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

Contrast sensitivity thresholds were studied during gradual ascent over 40 days to a simulated altitude of 25,000 feet in a decompression chamber. Only ambient pressure, and thus inspired oxygen pressure was varied, thereby eliminating many of the confounding effects of cold, dehydration, malnutrition and exhaustion, inevitably encountered on very high mountains. Contrast sensitivity thresholds were measured by the Ginsburgh Vistech test, and showed no overall impairment as altitude increased, in contrast to findings of earlier vision studies which involved acute exposures and lower altitudes. The present results may be attributed

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20. ABSTRACT (Cont'd.)
to higher stimulus luminances being used in contrast sensitivity testing compared to lower luminance levels involved in previously reported research, and which thus could be less affected by hypoxia.

Title:
Operation Everest II: Lack of an Effect of Extreme Altitude on Visual Contrast Sensitivity

Authors:
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Running Head:
Contrast Sensitivity at Altitude

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Abstract

Contrast sensitivity thresholds were studied during gradual ascent over 40 days to a simulated altitude of 25,000 feet in a decompression chamber. Only ambient pressure, and thus inspired oxygen pressure was varied, thereby eliminating many of the confounding effects of cold, dehydration, malnutrition and exhaustion, inevitably encountered on very high mountains. Contrast sensitivity thresholds measured by the Ginsburgh Vistech test showed no overall impairment as altitude increased. These results are in contrast to findings of other previously reported vision studies involving shorter exposures and lower altitudes than those of the present study. However, our findings can be reconciled with previous contrary results on the basis of the higher stimulus luminances used in our contrast sensitivity testing. Compared to the luminance levels involved in previously reported night vision testing, our stronger stimuli would be less likely to be affected by hypoxia. Keywords:

Index Terms:

Acclimatization,
Contrast sensitivity
High altitude,
Mountaineering.
Hypoxia

One of the fundamental attributes of visual experience is the perception of differences in stimulus luminance. The ability to detect these differences is fundamental to all functional vision since, except for color differences, objects are visible only when different enough in brightness to contrast effectively with the background against which they are seen.

Visual acuity is universally regarded as the traditional threshold index of clear vision (2), and is based fundamentally on the detection of brightness contrast between figure and background. However, as conventionally measured, acuity involves only the response to black-white contrast at high levels of illumination. Consequently, the more sensitive detection of shades of gray is not measured by conventional visual acuity tests. Attempts to measure visual resolution along the whole stimulus brightness continuum have led to the development of contrast sensitivity tests (1,4,5,6). In these tests, the subject is required to detect fluctuations in brightness contrast at various spatial frequencies, stated in cycles per degree of visual angle subtended at the retina. Contrast is defined as $(L_{max} - L_{min})/(L_{max} + L_{min})$, in which L_{max} is the highest luminance and L_{min} is the lowest luminance (11). The reciprocal of this contrast value is typically plotted as contrast sensitivity (15).

Many earlier studies have shown that visual performance tasks which depend on detection of light intensity and on discrimination of differences in intensity are adversely affected by hypoxia (16). Specifically, dark adaptation is rapidly impaired above 10,000 feet (10,11,13). Other visual tasks which depend on brightness detection have also shown impairment under hypoxia (8,9,10). Since contrast sensitivity is fundamentally a response to brightness levels along the entire visible range of achromatic luminance, one might logically expect it to be especially affected by hypoxia.

A recent project titled "Operation Everest II" (OE II) provided an opportunity to study the effects of prolonged exposures to extreme altitudes in a hypobaric chamber on contrast sensitivity, as part of a larger study involving various other medical, physiological and psychological aspects of human performance. The purpose of this project was to examine many aspects of acclimatization to hypobaric hypoxia under controlled conditions. The rate of ascent and altitudes reached were patterned after those of major Himalayan expeditions to Mount Everest (17). However, aspects of cold, dehydration, malnutrition, and fatigue were notably absent, since the chamber was kept at comfortable conditions and the subjects were given ample food, fluids, rest, and the opportunity to exercise at will. The project, thus, was a study of the effects of "pure hypoxia", and was not a simulated mountain ascent. See Houston (7) for a detailed account of the OE II project.

This paper is concerned only with measurements of contrast sensitivity which were obtained periodically throughout the course of exposure; the results of other tests conducted during the study are reported elsewhere.

MATERIALS AND METHODS

Eight male subjects and one alternate were selected from a large pool of applicants on the basis of their ages (21-31 years), motivation, physical fitness and interest in human physiology. After intensive medical screening and a flight physical examination, they were given five days of training and baseline testing at sea level. They were then briefed about the details of the study and signed an informed consent agreement prior to participation. They were also instructed in emergency procedures within the chamber. The schedule of altitudes employed is listed in Table I, and is shown graphically in Figure 1.

Table I about here

Figure 1 about here

Two subjects were removed from the chamber at 18,000 and 25,000 feet respectively because of hypoxic episodes from which they recovered immediately. The remaining six subjects completed 40 days of ascent. Because of headache and insomnia above 20,000 feet, the simulated altitude was decreased by 1000 to 1500 feet at night, thus following the mountaineers' practice of "working high and sleeping low". On the 41st day of exposure, the chamber was rapidly returned to sea-level, and the six subjects who completed the entire study underwent follow-up testing and debriefing during the next two days.

The contrast sensitivity measures were obtained by use of the Vistech test (4), using the hand-held technique of administration. In this version of the test, the subject views a display containing five rows of circular test targets mounted on a 5-in. x 7-in. plastic card. This card is viewed in a plastic template held against the face, which positions the card in direct line of sight and at a fixed 15-in. viewing distance. The rows on the card (labeled A through E) represent five different spatial frequencies (1.5, 3, 6, 12 and 18 cycles per degree of visual angle subtended at the retina), and each row contains nine targets representing a threshold sequence of increasing contrast sensitivity for that spatial frequency. The array of contrast sensitivity levels versus spatial frequencies contained on the card is summarized in Table II.

Table II about here

The alternating contrasts contained in the targets give them a striped appearance, which in the design of the test are intentionally tilted to the right, tilted to the left, or oriented vertically. Each row on the card consists of a different randomised order of right-tilt, left-tilt and vertical targets. The ninth target of each row is homogeneous gray, and is intended to serve as a test of no-response. The subject's task is to indicate the apparent direction of tilt of each of the targets successively in sequence along each row. The highest numbered target in each row for which stripes are still visible is considered the limit threshold for that row.

Three equivalent forms of the test card were alternated daily in this study in randomized order to minimize possible learning effects. Because of restrictions due to operation of the chamber and the extreme altitudes involved, it was necessary for the subjects to self-administer the test, and to call out their answers ("right", "left", "straight", "blank") over the intercom to a technician outside the chamber who recorded the data. All subjects performed the test once daily between approximately 1500-1700 hours, on the days indicated by asterisks in Table I. The ambient illumination level within the chamber was virtually identical for all test sessions and was found to fall within the normal range recommended for correct administration of the Vistech test.

RESULTS

For scoring purposes, the records of all subjects for all test sessions were evaluated using a performance criterion of the highest-numbered contrast sensitivity target correctly identified at each spatial frequency. These scores were first converted to their equivalent contrast sensitivity values and then were collated for each subject in each test session. The resulting database was used for analysis of the results. In order to retain the maximum possible hypoxia data for analysis, the appropriate group mean values for the subjects were substituted for missing data caused by required removal of the two subjects from the chamber at 18,000 feet and 25,000 feet, respectively. Compared to the alternative of excluding these two subjects from the database entirely, this procedure allowed us to retain maximum data for all subjects under the exposure conditions which they completed. We considered this option to be a legitimate compromise which was based on the prevailing group mean values, and which arithmetically gave the same numerical group mean values as those for subjects who completed the exposure conditions. Without these substitutions, the computerised statistical programs used in the analyses could not have been conducted, since they require complete data blocks in order to run.

In order to identify and interpret the changes in contrast sensitivity which may have occurred during the course of exposure to the sequence of altitudes, an overall subjects x treatments analysis of variance for repeated measures was first performed based on the individual contrast sensitivity scores for each spatial frequency for each subject across the daily test sessions indicated by asterisks in Table I. This analysis was performed by means of Program 2V of the Biomedical Data Programs (BMDP) library (3), running on a VAX 11/750 computer. The results indicated a significant main effect attributable to the different spatial frequencies (F) involved in the test ($F=226.55; df=4,24; P<.0001$). None of the other main effects or associated first-order interactions approached significance. The daily group means of the contrast sensitivity scores are plotted in Figure 2 as separate curves for the respective spatial frequencies.

Figure 2 about here

It is clear that the highest contrast sensitivities were obtained for the mid-range spatial frequencies (3,6,12), while lesser values occurred for the low and high spatial frequencies (1.5 and 18). This differential effect has been reported in the literature as characteristic of response to spatial frequency in general, notably by Sekuler, et al (14), who have referred to this phenomenon as the "window of visibility".

From these results, it appears that the Vistech contrast sensitivity test was sufficiently sensitive to detect differential reactions of the subjects to separate spatial frequencies. However, the effects of increasing altitude exposure were apparently not strong enough to impair overall judgments of contrast sensitivity. These results are in contrast to other reports in the literature of impaired night vision and brightness discrimination during acute exposures to much lower altitudes.

In order to determine whether altitude exposure might have differentially influenced contrast sensitivity for certain but perhaps not all spatial frequencies, the same data were then divided into five sub-sets, each corresponding to one of the five spatial frequencies involved in the Vistech test (1.5, 3, 6, 12 and 18 cycles/degree). A separate BMDP2V analysis of variance was then conducted on each of these data sets. The only significant main effects obtained in any of the five analyses were those attributable to subjects ($P<.001$). These results indicated again that altitude exposure had neither an overall effect on contrast sensitivity, nor separate effects within the respective spatial frequency ranges.

Despite these findings, significant trends might still be present within the individual performances, which could have been masked by the pooling processes inherent in analysis of variance techniques. In order to investigate this possibility, the contrast sensitivity values for all subjects were tallied overall and then combined in two separate counts reflecting each of the two basic dimensions of the study design (altitude combined across all spatial frequencies, and spatial frequency combined across all altitudes). These frequency counts are summarized in Table III (altitude count) and Table IV (spatial frequency count).

Tables III and IV about here

Frequency histograms of the respective arrays were then plotted, and are displayed in Figure 3 for the spatial frequency counts, and in Figures 4a and 4b for the altitude counts.

Figures 3, 4a and 4b about here

An inspection of these histograms indicates a generally close correspondence among the distributions of scores for the various test targets, in that the majority of higher counts occurred for the normal- to high-normal range of contrast sensitivity values. This was true both for the overall range of altitude conditions (Figure 3), and over the range of spatial frequencies (Figures 4a and 4b). These results indicate clearly that the thresholds of resolution remained at typical to somewhat high levels of sensitivity over the course of the study, and resembled those obtained in baseline testing.

The lower overall totals in Figures 4a and 4b for altitudes from 18,000 to 25,000 feet are attributable to the removal of two subjects from the chamber at 18,000 feet for medical reasons. This reduced the number of responding subjects by one-third, and thus the target totals shown in the figures. The subsequent increase in targets at the final sea level testing appears to be due to a re-distribution of target choices primarily to the middle target.

As a final check on the individual distributions of threshold scores, the contrast sensitivity values for the various spatial frequencies were profiled separately for each daily session for each subject, using a standard form supplied with the Vistech test. A visual inspection of these profiles revealed a high consistency within the separate sets of curves for respective subjects, and indicated that they retained a remarkable continuity in their performances. Also, the performances of the individual subjects all were highly similar; in fact, the graphic profiles were scarcely discernible from each other. All of the individual profiles showed a clear overall trend of higher contrast sensitivity for the mid-spatial frequencies, and lower sensitivity for the low and high spatial frequencies, which mirrored the trends in the overall data evident in Figure 2.

DISCUSSION

The results indicate clearly and consistently that contrast sensitivity was affected only slightly, if at all, by the hypoxic conditions of this study. Our data do not agree with previous reports of impaired night vision at moderate altitude (8,9,10,12). One explanation may be that the subjects were acclimatized in this study, whereas the previous night vision studies were done on unacclimatized subjects acutely exposed to mild hypoxia. Another possibility is that night vision and contrast sensitivity are distinctly but subtly different, resulting in a segmented or differential hypoxia effect on the visual response to stimulus luminance. If this is true, then weak scotopic stimulus levels would logically be more affected by hypoxia than would stronger mesopic and photopic stimulus levels. The much lower stimulus energy of scotopic stimuli would fall below a minimum threshold of excitation for retinal photoreceptors due to the conditions of reduced oxygen and lowered atmospheric pressure. Mesopic and photopic stimulus levels, on the other hand, would be above this threshold, and therefore might not be affected. By this reasoning, the faint near-threshold stimuli involved in dark adaptation testing should be more vulnerable to hypoxia than should those at the much higher luminance levels employed in contrast sensitivity tests. This seems a reasonable argument, but one still must consider the severity of the extreme altitudes and extended exposure conditions involved in this study. The conditions used here have rarely been employed in other altitude research involving visual tasks.

It may also be possible that the particular manner in which this study was conducted affected the contrast sensitivity results obtained, or that the choice of subjects and/or the small number of subjects tested were insufficient to distinguish the effects of altitude. However, the high comparability of performance among the subjects would argue against this latter point.

It is unfortunate that practical limitations prevented obtaining both dark adaptation profiles and contrast sensitivity data on the subjects through the course of the study, and so a definitive test of the proposed explanation of the contradiction between our results and those of previous literature cannot be reached on the basis of the present data.

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Disclaimer Statement to Accompany Article

1. The views, opinions and/or findings contained in this report are those of the author(s), and should not to be construed as an official Department of the Army position, policy or decision, unless so designated by other official documentation.

2. Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.

TABLE I

DAILY SEQUENCE OF ALTITUDE CONDITIONS

TEST DAY	CONT. SENS. TESTS	DAYTIME ALTITUDE FEET	DAYTIME ALTITUDE METERS	BARO. PRESS. (TORR)	NIGHTTIME ALTITUDE FEET	NIGHTTIME ALTITUDE METERS	BARO. PRESS. (TORR)
1	****	4000	1219	656			
2		7500	2286	576			
3		10000	3048	523			
4	****	11000	3353	503			
5		12000	3658	483			
6		13000	3962	464			
7		14000	4267	447			
8	**	15000	4572	429			
9	**	15000	4572	429			
10		15000	4572	429			
11		15000	4572	429			
12		16000	4877	412			
13		17000	5182	396			
14		18000	5486	380			
15		18000	5486	380			
16	****	18000	5486	380			
17		19000	5791	364			
18		20000	6096	347			
19		20000	6096	347			
20		20000	6096	347	18000	5486	380
21		18000	5486	380	18000	5486	380
22		20000	6096	347	19000	5791	364
23	****	20000	6096	347	20000	6096	347
24		20000	6096	347	20000	6096	347
25	****	20500	6248	342	20500	6248	342
26		22000	6706	320	21500	6553	328
27		23000	7010	308	22000	6706	320
28	****	23000	7010	308	22500	6858	314
29		23500	7163	301	20000	6096	347
30		24000	7315	295	21000	6401	335
31		24500	7468	289	22500	6858	314
32	****	25000	7620	282	22500	6858	314
33		25000	7620	282	22500	6858	314
34		25000	7620	282	22500	6858	314
35		25000	7620	282	23500	7163	301
36		25000	7620	282	24000	7315	294
37		25000	7620	282	22500	6858	314
38		25000	7620	282	22500	6858	314
39	****	25000	7620	282	22500	6858	314
40		25000	7620	282	22500	6858	314

Note: Half of the subjects were tested on Days 8 and 9 each, due to administrative problems.

TABLE II

SPATIAL FREQUENCIES AND CONTRAST SENSITIVITIES

OF THE TEST STIMULUS TARGETS

TEST ROW	SPATIAL FREQUENCY	TEST TARGET NUMBER 1	2	3	4	5	6	7	8	9
A	1.5	11	22	30	40	53	71	95	126	BLANK
B	3	17	31	41	55	73	98	130	174	BLANK
C	6	20	41	54	72	96	128	171	230	BLANK
D	12	13	25	39	52	70	93	125	168	BLANK
E	18	8	12	16	22	30	40	53	71	BLANK

TABLE III

GROUP TOTALS OF TEST TARGETS RESOLVED FOR EACH SPATIAL FREQUENCY COMBINED ACROSS ALL ALTITUDES

TEST TARGET	SPATIAL FREQUENCY (CYCLES PER DEGREE) 1.5	3	6	12	18
1					1
2					
3					1
4	1	1	4		17
5	34	11	9	11	29
6	38	69	69	70	46
7	21	19	20	17	5
8	8	5	3	4	6

TABLE IV

GROUP TOTALS OF TEST TARGETS RESOLVED FOR EACH ALTITUDE COMBINED ACROSS ALL SPATIAL FREQUENCIES

TEST TARGET	ALTITUDE (FEET) 0000	4000	11000	15000	18000	20000
1			1			
2						
3						
4	3	7	1		1	3
5	15	9	7	7	9	12
6	40	25	31	38	20	25
7	20	4	5			5
8	12					

TEST TARGET	21000	23000	25000	25000	0000	SUM
1						1
2						
3	1					1
4	7		1			23
5	6	12	16	17	39	29
6	15	8	12	3	10	82
7	6	3	1		4	26
8						

Figure Captions

Figure 1. Profile of the daily sequence of altitude exposure conditions

Figure 2. Daily group means of contrast sensitivity for each spatial frequency

Figure 3. Frequency histograms of overall targets chosen for each spatial frequency combined across all altitude conditions

Figure 4a. Frequency histograms of overall targets chosen for each altitude condition combined across all spatial frequencies

Figure 4b. Frequency histograms of overall targets chosen for each altitude condition combined across all spatial frequencies (continued).

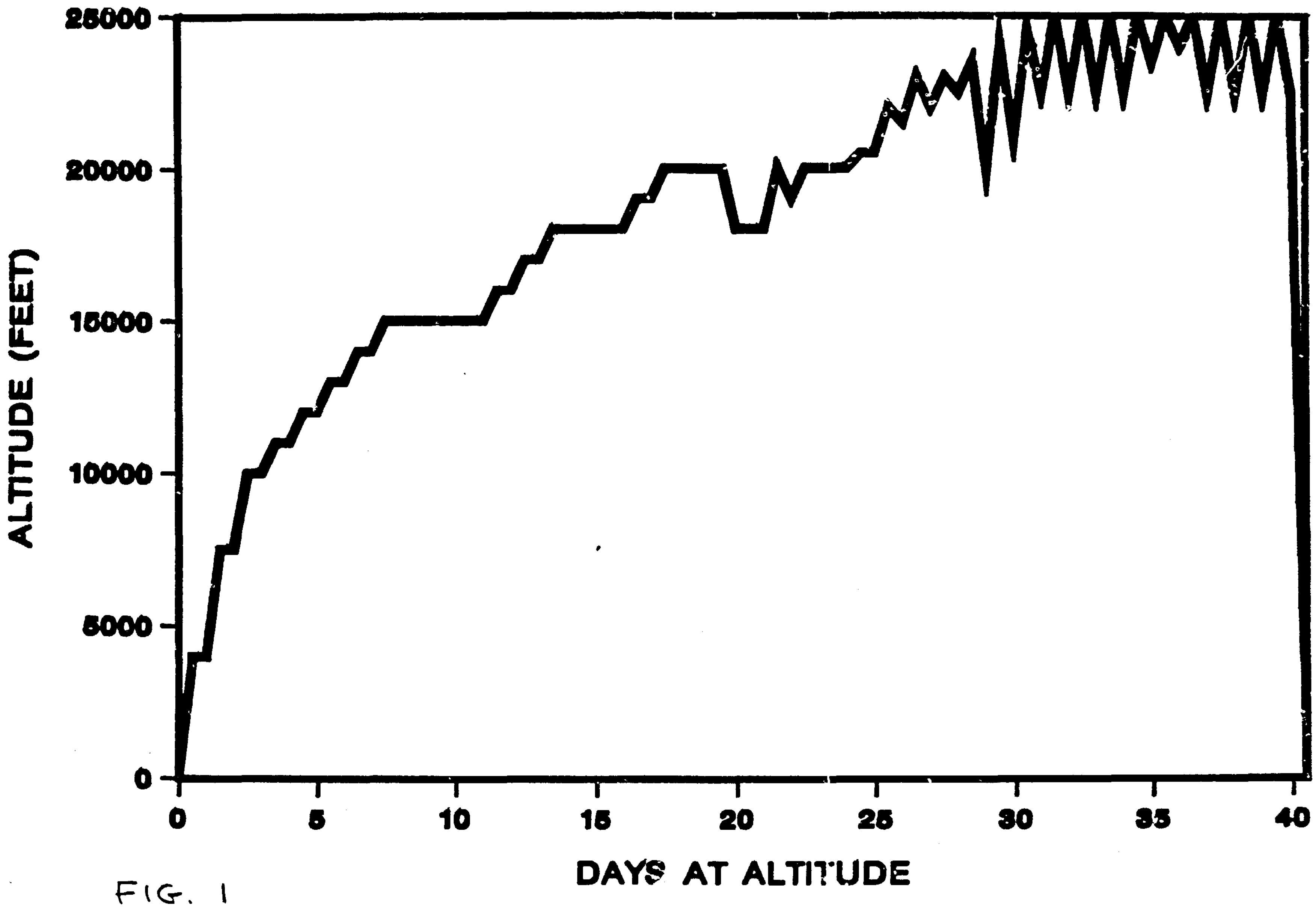
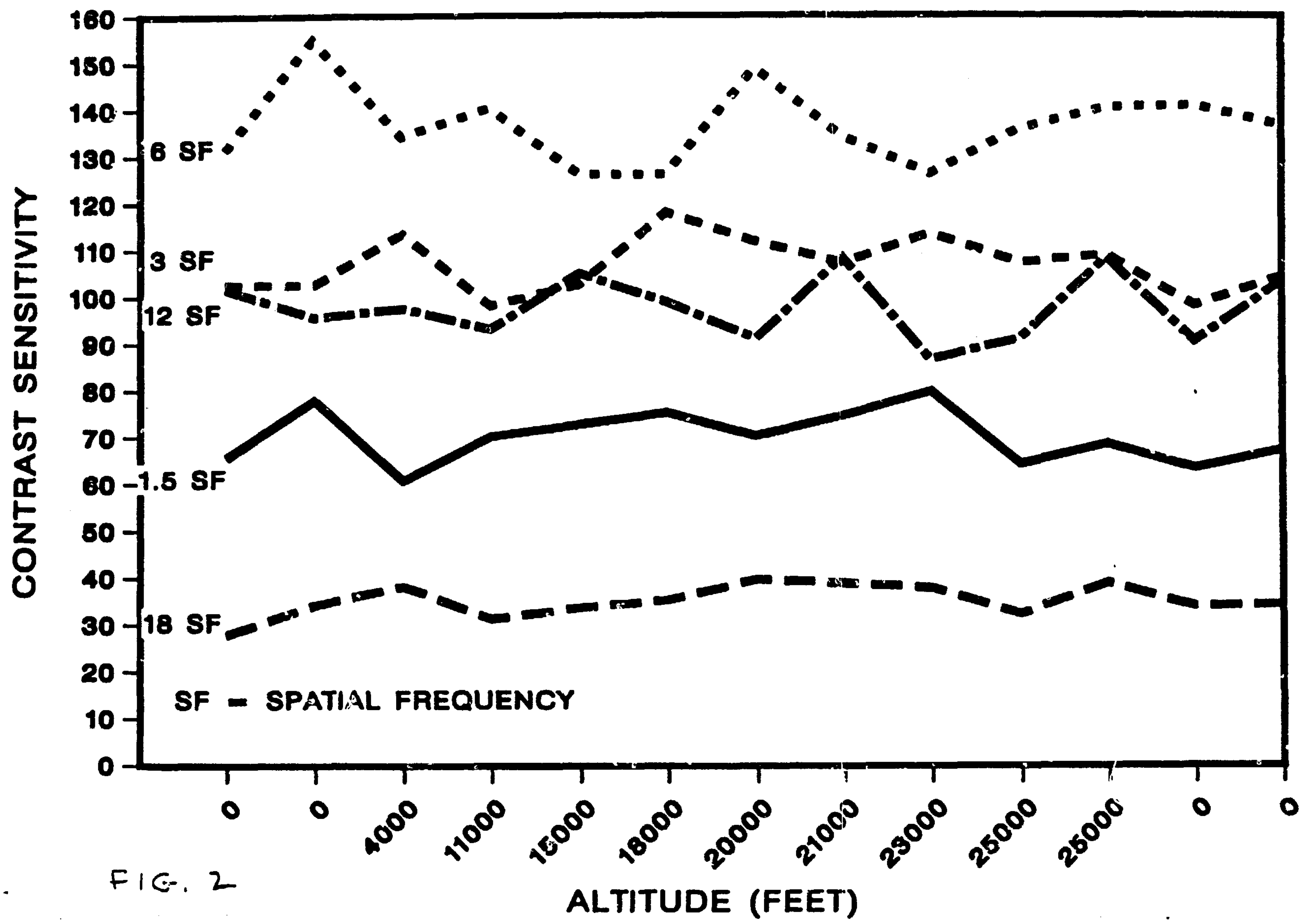
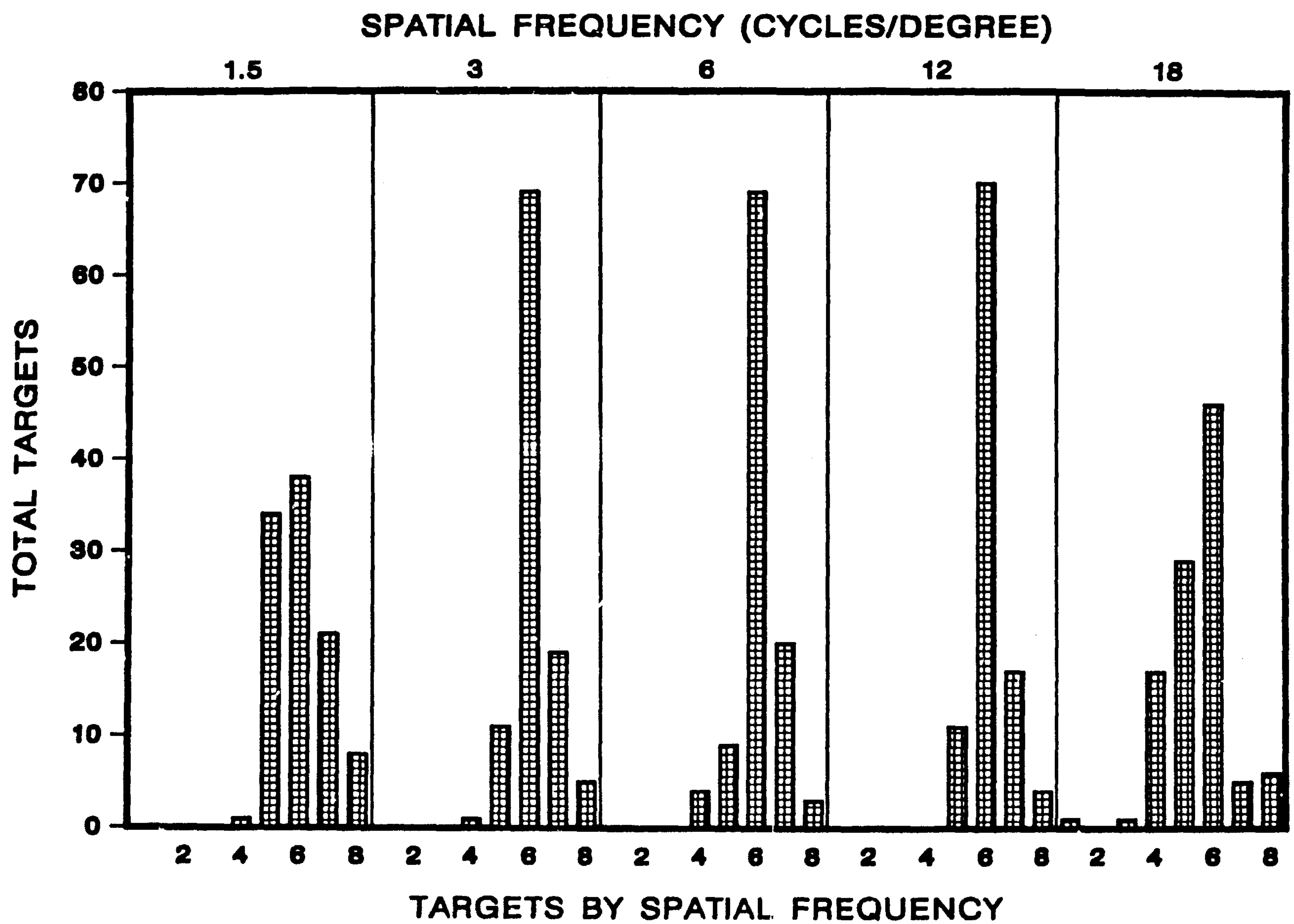

25000
20000
15000
10000
5000
0
ALTITUDE (FEET)
0
5
10
15
20
25
30
35
40
DAYS AT ALTITUDE

FIG. 1



CONTRAST SENSITIVITY
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
6 SF
3 SF
12 SF
1.5 SF
18 SF
SF = SPATIAL FREQUENCY
0
0
4000
11000
15000
18000
20000
21000
23000
25000
25000
0
0
ALTITUDE (FEET)

FIG. 2



SPATIAL FREQUENCY (CYCLES/DEGREE)
1.5
3
6
12
18
TOTAL TARGETS
80
70
60
50
40
30
20
10
0
2 4 6 8 2 4 6 8 2 4 6 8 2 4 6 8 2 4 6 8
TARGETS BY SPATIAL FREQUENCY

FIG. 3

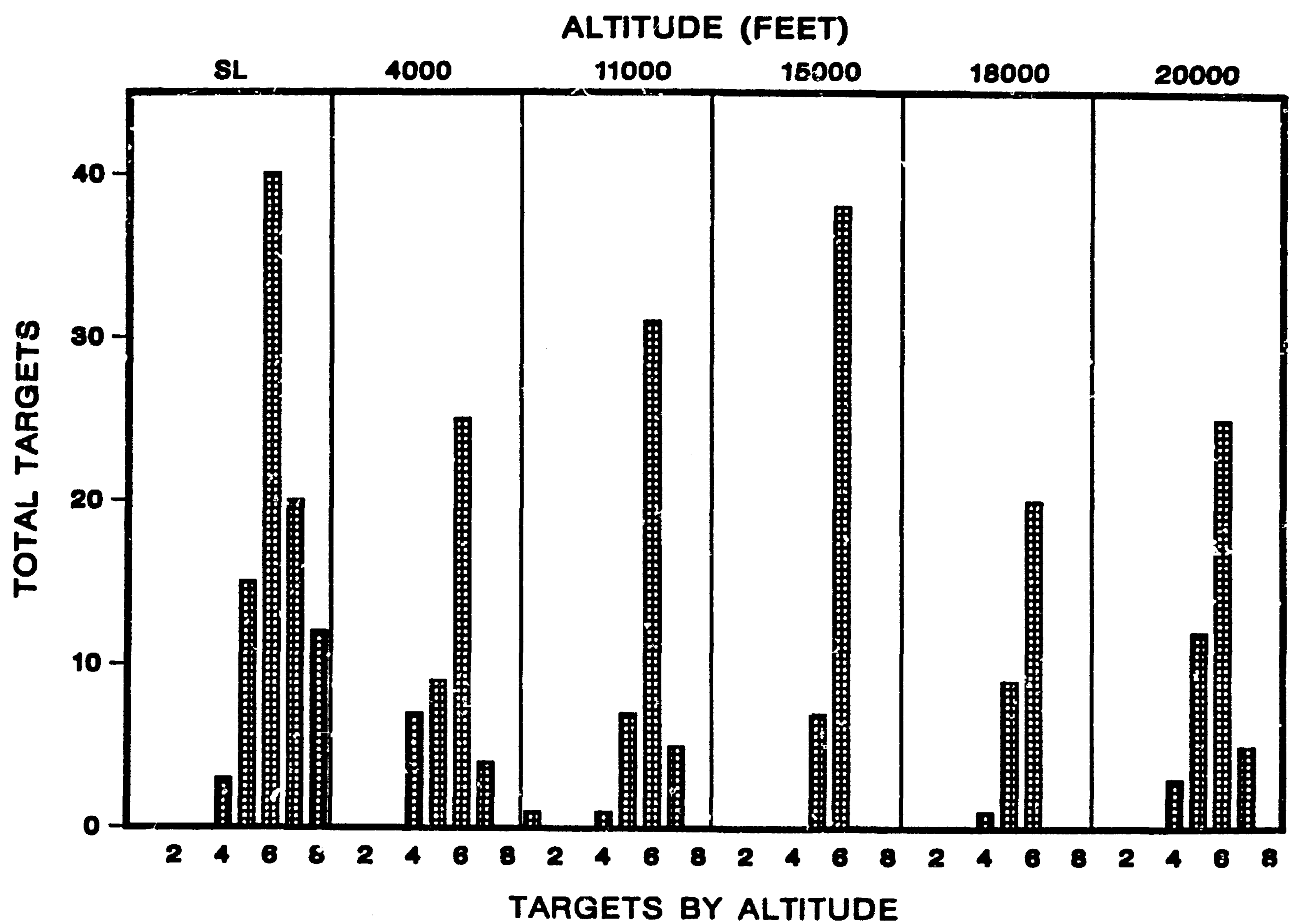

ALTITUDE (FEET)
SL
4000
11000
15000
18000
20000
TOTAL TARGETS
0
10
20
30
40
2 4 6 8 2 4 6 8 2 4 6 8 2 4 6 8 2 4 6 8 2 4 6 8
TARGETS BY ALTITUDE

FIG. 4A

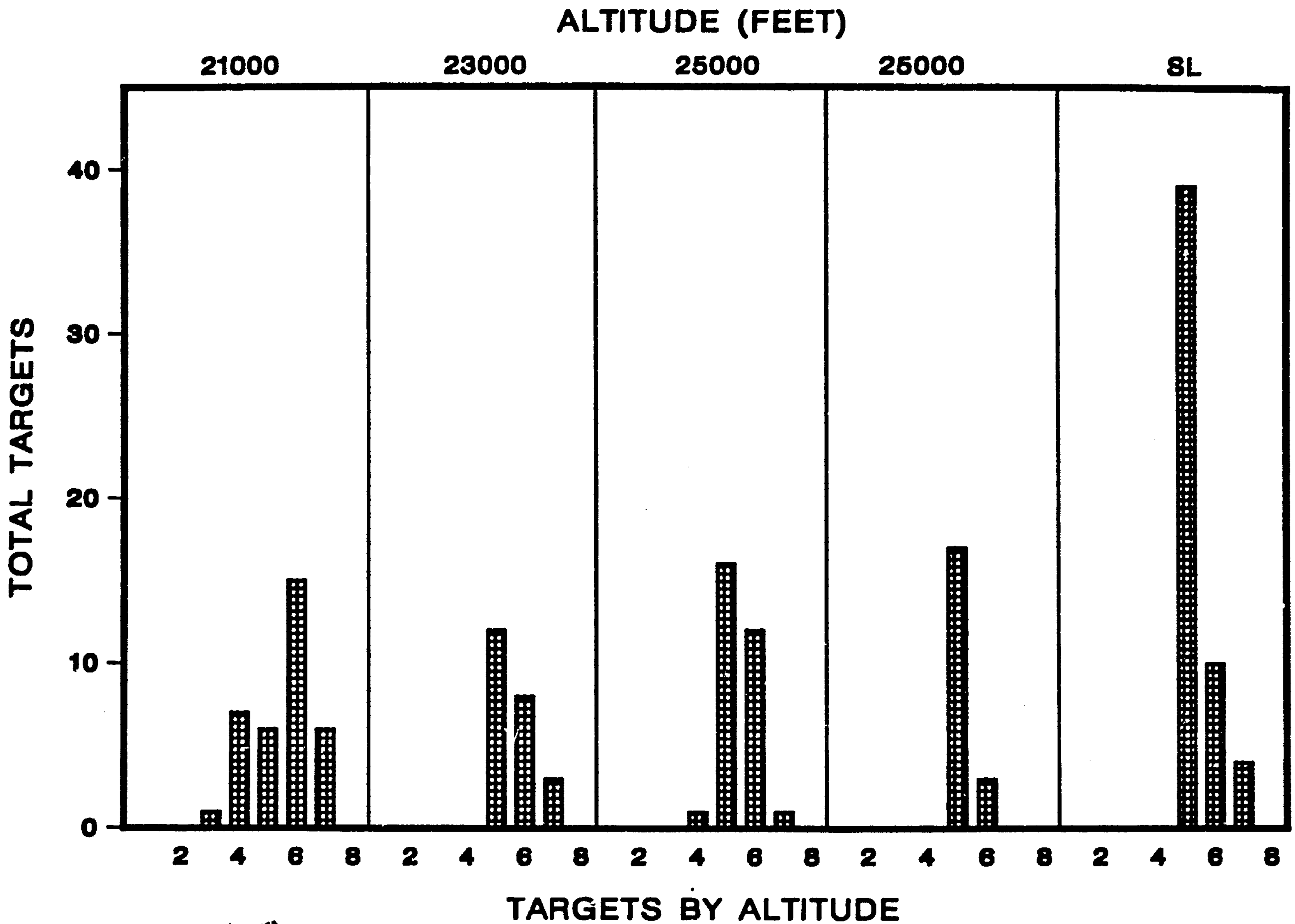

ALTITUDE (FEET)
21000
23000
25000
25000
SL
TOTAL TARGETS
0
10
20
30
40
2 4 6 8 2 4 6 8 2 4 6 8 2 4 6 8 2 4 6 8
TARGETS BY ALTITUDE

FIG. 4B