

**NAVAL SUBMARINE MEDICAL
RESEARCH LABORATORY
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REPORT NUMBER 966

THE F-M 100-HUE TEST FOR ASSESSING
THE EFFECT OF OXYGEN ON COLOR VISION

by

Helen M. Paulson
and
Alma P. Ryan

Naval Medical Research and Development Command
Research Work Unit M0099.PN.001-8013

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SUMMARY PAGE

The Problem

United States Navy saturation divers are occasionally exposed to partial pressures of oxygen which may lead to toxic effects on their central nervous system if such exposures are extensive in amount or time. The Farnsworth-Munsell 100-Hue Test is proposed for use as an early warning detector for such toxic effects.

Findings

The results of the F-M 100-Hue testing on Navy divers during four experimental saturation dives showed no statistically significant results at the particular exposure level and duration of that dive series.

Application

This technique may be useful as a detector in future experimental dives in which the exposure and duration will be greater.

ADMINISTRATIVE INFORMATION

This investigation was conducted in conjunction with the AIRSAT Dive Series. This report was submitted for review on 5 November 1981 and approved for publication on 2 December 1981. It has been designated as NavSubMedRschLab Report No. 966.

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ABSTRACT

Twelve Navy divers were tested in the Farnsworth-Munsell 100-Hut Test during a series of experimental saturation dives to investigate the effect of oxygen partial pressure on color vision. Although no statistically significant results were found, the procedure and technique were established. Effect of illumination and analyses of error scores in the tritan areas of color confusion are discussed as well as the poorer performance of the diver population compared to the non-diver population.

The Farnsworth-Munsell (F-M) 100-Hue Test,¹ developed in the early forties by Dean Farnsworth, has been widely used by industry and in research laboratories to determine whether a person has superior, average, or low aptitude for discriminating colors. Of the three aspects of color--hue, saturation, and brightness--the test evaluates the subject's hue discrimination; the stimuli were produced so that they are constant in saturation and in brightness, differing only in hue. In addition, the test can be used to identify color defectives as to type of defect--protan, deutan, or tritan*--by analysis of the area or areas where the subject makes gross hue confusions.

In the past decade, this test has found increasing use, nationally and internationally, as a detector and monitor of various diseases or drugs which deleteriously affect one's color vision. In fact, there have been several symposia on the topic of color vision deficiency where the entire symposium² or parts of the symposia^{3,4} have been concerned with acquired defects and the use of the F-M 100-Hue Test by such investigators has become quite routine. It is preferred over pseudo-isochromatic plates because it is more sensitive and more informative.

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*A protan, commonly called "red defective," confuses certain reds, grays, and bluish greens and has a reduced sensitivity in the red end of the visible spectrum. A deutan, commonly called "green defective," confuses greens, grays, and purplish reds. A tritan, commonly called "blue defective," confuses violets, grays, and greenish yellows.

This paper reports a new use of the 100-Hue Test--the assessment of the effect on color vision of breathing the increased oxygen in a series of saturation dives. Simulated saturation dives have been conducted in the past few years by this Laboratory to investigate the divers' physiological and behavioral responses to various gas mixtures and to develop decompression schedules for divers to shallow and intermediate depths. In some of these dives, the authors have collected hue discrimination data by means of the F-M 100-Hue Test. This paper reports the data collected in four dives entitled AIRSAT 3A, 3B, 3C, and 3D, which were identical in dive protocol. Figure 1 presents the protocol for this particular dive series.

Breathing partial pressure of oxygen in excess of 2 atmospheres absolute (ATA) is known to have toxic effects on the central nervous system which may culminate in generalized convulsions.⁵ Since early warning signals of oxygen toxicity sometimes occur in the visual system,⁶ it was decided to assess the divers' visual performance during and following the Laboratory's saturation dive experiments with a few such tests--peripheral visual fields, electroencephalograms, and hue discrimination. Breathing 100% O₂ at the surface for 24 hours is not considered to be a hazard to the central nervous system.^{7,8} However, the protocol in this AIRSAT series of dives extends the duration of oxygen exposure, during the decompression on air, to a length not previously investigated. Future AIRSAT series will involve even more lengthy exposures to oxygen.

DIVE PROTOCOL FOR NSMRL AIRSAT DIVES 3A-3D

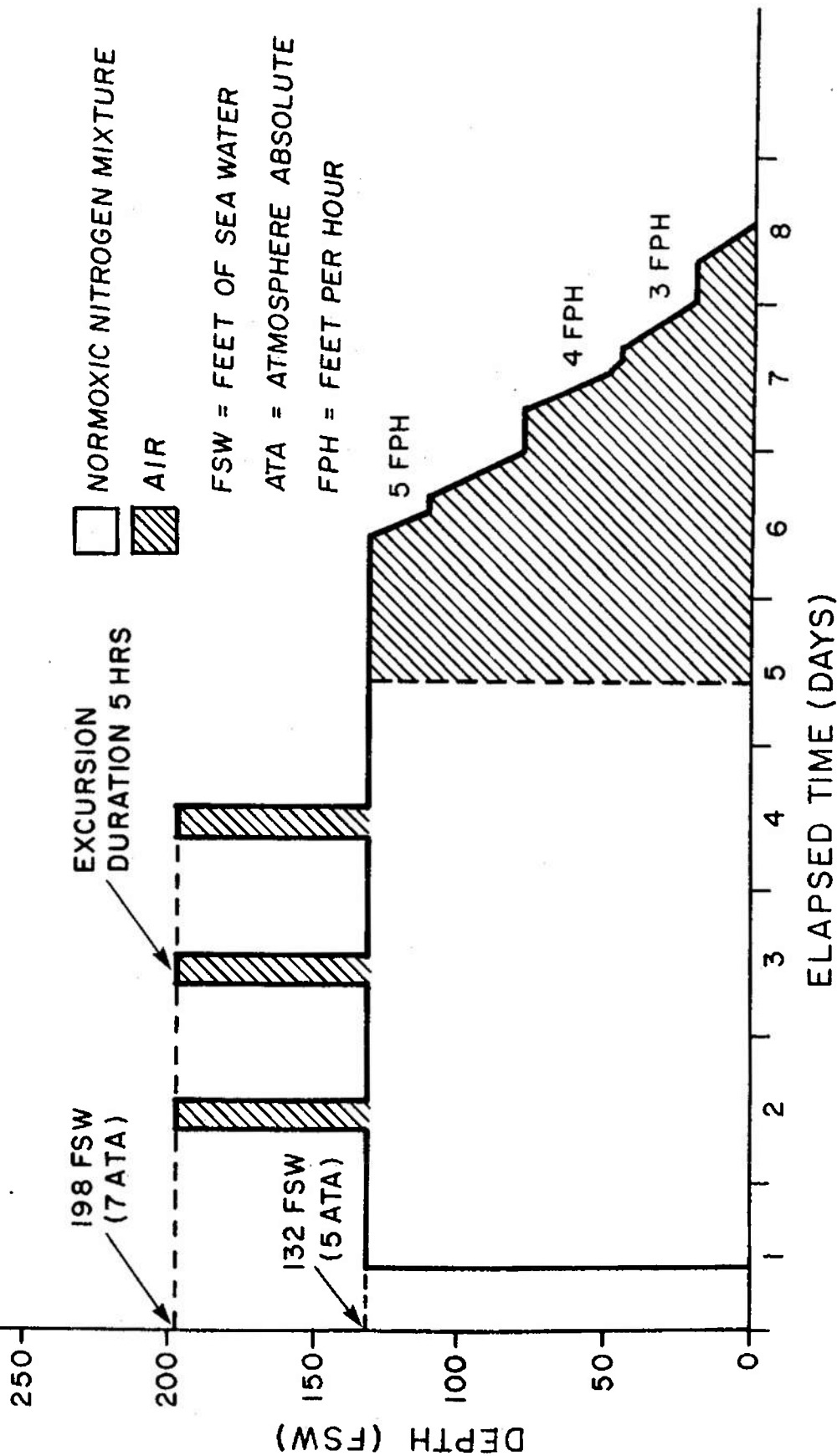


Fig. 1. Dive protocol for NSMRL AIRSAT Dives 3A-3D.

PROCEDURE

In each experimental dive, three different qualified Navy divers, aged 26-36 and all color normal, were used as subjects. Each of the divers was tested seven times--twice predive in the chamber, three times during the dive, and twice postdive, with one to several days separating the administrations. The predive tests were administered on the eighth and fifth days prior to the dive. The tests during the dive were on days two and four (one hour after decompression to 132 fsw) and on day 6 (five hours after decompression to the surface began). The postdive tests were on the first and second days after the divers had surfaced.

The standard illuminant specified for administration of the F-M 100-Hue Test is Macbeth Daylight (Illuminant "C") of approximately 6740K at 25 footcandles or more. Lack of space prohibited the installation of the specified illumination. The illumination available in the chamber--an incandescent of 2400K and 4 footcandles--was used and burned at constant voltage. Use of non-standard illumination should not influence analyses done here since all data were collected under the same illumination.

All other instructions for administration of the test, as stated in the F-M 100-Hue Test Manual, were followed with two exceptions: (1) the subject was not reminded when he had spent two minutes arranging the colored buttons of the panel, and (2) a practice panel of greater difficulty than the test itself was

constructed and administered to each subject to familiarize him with the task prior to commencing data collection.

In conjunction with the four dives, data were collected in a separate control dive, in which all aspects of the dive were identical except that gas mixtures and pressurization were eliminated and the subjects were Navy men but not divers.

Previous investigations of effects on color vision of drugs, disease, etc., have found acquired color vision defects which were similar to the color confusions made by persons with an inherited tritan defect.²

In this paper, two different but similar areas of tritan confusion are used to analyze the data. One set is based on unpublished data obtained in this Laboratory from four persons with inherited tritanopic or severe tritanomalous deficiency; Area #1 includes test buttons numbered 85-11 and Area #2 includes test buttons numbered 43-55. The other set is based on tritan midpoint data from Verriest,⁹ whose subjects had acquired tritan deficiencies; Quadrant I includes test buttons numbered 75-11 and Quadrant III includes test buttons numbered 33-53.

RESULTS

The total error scores for each test administration to the twelve divers and to the three subjects in the control dive are found in Table I and the diver's averages and standard deviations are presented in Fig. 2. Table I indicates no consistent decrease nor increase in the total error score in first test

Table I. Total error scores on F-M 100-Hue Test

Dive S#	Age	Predive		Dive			Postdive	
		Test #1	Test #2	Test #1	Test #2	Test #3	Test #1	Test #2
AIRSAT 3A								
Subj.#1	33	152	96	104	148	148	124	120
#2	33	52	92	88	56	64	96	76
#3	31	164	120	128	116	168	152	172
AIRSAT 3B								
Subj.#1	36	32	52	36	20	20	64	76
#2	27	36	56	32	36	16	88	72
#3	26	44	40	24	20	8	32	68
AIRSAT 3C								
Subj.#1	32	32	36	52	32	20	44	20
#2	36	76	40	40	44	72	44	48
#3	29	84	24	36	28	28	44	24
AIRSAT 3D								
Subj.#1	34	40	32	92	52	72	44	64
#2	29	52	56	52	68	72	48	60
#3	26	40	40	96	48	68	40	40
CONTROL GROUP								
Subj.#1	21	12	-	20	24	16	32	20
#2	20	20	-	20	28	16	32	20
#3	20	20	-	16	28	44	24	16

versus second test; six subjects decreased their error score, five increased, and one had the same error score. The practice panel given to all subjects prior to their first test administration is probably the reason for no consistent improvement on retest, as has been found by other investigators.¹⁰

On the last day of the dive, when the divers had received the maximum amount of oxygen exposure, the F-M 100-Hue error scores did not differ significantly from the average of their two predive scores. Also, for each individual, the average error score of the two post-dive tests are neither consistently lower nor higher than the scores on

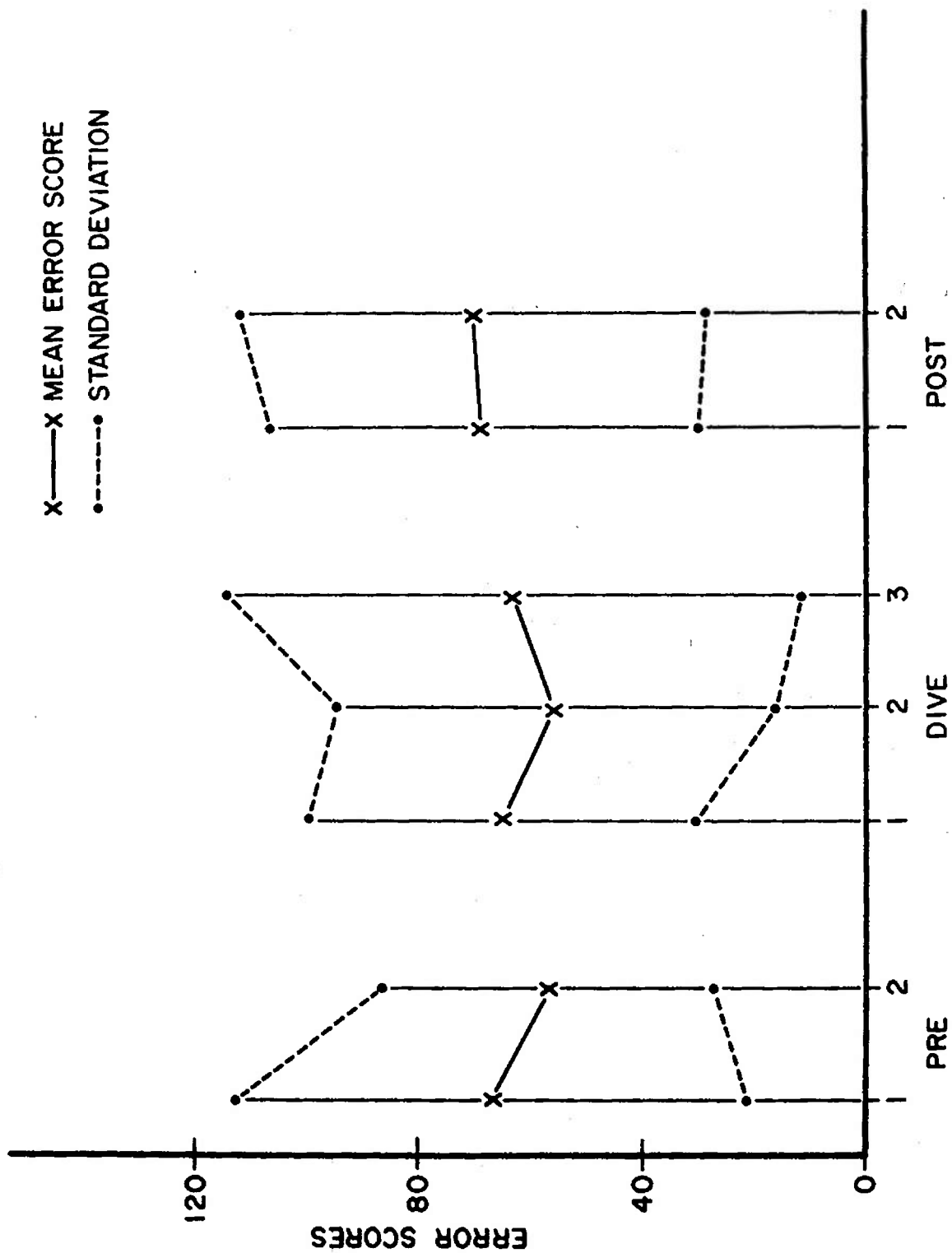


Fig. 2. F-M 100-Hue mean error score for divers in AIRSAT 3A-3D.

the last day of the dive.

While there are no differences in color discrimination in the twelve experimental subjects as a function of the dive conditions, it should be noted that the color discrimination of the subjects in the control dive (all non-divers) is considerably better than those of the subjects in the actual dive (all Navy divers) in pre-dive, dive, and post-dive periods. Although these non-divers were somewhat younger than the divers, an investigation of performance on the 100-Hue Test as a function of age has not shown any significant differences among men under forty.⁹ Also, the color discrimination of the twelve divers is considerably poorer than that normally found among young Navy men tested with the F-M 100-Hue Test.¹¹

Analysis of the error scores made in the tritan areas of confusion failed to show any effects of the dive protocol, by either method of analysis. Figures 3 and 4 contain the average percentage of errors which occurred in the tritan confusion zones (Areas 1 and 2 and Quadrants I and III, respectively) for all twelve divers for all seven test administrations. When the individual diver's total error scores in the various dives were examined, the only finding was that two divers had considerably higher scores in their postdives than in most of their other dives. These divers were 3A/#2 and 3A/#3 and the finding held true under both methods of analysis.

Figure 5 shows one of these post-dive F-M 100-Hue profiles for Diver 3A/#3.

There was great variability in the amount of time the divers spent on each test administration and on the various panels within the test. Of the 84 test administrations, the range of time spent per administration was 4 minutes to 22½ minutes. The length of time the diver spent per test and per panel was compared with the error score per test and per panel and there was no consistent relationship between the two.

The only finding of interest was that not only did the divers in 3B obtain lower error scores during the dive than during pre-dive and post-dive, but they also spent less time on the test during the dive.

DISCUSSION

Two other studies have investigated the effect of color vision on breathing unusual amounts of oxygen. One was undertaken by Smith, Ernest, and Pokorny¹² involving hypoxic conditions and the other was by Gallagher et al.⁷ which, like ours, involved hyperoxia.

Smith, Ernest and Pokorny also used the F-M 100-Hue Test. In an attempt to obtain an effect, they reduced the illumination 45-fold. They first administered the test under the "normal" illumination of 1670 lux, which is 155 footcandles or six times the amount specified in the Test Manual. Finding no effect on test results from breathing the reduced oxygen mixture, they then reduced the illumination to 37 lux, or 3.4 footcandles (which is approximately the level of the illumination available to us in the chamber). Under this reduced illumination, two of their five subjects showed increases in error scores in the tritan areas of

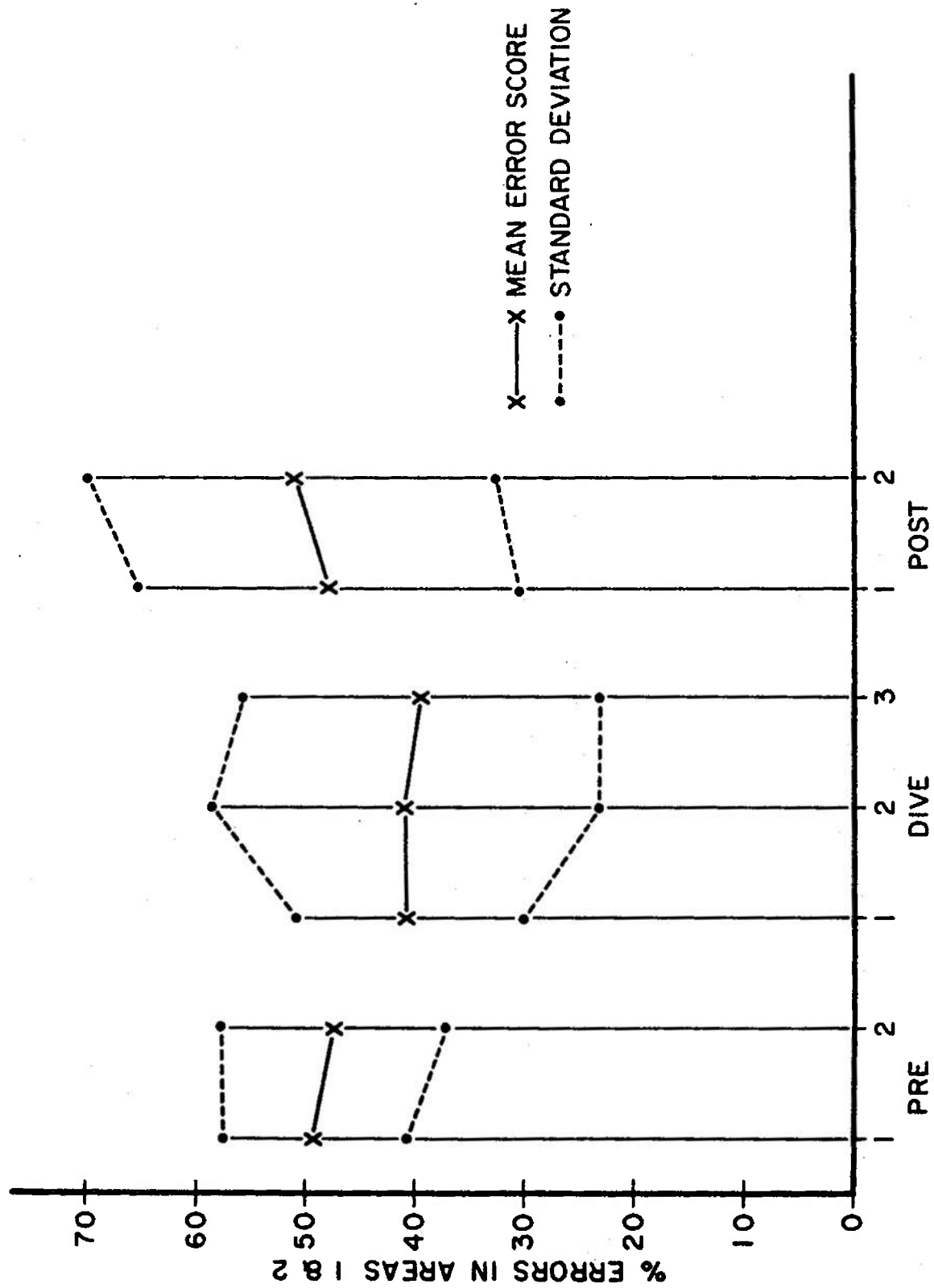


Fig. 3. Percentage of error scores in Tritan areas #1 and #2.

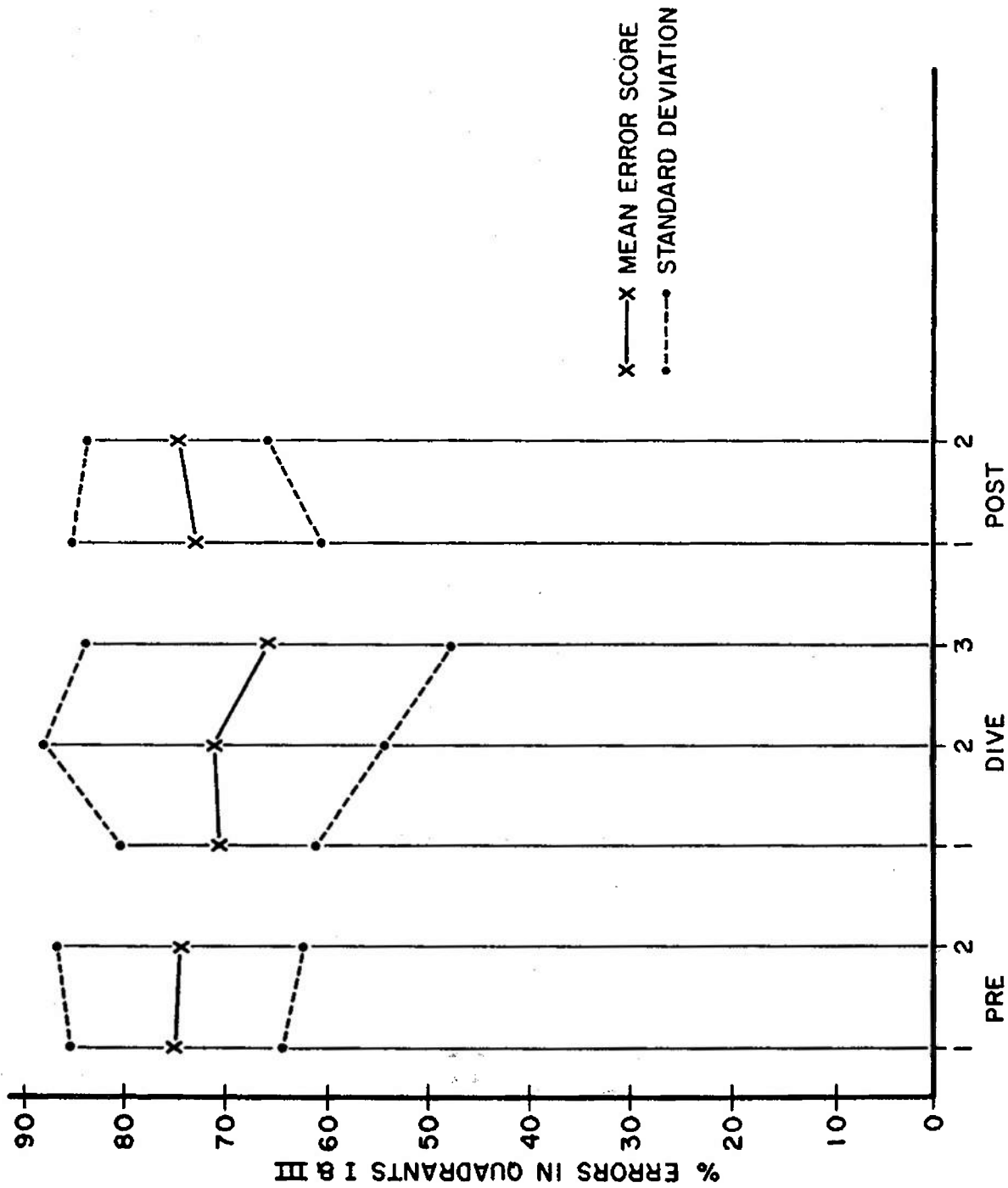


Fig. 4. Percentage of error scores in Tritan Quadrants I and III.

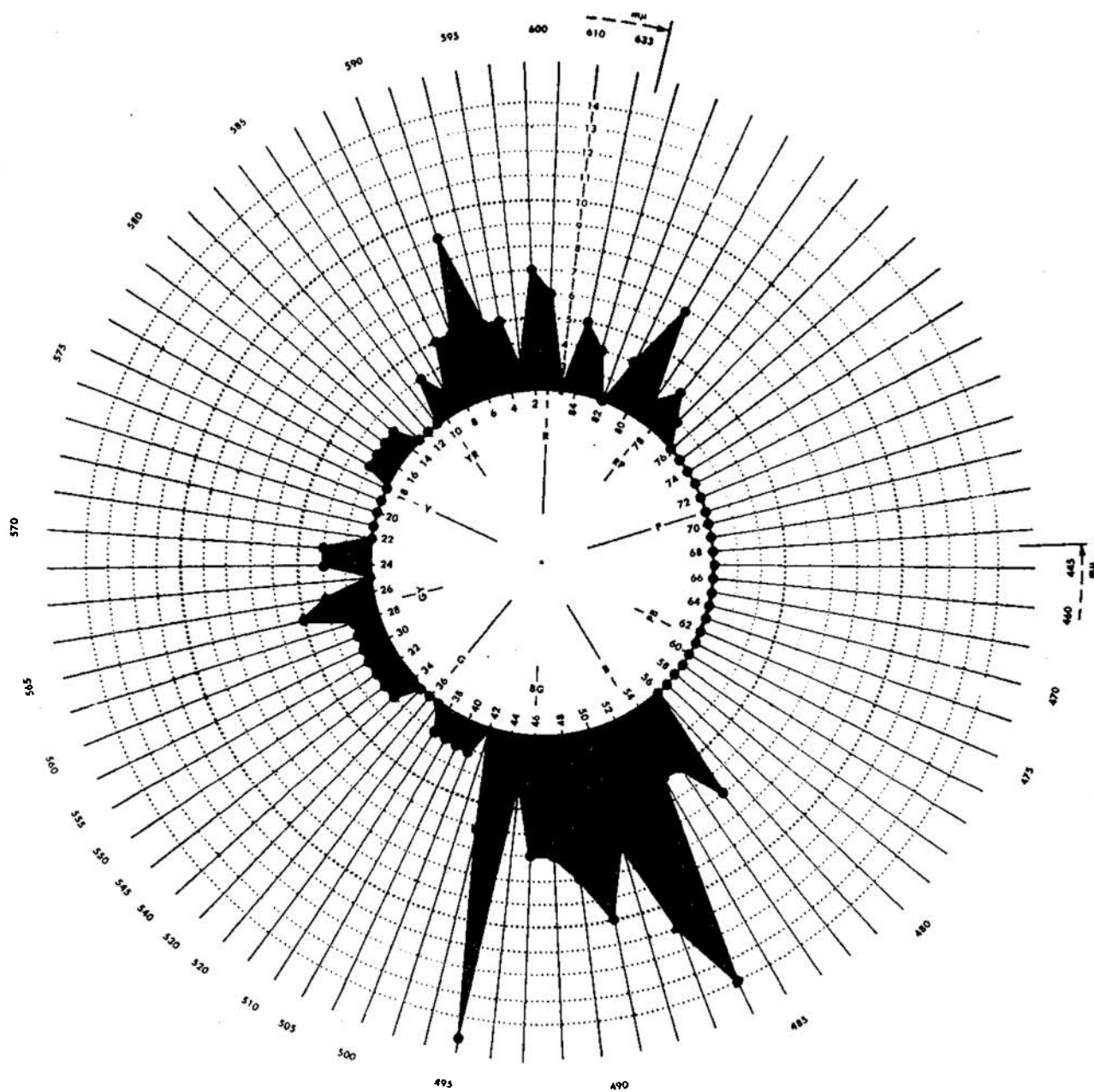


Fig. 5. F-M 100-Hue profile of Diver 3A/#3 postdive #1

Table II. Effect of Illumination on F-M 100-Hue Test Scores

Series/Ss	Color Vision Lab (25 fc, 6740K)			Chamber (4 fc, 2400K)					
	Total Error Score	Areas 1 & 2	Quadrants I & III	Total Error Score	Pre-Dive #1		Total Error Score	Pre-Dive #2	
					Areas 1 & 2	Quadrants I & III		Areas 1 & 2	Quadrants I & III
3A/Subj. #1	108	22	60	152	80	100	96	48	71
#2	44	16	28	52	25	36	92	49	65
#3	108	41	57	164	67	120	120	64	93
3B/Subj. #1	8	0	4	32	14	26	52	28	34
#2	36	8	20	36	24	28	56	28	51
#3	8	4	4	44	20	39	40	20	32

Note: Areas 1 & 2 represent 29.4% of total F-M 100-Hue Test area, whereas Quadrants I and III represent 50%.

confusion when merely breathing air, which were magnified when breathing 10% oxygen.

In a comparative study, six of our twelve divers were administered the F-M 100-Hue Test in our color vision laboratory under the specified illuminant prior to any testing in the chamber. Table II contains these results and the predictive results obtained in the chamber. This table shows that, as with the Smith, Ernest and Pokorny data, there is an increase in the error scores under the reduced illumination and this increase is due to the increase in the error score in the tritan areas of confusion.

Gallagher et al.⁷ investigated the effects of breathing 100% oxygen at sea level for 24 hours and found no significant changes in a wide variety of visual functions including acuity, stereopsis, perimetry, color vision, and dark adaptation. Their conditions are comparable to ours, of course, since air at 5 ATA yields approximately the same partial pressure of oxygen as 100% oxygen at sea level. Their particular test of color vision was admittedly a poor choice since the six photographic reproductions of the Ishihara plates were readily memorized. Nonetheless, we have substantiated their lack of evidence for an effect on color vision with a much more sensitive test.

Despite the fact that there are no changes in vision attributable to breathing 800 Torr of oxygen for 24 hours, it is predicted that significant deterioration will occur with higher pressures or longer exposures.

A number of investigations employing animals have documented visual changes with high partial pressures of oxygen.^{6,13} Also, Wolbarsht¹⁴ has evolved a theory explaining the loss of peripheral vision with hyperbaric oxygen; this theory predicts significant deterioration can occur at 5 ATA of air.

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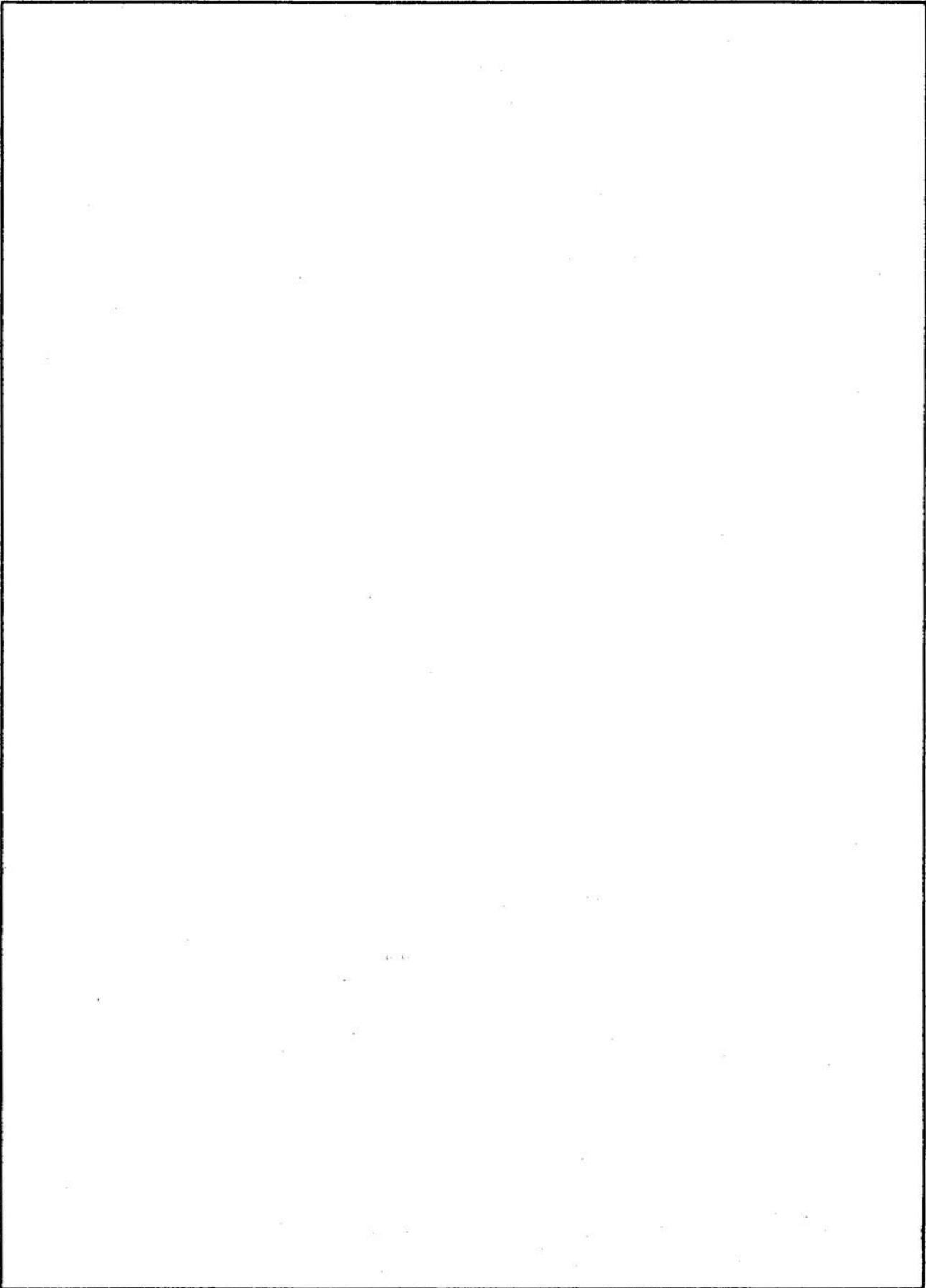
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