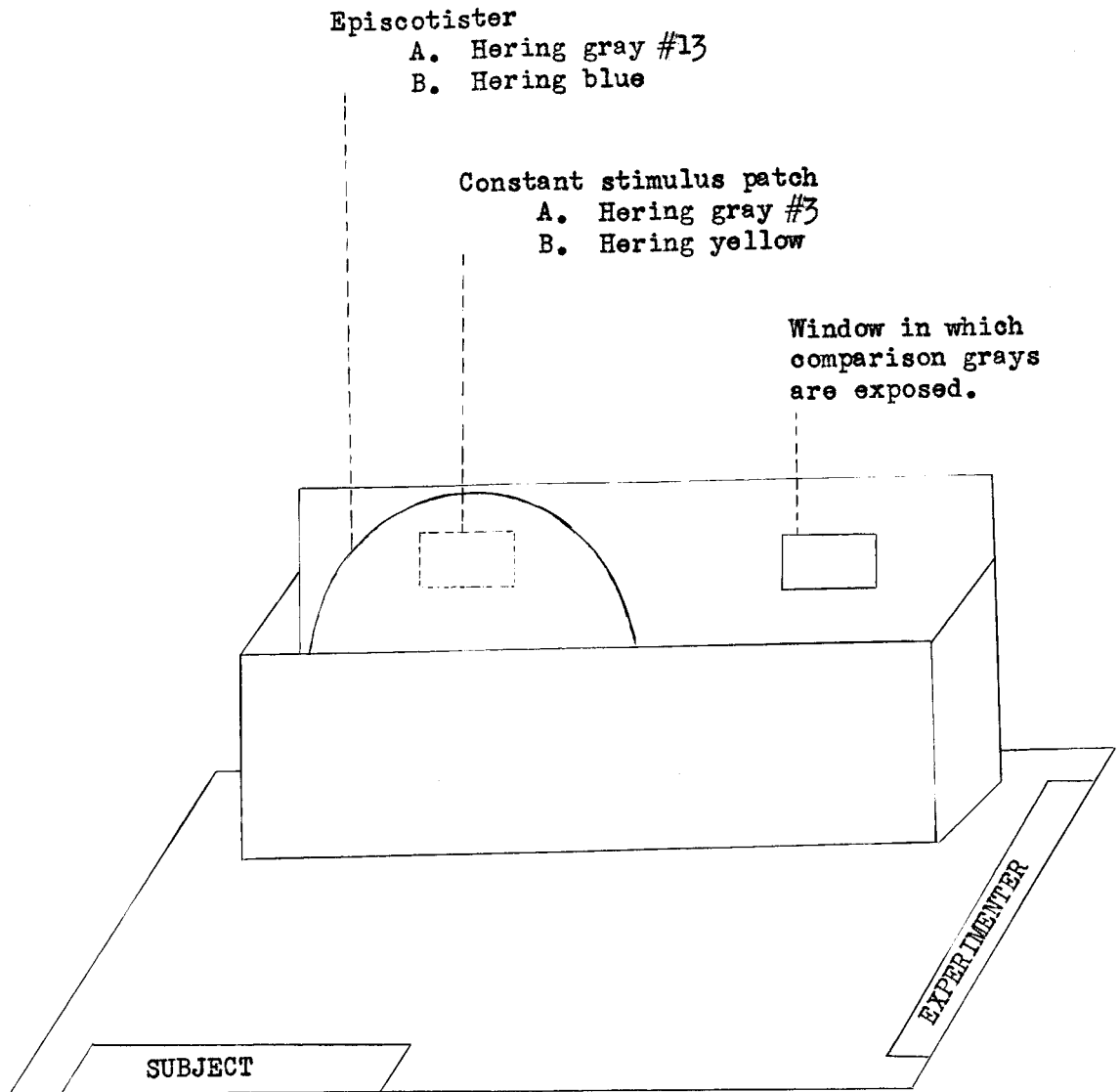


FIGURE 1

EXPERIMENTAL SET-UP OF THE PRESENT INVESTIGATION

- A. DENOTES CONDITIONS PRESENT IN THE GRAY-GRAY SITUATION.
 B. DENOTES CONDITIONS PRESENT IN THE BLUE-YELLOW SITUATION.

to be used as the episcotister in one half was matched to the Hering blue episcotister in the other half by the same method. Thus, the two parts of the experiment were equal in all respects except for the presence of colour where the Hering yellow was used with the Hering blue to produce gray, and the absence of colour when the Hering gray #3 was used with the Hering gray #13.

After some initial experimentation with various degrees cut from the episcotister, 10 degrees was taken from the episcotister. This would allow $1/36$ of the illumination from the constant stimulus patch, gray #3 or yellow, as the case may be, to reach the eye, on the assumption that the episcotister had been totally black. This insured the existence of a wide difference between the stimulus value of the constant stimulus patch seen through the light interrupter and the comparison grays viewed directly. Actually, an equal stimulus match response would be made by the subject, discounting light reflected from the episcotister, if he named as equal a gray whose brightness value was $1/36$ of that of the Hering gray #3. The brightness value of the Hering gray #3 is 65%. Since only $1/36$ of the illumination is permitted to reach the eye, the actual stimulus value has been reduced to $1/36 \times 60$, or 1 and $4/5\%$. Whereas, an object match or albedo match, with almost 100% constancy would be made by the subject if he named the Hering gray #3 as equal.

Upon consulting Woodworth on the perception of colours to find the optimum distance between the episcotister and the stimulus patch for individual brightnesses, three inches was chosen.

A series of 14 gray papers ranging from 94% white down to only 12.5% white was prepared. These are the comparison patches which are exposed in the window to the right by the experimenter. The ascending and descending method, progressing from almost white to almost black and then from almost black to almost white, was used. From this, a P.S.E. for each half of the experiment was obtained, and a percentage-of-white score computed.

The subject was instructed as follows:

In this experiment, you are to compare two patches as to their relative brightness. The one, which you see through the wheel, will remain unchanged through the first part of the experiment. Others of various degrees of brightness will be presented in the window to the right. You are merely to report whether the one on the right appears "brighter than", "equal to", or "darker than" the patch on the left.

Try to judge quickly with only one purpose in mind; namely, to discover the similarity or difference between the two patches, if any there be. If no difference is noticed, after glancing at the patch on the left, then the right patch, and again back at the left patch, answer either by saying they are equal or you do not know.

The comparison patches were viewed directly by the subject; only the constant stimulus patch on the left was viewed through the episcotister.

At this point, the subject was invited to ask any questions which might be necessary to clarify the instructions. Then these were re-affirmed and further instructions were given:

After each new patch is shown and you have given your report, look away into the corner while the next patch is being inserted.

Some subjects preferred to merely close their eyes momentarily after each presentation, and this, of course, was acceptable. The suggestion was aimed at avoiding adaptation of the eyes to the colour wheel, and this was as easily accomplished through the latter practice.

I will begin with a series of patches, the first of which appears noticeably brighter than the patch behind the revolving wheel on the left. I will continue to present patches which are progressively darker than the first one until I tell you the first series is over.

The first series was then presented in order, beginning with the paper containing 94% white and proceeding toward the one at the other end containing only 12.5% white. After the first series the order of presentation was reversed.

Now I am beginning with a patch noticeably darker than the one on the left, but you do not know how much darker it is. I shall continue to present patches which are progressively brighter than the first one of the series until I tell you the series is over.

Ten such series of trials were given for one half of the experiment. Upon completion, the other half of the experiment was administered in the same way.

The experiment was administered to fifty persons in all. These were both men and women, undergraduates, graduates, and a few members of the faculty in the department of psychology.

In an effort to eliminate the practice effect which might enter into such an investigation, the gray-gray half of the experiment was given to

about twenty-five of the subjects first, while the others were given the yellow-blue first.

Upon completion of the entire experiment, each subject was asked: "Did you find either the gray-gray or the yellow-blue more difficult to judge?" The introspections arrived at through this simple question were noted, but these are used only incidentally to the actual experiment.

The entire observation is based on the hypothesis that if some people respond more deeply to colour stimuli than do others, their object-surface seeing capacities should differ. The independent variable, as previously stated, is the colour of the constant stimulus patch behind the episcotister and the episcotister, itself. The remaining factors of the gray-gray situation have been equated with those of the yellow-blue phase.

CHAPTER III

FINDINGS AND CONCLUSIONS

The data obtained from the present series of experiments was then studied statistically.

The initial step in the statistical analysis involved the calculation of a percentage-of-white score for each half of the experiment. Thus, two such scores were assigned to each subject, one for the gray-gray set-up and another for the blue-yellow set-up.

The score for the gray-gray part of the experiment was obtained first. A P.S.E. was found through totalling and averaging the subjects' judgments of brightness matches in the ten series of trials for the gray-gray set-up. This, as given, was an arbitrary number, comparable to those designating the Hering grays, ranging from Hering gray #1, containing 94% white, down to Hering gray #21, containing 12.5% white, which were used as comparison patches throughout the experiment. (See Table I) By means of a conversion table giving the graduated decrements of white from Hering gray #1 to Hering gray #2, and so forth, a percentage-of-white score was obtained. This score now, was, in reality, equivalent to the amount of white necessary for a judgment of phenomenal equality by the subject in the gray-gray situation.

In the same way, a percentage-of-white score was found for the subjects' judgments of brightness matches in the blue-yellow half of the experiment.

TABLE I

THE PERCENTAGE-OF-WHITE VALUES OF THE COMPARISON GRAYS

COLUMN I SHOWS THE NUMBER OF THE HERING GRAYS USED.

COLUMN II GIVES THE ARBITRARY NUMBER WE HAVE ASSIGNED TO EACH GRAY IN THE PRESENT EXPERIMENT.

COLUMN III GIVES THE PERCENTAGE-OF-WHITE CONTAINED IN EACH COMPARISON PATCH USED.

* MEANS VALUES USED IN THE RE-CHECK.

I	II	III	
1	1	.94	*
2	2	.75	
3	3	.65	*
4	4	.54	
5	5	.48	*
6	6	.39	
7	7	.37	*
8	8	.31	
10	9	.27	*
11	10	.25	
13	11	.205	*
15	12	.172	
18	13	.148	*
21	14	.125	

The statistical analysis which follows is based on these tables, and re-checked, using the cut-tail method, to equalize the class intervals.

In either half of the experiment, a practically perfect object match would have been a Hering gray #3, which is known to contain 65% white. This was used as the constant stimulus patch behind the episcotister in the gray-gray part of the experiment, and its equivalent in a Hering yellow of the same brightness was used for the blue-yellow set-up. This Hering gray #3 was used as the third brightest comparison patch in each half of the experiment, Hering gray #1 and Hering gray #2 being the only ones shown for comparison which contained larger percentages-of-white.

On the other hand, a perfect stimulus match, disregarding light reflected from the episcotister, would have been a gray equal to $1/36 \times 65$, since the stimulus given was a gray containing 65% of white, or its equivalent, viewed through an episcotister with a 10° opening, allowing $1/36$ th of the reflective value of the stimulus-object patch to reach the eye.*

It was found that the percentage-of-white scores for the blue-yellow experiment ranged from .75 to .241. The percentage-of-white responses given in response to the gray-gray situation were confined to a slightly narrower range, that is, .522 to .242. It is readily observable that the lower scores are not significantly different. The wide difference in the range of scores is evident at the upper end of the scales.

NOTE: If the object brightness of the gray episcotister is considered as being fused with the stimulus value of the Hering #3 gray patch seen through it, a correct stimulus match would require about 21.4% gray. Actual matching with the reduction screens requires a 20% to 25% gray. cf. Woodworth, 610.

This wide divergence of scores at the upper end is chiefly attributable to the responses of one subject, ZA, to the blue-yellow situation. ZA's percentage-of-white score for the blue-yellow situation is .750. The next highest percentage-of-white response to the blue-yellow was that of PE, giving .552.

Elimination of this one subject, ZA, would yield a narrower range for the blue-yellow scale, closely approximating the range of the gray-gray scale. However, the present investigation, as previously stated, attempts to study subjective differences in reaction to colour, if such exist. Therefore, it was decided to retain the fifty pairs of original scores as obtained in the present series of experiments.

A casual inspection of the responses as a whole reveals a tendency toward object colour. The response is always, except in the case of ZA's responses to the blue-yellow set-up, a compromise between the object value, 65%, and the actual stimulus value, $1/36 \times 65$. The illumination was homogeneous for the entire field, including the standard object patch and the grays presented for comparison purposes. Daylight illuminated the entire field through a large window situated very close to the left side of the subject and experimental set-up.

At this point, the writer would like to review the findings of some previous investigators somewhat analagous to her own as regards this tendency toward object colour.

The problem of constancy has been attacked variously by many experimenters. But constancy of size, shape, and colour seem to have received

much more attention than has the problem of brightness constancy.

Hering was one of the first to discuss phenomenal constancy. He was concerned with the approximate constancy of the colour of visual objects when undergoing changes of the illumination; and he concluded that we view the world about us through memory colours, as mentioned previously in the present paper. That is, we come to know a thing as of a given colour through repeated contact with the thing in this colour. Then we continue to perceive it as of this colour, regardless of changes in the illumination.

The artificial laboratory conditions of the present study were an attempt to rule out the factor of memory colour. The subject had no previous contact with the experimental set-up, as such, nor was he told of the nature of the object behind the episcotister in either half of the experiment. Memory colour could not have been an operational factor, except insofar as the subject may have been conversant with the rules of colour mixture. Yet, even this knowledge would be a cue only to the colour of the object patch; it could not give any indication of the brightness, since the subject cannot foresee what the value of the variable is going to be.

Much of the work of Katz, designed to test Hering's hypothesis, remains untranslated. So we will rely on MacLeod's summary of Katz's experiments in order to discuss it here.

The observer sat under a strong light at one end of an otherwise dark room. One metre before him at the level of his eyes was placed a scale of 18 gray papers,

arranged in equal steps from bright white to deep black. At the other end of the room, 5 m. away, larger papers of the same albedo as those on the scale were presented so that a direct comparison of the colour of the larger paper with that of the papers on the scale was possible. The observer's task was to locate the colour of the larger paper on the scale of grays before him.¹

Only one of the results of this investigation is of importance to our own study.

...The paper at the end of the room always reflected very much less light than the paper on the scale which was judged to be of equal brightness.... Katz estimated that a white paper at the end of the room reflected about $1/20$ of the light reflected by the paper on the scale judged to be its equal.²

These findings are not unlike our own. There is evident the tendency toward object colour, and the compromise between object value and stimulus value, as in the present investigation, since equality was perceived when a vast difference in brightness actually existed.

In speaking of another experiment of Katz, employing the episcotister method, MacLeod states:

Under ordinary circumstances, one would expect that the mixture on the colour wheel of 357° black and 3° white would produce a definite black. Photometrically, a white disc seen through a black episcotister with an opening of 3° represents exactly this situation. Nevertheless, Katz's experiment yielded a quite different result. The disc, B_2 , contained throughout 360° white, and the episcotister openings were varied from 270° to 3° . The corresponding equations on B_1

¹ MacLeod, R.B., "An Experimental Investigation of Brightness Constancy", Archives of Psychology, 21, 1932, 25.

² Ibid., 25.

ranged for a typical observer from 298° white to 63° white.³

The results of this study are summarized briefly:

1. In no case did the equations made correspond to the stimulus conditions.
2. The white disc retained relatively more of its white character the more it was obscured by the episcotister.⁴

We may conclude from a consideration of the range of scores obtained in the present experiments, and from the findings of other investigators consulted, that the response is, almost without exception, a compromise between object value and stimulus value. One subject exhibited an "over-constancy" tendency, but this, too, has been discovered in some few cases by previous experimenters.

The next step in the statistical analysis of our findings comprises a study of the mean scores for each scale. These are found to be almost identical. The mean score of the blue-yellow scale is .3575; that of the gray-gray scale is .3574.

Immediately, then, colour might seem to have had no effect on the brightness matches. Yet, this cannot be the only true conclusion, because the highs and lows could have neutralized each other, as, for instance, FY and GS, or ZA and EI.

FY gave 52.2% as the judgment of phenomenal equality in the gray-gray situation and 36.4% for the blue-yellow, while GS responded with 35.8% on the gray-gray and 43.5% on the yellow-blue.

³ Ibid, 28.
⁴ Ibid, 28.

ZA gave 75.0% for phenomenal equality on the blue-yellow and 43.5% on the gray-gray set-up. EI responded with 37.2% on the blue-yellow and 48.0% on the gray-gray.

The possibility of neutralization effects is very readily apparent.

Hence, apart from correlations, a comparison of mean scores is misleading; although the almost exact repetition of mean scores for the coloured and non-coloured set-up does show that the brightness ratio of the two settings was adequately equated.

The correlation between the two sets of scores was calculated according to the Product-Moment Formula.

$$r = \frac{\frac{\sum x' y'}{N} - \left(\frac{\sum x'}{N} \right) \left(\frac{\sum y'}{N} \right)}{.6 x \cdot .6 y}$$

This was found to be .685.

Then, the P.E. of "r" was obtained as follows:

$$P.E._r = .6745 \frac{1 - N^2}{\sqrt{N}}$$

The P.E. was found to be .051. The fact that "r" is at least 13 times its probable error would indicate an acceptable degree of reliability.

A slightly higher coefficient of correlation was found using the Spearman Rank-Difference Method.

$$r = 1 - \frac{6 \sum D^2}{N (N^2 - 1)}$$

Here, "r" was found to be .715. This discrepancy can probably be accounted for by the difference in the relative identity of scores lost through grouping. However, either result can be employed for comparison with the findings of another experimenter.

Richard Hubard Henneman, working at Columbia University, undertook a rather extensive study of color constancy in the achromatic scale, which he titles, "A Photometric Study of the Perception of Object Color."

The test objects used in most of the experiments were cardboard disks, a flat white on the left, a flat black on the right, approximately equated to their respective backgrounds in color, but visible by virtue of contour and of their being in front of the backgrounds.... The two disks were of the same size and in the same position in the

field.... Speed of rotation was maintained above the flicker point. The left-hand disk was used as the standard, its color remaining unchanged; the right disk was variable in brightness and adjustable to phenomenal equality with the standard...a spot of light was focussed on the right-hand black disk from a concealed projection lantern, the apparent shade of gray in the black-white scale of the variable disk then being determined by the intensity of this special spotlight...advantages were: (1) changes could be made without stopping the motor, (2) the brightness could be varied by "remote control"...⁵

In order to clarify this review, it was deemed advisable to reproduce Henneman's diagram of the experimental set up, as shown in Figure 2.

Henneman then speaks of the location of the subject and the preliminary instructions given to each subject as follows:

...The observer sat at the end of a table and 3 meters from the test disks directly in front of the central partition...a 3-second time of exposure was adopted and kept constant in all of the experiments. Subject was....told of the standard and variable disks and instructed to report on each subsequent exposure whether the right-hand disk was darker, equal to, or "whiter" than the standard. He was instructed to observe with both eyes and to fixate each disk separately looking from one to the other and not attempting to see both...⁶

The similarity between Henneman's study and our own is immediately apparent. This similarity is developed further when we consider additional factors in the investigations.

Method of limits was used in making phenomenal equality between the two test disks.... As there was little change in the equation after

5 Henneman, R. H., "A Photometric Study of the Perception of Object Color", Archives of Psychology, New York, 1935, 27, 29.

6 Ibid, 31-32.

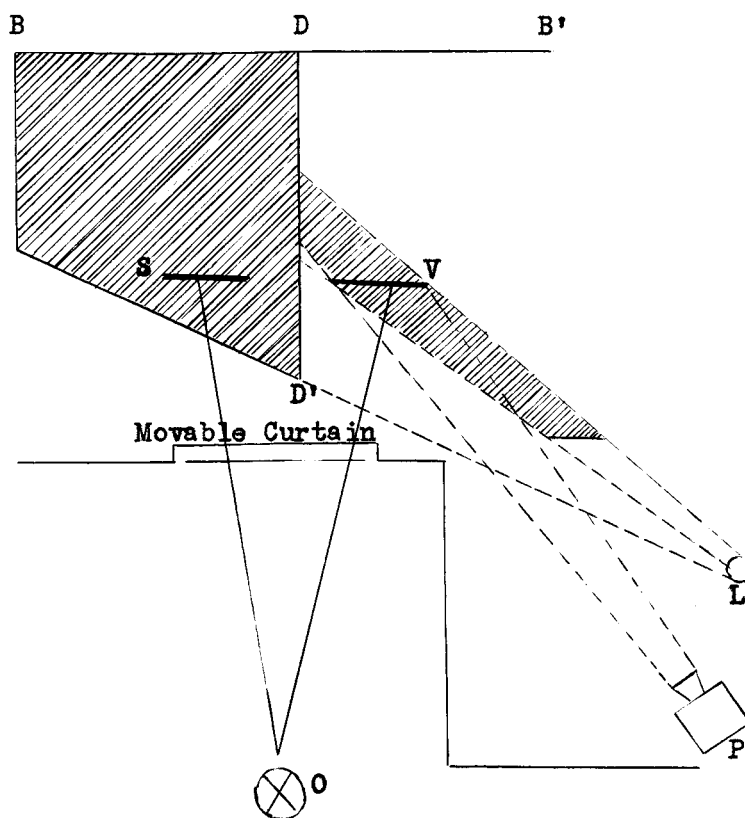


FIGURE 2

THE EXPERIMENTAL SET-UP OF HENNEMAN'S INVESTIGATION

BD--white background; DB'--black background; DD'--partition;
 S--shaded white disk; V--variable disk; L--general illumination
 source; P--projection lantern; O--position of the observer.

three complete ascending and descending series...three such series constituted a judgment for that particular condition.⁷

...The observers used in the present study were for the most part graduate students in psychology.... The number of observers was about equally divided between men and women.⁸

The first series of experiments was then run to determine for each subjects' judgments of phenomenal equality a P.S.E., as given in response to the homogeneous field described above. In this initial undertaking, the effects of the varying reflectivities in the remote background became apparent to both Henneman and his subjects. And the experiments in field complexity were undertaken.

Accordingly, an artificial "window" was installed...so that...the observer's view was restricted to the photometrically equated backgrounds around the test disks... let us now turn to the principal...quantitative studies...on the effect of surrounding objects in a controlled field on the perceived color of the test disk. Several factors suggested themselves as important ones to isolate and vary one at a time-- number, size, albedo, and position of the field objects.⁹

For the purposes of comparison with our own results, we may accept any specific experiment from the series Henneman conducted. Each is in the form of test and re-test with one variable factor introduced. Therefore, the judgments of phenomenal equality given in response to any one of these situations should correlate with the judgments given in response

7 Ibid, 32.

8 Ibid, 35.

9 Ibid, 43-48.

to the homogeneous field at least as high as would the test and re-test of colour constancy with the achromatic scale. We shall give, as briefly as possible, the correlational findings in each instance.

In the first, the responses to the homogeneous field of Henneman outlined above were compared with the responses to an equated situation into which was introduced one, two, or three small disks around the standard test disk. These were medium gray in colour, with a reflective value of .162. Correlations of the responses to the homogeneous field with those of the equated field containing one small object was .96; with those of the equated field containing two small objects was .94; and with responses to the equated field containing three small objects was .94.

Correlations investigating the relation of the homogeneous field to an equated field containing a small, a medium, or a large object yielded similarly high results.

The same was true of the study of the effect of albedo on the judgments of phenomenal equality. The correlation of the responses to the homogeneous field with those given in response to an equated field containing three objects of no albedo difference was .99. When these objects were of medium albedo difference, the "r" was .95. While objects of small albedo difference correlated with the homogeneous field yielded .91.

Finally, correlation of the homogeneous field with an equated field containing background figures yielded .99.

It is readily obvious from the correlations obtained by Henneman, that an exact test and re-test of colour constancy with the achromatic scale would probably yield a correlation close to unity, since, in spite of

all the various factors introduced by Henneman, his subjects showed a strong consistency of response, all correlations being .91 or above.

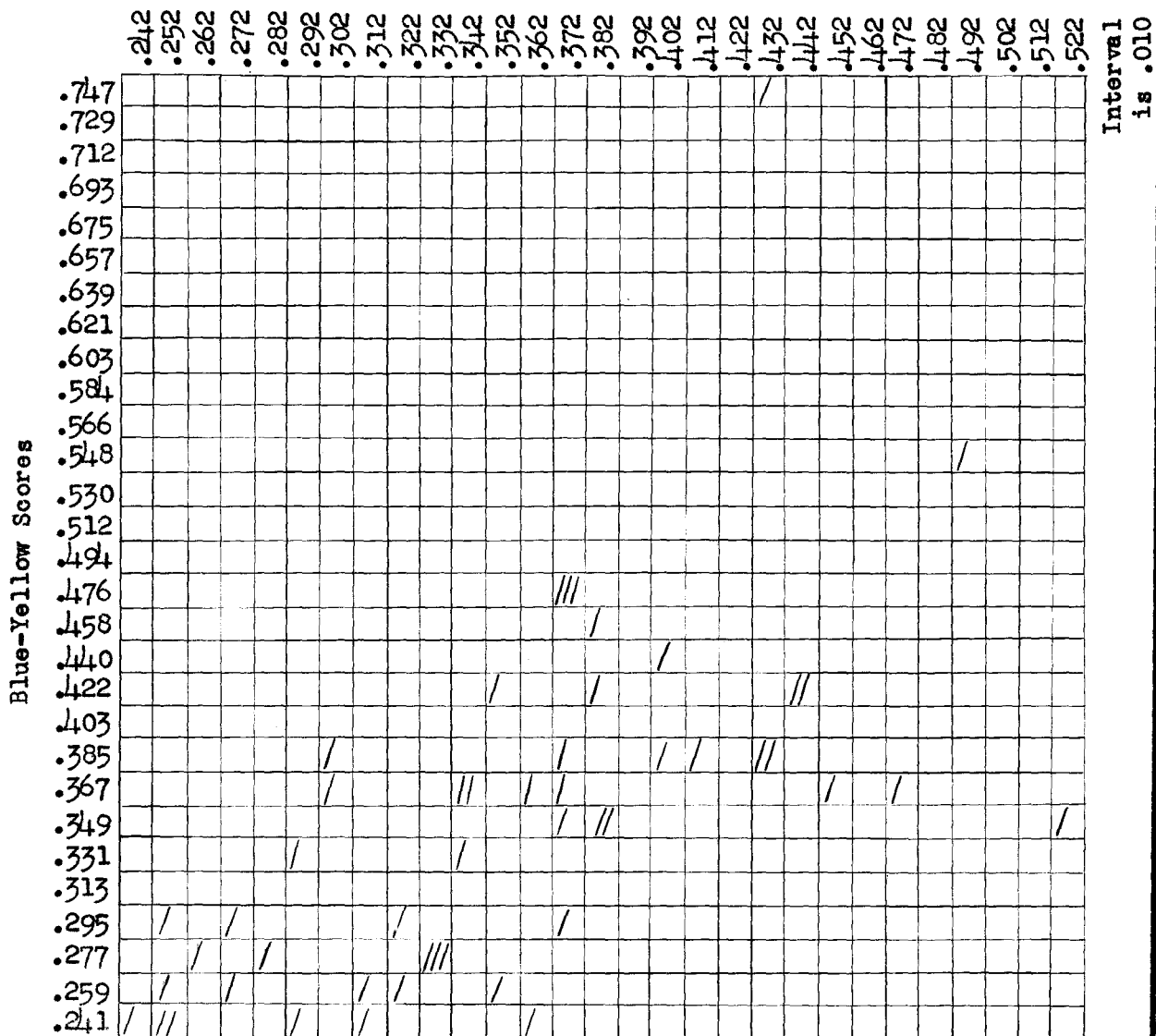
However, the difference in the subjects tested should be noted. In the present study, fifty subjects participated. These were men and women, graduate and undergraduate students, and members of the faculty. Most of the findings of Henneman were based on the observations of eleven or twelve subjects, all of whom were graduate students in psychology. The smaller group of graduate students would naturally tend to yield a somewhat higher correlation.

In spite of this fact, we may state that the correlations between the blue-yellow scores and the gray-gray scores in the present research was far below those of Henneman, leading us to suspect that the presence or absence of colour was probably the element to which this low correlation is attributable.

With this mere suggestion of the existing possibility of the effect of colour, we will proceed to the next step in the statistical analysis of the present inquiry.

A further analysis of the nature of the relationship between the two sets of scores obtained for the blue-yellow and gray-gray situations was made through the construction of the scatter diagram. (Figure 3) From this an imperfect correlation is seen. The scores do not center around any given axis in the field, but, rather, are spread out quite irregularly. The gray-gray scores show some consistency of grouping, the blue-yellow scores exhibiting more spread and uniqueness of position. The influence of these extreme cases on the mean and the correlations given above is

Gray-Gray Scores



Interval is
.0181

FIGURE 3

SCATTER-DIAGRAM SHOWING THE RELATION OF
THE BLUE-YELLOW SCORES AND THE
GRAY-GRAY SCORES OBTAINED

readily understandable.

These extreme cases also effect the S.D.s which are the next items to be considered. In these, too, greater variability is evidenced in the blue-yellow scores, having an S.D. of .093. The gray-gray scores give an S.D. of .066. Some distracting element is indicated. Since the two test situations were perfectly equated, with colour, alone, the varying factor, we can assume that colour interferes with the brightness matches.

This, too, is easily seen through an inspection of the distribution charts, (Tables II and III). These give a graphic picture of both inter and intra individual variations. From them we see that the blue-yellow experimental set-up caused most subjects greater uncertainty than did the gray-gray. A careful scrutiny of the tables reveals that for 43 subjects the zone of uncertainty was approximately equal for the two tests, or greater for the blue-yellow phase. Only 7 subjects exhibited greater uncertainty in responding to the gray-gray situation. These 7 do not constitute any given portion of the gray-gray scale, but are scattered almost equidistantly throughout the entire range.

The phenomena of regression was the next statistical analysis drawn from the present findings.

An averaging of the persons' scores who made up the upper 10% on the blue-yellow scale yields .580; an averaging of these same persons' scores on the gray-gray scale yields .412.

A comparable study was made of the gray-gray scale. An averaging of the persons' scores who made up the upper 10% of the gray-gray scale yields .479; an averaging of these same persons' scores on the blue-yellow scale

TABLE II

DISTRIBUTION CHART FOR THE BLUE-YELLOW SCORES

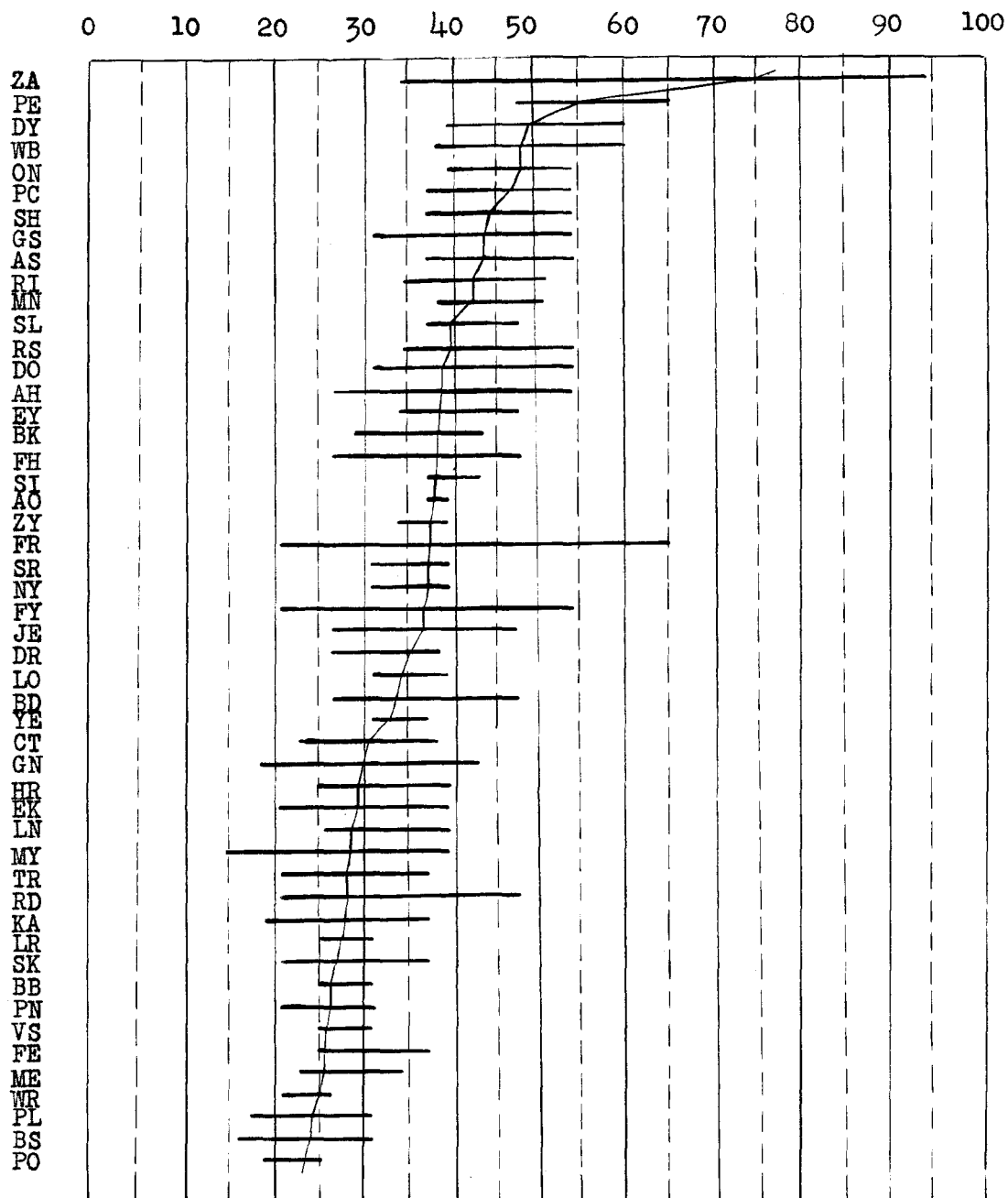
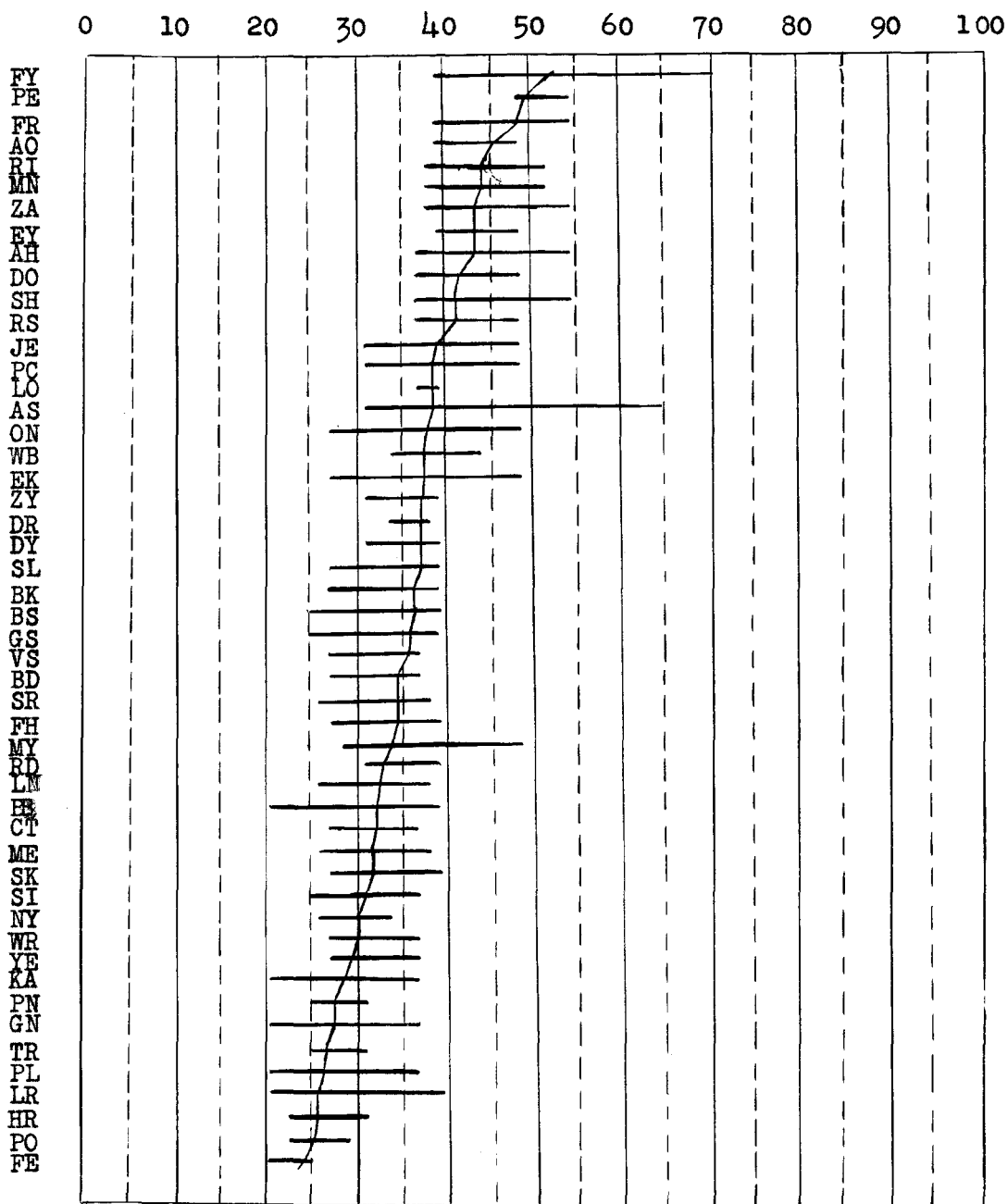


TABLE III

DISTRIBUTION CHART FOR THE GRAY-GRAY SCORES



yields .418.

The lower end of each scale of scores was then handled in the same manner. An averaging of the persons' scores who made up the lower 10% of the blue-yellow scale yields .246; and an averaging of these same persons' scores on the gray-gray scale yields .298.

An averaging of the persons' scores who made up the lower 10% of the gray-gray yields .253; while an averaging of these same persons' scores on the blue-yellow scale yields .261.

The phenomenon of regression is found in the first three of the foregoing analyses. Evidence for this in the last given analysis is negligible, however.

These findings would indicate that colour has a distracting effect on the brightness match, but a more definite distracting element seems to appear at the upper end of the scales. Since colour is the only independent variable between the two parts of the present inquiry, we can only assume that the presence of colour is the distracting factor influencing the judgments of phenomenal equality given by the subjects.

The final analysis in the present investigation is an examination of the introspections given.

Upon completion of both parts of the experiment, the subject was asked, "Did you find either part of the experiment easier or more difficult to judge?" Twenty-two of the subjects were undecided or found the two parts of the experiment equally difficult in judging phenomenal equality. Fifteen reported the gray-gray easier. Thirteen said the blue-yellow was easier to judge.

Of those 15 reporting the gray-gray easier, 1 fell within the lower 10% and one within the upper 10% of the gray-gray scale. The other 13 ranged between these two extremes.

Of the 13 subjects reporting the blue-yellow easier to judge, 3 were within the upper 10% on the blue-yellow scale, 3 were within the lower 10% on the blue-yellow scale, and the other 7, again, fell somewhere between these two extremes.

The introspections given are of incidental interest only. One cannot discuss the relationship between the subjects' ability to judge ease of matching and correctness of response without knowledge of what the subject was attempting to give, object or stimulus response. The instructions were purposely worded to leave either alternative open to the subject.

It was hoped, in this way, to achieve a naive attitude on the part of each subject. But even the term "naive" is ambiguous, since one cannot say whether a naive attitude should be object directed or stimulus directed. Furthermore, even in the course of a single experiment, fluctuations in a attitude may take place below the conscious level. Other investigations, studying the effects of attitude on constancy response, have shown that the responses given can be altered somewhat by instructions given to direct the attitude to a value desired, object or stimulus. Another phase of Henneman's inquiry, not included in our review of his work above, was devoted to the investigation of this point. He was able to change the responses of his subjects in judging phenomenal equality merely by changing the preliminary instructions, in one case directing their attention toward object value, and in the other case calling their attention to stimulus

value desirability.

Therefore, we may summarize the present findings as follows:

1. The range of the blue-yellow scores is wider than that of the gray-gray scores. The blue-yellow scores range from .750 to .241. The gray-gray scores range from .522 to .242.

2. Like means, .3575 for the blue-yellow scale and .3574 for the gray-gray scale, indicate that the brightness ratio for the two settings was adequately equated.

3. A correlation of .685 or .715 was found to exist between the two sets of scores in this particular sampling, depending upon the formula used in calculation.

4. The P.E. of "r" is .051. The fact the "r" is at least 13 times its P.E. would render it acceptably reliable.

5. The correlations obtained by Henneman in situations which would closely approximate test and re-test for brightness constancy with grays were .91 or higher.

6. There is a wide difference in the correlations obtained by Henneman and that yielded by the present investigation which may be due to the number of subjects tested, the particular sampling in each case, or the methods employed. Our low correlation, as compared to Henneman's higher correlations, may be due to the differentiating factor which we attempted to isolate for study, that is, colour.

7. Examination of the S.D. for the two scales shows that a greater variability exists for the blue-yellow, thus indicating some distracting element is present. The S.D. of the blue-yellow scores is .093; that of

the gray-gray scores is .066.

8. The distribution charts show greater uncertainty exhibited in the blue-yellow matches.

9. A study of the phenomenon of regression indicates the presence of some distracting element. The findings show that the effect of this distraction is more pronounced at the upper levels of the scales.

10. The introspections given are of incidental interest only, but indicate individual differences in the apparent difficulty of the task.

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APPROVAL SHEET

The thesis submitted by Lillian-Frances Bowden has been read and approved by three members of the Department of Psychology.

The final copies have been examined by the director of the thesis and the signature which appears below verifies the fact that any necessary changes have been incorporated, and that the thesis is now given final approval with reference to content, form, and mechanical accuracy.

The thesis is therefore accepted in partial fulfillment of the requirements for the Degree of Master of Arts.

May 21, 1949
Date

Vincent V. Herr, Jr.
Signature of Adviser