U. S. ARMY

Technical Memorandum 20-70

COLOR AND SUBJECTIVE DISTANCE

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August 1970
AMCMS Code 501B.11.84100

HUMAN ENGINEERING LABORATORIES

ABERDEEN RESEARCH & DEVELOPMENT CENTER

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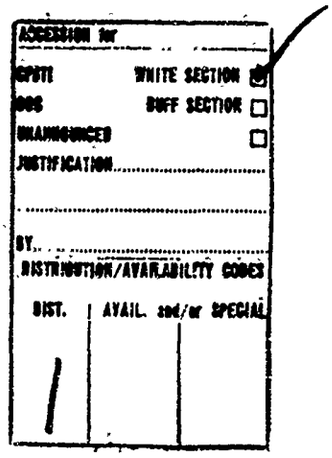

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ABSTRACT

Sixteen observers adjusted the position of a white or colored rod until it seemed to be alongside a reference white or colored rod. The colors used were blue and red of matched luminances. Observers tended to see the red rods as nearer and the blue rods as further away. It was concluded that red and blue are used as cues for depth perception.

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COLOR AND SUBJECTIVE DISTANCE

INTRODUCTION

The phenomenon of differential subjective distance of objects as a function of their color is readily observable if only rarely noted. Artists use "retiring" and "advancing" colors to develop a third dimension by bringing objects subjectively closer with warm tones. M. Luckiesh (1918) quantified such a Red-Blue relationship with two-dimensional figures by having his observer position rear illuminated red "X's" and blue "E's" in the same plane when viewed down parallel tracks.

The current study was intended to evaluate this phenomenon in the presence of the additional depth cues afforded by three-dimensional targets. Johns and Sumner (1948) approached a related question using tubes made of Hering's colored papers which were placed over the rods of a Howard-Dohlman type depth-perception apparatus. When comparing red, yellow, green, blue, white, and black against neutral grey, they found a high correlation between "brightness" (reflectance) and apparent distance. Red elicited the only obvious exception to higher liminance papers appearing closer. Relevant to the current interest are their findings that green and blue stimuli appeared more distant than the grey reference, and red appeared closer even though the decreasing luminance order was green, grey (reference), red and blue. Additionally, the means for red (reflectance 11.6%) and blue (reflectance 7.3%) were equal but opposite in direction. (When seen as equal to the grey reference rod of 12% measured reflectance, and red was 2.7mm more distant and under the same conditions blue was 2.7mm closer).

For consideration in screening observers for future investigations, we were also interested in the correlation of stereopsis measured as "depth perception" by the Bausch & Lomb Orthorater and performance on our version of a Howard-type task.

METHOD

Observers

Data from 16 observers (Os) were used for this study. The Os were selected from a group of 29 soldiers from Ft. Knox, Kentucky, on the basis of color and far-vision scores on a Bausch & Lomb "Modified" Model Orthorater. Selection criteria were color vision $\geq$ =4 and far-visual acuity $\leq$ 10 (20/20 Snellen). This selection is based on earlier findings of correlation between stereoscopic and visual acuity (Davson, 1962).

The Os were tested for phoria, far acuity (left eye, right eye and both eyes), depth (stereopsis), and color vision. Data on all 29 soldiers are shown in Appendix A, and Table 1 summarizes the measures for the 16 Os used.

TABLE 1

Orthorater Scores for 16 Observers

		Range	$\bar{X}$
Age		17 - 24	20.31
Far Acuity	Both eyes	10 - 12	11.56
Far Acuity	Right	10 - 12	11.19
Far Acuity	Left	10 - 12	11.31
Depth		0 - 9	6.31
Color		4 - 6	5.75

Apparatus

The modified Howard (1919) type depth-perception apparatus used for visual target presentation is shown in Figure 1. The machine housing is wood and measures 145 cm long x 20 cm wide x 36 cm high overall, excluding a removable shield which prevents O's view of target positioning operations. A sheave arrangement allows Os to position one target by means of a continuous string loop which is connected with a clip fastener prior to each trial (it was disconnected by the experimenter (E) for pre-trial positioning to preclude a trial-to-trial relationship between the control strings and stimulus position). In use, the shutter is closed between trials to define the trial period and to occlude O's view of pre-trial target rod setting. The full-length flat black septum prevents reflected light interaction cues between reference and controlled rods.

Readily interchangeable 1.25 cm diameter target rods are separated by 7 cm center to center when in a plane perpendicular to the O's line of regard. The luminances of the rods in foot-lamberts were red-10.3, blue-10.4 and white 24.0. A +40 to -40 cm scale positioned between the target carrier tracks allows target position to be read directly to 0.5 cm. For this study, the adjustable front aperture was set at 12 cm wide x 5 cm high.

Uniform illumination throughout the track length and between tracks was obtained after four-hour aging of 12 new 40-watt fluorescent lamps and individually scanning them with a Spectra Model Pritchard Photometer to select a matched pair for the exposed lengths of the lamps.

At the O's position, a fixed hood was installed to insure a uniform viewing distance of 6 meters from his forehead to the reference rod, and to align his view with the septum.

The experimental room walls and ceilings were painted flat black. Illumination of 0.20 foot-candles at the O's position and 0.25 foot-candles at the target machine was from two dimmer-controlled lamps which were centered over the O and the target machine. Both lamps were screened from the O's view by the viewing hood.

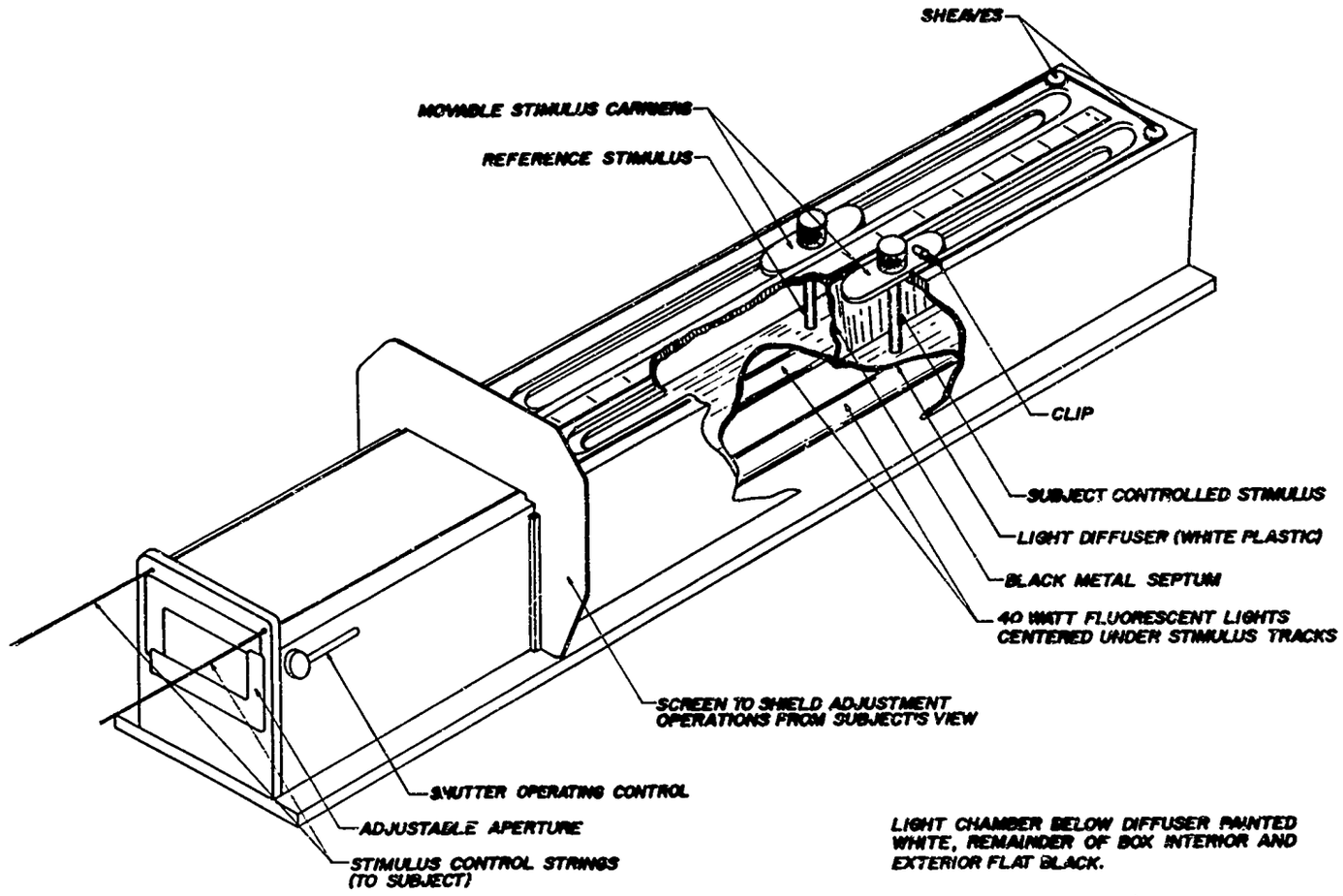

Fig. 1. STIMULUS PRESENTATION APPARATUS

Procedure

The apparatus was set at one end of the vision room and the O sat six meters away with his head positioned by the viewing hood.

For each trial, the E first closed the shutter and then set the adjustable rod at a preselected random position on the scale. He then connected the string to the adjustable rod. The shutter was opened and the O proceeded to make his adjustment. He was permitted to pull each string moving the adjustable rod back and forth as often as he wished until he judged it to be alongside the reference rod. He then indicated he was through by saying "OK". The E then closed the port, disconnected the string from the adjustable rod, recorded the results and proceeded to the next trial.

There were 20 trials per session and four sessions for each O. For the first 10 trials of each session, white was used for both the reference and the adjustable rods.

In the last 10 trials of the session, colored and white rods were used according to the schedule shown in Table 2.

TABLE 2

Order of Color-Pair Presentation

	Session 1 Ref Adj	Session 2 Ref Adj	Session 3 Ref Adj	Session 4 Ref Adj
8 Observers	W - R	W - B	R - B	B - R
8 Observers	B - R	R - B	W - B	W - R

W - White; R - Red; B - Blue
Ref - Reference; Adj - Adjustable

All 29 Os served in the first session during which both white rods were used. This was a practice session for the 16 Os used in the whole experiment and the data of all 29 Os were used to test for correlation between the steropsis scores of the Orthorater and performance on this task.

Two Os served at a time so that while the second O was performing in his first session, the first O was resting and so on through the four sessions. The sessions, and consequently, the rest periods, lasted from 6 to 20 minutes depending on how fast the Os worked.

The first session of each O was with two white rods for a practice session. At the beginning of each other session, the white-white comparisons were made to determine what change, if any, occurred in the threshold of the O. The first row of Table 3 summarizes the data from these three white-white comparisons. Note that the differences among these comparisons are not significant. The various combinations of red and blue rods do show significant differences.

TABLE 3

Summary of Friedman Two-Way Analysis of Variance

Conditions	X_r^2	d. f.	p
WW WW WW	2.306	2	< .5- > .3
BR RB	4.0	1	< .05- > .02
WR WB	4.0	1	< .05- > .02

W - White; R - Red; B - Blue
1st letter denotes color of stationary reference
2nd letter denotes color of adjustable rod

Table 4 shows the mean error in centimeters and the standard deviation for each color pair comparison. Each entry represents 160 trials (10 trials of each condition for 16 Os). Note that the O adjusted the position of the blue rod to place it closer to himself than a red reference rod. When red was the adjustable rod, the O tended to place it further away from himself than the blue reference rod. Likewise, the blue rod was set significantly closer to O than the red rod when they were paired individually with a white reference rod.

TABLE 4

Mean Error by Color Comparison Pairs
(10 trials each pair for 16 observers)

Color Pair Ref	Adj	*Error (Centimeters)	σ
W	W	+1.77	3.44
W	W	+3.35	7.40
W	W	+1.54	6.21
W	W	+1.63	5.37
W	B	+7.51	10.30
W	R	+2.98	9.88
R	B	+8.16	9.82
B	R	-2.18	8.10

* + value indicates adjustable in front of reference

Figure 2 gives a graphic picture of the various color combination error means referenced to the overall white-white error mean. Note that the red-blue pair and the blue-red pair yielded opposite but practically equal results.

The results of the Orthorater examinations are presented as Appendix A. The white-white comparison performance of all 20 Os was checked for correlation with their Orthorater "Depth" scores. No significant correlation was found either for the white-white means or white-white σ ($r = 0.031$ and $r = 0.068$ respectively).

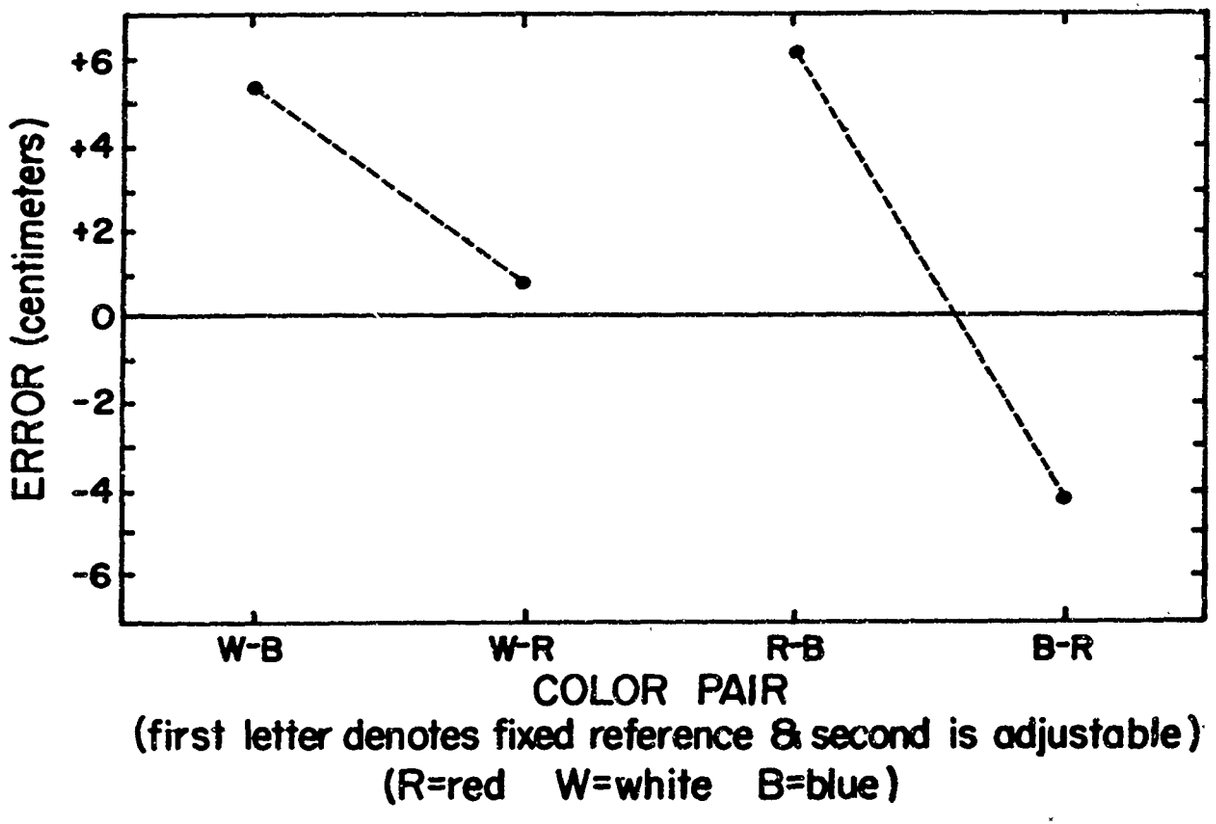

Fig. 2. MEAN ERROR BY COLOR PAIRS REFERRED TO W-W ERROR AS ZERO

DISCUSSION

The white-white comparisons were used at the beginning of each session. There were several reasons for this: first, to vitiate or minimize the effects of the preceding trial; second, to detect and define any bias, either experimentally induced or physiological in nature, such as aniseikonic errors (Sloan and Altman, 1953, 1954); third, to provide evidence and /or measurement of practice or fatigue effects. (The sessions were counterbalanced and the statistical test showed no significant differces in the counterbalancing.) Finally, the first white-white trials were used as a practice session.

As Table 3 shows, within Os there was no significant difference among the white-white trials and, in fact, there was practically no difference, ($p = 0.5$). This leads to the conclusion that there were no appreciable changes in the thresholds of the Os throughout the study.

There were differences in the means among the red-blue, red-white and blue-white comparisons. The red rods appeared nearer to the Os than the blue rods and so they were set further away by the Os. The difference in the means were significant at the <0.05 level as may be seen from Table 3. This is predictable and lends additional support to the idea of artists and others that warm tones give the appearance of nearness and cool tones the appearance of distance.

Ordinarily one might argue that the differences in apparent distance are due to the differences in the luminance of the colored rods. This is not true here since the slightly ($< 1\%$) brighter and higher luminance rod was blue and it was seen as farther away than the red rod. Furthermore, the white rods were almost 2 1/2 times the luminance of the blue and the red rods, yet in comparing the blue with the white and the red with the white, the blue appeared further away from the O than did the red. Obviously the differences in the means cannot be attributed to differences in luminance and must be considered as the result of subjective distance based on color.

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APPENDIX A

VISION DATA ON SUBJECTS

TABLE 1A

Phoria, Far Acuity, Depth and Color Vision for Each Subject

Observer	Age	Phoria		Far Acuity			Depth	Color
		Vertical	Lateral	Both	Right	Left		
K.B.	17	3	10	7	8	4	X	5
R.B.	22	6	8	10	9	10	7	4
* M.B.	19	6	9	12	12	12	9	6
J.B.	20	7	8	11	9	11	9	5
T.B.	18	7	8	12	12	9	8	6
L.C.	19	4	8	9	10	9	4	6
* D.C.	18	6	13	12	12	12	9	6
* W.F.	21	8	6	12	11	12	7	6
N.G.	24	6	7	12	9	11	5	6
* T.H.	21	3	7	12	12	12	9	6
L.K.	20	6	8	10	10	8	7	1
D.L.	20	6	8	10	9	10	7	6
* S.M.	21	6	6	10	11	10	4	4
* P.M.	21	4	12	12	11	10	4	6
* A.P.	22	6	12	12	10	11	X	6
W P.	20	6	8	9	8	9	7	6
* T.R.	24	6	4	10	10	11	9	6
T.S.$_1$	19	6	4	8	10	11	4	5
* H.S.	20	4	5	12	11	10	3	6
* G.S.	17	5	7	12	12	12	7	5
J.S.	20	6	8	12	12	12	2	2
* T.S.$_2$	19	6	9	11	10	12	9	6
* L.T.	21	5	8	11	12	11	5	6
* C.W.$_1$	22	5	8	12	10	12	4	6
L.W.	21	3	6	9	8	12	6	6
* F.W.	21	5	9	12	12	12	6	6
W.W.	26	5	6	9	9	8	5	6
* C.W.$_2$	20	3	7	11	11	10	7	5
* M.Y.	18	5	8	12	12	12	9	6
Range	17-26	3-8	4-13	7-12	8-12	4-12	0-9	1-6
Mean	20.38	5.31	7.83	10.79	10.41	10.52	5.93	5.38

* Used as Observers

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Human Engineering Laboratories Aberdeen Proving Ground, Maryland 21005	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

COLOR AND SUBJECTIVE DISTANCE

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

5. AUTHOR(S) *(First name, middle initial, last name)*

Claude N. McCain, Jr.
A. Charles Karr

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
August 1970	15	6

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO.	Technical Memorandum 20-70
c.	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
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	ROLE	WT	ROLE	WT	ROLE	WT
Human Factors Engineering Vision Color Vision Depth Perception						

Security Classification