Technical Memorandum 17-76

RELATING TARGET VISIBILITY FACTORS TO SMALL-ARMS COMBAT EFFECTIVENESS

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April 1976
AMCMS Code 672716.11.H7000

U. S. ARMY HUMAN ENGINEERING LABORATORY

Aberdeen Proving Ground, Maryland

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: Technical Memorandum 17-76	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): RELATING TARGET VISIBILITY FACTORS TO SMALL-ARMS COMBAT EFFECTIVENESS	5. TYPE OF REPORT & PERIOD COVERED: Final
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Timothy W. Brauneck, John L. Miles, Jr., Ralph J. Kibler	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: U.S. Army Human Engineering Laboratory, Aberdeen Proving Ground, MD 21005	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: AMCMS Code 672716.11.H7000
11. CONTROLLING OFFICE NAME AND ADDRESS	12. REPORT DATE: April 1976
	13. NUMBER OF PAGES: ~~40~~ 44
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Color Vision
Effectiveness
Experimental Control
Human Factors Engineering
Perception
Small Arms
Target-Background Contrast
Visibility

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An experiment was conducted to determine how varying target-background contrast affects two common measures of military rifle marksmanship. Only one of the performance measures correlated significantly and in the expected direction with mean readings from a visibility meter. Two subsequent experiments were conducted to help determine the appropriateness of basing experimental control of target-background contrast on visibility-meter readings. Three difficulties in using the Blackwell Visual Task Evaluator (VTE) for this purpose were identified and analyzed.

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RELATING TARGET VISIBILITY FACTORS TO SMALL-ARMS COMBAT EFFECTIVENESS

INTRODUCTION

Summary of the Problem

For many years, small-arms studies have been conducted on terrain where several targets were emplaced at roughly the same distance from the gunner. In subsequent analyses, data concerning subjects' engagements of these targets have been combined. Such a procedure has the advantages of: (a) increasing sample size (and, hence, the power of the statistical techniques used to examine the effects on the performance measures of such parameters as weapon configuration and technique of fire), and (b) attaining a larger measure of surprise for the gunner, who will not be able to "learn the range" as easily as if only one target were exposed for each range (thus strengthening the authenticity of generalizations from the test situation). The validity of this procedure, however, depends in part on effective controls to insure that all other characteristics of the targets are the same.

However, terrain varies. Color, configuration, clutter, shadow, and type and amount of vegetation are but a few of the characteristics which can exist at different levels on nearby terrain. In the past, these characteristics could not be measured quantitatively with any kind of precision. Hence, it was "assumed" that their variability did not affect performance measures.

Yet there is adequate evidence (perhaps best illustrated by the statistics on highway accidents) that the performance level of tasks which involve visual perception is often dramatically affected by the difficulty and complexity of the visual requirements. Whether these same factors affect shooting performance— and how much— has not been documented. Miles and Johnson [11, p. C-1] cite laboratory evidence suggesting that the color of a target and its contrast with the terrain on which it is emplaced can affect the two most popular performance measures in small-arms tests: hit probability and rate of fire. Given the possibility that a target's visual characteristics can bias these performance measures, it becomes important to determine the amount of the bias and whether effective experimental controls can be developed to minimize it.

General Approach

The problem which we have outlined is not a new one, nor are we the first researchers to have grappled with it. The principal previous approach has been to measure target brightness and background brightness, and then compute target-background contrast (TBC) by such formulae as:

$$C = \frac{B_t - B_b}{B_b}$$

where C = TBC, B_t is the target-brightness measurement, and B_b the background-brightness measurement [6, p. 25]. The U. S. Army Infantry Board, at Fort Benning, used a Pritchard Telephotometer to make separate readings of target and background brightnesses. By using very dark targets (such that the background-brightness reading was always larger), C was determined as an index with a fixed range of 0 to -1.

The theoretical difficulty with this approach is that TBC is treated as a relatively simple phenomenon consisting of only two components. In an extremely thorough analysis of the TBC problem, Downs, et al. [5] propose instead that TBC has at least 11 components:

(1) the absolute value of the light level (illuminance)

(2) the distribution of light incident on the path between the target and the observer

(3) the position of the sun (if visible)

(4) the nature of the reflectivity of the target's surface (requiring at least two variables: the fraction of light reflected, and the distribution between the diffuse and specular reflection components)

(5) the scattering and absorption coefficients of the atmosphere along the light path

(6) the range to the target

(7) the size and shape of the target

(8) the nature of the background (which requires three variables— color, texture, and luminance)

(9) the size of the instantaneous field of view of the instrument

(10) the spectral region utilized, and

(11) the shape of the spectral-response curve of the instrument [5, p. 5]

Moreover, that report correctly notes that several of these variables undergo frequent and unpredictable changes (largely as a function of the vagaries of weather), and that there are likely to be intercorrelations among the 11 components [5, p. 5].

Consideration was given to using a physical measurement to estimate the perceived size of color difference (CTE unit Δ E) of a task, as Judd and Eastman did in predicting target visibility [8]. Under field conditions, it is obviously difficult to formulate Δ E because trichromatic values are needed for the background, which would be made up of vegetation and soil.

With this theoretical framework in mind, we sought to address the problem with technology which would account for as many of the 11 postulated variables as possible, without compromising the element of realism which we strive to introduce into our field tests. What appeared most desirable was a single instrument which would account simultaneously for the net effect of the 11 (or more) variables affecting TBC. That is, rather than measuring (or attempting to control for) each of the variables in the field, and then using some formula to calculate an index of TBC, what we sought was a device which would, reliably, put an index number on an entire visual task— preferably at the "eyeball" of the observer. If we knew how the visual task appeared to the observer (in this case a rifleman), and if we could express that "how" in a number, we felt we would then be in a position to determine whethe. hanges in our TBC index were associated with actual performance changes.

The feasibility of using a visibility meter, a device used for psychophysical measurements of task visibility, to define visual-performance potential for a given visual task has been substantiated by several vision researchers [2]. The U.S. Army Human Engineering Laboratory considered the types of visibility meters available which would meet the requirements of working under atmospheric conditions. The Visual Task Evaluator was chosen because of its apparent suitability for use "in the field" [2] due to improved features over other visibility meters; i.e., (a) "The relatively small field of view does not allow for aspects of the surround to influence visual assessments of foveally viewed tasks" [2], and (b) the product of VTE is a measurement of visual-performance potential expressed in a standard unit, VL, visibility level. The following brief explanation tells how the VTE derives this standard unit:

Visual task evaluation is the process of assessing the difficulty of seeing a practical task which renders it equal in difficulty to seeing a standard task. Equality of difficulty is established as the visibility threshold for each. All of the work with the standard task is done in the laboratory, which reduces the problem in the field to one of simply measuring "the difficulty of seeing the practical task." By increasing a veiling luminance produced within the VTE, each task is gradually reduced to its visibility threshold, which in turn reveals how much above threshold the task actually is [2]. Basically, this measurement above threshold is the task's suprathreshold or visibility level (VL). When the VL has been adjusted (reduced in value) due to the influence of such things as disability glare, transient adaptation, etc., it becomes the effective visibility level (VLE) which "describes the visual performance potential of a luminous environment." [4, p. 30]. As will be seen later in this report, special means were used to avoid disability glare, transient adaptation, etc., so the visibility term used hereafter will be simply VL.

EXPERIMENT I

Purpose

This experiment was designed to provide a gross indication of the amount of bias (i.e., the range or extent of variation in performance measures) in a field test in which riflemen engaged targets at the relative extremes of visibility. It was anticipated that the results of this experiment would enable us to describe quantitatively the seriousness of the TBC problem, and indicate directions for further research related to the design of small-arms test ranges.

Independent Variables

Given an unvarying target size, shape and surface,[1] and assuming (for the moment) that the background against which the targets were emplaced was relatively constant, the most important determinant of target visibility would be contrast. It could be controlled by varying either target brightness or target color with respect to the background. As target color could be more easily controlled in a field situation, this was the method chosen. Three colors were selected:

a. Fluorescent orange (Krylon No. 3102)

b. Yellow (Color No 23695, Fed. Std. 595)

c. Dull green (Color No. 34151, Fed. Std. 595)

Two other independent variables were considered in this experiment: gun-target range and ammunition type. Two targets each at nominal 300– and 500–meter distances from the firing point were used (exact distances and altitudes are shown on p. 37). Equal amounts of 7.62mm ammunition, M80 ball and M62 tracer, were fired by each subject.

Subjects

Subjects were 12 enlisted men holding Infantry MOS from units at Fort Benning, GA. All had completed infantry advanced individual training (AIT), but none were combat veterans. Other characteristics of the subject group are given on page 39 .

Instrumentation

Performance data were gathered electronically:[2] an acoustic transducer located near the muzzle of the weapon sensed each round fired, and a target hit was sensed each time a bullet

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[1]The targets conformed to the dimensions of the standard E-type silhouette, but were bent along the longitudinal axis in an arc of approximately 12-3/8 inches radius of curvature to provide rigidity.

[2]With a system designed by Otho C. Wolfe.

passed through an exposed target, momentarily closing the normally-open circuit between the metal front and rear of each E-type silhouette. These and other sensings were fed to an Esterline-Angus Event Recorder, which transcribed them graphically on a common time base.

Procedure

The independent variables used in this experiment produced 12 combinations of levels (Fig. 1). An experimental design counterbalancing the sequence of these levels by subject number was included in the test plan. However, because the field firing for this experiment used the facilities and personnel intended primarily for Tracer Experiment 7,[3] which was already behind schedule, the design was rewritten in the field to reduce the number of required target-location changes (moving a particular colored silhouette from one target location to another). This change saved nearly two hours of "downtime," but the resulting design (Fig. 2) is only partially counterbalanced.

The test subjects, who had fired on the same range with the same zeroed weapons every other day for the previous 10 days, were given an initial briefing (page 31) behind the firing point. Thereafter, in two trips each to the firing point, the 12 subjects fired five rounds at each of 12 presentations of stationary targets in the sequence shown in the revised design (Fig. 2).

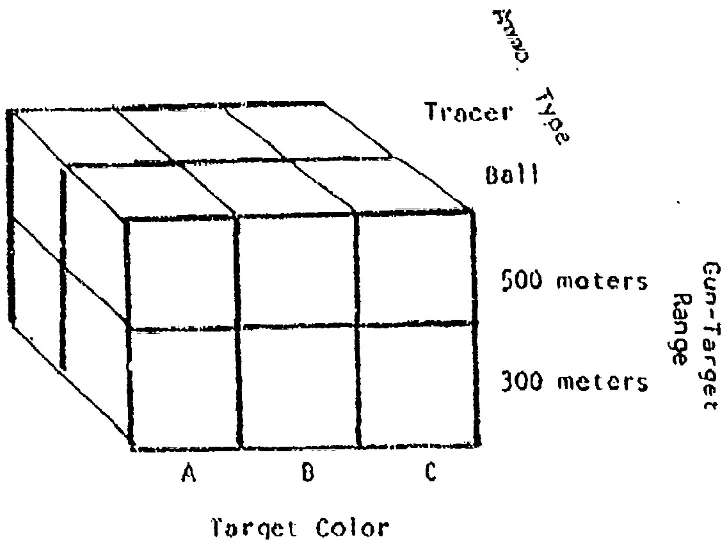

Fig. 1. Levels of independent variables.

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[3]One of the preliminary experiments in the HEL Tracer Program, a report of which will be published separately.

Events

Subject Number	A	B	C	D	E	F	G	H	I	J	K	L
101	1	2	3	4	5	8	6	9	10	7	11	12
102	4	1	5	2	6	9	7	10	12	3	8	11
103	5	3	12	6	4	11	7	8	2	1	9	10
104	6	4	2	1	7	12	3	11	8	5	10	9
105	7	3	11	5	1	10	4	9	6	2	12	8
106	7	6	4	2	1	8	9	12	5	3	10	11
107	2	3	5	10	7	12	1	8	4	6	11	9
108	2	6	1	4	5	10	8	11	3	7	9	12
109	3	5	7	9	2	11	6	12	1	4	8	10
110	4	6	8	3	5	12	2	11	7	1	10	9
111	5	4	7	8	3	9	2	10	1	6	11	12
112	6	7	3	5	4	12	11	10	2	1	9	8

<u>Identification of Events</u>

A = Tracer, 300 meters, Tgt Color B
B = Ball, 500 meters, Tgt Color A
C = Ball, 300 meters, Tgt Color A
D = Tracer, 500 meters, Tgt Color C
E = Ball, 300 meters, Tgt Color B
F = Tracer, 300 meters, Tgt Color C
G = Tracer, 300 meters, Tgt Color A
H = Ball, 500 meters, Tgt Color B
I = Ball, 500 meters, Tgt Color C
J = Tracer, 500 meters, Tgt Color A
K = Ball, 300 meters, Tgt Color C
L = Tracer, 500 meters, Tgt Color B

Fig. 2. Sequence of events.

Performance Measures

The two performance measures used were the number of target hits and the mean time (in seconds) between rounds.

Results

As a function of independent variables

Summaries of the data are given in Tables 1 and 2. An analysis of variance was conducted on each performance measure, as summarized in Table 3. Target color was a significant main effect in both analyses, and hit probability varied significantly by gun-target range.

Tukey-a tests were conducted on the subclass means of both dependent variables. Results of these tests showed that gunners:

– achieved a higher percentage of hits against the orange and green targets than against the yellow targets ($p < .10$);

– achieved a higher percentage of hits against the 300-meter targets than against the 500-meter targets ($p < .001$); and

– fired subsequent rounds faster against the orange and yellow targets than against the green targets ($p < .01$).

As a function of visibility levels

Target-visibility measurements were made several times throughout the testing period. Summaries of these measurements are shown in Figures 3 and 4. The mean VL for each target color at each range was computed, and these means were correlated (using the Pearson product-moment coefficient) with the means of the two performance measures for each range. Table 4 shows correlations in the expected direction for the correlations between mean VL and mean time between rounds at both ranges. Although both coefficients are high, only one (for the 300-meter data) is statistically significant. The lack of strong statistical significance is primarily an artifact of the inefficient design (correlating three pairs of means) which was found to be necessary (see discussion, p.26). The hypothesis that, as target-visibility level rises, a rifleman will require less time to regain the sight picture and fire a subsequent round is taken to be substantiated. However, the companion hypothesis, that the rifleman's accuracy will increase as target-visibility level increases, is supported neither by the correlations in Table 4 nor by inspection of the means in Table 1.

TABLE 1

Summary of Target Hits By Range, Ammunition Type and Target Color

Gun-Target Range	Target Color	No. of Rounds Fired	Ammunition Type: Ball		Ammunition Type: Tracer	
			No. Hits	Percent Hits	No. Hits	Percent Hits
300 Meters	Orange	60	15	25	13	22
	Yellow	60	6	10	8	13
	Green	60	12	20	10	17
500 Meters	Orange	60	7	12	3	5
	Yellow	60	1	2	0	0
	Green	60	6	10	8	13

TABLE 2

Mean Time (Seconds) Between Rounds By Range, Ammunition Type and Target Color

Gun-Target Range	Target Color	Ammunition Type: Ball			Ammunition Type: Tracer		
		Mean	S.D.	N	Mean	S.D.	N
300 Meters	Orange	2.48	.91	12	2.71	.57	12
	Yellow	2.92	.70	12	3.21	.98	12
	Green	3.44	1.77	12	3.38	1.51	12
500 Meters	Orange	2.85	.74	12	3.08	.65	12
	Yellow	2.63	1.10	12	2.81	.83	12
	Green	3.77	1.02	12	3.48	.91	12

TABLE 3

Main Effects and Significant Interactions in Analyses of Variance of Two Performance Measures in Experiment 1

	Percent Hits			Mean Time Between Rounds		
	df	ms	F	df	ms	F
Within Subjects						
Main Effects						
Ammunition Type (A)	1	.007	.333	1	.340	.921
Error (A)	11	.021		11	.370	
Gun-Target Range (R)	1	.422	11.994**	1	.250	
Error (R)	11	.035		11	.306	.817
Target Color (C)	2	.135	4.156*	2	7.535	
Error (C)	22	.033		22	.821	9.176**
Significant Interactions		None			None	

* P <.05
** P <.01

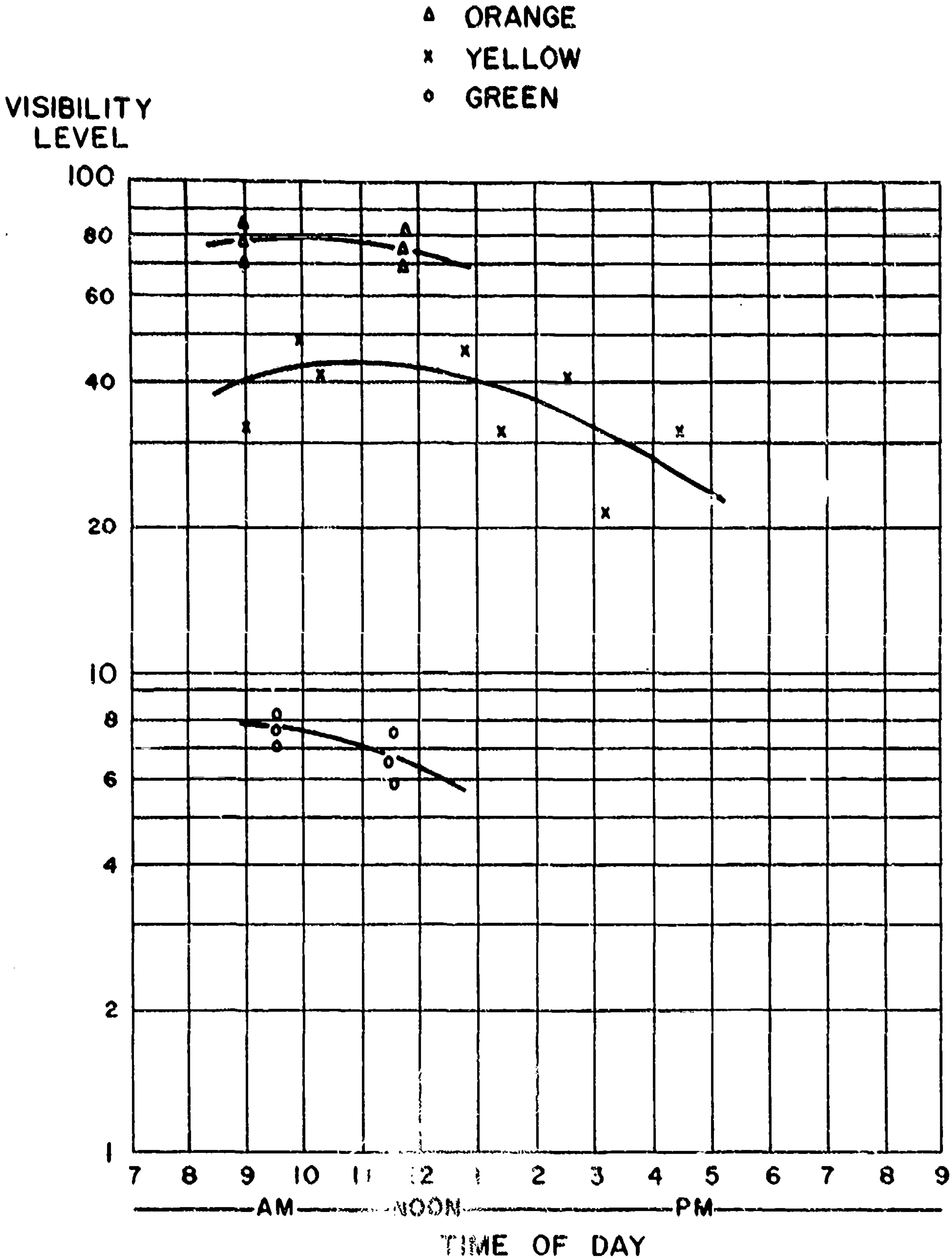

Fig. 3. Mean visibility levels of targets at 300 meters.

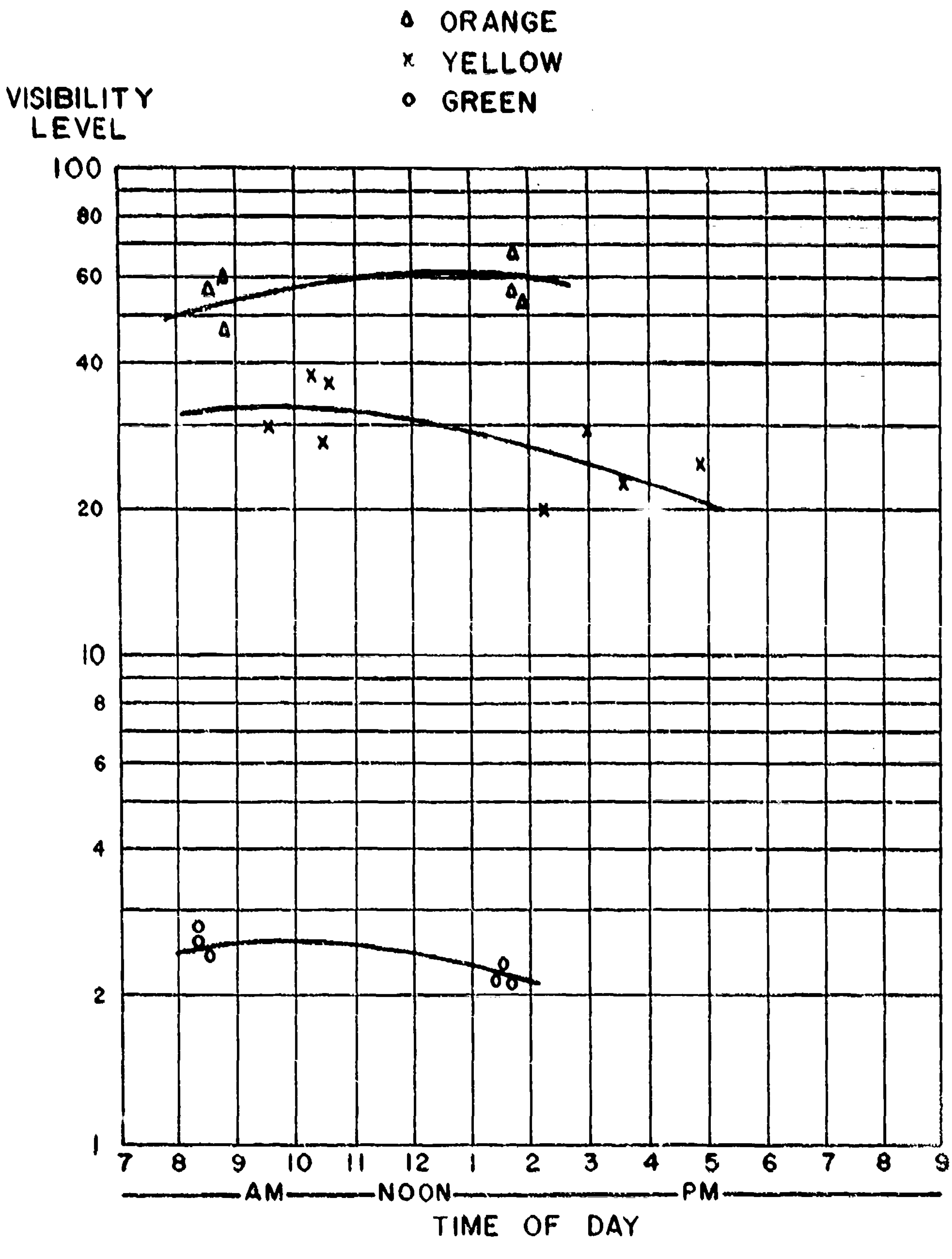

Fig. 4. Mean visibility levels of targets at 500 meters.

TABLE 4

Correlation Between Mean Performance and Mean Visibility Levels in Experiment 1

300 Meters		Mean Percent Hits	Mean VL	Mean Time in Seconds Between Rounds
Target Color	Orange	.233	72.92	2.59
	Yellow	.117	42.31	3.06
	Green	.183	6.14	3.41
		r = .38 (n.s.)	r = -.99 ($p < .05$)	

500 Meters		Mean Percent Hits	Mean VL	Mean Time in Seconds Between Rounds
Target Color	Orange	.083	53.33	2.96
	Yellow	.008	31.56	2.72
	Green	.117	2.22	3.63
		r = -.39 (n.s.)	r = -.76 (n.s.)	

EXPERIMENT 2

Purpose

This experiment was designed to provide data for a validity study of the Blackwell Visual Task Evaluator (VTE) in a small-arms field-test environment.

Background

Performance of riflemen is dependent on seeing, thinking, and responding. The initial input, seeing, is the most important in this deceptively easy three-step procedure, because thinking and responding are dependent upon the quality of the visual input. The visual input must be such that the thinking phase takes place quickly and without hesitation. The thinking phase includes determining what has been seen, applying prior knowledge and previous training, and selecting the response [10].

Many factors contribute to the seemingly simple but dynamically complex three-step performance procedure. In testing under field situations, as many of these factors or variables should be controlled as possible, but not to the extent that the test becomes a laboratory exercise. The following list shows some controllable, semi-controllable, and uncontrollable variables which affect visibility, derived from references [9] and [10]:

<u>Controllable</u>

1. Target size and shape
2. Distance-range
3. Time task is presented
4. Color of target
5. Search and scan requirements; placement, stationary or movement
6. Viewing angle
7. Adaptation of operator (VTE)

<u>Semi-controllable</u>

1. Texture of surround
2. Visual system of observer - recorded
3. Stress, fatigue, motivation of subject
4. Atmosphere - without rain, fog, dust, etc.
5. Line of sight - minimum glare, reflections

<u>Uncontrollable</u>

1. Luminance
2. Atmosphere, clouds, temperature
3. Background - changes

Instrumentation

Prior to using the VTE, potential VTE operators were examined for visual acuity with an Ortho-Rater and for color perception with the Farnsworth Dichotomous test, and were found to have no deficiencies. Their vision was then calibrated under laboratory conditions with the VTE, using the VTE-calibration attachment with the standard laboratory task targets.

Field instrumentation consisted of the VTE and a Pritchard Photometer (Model 1980). These instruments were located inside a three-sided, covered shelter to eliminate glare effects in the optical systems and to keep the operator's environment darker than the one he would be required to view.

Procedure

Each of the four E-type silhouette targets was painted a distinctive color. Each color represented a different section of the visible spectrum, and each had a lusterless matte finish to minimize glare effects.

These four chromatic targets were placed at a distance of 450 meters and within ± 0.5° of 0° azimuth line of sight. The VTE's 1.5° viewing aperture (the smaller of the two sizes available) was used, due to the distance and small size of the targets.

The area of the range (the Light Rifle Range at Aberdeen Proving Ground) selected for target placement was free from tree shadows and consisted of grassy foliage and sandy loam soil. Because of the time of year (January), the foliage was very short (2 to 4 inches), and the colors were various hues of brown.

On 29 January the photometer was used as a spot photometer with a 2-minute field of view. The readings taken are not totally representative of the luminance in the target area, but were merely intended to show the variability of the light reflected from each of the four E-type silhouette targets and a portion of the immediately adjacent background. (Determination of target-background luminance with the VTE is one of the steps in determining the target's visibility level with the VTE.) Visibility level (VL) readings (Tables 5, 6 and 7) were taken on three consecutive days between 0900 and 1540 hours, with atmospheric conditions as noted in the table for each day.

Disability glare was avoided by arranging the targets and instrumentation so that the line of sight was never within 15° of the sun. Of course, other variables, such as sun brightness, cloud movement, changes in perceptual appearance of the background, etc., were not controllable.

Results

The visibility levels calculated for each of the four targets during the 3 days of this test are shown in Tables 5, 6 and 7. Data in Tables 5 and 6 show that, in all cases, higher VLs were obtained under lower light levels. Also, although light levels were roughly the same on 27 and 29 January (Tables 5 and 7), VLs were much higher on the 29th. It can also be noted that, with the

TABLE 5

Visibility Levels Calculated for Four Targets on 27 January 1975

Target	Time	Background Luminance (FL)	Filter	VL
Red	1059	955	.7	7.69
	1105	1240	.7	7.45
	1246	1980	1.0	3.57
	1343	1985	1.0	2.67
Yellow	1145	1910	1.0	4.60
	1150	1910	1.0	4.09
	1405	Unable to see target through VTE - very bright.		
Green	1115	1570	1.0	7.69
	1122	2440	1.0	4.82
	1352	1910	1.0	2.18
	1358	1910	1.0	1.96
Blue	1206	1520	1.0	5.74
	1213	1520	1.0	6.11
	1410	1535	1.0	2.27
	1415	1540	1.0	2.35

Atmospheric conditions: Bright, clear, scattered cirrus clouds.
Temperature: 38° - 44° F.

TABLE 6

Visibility Levels Calculated for Four Targets on 28 January 1975

Target	Time	Background Luminance (FL)	VL
Red	0928	131	19.2
	0935	340	24.4
	1050	190	16.7
	1058	223	16.2
Yellow	0950	220	25.90
	0958	250	29.40
	1113	215	17.55
	1115	250	18.9
Green	0940	210	10.6
	0945	220	10.0
	1104	205	6.7
	1108	190	5.6
Blue	0959	250	20.8
	1007	270	25.3
	1056	230	17.5
	1100	240	15.6

Atmospheric conditions: Heavy overcast, stratus clouds.
Temperature: 41° - 53° F.

No filters

TABLE 7

Visibility Levels Calculated for Four Targets
on 29 January 1975

Target	Time	Background Luminance (FL)	VL
Red	1055	740	21.8
		899	31.3
		894	33.3
		901	28.4
	1120	905	34.2
Yellow	1126	1492	3.03
		1836	1.85
		1432	2.7
		894	11.4
		944	8.9
		956	8.7
		982	7.4
	1200	1483	3.7
Green	1212	1870	38.0
		1850	36.2
		1960	51.0
		1842	40.0
	1235	1802	36.1
Blue	1310	1424	38.0
		1422	46.3
		1136	28.7
		1404	45.0
	1353	1487	50.2

Atmospheric conditions: Bright, scattered cumulus clouds.
Temperature: $48^\circ - 65^\circ$ F.

Filter 1.0

addition of a neutral density filter on 29 January (Table 7), the calculated VLs for the yellow target were much lower than on 28 January (Table 6), even though the background luminance was much higher.

Gathering all the readings required to calculate a single VL requires approximately 10 minutes. However, the data in Table 8 show that task luminance may vary substantially during a 10-minute period. Thus the reliability of calculated VLs is suspect.

TABLE 8

Variability of Photometric Readings (in Foot-Lamberts)
Within 10-Minute Time Periods for
Each Target and Its Background

Target	Target	Background	Target	Target	Background
Red	632	1004	Yellow	526	544
	559	949		617	660
	850	1347		617	709
	810	1010		634	715
	817	1305		1060	1911
	821	1348		1150	1480
	715	1205		901	1084
	691	875		962	1135
	450	807		999	1196
	456	675		1001	1229
	440	751		1108	1451
	467	790		936	123
	Mean = 642	Mean = 1006		Mean = 968	Mean = 1103
	S.D. = 163	S.D. = 242		S.D. = 286	S.D. = 400

Target	Target	Background	Target	Target	Background
Green	598	966	Blue	877	1110
	685	1009		860	1767
	512	760		765	1122
	575	903		744	1101
	685	1053		825	1198
	716	1094		773	1107
	701	1048		758	1069
	798	1186		794	1202
	822	1243		764	1159
	778	1174		738	1052
	735	997		765	1109
	673	1021		820	1805
	Mean = 690	Mean = 1038		Mean = 790	Mean = 1233
	S.D. = 92	S.D. = 131		S.D. = 45	S.D. = 262

EXPERIMENT 3

Background and Purpose

An unexpected phenomenon was noted during Experiment 2: when background luminance increased, so that filters had to be added to the optical system, the VTE operators subjectively felt that discrimination among the four targets became more difficult. Because it was not clear whether this increased difficulty resulted from the environmental changes or from adding the filters (or both), it was decided to conduct a supplementary experiment to investigate how neutral-density filters affect the perception of color contrast.

Procedure

This experiment, unlike its two predecessors, was conducted under laboratory conditions in order to reduce the effects of the uncontrollable factors which affect visibility in the field.

A Blackwell VTE (Model 3), with the internal luminance source disconnected, was used to determine the contrast of a chromatic target. When using the VTE in this manner, only the contrast-reducing wedges are used; the internal veiling luminance and lighted annular ring are disabled. Thus the numbers obtained are not VLs, but merely represent the amount of contrast-wedge rotation necessary to reach visibility threshold. These numbers are, then, comparable only with one another. The chromatic target was viewed through four filtering modes in the VTE, but the viewed luminance level in the target area was held constant. This was done by increasing the intensity of the target-illuminating light source as filters of greater density were added into the VT" optical system. The illuminating light level was controlled and measured to 25-foot lamberts by placing the filter to be used over the lens of a Pritchard Photometer (Model 1960) prior to installing the same filter into the VTE system. Numerical values representing contrast were taken directly from the scale on the contrast-wedge dial.

Observations were made by five HEL personnel. These subjects had no color-perception deficiencies, as determined by the Farnsworth Dichotomous test. Each subject made 10 observations of the chromatic target under each of the four filtering modes. The test controller presented filtering modes randomly, to avoid order effects.

The data were obtained by approaching the subject's threshold from below, by reducing the contrast until the target was not visible, and then increasing the contrast until the task became just visible to the subject. The subject was instructed to respond "Stop" at this point, and the experimenter then recorded the contrast-control setting. All threshold readings were obtained by this procedure.

Results

A two-way analysis of variance (ANOVA) was performed on the readings taken from the contrast-control setting when the subjects indicated threshold had been reached (Table 9). As expected, subjects were a significant main effect in this analysis. However, filters were also shown to be statistically significant beyond the .001 level. To determine where the statistical significance lay, a computerized version[4] of the Tukey-a test was performed on the ANOVA subclass means for filters. As shown in Figure 5, the mean threshold reading for the same perceptual task differed significantly at each filter increment.

TABLE 9

Summary of Analysis of Variance of Five Subjects' Threshold Readings of the Chromatic Target Observed Through Four Different Filters

Source	df	ms	F
Filters (F)	3	5020.81	79.20***
Subjects (S)	4	58968.97	930.23***
(F) x (S)	12	115.40	1.82
Error	180	63.39	

***$p < .001$

[4]Developed by David J. Ursin

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THE TUKEY-A (HONESTLY SIGNIFICANT DIFFERENCE) PROCEDURE
                          FOR
          A POSTERIORI TESTING OF ORDERED MEANS

                     EXPERIMENT 3

          THRESHOLD READINGS OF CHROMATIC TARGET


ORDERED MEANS

A= 80.6              FILTER 1.0
B= 91.98             FILTER  .7
C= 98.88             FILTER  .5
D= 103.8             FILTER 0.


                     TABLE OF 0.95 LEVEL
                   SIGNIFICANT DIFFERENCES
                       A  B  C  D
                     A    *******
                     B       ****
                     C          *


MEAN SQUARE ERROR TERM= 63.39            DEGREES OF FREEDOM= 180

STUDENTIZED RANGE STATISTIC FROM TABLE=     3.66
COMPUTED CRITICAL VALUE =       4.1210
OBSERVATIONS PER MEAN= 50
```

Fig. 5. Computer printout of Tukey-a Test

DISCUSSION

The results of the experiments reported here highlight three difficulties in using the VTE in a small-arms field test: time, color, and aperture size.

- Although the Army has not established a standard target-exposure time for small-arms R&D field tests, times between 3 and 12 seconds are most often used in defense scenarios [7]. Thus the most accurate record of the rifleman's visual input as he engages a target would be the mean VL reading during the few seconds the target is exposed. Such a record would account for all of the visibility changes during the time he was attempting to bring fire on the target, and would exclude visibility conditions before and after the engagement (which are not relevant to determining the consistency of the visual task across actual engagements). To obtain the mean VL reading during target exposure would require one or more VL readings per second of the exposed target. Yet the time required to obtain the background luminance and the contrast threshold inputs to a single VL calculation (by averaging multiple settings of the respective dials) normally exceeds 10 minutes. One solution to this problem is to take readings of each target with the VTE during non-firing times in the field test when the firers are not watching the range[5] and then to assume (as in Experiment 1) that the VL readings are representative of visual conditions during actual target engagements. However, the results of Experiment 2 show that this assumption is unsound: there are substantial uncontrollable changes in the target area's luminance which, combined with the 20 percent (or greater) variability[6] in the psychophysical measurements obtained with the VTE, tend to make the subsequently calculated VL's misleading, if not incorrect.

- As in the case of target-exposure time, the R&D community has as yet been unable to agree on a standard target color for small-arms tests. We are aware of at least four general colors which have been used (silver, black, yellow and olive drab) and—with the exception of the HEL tracer experiments—the test reports do not disclose precise descriptions of these colors. As pointed out in the introduction (above), the VTE appears to be the perfect instrument for assuring the equality of the visual task across multiple targets in a single array, since it yields a single index number purportedly accounting for the myriad of factors which affect the shooter's visual task. We believe that our inability to obtain VL data which consistently make sense, when compared to shooters' performance data, may at least partially be explained by the following analysis:

---

[5] It is generally recognized that firers should not be permitted to learn where on the range the pop-up targets are located prior to the time they participate in the test.

[6] Blackwell, in discussing the error-likeliness of psychophysical measurements, says [1]:

> "threshold measurements made by psycho-physical methods exhibit unreliability from session to session"
>
> and
>
> "differences in the value of the threshold will usually reach 10-20 percent. They will sometimes reach 50-75 percent."

As noted earlier, one of the first steps in determining a visibility level with the VTE is establishing the luminance of the background adjacent to the target. This is done by adjusting an annular luminance ring surrounding the field of view through the VTE. (Figure 6 is a schematic representation of the picture the VTE operator sees when viewing a silhouette target.) The luminance output of the ring is adjusted to match the luminance of the background in the target area. This knob setting can then be directly converted to background luminance values in foot-lamberts. The lamp used to vary the luminance ring has a maximum output of 354 FL [3]; but since the average clear, bright day is 1,000+ FL [12], it is apparent that, in a field situation, the amount of background luminance is quite often greater than 354 FL. To compensate for this limitation, neutral-density filters are inserted into the VTE optical system to reduce the luminance in the field of view. The luminance ring can then be matched with the reduced background luminance in the target area. The filters do not seriously change the wavelengths of the light entering the VTE; however, they do cause a reduction in amplitude and a loss of color perception.

In Experiment 2, field observations through the VTE of four chromatic E-type silhouette targets at 450 meters sometimes appeared achromatic when filters were introduced into the VTE optical system. In all our tests, whenever it became necessary to use filters, color perception was reduced and, at times, was practically nonexistent. Target detection then became dependent upon factors other than chromaticity, such as size, atmospheric conditions, luminance contrast, etc.

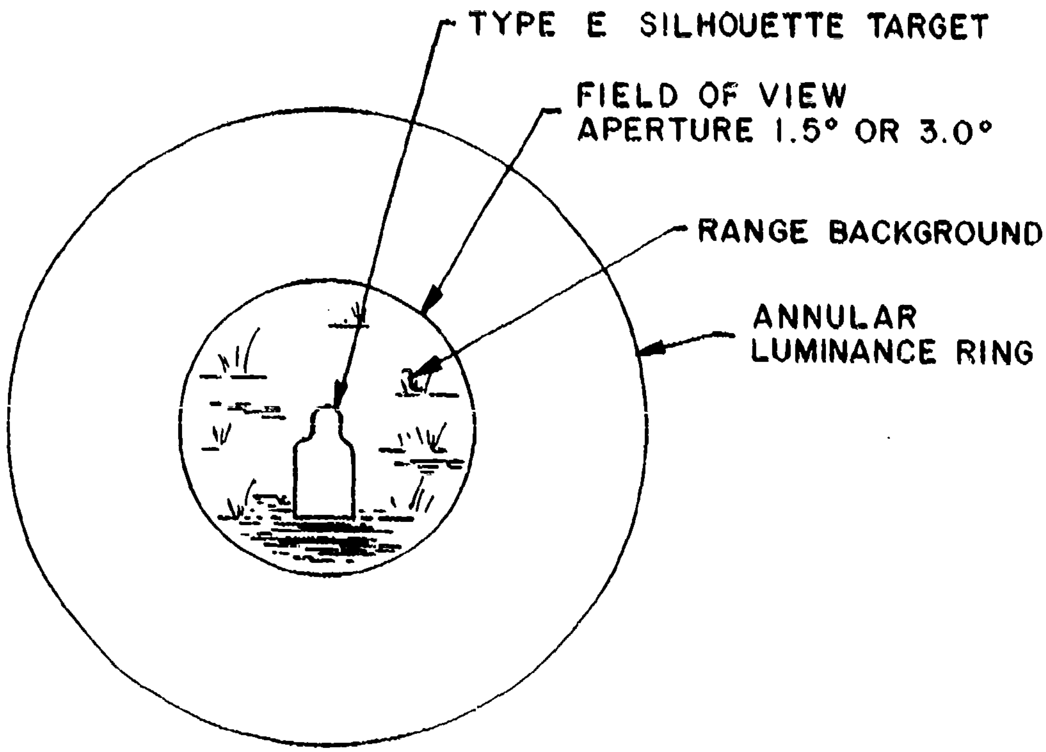
• A third possible source of error in our VL readings arises from the design of the aperture in the VTE. Blackwell describes the ideal relationship between aperture size and task area viewed as "just large enough to allow an unrestricted view of the task" [4, p. 61], such that "aspects of the surround of the visual task should not be allowed to influence visual assessment of foveally viewed tasks" [2, p. 267]. The VTE offers only two aperture sizes: a 3-degree and a 1.5-degree field of view. During the field work in Experiments 1 and 2, the smaller aperture was used. However, its 1.5-degree field of view circumscribed an area which, at 450 meters[7] has a diameter of 11.8 meters. Since the E-type silhouette target has a width of only 50.8 cm, and a maximum length of 100 cm, a very large component of the visual task observable through the VTE was background. The non-uniform character of the foliage and soil around the target caused the VTE operator difficulty in matching the instrument's veiling luminance with the background luminance. It seems reasonable to conclude that some of this difficulty was likely to have inflated the variability of operator readings.

Of the three difficulties identified, we can conceive of a practical solution—applicable to the small-arms field test situation—only for the third. Providing a third, smaller fixed-aperture selection on the VTE, or replacing one of the present selections with a smaller aperture ring, or (most useful) adding a variable-aperture control would eliminate the third difficulty.

However, the continued existence of the first two difficulties makes the VTE unsuitable for the task for which we were considering it. Until some more suitable instrument is developed, target-background contrast in small-arms field tests should be controlled by using targets of the same color, and selecting target locations which offer as much uniformity of terrain and vegetation as possible.

---

[7]The range at which the targets were emplaced in Experiment 2.



The size of the target in the Field of View depends on its distance from the VTE.

Fig. 6. Operator's View Through VTE

CONCLUSIONS

In attempting to relate target-visibility factors to small-arms combat effectiveness, the use of a visibility meter (the Blackwell VTE Model 3) during a field test appeared to be an entirely feasible approach. The results of the experiments reported here, however, have shown deficiencies in field use of that type of meter in its present form.

Three difficulties identified from the data gathered were:

a. Establishing the input measurements to calculate a visibility level takes so much time that significant changes in target-area luminance cannot accurately be accounted for.

b. When a task is viewed under bright sunlight conditions, the VTE's optical system requires using neutral-density filters which degrade perception of the color component of target-background contrast.

c. The smallest aperture setting is too large for accurate readings at gun-target ranges greater than approximately 350 meters.

Still another deficiency may have been the error inherent in the procedures for making the necessary psychophysical measurements, aggravated by the rapidly changing illumination encountered in the field experiments. Although we did not analyze our data to isolate the effects attributable to this error source, it may have been as important as the three difficulties listed above.

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APPENDIX A

STANDARDIZED INSTRUCTIONS

SUBJECTS' ORIENTATION TO TEST

NOTE: Orientation will be given from position behind the firing point.

Today your firing on Griswold Range will be similar to what you have done on previous days, but there will be a few changes. The purpose of this briefing is to tell you what the changes will be, and to review with you what we expect you to do.

As before, you'll be firing 12 missions of five rounds each at targets presented one at a time from the same range fan you fired previously. Today, however, there will be no moving targets. Each of the 12 targets that comes up will be exposed in one place until you've fired all five rounds in the mission. So what's new, you ask?

In the previous test firing, we've made target detection fairly simple for you. All the targets have been painted this nice shade of yellow. Today, however, we will be using several different target colors. Here they are.

(NOTE: Show three target colors)

No matter which target color comes up, we want you to do exactly the same thing. The situation we're going to give you is nearly the same as before:

> Pretend you're in a hasty defensive position on this hill. The enemy is moving toward you. You will see him before he sees you. Commence firing as soon as you have a good sight picture on the target. Try to hit it as many times as possible. It will not drop until you've fired all your rounds. But remember: as soon as you've fired your first round, he will know where you are. The idea is to get him before he has time to get you.
>
> Are you ready?
>
> Unlock your weapon. Watch the range.

Once again, as soon as the firing-point operator says, "Watch the range," that's your clearance to fire. It means that your target is about to come up. As soon as you see it come up, get a good sight picture and commence firing. Fire all five rounds at the one target that comes up. Now, if you don't see a target, don't shoot. Search the range until you find it.

Do you have any questions about what we're going to do today?

OK. First man stay here. The rest of you move back to the holding area.

INSTRUCTION SET 1

NOTE: Begin on green light. If red light comes on, immediately say, "Cease fire. Lock your weapon. Relax."

Say to the subject as he stands behind the FP-- YOU ARE NOW GOING TO DO TEST FIRING.

GET INTO A PRONE POSITION FACING DOWNRANGE. LOAD THIS MAGAZINE OF ____ AMMUNITION INTO YOUR WEAPON. PULL THE OPERATING ROD BACK AND PUT THE SAFETY ON.

WE WANT YOU TO PRETEND YOU'RE IN A HASTY DEFENSIVE POSITION ON THIS HILL. THE ENEMY IS MOVING TOWARD YOU. YOU WILL SEE HIM BEFORE HE SEES YOU. COMMENCE FIRING AS SOON AS YOU HAVE A GOOD SIGHT PICTURE ON THE TARGET. TRY TO HIT IT AS MANY TIMES AS POSSIBLE. IT WILL NOT DROP UNTIL YOU'VE FIRED ALL YOUR ROUNDS. BUT REMEMBER: AS SOON AS YOU'VE FIRED YOUR FIRST ROUND, THE ENEMY WILL KNOW WHERE YOU ARE. THE IDEA IS TO GET HIM BEFORE HE HAS TIME TO GET YOU.

ARE YOU READY?

UNLOCK YOUR WEAPON. WATCH THE RANGE!

INSTRUCTION SET 2

FOR YOUR NEXT TEST MISSION, LOAD THIS MAGAZINE OF ____ AMMUNITION INTO YOUR WEAPON, PULL THE OPERATING ROD BACK, AND PUT THE SAFETY ON.

REMEMBER THE TACTICAL SITUATION: YOU WILL SEE THE ENEMY BEFORE HE SEES YOU. BUT AS SOON AS YOU'VE FIRED, HE WILL KNOW WHERE YOU ARE.

ARE YOU READY?

UNLOCK YOUR WEAPON. WATCH THE RANGE!

SUBSEQUENT INSTRUCTIONS

AND NOW ANOTHER TEST MISSION.

REMEMBER THE TACTICAL SITUATION.

LOAD THIS MAGAZINE OF ____ AMMUNITION INTO YOUR WEAPON. PULL THE OPERATING ROD BACK AND PUT THE SAFETY ON.

ARE YOU READY?

UNLOCK YOUR WEAPON. WATCH THE RANGE!

APPENDIX B

EXPERIMENTAL CONTROL FOR EXPERIMENT 1

EXPERIMENTAL DESIGN, VARIABLE CONTROL SHEET

CLASSIFICATION OF VARIABLES Weapon

CLASSIFICATION REFERENCE NO. 1

PROJECT Target Visibility

EXPERIMENT NO. 1

REF. NO.	CROSS REF.	IDENTIFICATION OF VARIABLE	PROPOSED CONTROL
3.01		Caliber	7.62mm
3.02		Stability aids a. Bipod b. Tripod c. T&E Mechanism	Not used in this experiment.
3.03		Optics and sighting devices (including aiming stakes)	Not used in this experiment.
3.04		Night vision devices	Not used in this experiment.
3.05		Age and condition	The three weapons are nearly new, having been fired only in the gun-camera acceptance test (fewer than 2,000 rounds).
3.06		Flash suppressor	The standard flash suppressor was retained on all weapons.
3.07		Lans and grooves (muzzle spin rate)	Diameter of lans in barrel of M14 is .2995 ± .002 inches, groove diameter is .3075 ± .002 inches, with one revolution per 12 inches.
3.08		Temperature of barrel (number by time of previously fired rounds)	Uncontrolled.
3.09	7.02	Cyclic rate	Cyclic rate of the weapon has been slowed.
3.10		Zeroing	Each subject obtained a satisfactory battlesight zero with the M14 with which he fired the test course. Zero firing was conducted on a 25-meter range as described in FM 23-71. Achievement of satisfactory zero was defined as a 3-round shot group centered on the target and lying within the "A" ring of the shot group template.

HumRRO-TEL FORM 1 (OT) 30 JULY 70

EXPERIMENTAL DESIGN, VARIABLE CONTROL SHEET

CLASSIFICATION OF VARIABLES Physical and Geological **CLASSIFICATION REFERENCE NO.** 2

PROJECT Target Visibility **EXPERIMENT NO.** 1

REF. NO.	CROSS REF.	IDENTIFICATION OF VARIABLE	PROPOSED CONTROL
4.01	4.02 4.04g	Slope of range	From the firing point, the terrain drops off sharply down to a creek, then rises on the other side of the creek to an equal elevation.
4.02		Width of range	The firing fan (safety limits) at 500 meters is nearly 1500 meters wide. However, this firing fan is merely a portion of a much larger range.
4.03		Clutter	The range is heavily cluttered. At 300 meters there is thick low vegetation. At 500 meters there are a few small pine trees, grass, 3 tank hulls, and mud. A dirt road runs through the right center of the range with a spur (which cannot be seen from the firing point) just forward of the 300-meter bank of targets.
4.04		Targets	
		a. Size	E-type silhouettes were used.
		b. Shape	Same as 4.04a.
		c Movement	Six "stationary" targets moved only up and down.
		d Color	See p. 6.
		e. Reflectance	Because the reflection factor of the target as measured at the firing point would vary with the wavelength and direction of the incident light (which would change with time) as well as with the orientation of the target to the firer (which would change with target movement up and down), no control of reflectance was attempted.
		f. Number simultaneously visible	One.
		g. Distance and altitude from firing point	Target No. / Distance from FP / Altitude Relative to FP 3x / 351 meters / - .6 meters 3b / 279 meters / -2.9 meters 5a / 446 meters / +4.9 meters 5c / 470 meters / +1.8 meters

AMCD-HEL FORM 1 (OT) 30 JULY 70

EXPERIMENTAL DESIGN, VARIABLE CONTROL SHEET

CLASSIFICATION OF VARIABLES Climatic

CLASSIFICATION REFERENCE NO. 3

PROJECT Target Visibility

EXPERIMENT NO. 1

REF. NO.	CROSS REF.	IDENTIFICATION OF VARIABLE	PROPOSED CONTROL
5.01		Wind Speed	Measured with an anemometer located near the firing point. No mission was started in wind over 10 knots, and any mission once started was terminated and refired if wind speed reached 15 knots.
5.02		Temperature	80-86° F.
5.03		Humidity	Approximately 40%.
5.04		Precipitation	No firing was conducted under this condition.
5.05		Cloudiness	See 5.07 below.
5.06		Fog, smoke, dust	Firing was not conducted under these conditions.
5.07		Illumination	Firing was conducted within the general range of "partly cloudy" to "bright sunlight."
5.08		Direction of illumination	West. (General direction of fire was north-northwest.

[illegible]-HEL FORM 1 (OT) 30 JULY [illegible]

EXPERIMENTAL DESIGN, VARIABLE CONTROL SHEET

CLASSIFICATION OF VARIABLES Subjects **CLASSIFICATION REFERENCE NO.** 4

PROJECT Target Visibility **EXPERIMENT NO.** 1

REF. NO.	CROSS REF.	IDENTIFICATION OF VARIABLE	PROPOSED CONTROL
6.01		Months in US Army	Mean = 6.9 months, S.D. = 14.4 months
6.02		Grade structure	9 E-2, 3 E-3
6.03		Prior shooting experience	Varied widely: Mean Est. No. of Rounds Fired / S.D. BB Gun 59,366 / 142,026 Rifle 102,856 / 226,106 Shotgun 84,951 / 275,909
6.04		Qualification with M14 Rifle	Expert - 0, Sharpshooter - 0, Marksman - 1, Unqualified - 11
6.05		Self-rating with M14 Rifle	"Good shot" - 4, "Fair shot" - 5, "Poor shot" - 3
6.06		Experience firing tracer ammunition	Mean Est. No. of Rounds Fired / S.D. Day 800 / 4,067 Night 1,175 / 854
6.07		Visual acuity	Subjects scored 20/40 or better on the Armed Forces Clinical Visual Acuity Test.
6.08		Uniform and equipment	During all firing, subjects wore the fatigue uniform with boots, steel helmet, pistol belt, shoulder harness, first aid packet, ammo pouch, and canteen.
6.09		Combat experience	No subjects had combat experience.

[illegible]-HEL FORM 1 (OT) 30 JULY [illegible]

EXPERIMENTAL DESIGN, VARIABLE CONTROL SHEET

CLASSIFICATION OF VARIABLES: Experimental Control

CLASSIFICATION REFERENCE NO.: 5

PROJECT: Target Visibility

EXPERIMENT NO.: 1

REF. NO.	CROSS REF.	IDENTIFICATION OF VARIABLE	PROPOSED CONTROL
7.01		Method of Fire	Semiautomatic.
7.02		Number of simultaneous other firings	Only one subject fired the test course at a time.
7.03	3.10	Type and length of pre-test training	Subjects received a 45-minute period of refresher training (presented as a conference/demonstration) in basic marksmanship with the M14. They received a 30-minute period of night firing instruction (conference/demonstration/controlled practice) prior to firing the night exercises.
7.04		Firing position	Test firing was from the prone unsupported position atop a GI mattress.
7.05		Combat stress or counterfire (perception of personal vulnerability)	See 7.06 below.
7.06		Scenario	Given in Appendix A.
7.07		Stoppages and malfunctions	Any mission in which a malfunction of weapon or instrumentation occurred was cancelled and refired with the same subject at a later time.

[illegible] FORM [illegible] (OT) 30 JULY 70

APPENDIX C

TECHNICAL SPECIFICATIONS OF TEST MATERIEL

The four type-E silhouettes used in Experiment 2 were painted with the following colors:

Color	Color Numbers from Federal Standard No. 595	Chromaticity Coordinates X	Y	Z
Red	31136	.5367	.3188	.1112
Yellow	33538	.4902	.4491	.5426
Green	34087	.3550	.3730	.0785
Blue	37875	.3080	.3188	.8885

The length, width, and area of the type-E silhouette targets used in Human Engineering Laboratory studies are, respectively, 100 cm, 50.8 cm, 3386.7 cm^2.

In Experiment 3, the target was a yellow (Color No. 33538, Federal Standard No. 595) circle with a diameter of 6 cm, placed on a green (Color No. 34325, Federal Standard No. 595), background, having an area of 864 cm^2. The target was placed 2.5 meters from the VTE lens aperture. At this distance the 3^o photometric aperture of the eyepiece encompasses an area sufficient to include the target and a portion of the background directly adjacent. The diameter of a 3^o solid angle at this distance is 14 cm.