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TECHNICAL REPORT 3259

SMOKE MARKER DETECTION AND IDENTIFICATION STUDY

M. HAROLD WEASNER
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AUGUST 1965

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DA PROJECT 1X132401D050

PICATINNY ARSENAL
DOVER, NEW JERSEY

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by

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Feltman Research Laboratories
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ABSTRACT

A field study was conducted to determine the minimum volume and duration of colored smokes that could be detected, identified, and located by ground and aerial observers. The distances from observers to smoke emission sites varied from approximately 500 to 10,000 meters. Red, yellow, green, violet, and white smokes were generated by initiating U. S. Army standard M8 and M18 smoke grenades. Nine volume-duration combinations of smoke were tested. Volume of smoke was controlled by initiating various numbers of grenades (one, two, or three) simultaneously. Duration of smoke emission was controlled by initiating various numbers of grenades in succession so as to give a continuous smoke.

The larger volume-duration combinations (e.g., 2-2 and 3-3) yielded the highest rates of detection, color identification, and correct location of smoke emission sites. Observers located between 500 and 6000 meters from the smoke had higher rates of detection, identification, and location than did observers located at distances greater than 6000 meters. In terms of overall effectiveness, the best volume-duration combination is 2-3. White smoke yielded the highest rates of correct detection, correct identification, and correct location. Red was the next best color, while violet was the poorest.

INTRODUCTION AND PURPOSE

Colored smoke markers are used by the U. S. Army to designate both single and multiple ground targets, to outline or box-in larger target areas, to mark drop zones, and sometimes in rescue work (e.g., to guide rescuers to a downed pilot or a patrol that has been cut off). It is important that these markers be detected and identified as to color under widely varying and often adverse conditions. Until the present study was conducted, little or no data could be found which would provide information regarding the optimum duration, volume, and color of a smoke marker for a given terrain and a given slant range.

The purpose of this study was to obtain such data. Its primary objective was to determine what combination of smoke marker characteristics (duration, color, and volume) is most detectable, identifiable, and correctly locatable by both ground and aerial observers at various slant ranges.

The study was conducted at Hunter Liggett Military Reservation, a part of the U. S. Army Combat Developments Command Experimentation Center complex in California. It was conducted in two phases. The first phase, involving the use of ground observers only, was completed in November 1964. The second phase, in which aerial observers only were used, was conducted in December 1964.

PROCEDURE, PHASE 1

The same test area was used in both phases. It consisted of an irregularly shaped area approximately 2000 meters wide and 12,000 meters long (see Figure 1 (p 3) for test area layout). The smoke was initiated at nine marker locations. Six of these locations were in unwooded open fields while three were in wooded areas. The marker locations were in a flat valley. This valley, at the southeast end of Hunter Liggett Military Reservation, is surrounded by hills varying in height from 90 to 320 feet. During Phase 1, two observers were placed on each of ten different elevated points. One controller was assigned to every two observers. All observers and controllers were U. S. Army enlisted personnel.

The distances from the observers to the smoke marker locations varied from 350 to 10,222 meters.

Five colored smokes were used. Red, yellow, green, and violet smokes were generated by initiating U. S. Army standard M18 smoke grenades. White smoke was produced by the standard M8 smoke grenade. The smoke varied in both volume and duration as follows:

1. Duration. The various durations were obtained by initiating grenades in succession to produce a continuous smoke output. Durations obtained were as follows:

Red, yellow, green, violet: 60, 120, 180 seconds

White: 90, 180, 270 seconds

2. Volume. All five colors were produced in 1, 2, and 3 volumes. To produce the three different volumes, one, two, or three grenades were initiated simultaneously.

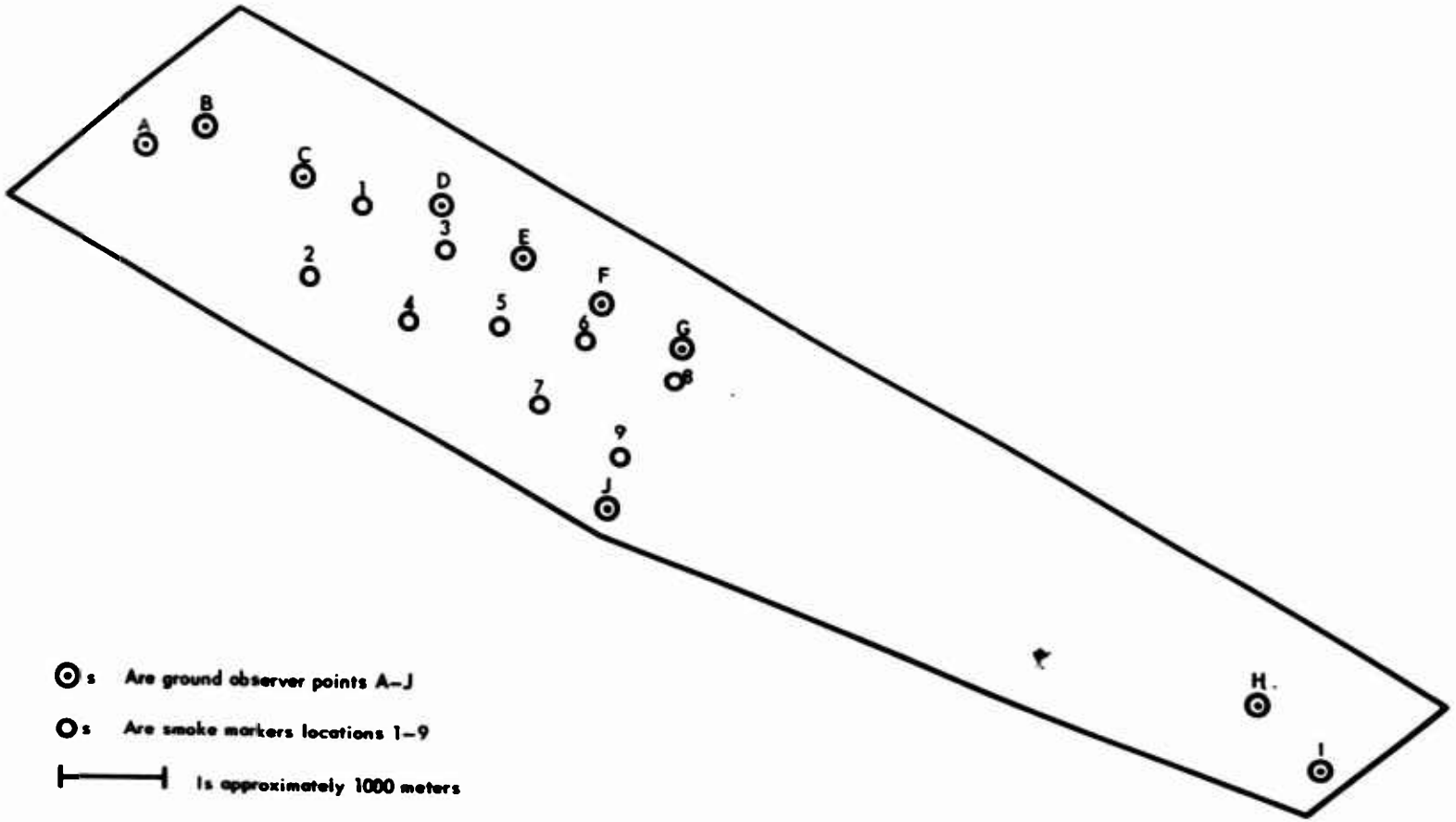

Fig 1 Test area showing relationship of ground observers and smoke markers

A total of 58 red shots, 58 yellow, 65 green, 58 violet, and 52 white were fired.

In each trial, smoke was initiated at one, two, or three different smoke marker locations. In a one-marker-shot trial, smoke was initiated at one marker location. In a two-marker-shot trial, smoke was initiated at two different marker locations simultaneously. In a three-marker-shot trial, smoke was initiated at three different locations simultaneously. During the three days of testing, 24 one-marker-shot trials, 21 two-marker-shot trials, and 75 three-marker-shot trials were run. Trials were spaced at sufficiently long intervals to allow complete dissipation of previously initiated smokes. The order of shot trials, colors, volume-duration combinations, and marker locations were randomized.

Before the actual testing began, all observers, controllers, and marker personnel were briefed as to their duties and the general purpose of the study. There was a dry run during which the observers, located at their assigned posts, had an opportunity to see the various colored smokes initiated at the nine marker locations. During the dry run, the observers were told both the colors and the locations of the smoke. During the actual testing, the only information given to the observers was a warning signal one minute before each trial. They were given data sheets on which they noted, during each trial, the number of smokes detected (1, 2, or 3), their colors, and their locations.

RESULTS, PHASE 1

Tables 1 through 6 (pp 7-12) present the data from phase 1. Percentages of correct detections, correct identifications, and correct locations are listed. Data for each of the five colors and also for all the colors combined is given.

To indicate trends more clearly, the data for all colors was also ranked in terms of each of the following five specific categories:

1. Correct detection, 0–6000 meters
2. Correct detection, over 6000 meters
3. Correct identification, 0–6000 meters

4. Correct identification, over 6000 meters

5. Correct location, 0–3000 meters

These rankings are presented in Tables 7 to 11 (pp 13-17).

This group of tables (7–11) provides a type of "field guide" for the optimal use of smoke markers. That is, data showing the relative detectability and identifiability of various color, duration, and volume combinations is presented.

Tables 12 through 16 (pp 18-22) give mean rankings showing separately the effects of each of the three variables (volume, duration, and color). There are separate tables for correct detection, correct identification, and correct location.

In summarizing the ranked data, one notes that white smoke appears above all colors in all categories (detection, identification, and location) regardless of the distance over which it is observed. Red and green rank above yellow and violet in all categories except location. In this category, green ranks above violet and red, which are about equal, with yellow lowest in rank.

In the data relating to volume and duration in combination, the 2-3 combination ranked consistently above all others. The 3-3 combination ranked next for consistency. Based on the data one could state that the larger volume-duration combinations consistently produce the highest rates of detection, identification, and smoke location over all distances considered.

If one were asked to state specifically which volume was best, he would be hard pressed for an answer. The data indicates that volumes 2 and 3 are significantly better than a single volume of smoke, but that neither is significantly better than the other.

As for an analysis of duration data taken alone, the longest duration ranks highest in general effectiveness, while the shortest duration ranks lowest.

In the final analysis it appears that the optimum smoke marker combination consists of the volume of white smoke emitted by three pairs of M8

grenades successively initiated (volume 2–duration 3) to produce a burning time of 270 seconds.

The 2-3 volume-duration combinations for the red and green smokes, which are about equal in rates of detection, identification, and smoke location, rank after white. Violet and yellow smoke appear to be equally poor when ranked across all variables.

In Figures 2 through 4 (pp 23-25) the findings from the ground observer phase are combined to compare volume-duration combinations.

It should be noted that the curves generally rise to the volume 2–duration 2 combination and then level off. It is also apparent that there is a distance effect in the identification figure, i.e., observers located at 0–6000 meters had higher scores than observers located at greater distances.

TABLE 1

Ground observation (phase 1) data for red smoke markers

Volume	Duration	Observer Distance, km	Correct Detection, %	Correct Identification, %	Correct Location, %
1	1	0–6	98.44	95.32	
		Over 6	93.75	81.25	
		0–3			90.75
1	2	0–6	90	89.37	
		Over 6	95	87.5	
		0–3			80.52
1	3	0–6	84.73	79.81	
		Over 6	83.4	80.62	
		0–3			72
2	2	0–6	92.3	88.14	
		Over 6	100	88.96	
		0–3			88.58
2	3	0–6	92.3	90.22	
		Over 6	100	94.52	
		0–3			82.46
3	2	0–6	92.3	89.53	
		Over 6	100	97.22	
		0–3			85.14
3	3	0–6	93.06	93.06	
		Over 6	91.74	91.74	
		0–3			86.12

TABLE 2

Ground observation (phase 1) data for yellow smoke markers

Volume	Duration	Observer Distance, km	Correct Detection, %	Correct Identification %	Correct Location, %
1	1	0–6	79.56	73.32	
		Over 6	62.5	25	
		0–3			70.72
1	2	0–6	83.97	81.89	
		Over 6	69.5	61.16	
		0–3			81.56
1	3	0–6	88.14	83.97	
		Over 6	77.84	58.38	
		0–3			82.56
2	2	0–6	83.28	83.28	
		Over 6	94.52	83.4	
		0–3			75
2	3	0–6	93.75	90.91	
		Over 6	86.18	50	
		0–3			85.28
3	2	0–6	93.75	90.22	
		Over 6	83.4	55.6	
		0–3			88.11
3	3	0–6	89.53	88.14	
		Over 6	94.52	88.96	
		0–3			81.49

TABLE 3

Ground observation (phase 1) data for green smoke markers

Volume	Duration	Observer Distance, km	Correct Detection, %	Correct Identification, %	Correct Location, %
1	1	0–6	86.25	82.5	
		Over 6	80	80	
		0–3			74.06
1	2	0–6	90.63	90	
		Over 6	80	80	
		0–3			83.64
1	3	0–6	88.13	87.5	
		Over 6	100	90	
		0–3			77.4
2	2	0–6	91.25	90	
		Over 6	90	77.5	
		0–3			86.39
2	3	0–6	95	92.5	
		Over 6	100	97.5	
		0–3			88.82
3	2	0–6	95.99	94.86	
		Over 6	97.73	97.73	
		0–3			88.33
3	3	0–6	94.44	93.75	
		Over 6	86.18	75	
		0–3			92.41

TABLE 4

Ground observation (phase 1) data for violet smoke markers

Volume	Duration	Observer Distance, km	Correct Detection, %	Correct Identification, %	Correct Location, %
1	1	0–6	82.5	72.5	
		Over 6	35	25	
		0–3			74.24
1	2	0–6	89.7	89.7	
		Over 6	43.75	28.13	
		0–3			81.81
1	3	0–6	88.14	78.42	
		Over 6	52.78	41.7	
		0–3			85.95
2	1	0–6	87.5	81.25	
		Over 6	100	0	
		0–3			100
2	2	0–6	92.82	87.36	
		Over 6	90.63	65.63	
		0–3			84.19
2	3	0–6	92.3	85.36	
		Over 6	88.96	61.16	
		0–3			92.41
3	2	0–6	89.53	87.45	
		Over 6	86.18	75	
		0–3			79.81
3	3	0–6	89.53	83.28	
		Over 6	100	72.22	
		0–3			84.48

TABLE 5

Ground observation (phase 1) data for white smoke markers

Volume	Duration	Observer Distance, km	Correct Detection, %	Correct Identification, %	Correct Location, %
1	1	0–6	98.44	96.88	
		Over 6	100	75	
		0–3			94.08
1	2	0–6	91.25	87.5	
		Over 6	100	100	
		0–3			84.97
1	3	0–6	89.7	89.7	
		Over 6	100	100	
		0–3			82.36
2	1	0–6	96.88	93.75	
		Over 6	100	100	
		0–3			87.49
2	2	0–6	94.34	92.56	
		Over 6	100	100	
		0–3			89.32
2	3	0–6	93.06	92.3	
		Over 6	94.52	94.52	
		0–3			87.7
3	2	0–6	89.7	87.36	
		Over 6	90.63	87.51	
		0–3			82.56
3	3	0–6	99.31	98.61	
		Over 6	94.52	83.4	
		0–3			94.34

TABLE 6

Combined ground observation (phase 1) data for all smoke markers tested

Volume	Duration	Observer Distance, km	Correct Detection, %	Correct Identification, %	Correct Location, %
1	1	0–6	88.64	83.52	
		Over 6	72.73	52.27	
		0–3			80.5
1	2	0–6	88.99	87.8	
		Over 6	76.79	70.24	
		0–3			82.25
1	3	0–6	87.78	83.89	
		Over 6	82.78	73.89	
		0–3			80.15
2	1	0–6	93.75	89.58	
		Over 6	100	66.67	
		0–3			91.67
2	2	0–6	90.7	88.23	
		Over 6	94.77	82.56	
		0–3			84.69
2	3	0–6	93.34	90.35	
		Over 6	94.02	79.89	
		0–3			87.29
3	2	0–6	92.53	90.22	
		Over 6	91.85	83.15	
		0–3			85.1
3	3	0–6	93.19	91.39	
		Over 6	93.33	82.22	
		0–3			87.92

NOTE: The volume 2/duration 1 data given above is for violet and white smokes only. All other combinations are for all five colors.

TABLE 7

Correct detection, 0–6000 meters

Rank	Color	Volume	Duration	Correct Detection, %
1	White	3	3	99.31
2.5	White	1	1	98.44
2.5	Red	1	1	98.44
4	White	2	2	96.88
5	Green	3	2	95.99
6	Green	3	3	95
7	Green	3	3	94.44
8	White	2	2	94.34
9.5	Yellow	2	3	93.75
9.5	Yellow	3	2	93.75
11.5	White	2	3	93.06
11.5	Red	3	3	93.06
13	Violet	2	2	92.82
15.5	Red	2	2	92.3
15.5	Red	2	3	92.3
15.5	Red	3	2	92.3
15.5	Violet	2	3	92.3
18.5	White	1	2	91.25
18.5	Green	2	2	91.25
20	Green	1	2	90.63
21	Red	1	2	90.0
23	Violet	1	2	89.7
23	White	1	3	89.7
23	White	3	2	89.7
26	Violet	3	3	89.53
26	Yellow	3	3	89.53
26	Violet	3	2	89.53
28.5	Yellow	1	3	88.14
28.5	Violet	1	3	88.14
30	Green	1	3	88.13
31	Violet	2	1	87.5
32	Green	1	1	86.25
33	Red	1	3	84.73
34	Yellow	1	2	83.97
35	Yellow	2	2	83.28
36	Violet	1	1	82.5
37	Yellow	1	1	79.56

TABLE 8

Correct detection, over 6000 meters

Rank	Color	Volume	Duration	Correct Detection, %
6.5	White	1	1	100
6.5	White	1	2	100
6.5	White	1	3	100
6.5	White	2	1	100
6.5	White	2	2	100
6.5	Red	2	2	100
6.5	Red	2	3	100
6.5	Red	3	2	100
6.5	Green	1	3	100
6.5	Green	2	3	100
6.5	Violet	2	1	100
6.5	Violet	3	3	100
13	Green	3	2	97.73
14	Red	1	2	95
16.5	Yellow	2	2	94.52
16.5	Yellow	3	3	94.52
16.5	White	2	3	94.52
16.5	White	3	3	94.52
19	Red	1	1	93.75
20	Red	3	3	91.74
21.5	Violet	2	2	90.63
21.5	White	3	2	90.63
23	Green	2	2	90
24	Violet	2	3	88.96
26	Yellow	2	3	86.18
26	Green	3	3	86.18
26	Violet	3	2	86.18
28.5	Red	1	3	83.4
28.5	Yellow	3	2	83.4
30.5	Green	1	2	80
30.5	Green	1	1	80
32	Yellow	1	3	77.84
33	Yellow	1	2	69.5
34	Yellow	1	1	62.5
35	Violet	1	3	52.78
36	Violet	1	2	43.75
37	Violet	1	1	35

TABLE 9

Correct identification, 0–6000 meters

Rank	Color	Volume	Duration	Correct Identification, %
1	White	3	3	98.61
2	White	1	1	96.88
3	Red	1	1	95.32
4	Green	3	2	94.86
5.5	White	2	1	93.75
5.5	Green	3	3	93.75
7	Red	3	3	93.06
8	White	2	2	92.56
9	Green	2	3	92.5
10	White	2	3	92.3
11	Yellow	2	3	90.91
12.5	Red	2	3	90.22
12.5	Yellow	3	2	90.22
14.5	Green	1	2	90
14.5	Green	2	2	90
16.5	White	1	3	89.7
16.5	Violet	1	2	89.7
18	Red	3	2	89.53
19	Red	1	2	89.37
20.5	Red	2	2	88.14
20.5	Yellow	3	3	88.14
22.5	White	1	2	87.5
22.5	Green	1	3	87.5
24	Violet	3	2	87.45
25.5	Violet	2	2	87.36
25.5	White	3	2	87.36
27	Violet	2	3	85.36
28	Yellow	1	3	83.97
29.5	Violet	3	3	83.28
29.5	Yellow	2	2	83.28
31	Green	1	1	82.5
32	Yellow	1	2	81.89
33	Violet	2	1	81.25
34	Red	1	3	79.81
35	Violet	1	3	78.42
36	Yellow	1	1	73.32
37	Violet	1	1	72.5

TABLE 10

Correct identification, over 6000 meters

Rank	Color	Volume	Duration	Correct Identification, %
2.5	White	1	2	100
2.5	White	1	3	100
2.5	White	2	1	100
2.5	White	2	2	100
5	Green	3	2	97.73
6	Green	2	3	97.5
7	Red	3	2	97.22
8.5	White	2	3	94.52
8.5	Red	2	3	94.52
10	Red	3	3	91.74
11	Green	1	3	90
12.5	Yellow	3	3	88.96
12.5	Red	2	2	88.96
14	White	3	2	87.51
15	Red	1	2	87.5
16.5	White	3	3	83.4
16.5	Yellow	2	2	83.4
18	Red	1	1	81.25
19	Red	1	3	80.62
20	Green	1	2	80
21	Green	2	2	77.5
23	Green	3	3	75
23	Violet	3	2	75
23	White	1	1	75
25	Violet	3	3	72.22
26	Violet	2	2	65.63
27.5	Violet	2	3	61.16
27.5	Yellow	1	2	61.16
29	Green	1	1	60
30	Yellow	1	3	58.38
31	Yellow	3	2	55.6
32	Yellow	2	3	50
33	Violet	1	3	41.7
34	Violet	1	2	28.13
35.5	Yellow	1	1	25
35.5	Violet	1	1	25
37	Violet	2	1	0

TABLE 11

Correct location, 0–3000 meters

Rank	Color	Volume	Duration	Correct Location, %
1	Violet	2	1	100
2	White	3	3	94.34
3	White	1	1	94.08
4.5	Green	3	3	92.41
4.5	Violet	2	3	92.41
6	Red	1	1	90.75
7	White	2	2	89.32
8	Green	2	3	88.82
9	Red	2	2	88.58
10	Green	3	2	88.33
11	Yellow	3	2	88.11
12	White	2	3	87.7
13	White	2	1	87.49
14	Green	2	2	86.39
15	Red	3	3	86.12
16	Violet	1	3	85.95
17	Yellow	2	3	85.28
18	Red	3	2	85.14
19	White	1	2	84.97
20	Violet	3	3	84.48
21	Violet	2	2	84.19
22	Green	1	2	83.64
23.5	White	3	2	82.56
23.5	Yellow	1	3	82.56
25	Red	2	3	82.46
26	White	1	3	82.36
27	Violet	1	2	81.81
28	Yellow	1	2	81.56
29	Yellow	3	3	81.49
30	Red	1	2	80.52
31	Violet	3	2	79.81
32	Green	1	3	77.4
33	Yellow	2	2	75
34	Violet	1	1	74.24
35	Green	1	1	74.06
36	Red	1	3	72.0
37	Yellow	1	1	70.72

TABLE 12

Mean rankings, correct detection, 0–6000 meters

Color	White	11.43
	Red	16.35
	Green	16.92
	Violet	24.87
	Yellow	25.64
Volume-Duration Combination	Vol 2–Dur 3	11.6
	Vol 3–Dur 3	14.3
	Vol 3–Dur 2	15.8
	Vol 2–Dur 1	17.5
	Vol 2–Dur 2	18
	Vol 1–Dur 1	22
	Vol 1–Dur 2	22.3
	Vol 1–Dur 3	28.6
Volume	Vol 3	15.05
	Vol 2	15.25
	Vol 1	24.63
Duration	Dur 3	18.16
	Dur 2	19.03
	Dur 1	20.16

TABLE 13

Mean rankings, correct detection, over 6000 meters

Color	White	10.87
	Red	14.42
	Green	19.42
	Violet	24.06
	Yellow	26.64
Volume-Duration Combination	Vol 2–Dur 1	6.5
	Vol 2–Dur 2	14.8
	Vol 2–Dur 3	15.9
	Vol 3–Dur 3	17.1
	Vol 3–Dur 2	19.1
	Vol 1–Dur 3	21.7
	Vol 1–Dur 2	24
	Vol 1–Dur 1	25.4
Volume	Vol 2	13.87
	Vol 3	18.1
	Vol 1	23.7
Duration	Dur 3	18.23
	Dur 2	19.3
	Dur 1	20

TABLE 14

Mean rankings, correct identification, 0–6000 meters

Color	White	11.37
	Green	14.42
	Red	16.28
	Yellow	24.21
	Violet	28.43
Volume-Duration Combination	Vol 3–Dur 3	12.7
	Vol 2–Dur 3	13.9
	Vol 1–Dur 1	15.8
	Vol 3–Dur 2	16.8
	Vol 2–Dur 1	19.25
	Vol 2–Dur 2	19.6
	Vol 1–Dur 2	20.9
	Vol 1–Dur 3	27.2
Volume	Vol 3	14.75
	Vol 2	17.16
	Vol 1	23.3
Duration	Dur 3	17.93
	Dur 2	19.1
	Dur 1	21.07

TABLE 15

Mean rankings, correct identification, over 6000 meters

Color	White	9
	Red	12.85
	Green	16.42
	Yellow	26.42
	Violet	30.25
Volume-Duration Combination	Vol 2–Dur 2	15.7
	Vol 3–Dur 2	16
	Vol 2–Dur 3	16.5
	Vol 3–Dur 3	17.4
	Vol 1–Dur 3	19.1
	Vol 2–Dur 1	19.75
	Vol 1–Dur 2	19.8
	Vol 1–Dur 1	28.2
Volume	Vol 3	16.7
	Vol 2	16.7
	Vol 1	22.36
Duration	Dur 2	17.16
	Dur 3	17.66
	Dur 1	25.78

TABLE 16

Mean rankings, correct location, 0–3000 meters

Color	White	13.18
	Green	17.92
	Violet	19.31
	Red	19.85
	Yellow	25.5
Volume-Duration Combination	Vol 2–Dur 1	7
	Vol 2–Dur 3	13.3
	Vol 3–Dur 3	14.1
	Vol 2–Dur 2	16.8
	Vol 3–Dur 2	18.7
	Vol 1–Dur 1	23
	Vol 1–Dur 2	25.2
	Vol 1–Dur 3	26.7
Volume	Vol 2	13.7
	Vol 3	16.4
	Vol 1	24.96
Duration	Dur 3	18.03
	Dur 1	18.42
	Dur 2	20.23

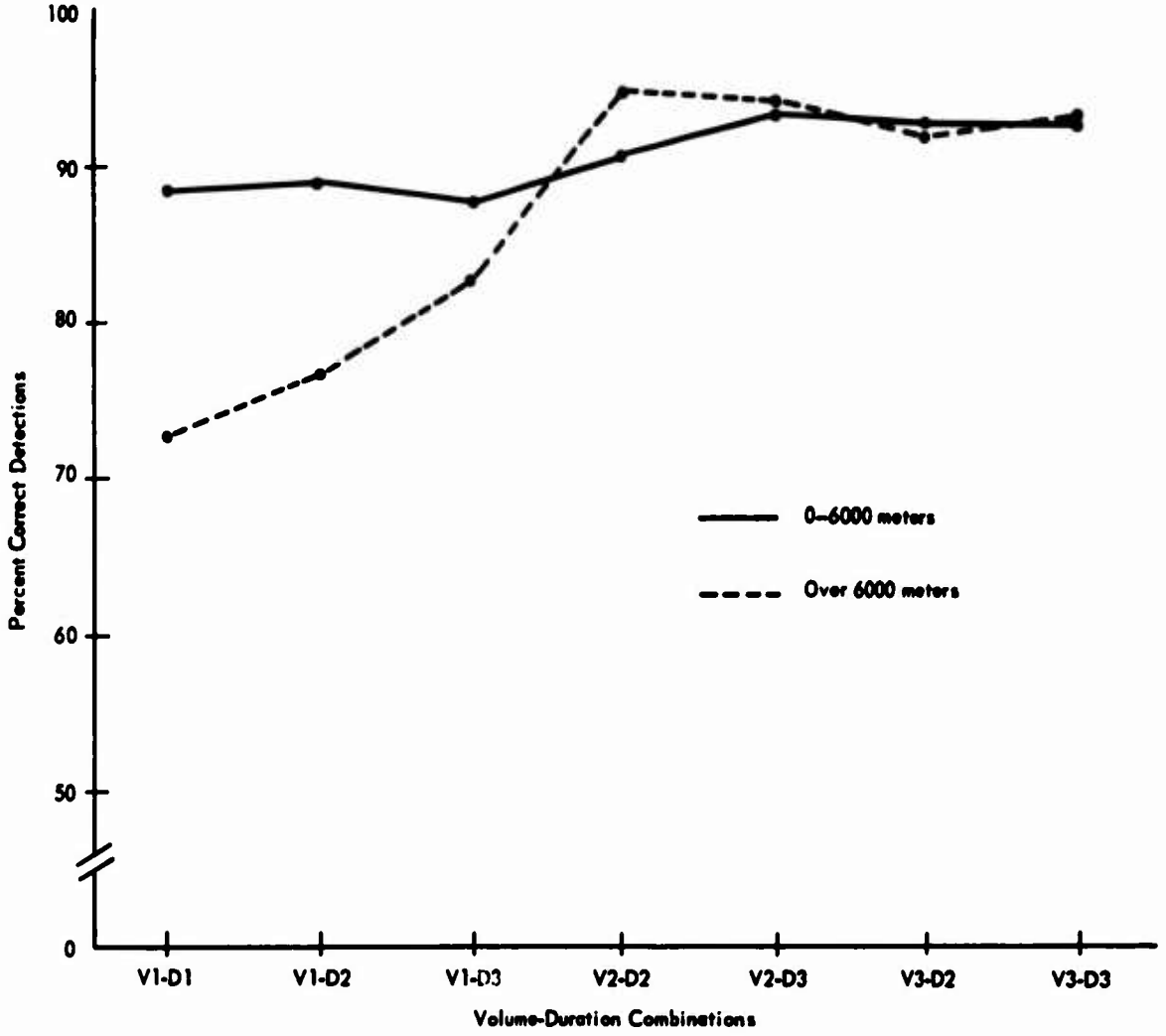

Fig 2 Combined data, percent correct detections vs volume-duration combination

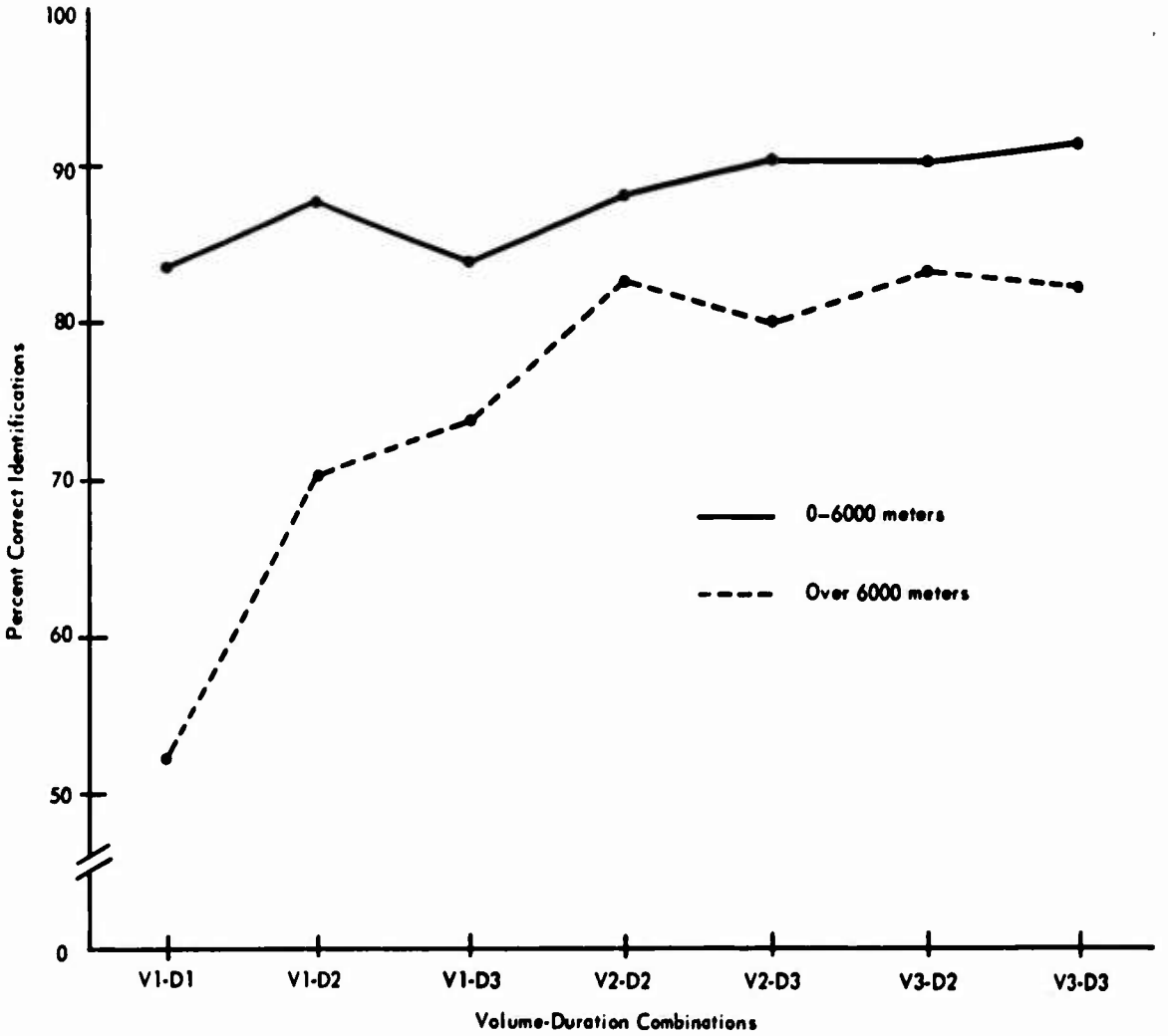

Fig 3 Combined data, percent correct identifications vs volume-duration combinations

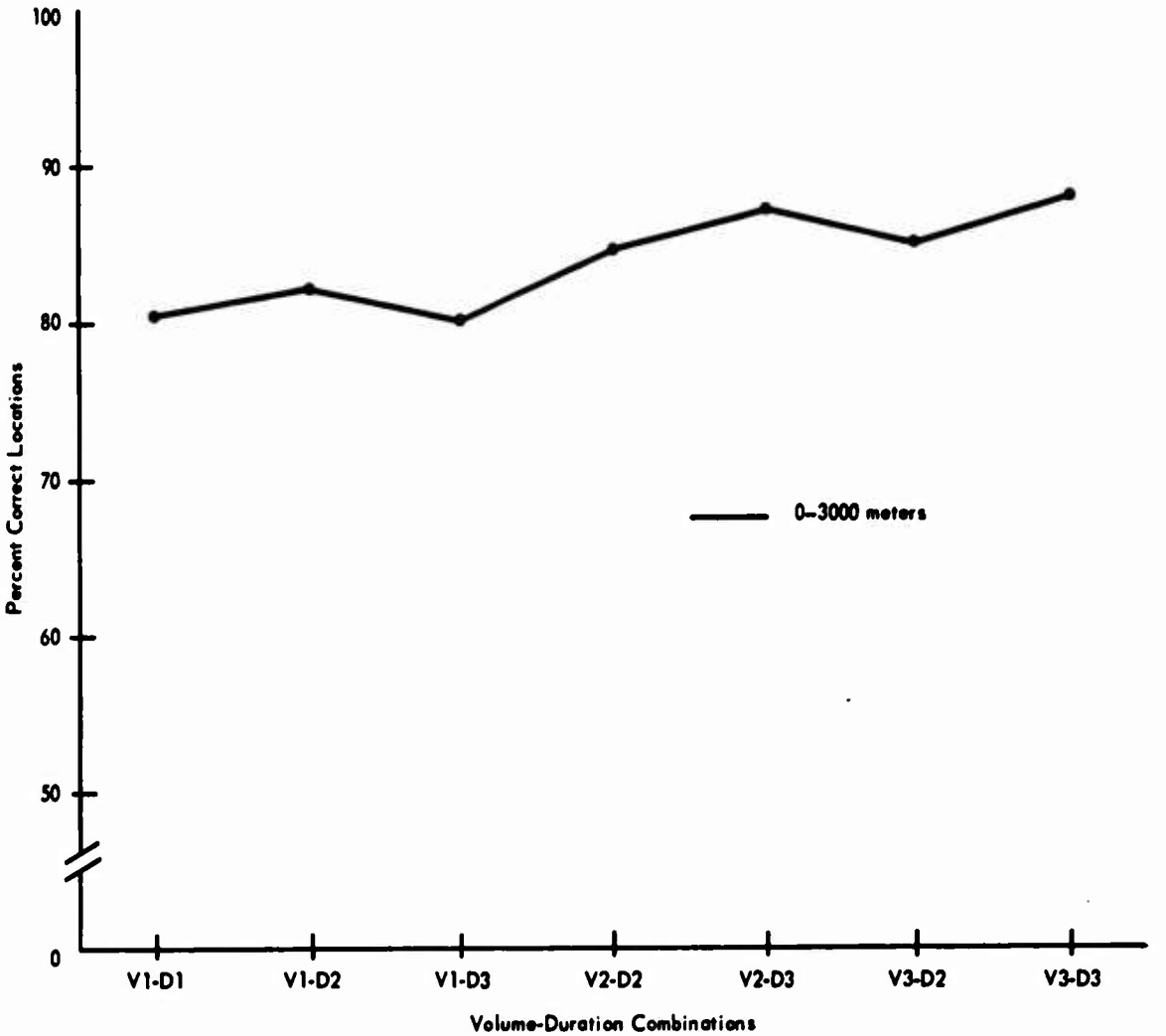

Fig 4 Combined data, percent correct locations vs volume-duration combination

PROCEDURE, PHASE 2

The same test area was used in the aerial observer phase as in the ground observer phase (phase 1).

Twelve observers (all U. S. Army enlisted men) were used in phase 2. Only four aircraft were available (two H-13 helicopters and two L-19 fixed wing observation planes); therefore, only four observers could be used at any one time. The four aircraft flew in a clockwise direction so that the observers always faced toward the area in which the smoke marker locations were situated.

The pattern that the aircraft flew carried them directly over the ground observer positions (A-J) used in phase 1. This pattern was chosen so that observers could specify their position in space in reference to known locations. The observers were instructed to record their positions as accurately as possible. During data reduction and analysis when the observer recorded that he was not directly over a ground observer position, the midpoint between positions (e.g., A-B) was used to determine slant ranges at which the smoke markers were observed.

The altitude of the helicopters was 500 and 1000 feet above the terrain. The altitude of the L-19's was 1500 and 2000 feet. The speed of all aircraft was approximately 60 mph.

During a one-day dry run, all observers had the opportunity to thoroughly familiarize themselves with the test area layout. They also had the opportunity to see smoke at each of the nine points and they were always told the color of smoke and the number of its ground location. In this dry run, they saw all five colors of smoke generated at each marker location.

During the actual testing, the observers were instructed to record the color(s) seen and the smoke location(s) for each trial. They also recorded their aircraft location in relation to the ten ground observer locations which were marked to be visible from the air. The only information they were given was a warning signal one minute before each trial.

The test lasted four days, with 16 trials on each day. Observers were rotated after every eight trials.

12

A trial consisted of a one, two, or three marker-shot procedure. In a one-marker-shot procedure, smoke was initiated at only one of the nine marker locations. A two-marker-shot procedure was one in which smoke was initiated at two different ground locations simultaneously. In a three-marker-shot procedure, smoke came from three different marker locations simultaneously.

All variables were randomly distributed. That is, the particular color, volume, and duration of the smoke; the marker location; and whether shots were to be fired at 1, 2, or 3 locations in each particular trial were randomized.

In the total 64 trials, there were 12 one-marker-shot procedures, 12 two-marker-shot procedures, and 40 three-marker-shot procedures. There were more three-marker-shot than one- or two-marker shot procedures because the 3-marker-shot procedure provided more information per trial. Restrictions on aircraft availability, time, and total allocated study time required the most efficient data-producing procedures.

During this phase, white smoke was initiated a total of 16 times, two times at each volume-duration combination except the volume 3-duration 2 and the volume 3-duration 3 combinations which were initiated once each. Red, yellow, green, and violet smoke were each initiated a total of 35 times, 5 times at each volume-duration combination except the volume 2-duration 3 and the volume 3-duration 2, which were initiated twice, and the volume 3-duration 3 combination, which was initiated once. The reason for the reduced use of white smoke and the large volume-duration combinations is that the white smoke and the large combinations yielded very high detection and the identification rates in the first phase.

RESULTS, PHASE 2

Tables 17 through 21 (pp 29-33) show percentages of correct detection, identification, and location for all volume-duration combinations of each color.

Tables 22 through 26 (pp 34-38) give ranking by colors and volume-duration combinations for the five basic categories (correct detection, 0-6000 meters; correct detection, over 6000 meters; correct identification, 0-6000 meters; correct identification, over 6000 meters; and correct location, 0-3000 meters).

Tables 27 through 31 (pp 39-43) give the mean rankings within each of the same five categories.

Figures 5 through 7 (pp 45-47) are graphs showing the relationship of the volume-duration combination to the accuracy of the observation. Combined data, all observers and all colors (except white), is used. Similar data, for white smoke markers only, is given in Figure 8 (p 48).

Although white smoke data is not included in the rankings or the mean rankings, inspection of the raw data would indicate that white smoke ranks first in terms of detection, identification, and location. This result agrees with that found in the ground observer phase. Once again violet proved to be the poorest color.

The volume 2-duration 3 combination was consistently ranked above all other combinations.

When considered separately volume 3 and duration 3 always ranked highest. Volume 3 and duration 3 were ranked about equal in all cases.

At the end of the study the 12 aerial observers were asked to state which color smoke was the most effective and which color was the least effective in terms of detection, identification, and location. The subjective evaluations shown in Table 32 (p 44) are in direct agreement with the experimental findings.

White was the most effective color, while red was next most effective. Violet appeared to be the poorest and was in fact judged least effective. It must be noted that the background against which the smoke markers were viewed was of varying shades of green, yellow and brown. If the smoke markers had been viewed against backgrounds composed of other colors, the relative effectiveness might have been different.

TABLE 17

Aerial observation (phase 2) data for red smoke markers

Volume	Duration	Observer Distance, km	Correct Detection, %	Correct Identification, %	Correct Location, %
1	1	0–6	72.7	72.7	
		Over 6	66.7	66.7	
		0–3			42.8
1	2	0–6	88.9	83.2	
		Over 6	100	100	
		0–3			63.6
1	3	0–6	93.8	93.8	
		Over 6	100	100	
		0–3			100
2	1	0–6	100	100	
		Over 6	100	100	
		0–3			83.3
2	2	0–6	86.7	86.7	
		Over 6	100	100	
		0–3			83.3
2	3	0–6	100	100	
		Over 6			
		0–3			100
3	1	0–6	100	100	
		Over 6	100	100	
		0–3			50.0
3	2	0–6	100	100	
		Over 6	100	100	
		0–3			75.0
3	3	0–6	100	100	
		Over 6	100	100	
		0–3			100

TABLE 18

Aerial observation (phase 2) data for green smoke markers

Volume	Duration	Observer Distance, km	Correct Detection, %	Correct Identification, %	Correct Location, %
1	1	0–6	87.5	87.5	
		Over 6	100	100	
		0–3			63.6
1	2	0–6	83.3	83.3	
		Over 6	100	100	
		0–3			62.5
1	3	0–6	100	100	
		Over 6	100	100	
		0–3			75.0
2	1	0–6	100	100	
		Over 6	83.3	83.3	
		0–3			100
2	2	0–6	100	91.7	
		Over 6	100	75.0	
		0–3			55.5
2	3	0–6	100	100	
		Over 6			
		0–3			80.0
3	1	0–6	100	100	
		Over 6	100	100	
		0–3			75.0
3	2	0–6	100	100	
		Over 6	100	100	
		0–3			100
3	3	0–6	100	100	
		Over 6	100	100	
		0–3			100

TABLE 19

Aerial observation (phase 2) data for yellow smoke markers

Volume	Duration	Observer Distance, km	Correct Detection, %	Correct Identification, %	Correct Location, %
1	1	0–6	72.7	72.7	
		Over 6	25.0	0	
		0–3			71.4
1	2	0–6	100	100	
		Over 6	50.0	50.0	
		0–3			100
1	3	0–6	100	100	
		Over 6	50.0	50.0	
		0–3			100
2	1	0–6	75.0	66.7	
		Over 6	50.0	50.0	
		0–3			40.0
2	2	0–6	92.9	85.7	
		Over 6	100	100	
		0–3			90.9
2	3	0–6	100	100	
		Over 6	100	100	
		0–3			0.00
3	1	0–6	100	100	
		Over 6	100	100	
		0–3			71.4
3	2	0–6	100	100	
		Over 6	100	100	
		0–3			100
3	3	0–6	100	100	
		Over 6	100	100	
		0–3			100

TABLE 20

Aerial observation (phase 2) data for violet smoke markers

Volume	Duration	Observer Distance, km	Correct Detection, %	Correct Identification, %	Correct Location, %
1	1	0–6	85.7	85.7	
		Over 6	0	0	
		0–3			87.5
1	2	0–6	69.2	69.2	
		Over 6	50.0	0	
		0–3			70.0
1	3	0–6	91.7	91.7	
		Over 6	100	100	
		0–3			70.0
2	1	0–6	100	100	
		Over 6	75.0	75.0	
		0–3			80.0
2	2	0–6	84.6	84.6	
		Over 6	100	100	
		0–3			50.0
2	3	0–6	100	100	
		Over 6	100	100	
		0–3			100
3	1	0–6	85.7	85.7	
		Over 6	100	100	
		0–3			69.2
3	2	0–6	100	100	
		Over 6	50.0	50.0	
		0–3			100
3	3	0–6	75.0	75.0	
		Over 6			
		0–3			100

TABLE 21

Aerial observation (phase 2) data for white smoke markers

Volume	Duration	Correct Detection, %	Correct Identification, %	Correct Location, %
1	1	85.7	85.7	57.1
1	2	100	66.7	100
1	3	100	87.5	87.5
2	1	100	100	83.3
2	2	100	100	66.7
2	3	100	100	100
3	1	100	83.3	83.3
3	2	100	100	66.7
3	3	100	75	100

TABLE 22

Correct detection, 0–6000 meters

Rank	Color	Volume	Duration	Correct Detection, %
11	Red	2	1	100
11	Red	2	3	100
11	Red	3	1	100
11	Red	3	2	100
11	Red	3	3	100
11	Green	1	3	100
11	Green	2	1	100
11	Green	2	2	100
11	Green	2	3	100
11	Green	3	1	100
11	Green	3	2	100
11	Green	3	3	100
11	Yellow	1	2	100
11	Yellow	1	3	100
11	Yellow	2	3	100
11	Yellow	3	1	100
11	Yellow	3	2	100
11	Yellow	3	3	100
11	Violet	2	1	100
11	Violet	2	3	100
11	Violet	3	2	100
22	Red	1	3	93.8
23	Yellow	2	2	92.9
24	Violet	1	3	91.7
25	Red	1	2	88.9
26	Green	1	1	87.5
27	Red	2	2	86.7
28.5	Violet	1	1	85.7
28.5	Violet	3	1	85.7
30	Violet	2	2	84.6
31	Green	1	2	83.3
32.5	Yellow	2	1	75
32.5	Violet	3	3	75
34.5	Red	1	1	72.7
34.5	Yellow	1	1	72.7
36	Violet	1	2	69.2

TABLE 23

Correct detection, over 6000 meters

Rank	Color	Volume	Duration	Correct Detection, %
12	Red	1	2	100
12	Red	1	3	100
12	Red	2	1	100
12	Red	2	2	100
12	Red	3	1	100
12	Red	3	2	100
12	Red	3	3	100
12	Green	1	1	100
12	Green	1	2	100
12	Green	1	3	100
12	Green	2	2	100
12	Green	3	1	100
12	Green	3	2	100
12	Green	3	3	100
12	Yellow	2	2	100
12	Yellow	2	3	100
12	Yellow	3	1	100
12	Yellow	3	2	100
12	Yellow	3	3	100
12	Violet	1	3	100
12	Violet	2	2	100
12	Violet	2	3	100
12	Violet	3	1	100
24	Green	2	1	83.3
25	Violet	2	1	75
26	Red	1	1	66.7
29	Yellow	1	2	50
29	Yellow	1	3	50
29	Yellow	2	1	50
29	Violet	1	2	50
29	Violet	3	2	50
32	Yellow	1	1	25
33	Violet	1	1	0

TABLE 24

Correct identification, 0–6000 meters

Rank	Color	Volume	Duration	Correct Identification, %
10.5	Red	2	1	100
10.5	Red	2	3	100
10.5	Red	3	1	100
10.5	Red	3	2	100
10.5	Red	3	3	100
10.5	Green	1	3	100
10.5	Green	2	1	100
10.5	Green	2	3	100
10.5	Green	3	1	100
10.5	Green	3	2	100
10.5	Green	3	3	100
10.5	Yellow	1	2	100
10.5	Yellow	1	3	100
10.5	Yellow	2	3	100
10.5	Yellow	3	1	100
10.5	Yellow	3	2	100
10.5	Yellow	3	3	100
10.5	Violet	3	3	100
10.5	Violet	2	3	100
10.5	Violet	3	2	100
21	Red	1	3	93.8
22.5	Green	2	2	91.7
22.5	Violet	1	3	91.7
24	Green	1	1	87.5
25	Red	2	2	86.7
27	Yellow	2	2	85.7
27	Violet	1	1	85.7
27	Violet	3	1	85.7
29	Violet	2	2	84.6
30	Green	1	2	83.3
31	Red	1	2	83.2
32	Violet	3	3	75
33.5	Red	1	1	72.7
33.5	Yellow	1	1	72.7
35	Violet	1	2	69.2
36	Yellow	2	1	66.7

TABLE 25

Correct identification, over 6000 meters

Rank	Color	Volume	Duration	Correct Identification, %
11.5	Red	1	2	100
11.5	Red	1	3	100
11.5	Red	2	1	100
11.5	Red	2	2	100
11.5	Red	3	1	100
11.5	Red	3	2	100
11.5	Red	3	3	100
11.5	Green	1	1	100
11.5	Green	1	2	100
11.5	Green	1	3	100
11.5	Green	3	1	100
11.5	Green	3	2	100
11.5	Green	3	3	100
11.5	Yellow	2	2	100
11.5	Yellow	2	3	100
11.5	Yellow	3	1	100
11.5	Yellow	3	2	100
11.5	Yellow	3	3	100
11.5	Violet	1	3	100
11.5	Violet	2	2	100
11.5	Violet	2	3	100
11.5	Violet	3	1	100
23	Green	2	1	83.3
24.5	Violet	2	1	75
24.5	Green	2	2	75
26	Red	1	1	66.7
28.5	Yellow	1	2	50
28.5	Yellow	1	3	50
28.5	Yellow	2	1	50
28.5	Violet	3	2	50
32	Yellow	1	1	0
32	Violet	1	1	0
32	Violet	1	2	0

TABLE 26

Correct location, 0–3000 meters

Rank	Color	Volume	Duration	Correct Location, %
7	Red	1	3	100
7	Red	2	3	100
7	Red	3	3	100
7	Green	2	1	100
7	Green	3	2	100
7	Green	3	3	100
7	Yellow	1	2	100
7	Yellow	1	3	100
7	Yellow	3	2	100
7	Yellow	3	3	100
7	Violet	2	3	100
7	Violet	3	2	100
7	Violet	3	3	100
14	Yellow	2	2	90.9
15	Violet	1	1	87.5
16.5	Red	2	1	83.3
16.5	Red	2	2	83.3
18.5	Violet	2	1	80
18.5	Green	2	3	80
21	Green	1	3	75
21	Green	3	1	75
21	Red	3	2	75
23.5	Yellow	1	1	71.4
23.5	Yellow	3	1	71.4
25.5	Violet	1	2	70
25.5	Violet	1	3	70
27	Violet	3	1	69.2
28.5	Green	1	1	63.6
28.5	Red	1	2	63.6
30	Green	1	2	62.5
31	Green	2	2	55.5
32.5	Violet	2	2	50
32.5	Red	3	1	50
34	Red	1	1	42.8
35	Yellow	2	1	40
36	Yellow	2	3	0

TABLE 27

Mean rankings, correct detection, 0–6000 meters

Color	Green	14.88
	Yellow	17.33
	Red	18.16
	Violet	23.61
Volume-Duration Combination	Vol 2–Dur 3	11
	Vol 3–Dur 2	11
	Vol 3–Dur 1	15.37
	Vol 2–Dur 1	16.37
	Vol 3–Dur 3	16.37
	Vol 1–Dur 3	17
	Vol 2–Dur 2	22.75
	Vol 1–Dur 2	25.75
	Vol 1–Dur 1	30.87
Volume	Vol 3	14.25
	Vol 2	16.7
	Vol 1	24.54
Duration	Dur 3	14.75
	Dur 2	19.83
	Dur 1	20.87

TABLE 28

Mean rankings, correct detection, over 6000 meters

Color	Green	13.5
	Red	13.75
	Yellow	19.88
	Violet	20.5
Volume-Duration Combination	Vol 2–Dur 2	12
	Vol 2–Dur 3	12
	Vol 3–Dur 1	12
	Vol 3–Dur 3	12
	Vol 1–Dur 3	16.25
	Vol 3–Dur 2	16.25
	Vol 1–Dur 2	20.5
	Vol 2–Dur 1	22.5
	Vol 1–Dur 1	25.75
Volume	Vol 3	13.54
	Vol 2	16.2
	Vol 1	20.83
Duration	Dur 3	13.88
	Dur 2	16.25
	Dur 1	20.08

TABLE 29

Mean rankings, correct identification, 0–6000 meters

Color	Green	15.5
	Yellow	17.72
	Red	18.11
	Violet	22.66
Volume-Duration Combination	Vol 2–Dur 3	10.5
	Vol 3–Dur 2	10.5
	Vol 3–Dur 1	14.62
	Vol 3–Dur 3	15.87
	Vol 1–Dur 3	16.12
	Vol 2–Dur 1	16.87
	Vol 2–Dur 2	25.87
	Vol 1–Dur 2	26.62
	Vol 1–Dur 1	29.5
Volume	Vol 3	13.66
	Vol 2	17.75
	Vol 1	24.08
Duration	Dur 3	14.16
	Dur 1	20.33
	Dur 2	21.0

TABLE 30

Mean rankings, correct identification, over 6000 meters

Color	Red	13.31
	Green	14.56
	Yellow	19.44
	Violet	20.37
Volume-Duration Combination	Vol 2–Dur 3	11.5
	Vol 3–Dur 1	11.5
	Vol 3–Dur 3	11.5
	Vol 2–Dur 2	14.75
	Vol 1–Dur 3	15.75
	Vol 3–Dur 2	15.75
	Vol 1–Dur 2	20.87
	Vol 2–Dur 1	21.87
	Vol 1–Dur 1	25.37
Volume	Vol 3	13.04
	Vol 2	16.95
	Vol 1	20.66
Duration	Dur 3	13.38
	Dur 2	17.12
	Dur 1	19.58

TABLE 31

Mean rankings, correct location, 0–3000 meters

Color	Yellow	17.77
	Violet	18.33
	Red	18.88
	Green	19.0
Volume-Duration Combination	Vol 3–Dur 3	7.0
	Vol 3–Dur 2	10.5
	Vol 1–Dur 3	15.12
	Vol 2–Dur 3	17.12
	Vol 2–Dur 1	19.25
	Vol 1–Dur 2	22.75
	Vol 2–Dur 2	23.5
	Vol 1–Dur 1	25.25
	Vol 3–Dur 1	26.0
Volume	Vol 3	14.5
	Vol 2	19.95
	Vol 1	21.04
Duration	Dur 3	13.08
	Dur 2	18.91
	Dur 1	23.5

TABLE 32

Observers' color ranking

Best Color	Number of Observers Ranking Colors
White	7
Red	4
Green	1
Poorest Color	
Violet	8
Yellow	3
White	1

Additional Colors Suggested by Observers	Number of Observers Making Suggestion
Black	9
Orange	4
Blue	3
Brown	1
Gray	1
Chartreuse	1
Pink	1
Purple	1

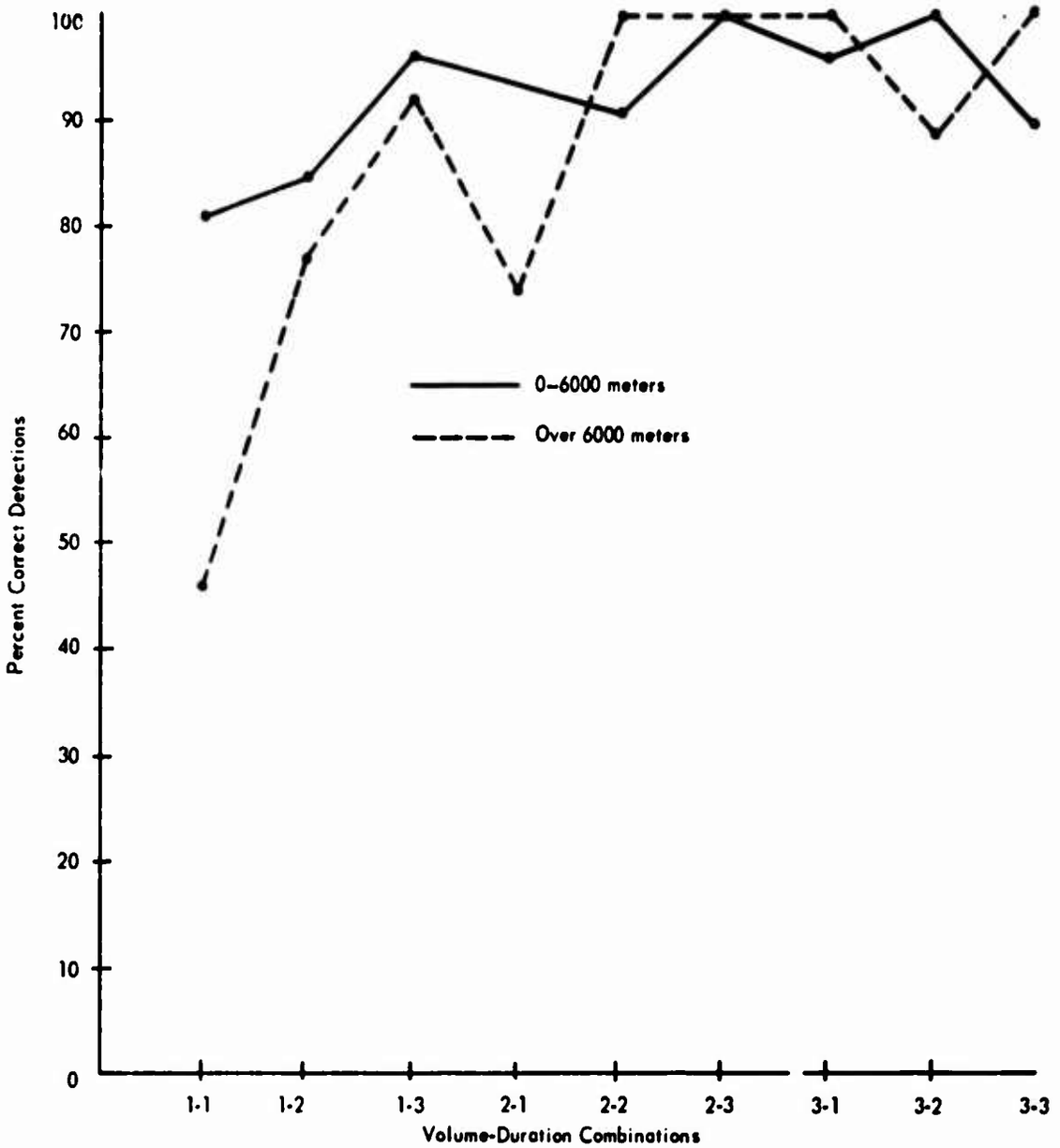

Fig 5 Combined data, percent correct detections vs volume-duration combination

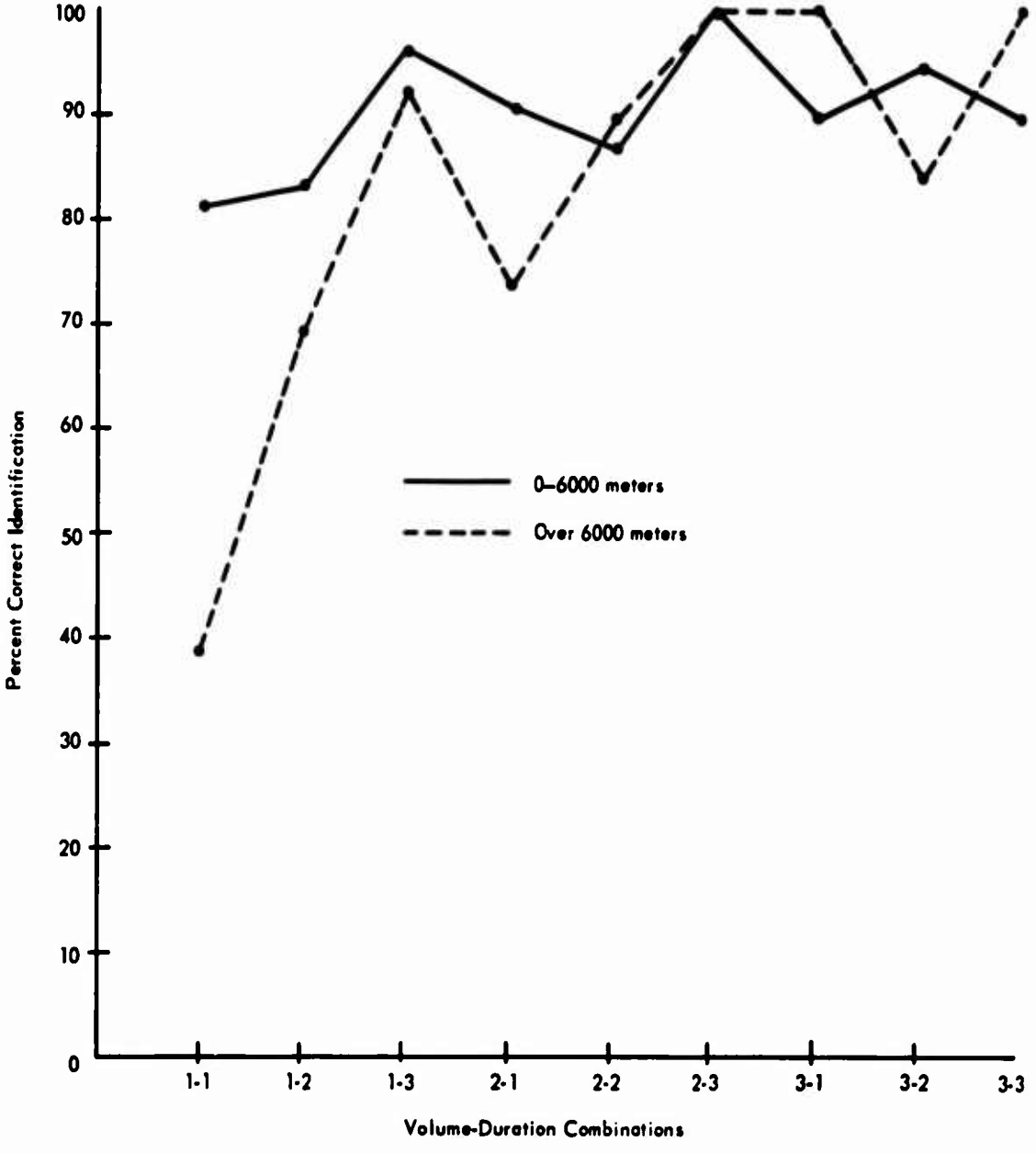

Fig 6 Combined data, percent correct identifications vs volume-duration combinations

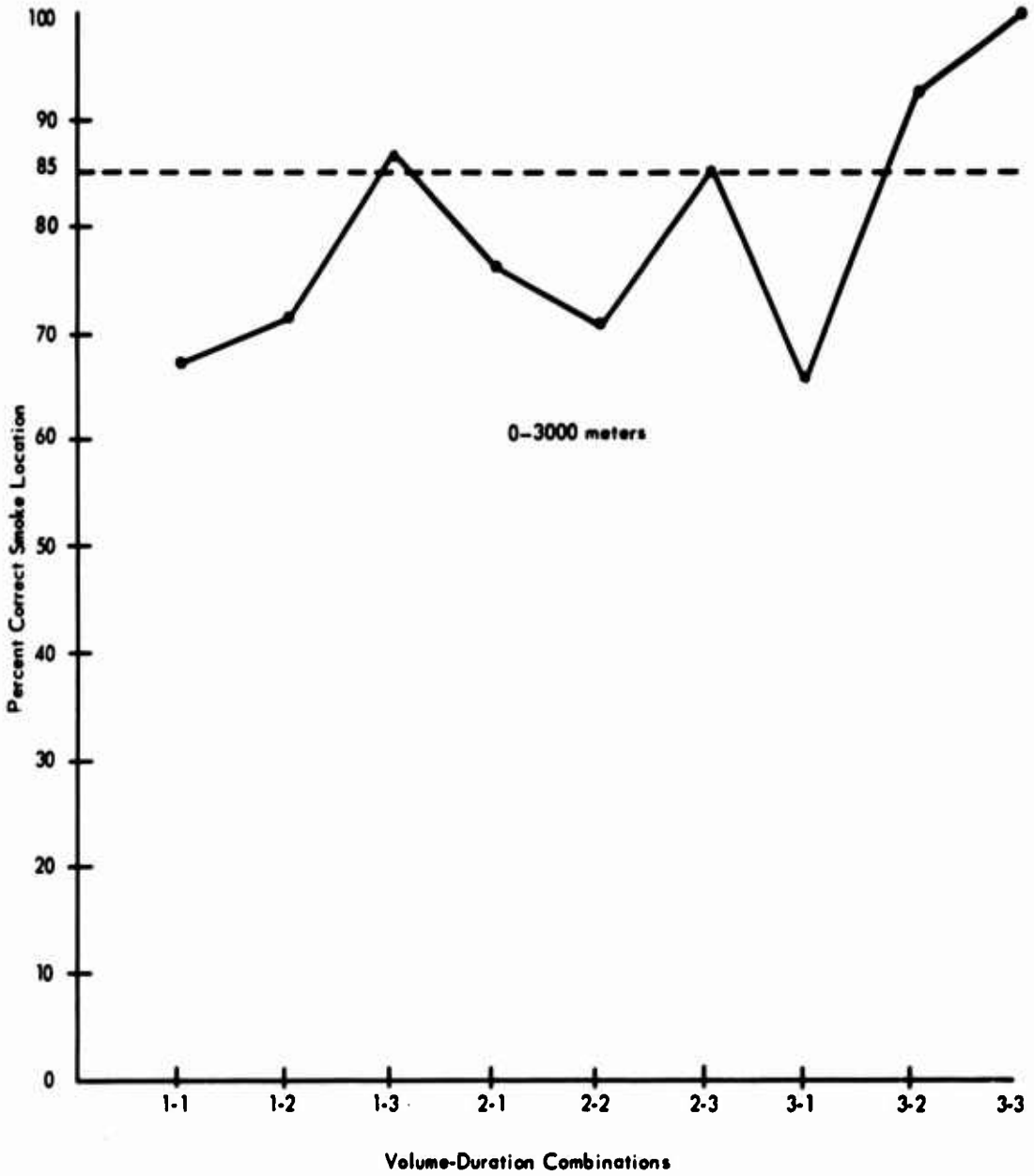

Fig 7 Combined data, percent correct locations vs volume-duration combination

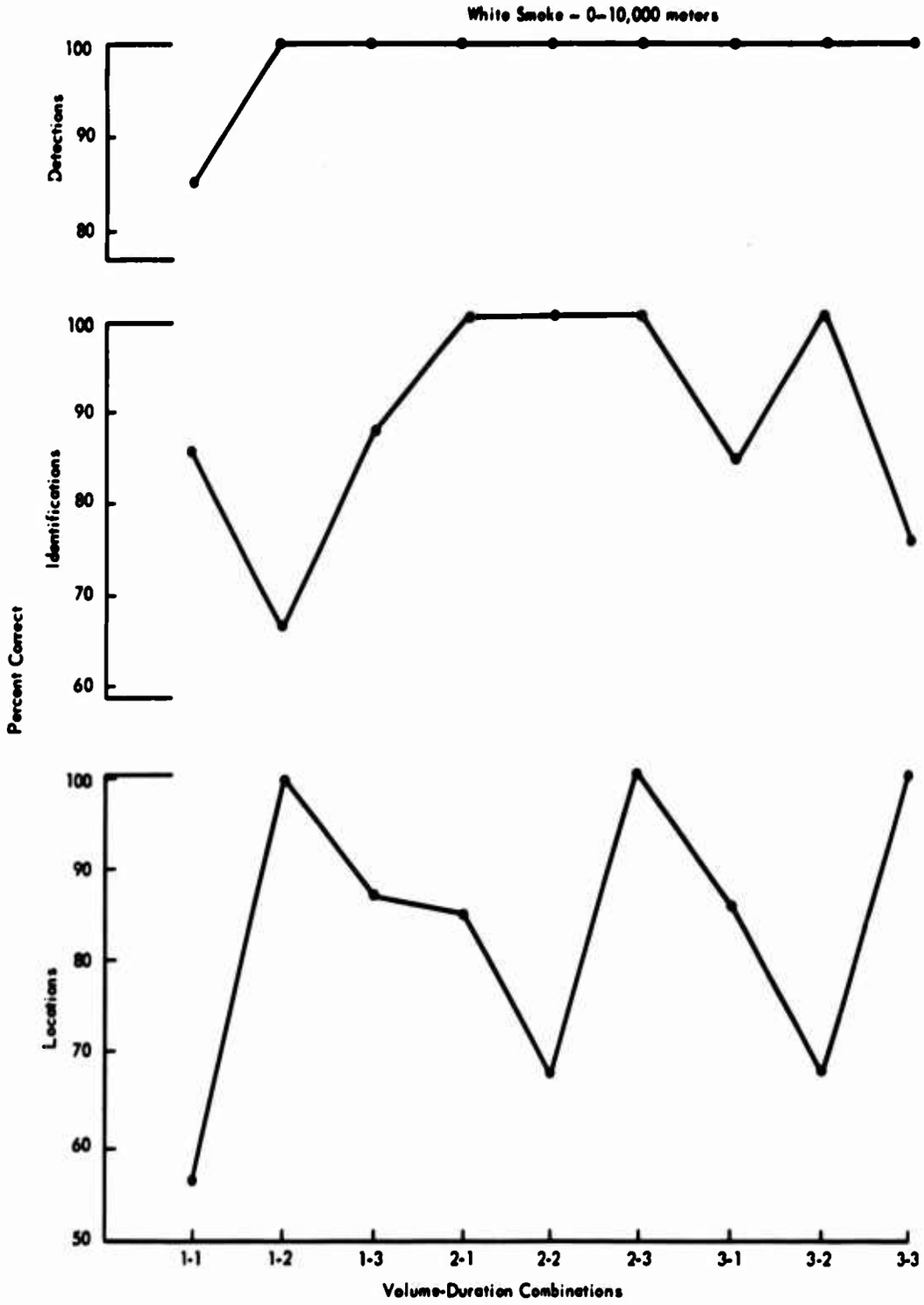

Fig 8 Percent correct detections, identifications, and locations (combined white smoke data) vs volume-duration combinations

DISCUSSION

The volume-duration combination which proved most effective with respect to percent of correct detections, correct color identifications, and correct locations of the source of smoke was volume 2–duration 3. Practically speaking, however, ammunition warheads have only limited capacity for pyrotechnics; therefore, even though the volume 2–duration 3 combination is most effective, a "tradeoff" may have to be made. That is to say, effectiveness may have to be sacrificed because of warhead size limitations. The cutoff point for pyrotechnic capacity would be determined by the user.

As had been expected, the larger volume-duration combinations (2-2, 2-3, 3-2, and 3-3) yielded the highest rates of detection, color identification, and correct location of smoke emission sites. Also as expected, observers located between 500 and 6000 meters from the smoke sources had higher rates than observers located at distances greater than 6000 meters.

In both phases, white was the best smoke while violet was the poorest. In the ground phase, red and green appeared to be about equally effective and ranked after white. In the aerial phase, red, green, and yellow were ranked about the same. One reason for yellow's higher position in the second phase may have been the change in background colors from the first phase to the second.

The data was ranked in order to show that the differences found to exist between colors were relative rather than absolute. The one exception indicated by the data was white smoke. It always ranked above the colored smoke when compared across all variables. At least two factors may have played a role in the white smoke's ranking. First, the chemicals used produced a larger and consequently heavier smoke particle and secondly, the burning times for white smoke markers were about 50% longer.

It should be noted that the volume 2–duration 3 combination described earlier in the report was not the best in all tests but rather it was found to rank above the other combinations more often than any other combination.

The authors realize that the present study is only a beginning. Future work is planned at which time the following questions will be considered:

1. Will detection and identification rates remain at the rather high level found in the present study if

a. smaller volumes and shorter durations of smoke are used?

b. larger volumes and shorter durations of smoke are used, etc, and trained observers are used?

2. Is the best time to initiate a smoke marker

a. when an aircraft is approaching?

b. when an aircraft is nearly overhead?

3. Will detection and identification rates be affected by training the people (i.e., pilot, artillery spotter) to initiate the markers when they have the best chance of being seen?

4. How will jungle canopy, desert sand, or snow affect detection and identification?

5. Will various methods of dispensing smoke affect detection? Among methods which might be considered are:

a. present canister type dispersal

b. rocket dispersal

c. artillery shell dispersal

d. tethered balloon with canister

e. parachute dropped, similarly to present hand-held signal flare

6. Should a smoke lie close to the ground or should it billow up in a column?

7. What happens to smoke under very cold and still air conditions?

8. What is the maximum wind speed at which smoke can be profitably used?

9. What are the basic terrain background features and colors which differentially affect the use of smoke?

10. How do weather conditions affect detection of the various smokes?

CONCLUSIONS

White smoke yielded the highest rates of correct detection, correct identification, and correct location. Red was the next best color, while violet was the poorest.

The best volume-duration combination in terms of overall effectiveness is the volume 2–duration 3 combination.

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13. ABSTRACT

A field study was conducted to determine the minimum volume and duration of colored smokes that could be detected, identified, and located by both ground and aerial observers. The distances from observers to smoke emission sites varied from approximately 500 to 10,000 meters. Red, yellow, green, violet, and white smokes were generated by initiating U. S. Army standard M8 and M18 smoke grenades. Nine volume-duration combinations of smoke were tested. Volume of smoke was controlled by initiating various numbers of grenades (one, two, or three) simultaneously. Duration of smoke emission was controlled by initiating various numbers of grenades in succession so as to give a continuous smoke.

The larger volume-duration combinations (2-2 and 3-3) yielded the highest rates of detection, color identification, and correct location of smoke emission sites. Observers located between 500 and 6000 meters from the smoke had higher rates of detection, identification, and location than did observers located at distances greater than 6000 meters. In terms of overall effectiveness, the best volume-duration combination is 2-3. White smoke yielded the highest rates of correct detection, correct identification, and correct location. Red was the next best color, while violet was the poorest.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Colored smoke markers						
Smoke duration						
Smoke volume						
Target area						
Ground target						
M8 grenade						
Ground observation						
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