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FRACTIONATION OF DISTANCE IN SIMULATED SPACE

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SUMMARY

Sixteen Ss made halving and doubling judgments of the distance of an object over two ranges in a simulated outer space. The psychophysical functions obtained were consistent with previous findings. The effects of response procedure, relative effectiveness of distance cues, distance range differences, and S's accuracy in judgments were discussed.

INTRODUCTION

Among the perceptual tasks of man in space is that of visually judging the distance between another object and himself. Distance judgments pose a unique perceptual problem in that most of the ordinary distance cues utilized in a terrestrial setting are absent when man is in outer space. Retinal size and relative brightness are the principal long distance cues available to judge the distance of a single object. Distance cues provided by terrain, texture, and context are not present. Binocular disparity and accommodation are thought to be ineffective at the longer distance ranges encountered in space.

Previous studies have shown that Ss are relatively inept at verbally reporting the distance of a target under conditions simulating outer space (Arnoult, Brown, Vincent, and Tees, 1968). When Ss were given no information other than target size (30 ft. long x 13 ft. in diameter), verbal estimates of distance over the 200-5000 ft. range tended to have a median error of about 55% with errors on individual trials running as high as 1000%. Arnoult, Brown, Vincent, and Tees (1968) pointed out that verbal anchors (selected distances which were identified to S periodically during the experimental session) and sequential stimulus presentation combine to reduce the median error in judgment to about 15%.

Arnoult, Brown, Vincent, and Tees (1968) reported that errors in judgment may be due either to difficulties in distance naming (verbal use of numerals as responses) or to an actual perceptual distortion. Their data indicated the need for studying Ss' estimations of distance using non-verbal or relative response procedures. In such a study, error due to the Ss' inabilities to make absolute numerical judgments would be eliminated. A judgment relative to some standard is also probably more consistent with tasks faced by observers in the real world.

Psychophysics offers several techniques for assessing apparent magnitude using a relative response procedure. Ratio production (fractionation) is one of a class of so-called direct scaling procedures developed by psychophysicists (Stevens, 1957). The S is required to indicate or produce a stimulus that is in magnitude a specific fraction or multiple of a standard stimulus.

Although psychophysical scaling represents an active research area, there have been few attempts to provide a psychophysical function relating perceived and objective distance. Most studies have used relatively short distances (under 200 ft.) and direct ratio scaling procedures. Generally, perceived and physical distance were found to be related by a power function whose exponent varied with the range of the stimuluation (Kunnapas, 1960), the portion of the sensory continuum covered by the stimuli (Vincent, Brown, Markley, and Arnoult, 1968a), and, perhaps, the response procedure.

Kunnapas (1960) scaled distance over three objective ranges and found that as the stimulus range increased the exponent decreased in an orderly fashion. Pairs of 18 in. squares were presented to each _S_, who scaled distance by the method of ratio estimation. The ranges were: 3.3 ft. to 19.7 ft.; 6.6 ft. to 59.0 ft; and 6.6 ft. to 68.9 ft. The exponents were 1.47, 1.22, and 1.16 respectively.

Vincent, Brown, Markley, and Arnoult (1968a) reported magnitude estimation scales from three objective ranges using the NASA-TCU Space Vision Simulator. Comparison with summated JND scales derived from data of Vincent, Brown, Markley and Arnoult (1968b) indicated that the location of the range (_i.e._, the number of JNDs available within the specified range) was also an important determinant of the psychophysical function.

The magnitude estimation exponents reported by Vincent, _et. al._ (1968a) and exponents derived by those authors from bisection data of Gilinsky (1951) and Gruber (1954) were equal to or less than 1.0 (0.48 for Vincent, _et. al._'s full range group), whereas Kunnapas' (1960) three ratio estimation exponents were all greater than 1.0. This variation in exponents emphasizes the importance of response procedure. Apparently, when making magnitude estimation and fractionation judgments, _S_s progressively underestimate the distance of an object, whereas they tend to over-estimate distance when making ratio estimation judgments.

More recently Kunnapas (1968) varied the number of depth cues available in a task requiring magnitude estimation judgments of distances ranging from 25 to 395 cm. Power function exponents were found to increase from .82 to .97 with the addition of various depth cues. Retinal image size was one of the most influential cues, being nearly as effective alone (exponent = .90) as a full set of cues. Accuracy of judgment was also found to vary directly with the number of available cues.

The present study further investigated the ability of Ss to judge the distance of an object using only the visual cues available in space and a relative response procedure. The effect of the range location variable reported by Vincent, et. al. (1968a) was also examined. The fractionation method was chosen for this study because it is unique among direct scaling procedures in that data generated by this technique are amenable to analysis both for a psychophysical function and for measures of judgmental error.

METHOD

Observers--Ss were 16 undergraduate male students at T.C.U. who were paid to participate in the research. All had 20/20 vision (or better) as determined by an optometrist. Nine Ss had participated in previous studies (Arnoult, Brown, Vincent, and Tees, 1968) of perceived distance; seven Ss had no previous experience with the Simulator.

Apparatus--Distance judgments were made in the NASA-TCU Space Vision Simulator (Arnoult, Vincent, Brown, Markley, and Hensleigh, 1968). The opto-mechanical stimultor offers a high-fidelity, three-dimensional presentation of a space vehicle (Apollo Command and Service modules) in a star-free outer space environment. Appropriate retinal sizes, binocular cues and relative brightness changes over a simulated range from 150 ft. to 20,000 ft. are generated by the device.

Because of the considerable distance through which some of the Simulator's optical elements must move, it was necessary that the cams controlling the movement of the optical system be cut logarithmically so that they could be accommodated within the simulator tube. Consequently, at the time the present study was conducted, the apparent velocity of the moving target varied as the logarithm of the apparent distance.

Stimuli--Ten stimulus distances were selected at logarithmic intervals from each of two distance ranges: a near range (500 ft. to 5000 ft.) and a far range (5500 ft. to 10,000 ft.). The ranges were selected in order to allow adequate distance for the fractionation and multiplication process at the maximum and minimum distances presented. Four random orders were constructed for each set of ten stimuli, and these were joined into a single list of forty stimuli for each of the two distance ranges.

Orientation--To acquaint Ss with stimulus distances that would be used in this experiment forty additional stationary target positions were presented and S required to make verbal estimations of the distance of the target. The stimuli consisted of ten target distances taken in logarithmic increments from each of the two ranges. These were randomized and each stimulus was presented twice with no one stimulus appearing more than once in the same block of ten stimuli. All Ss were given the same list of forty stimuli.

Procedure--Ss were divided into four groups with "naive" and "sophisticated" Ss in each group. Each S was required to indicate his perception of target distance by stopping the moving Apollo target at a point that seemed to be either half the distance (fractionation) or twice the distance (multiplication) of its original position. All Ss made judgments of apparent distance in four experimental conditions. The order of conditions was different for each group of Ss. The design is summarized in Table 1.

Over the four sessions, the two stimulus ranges were presented in AABB (or BBAA) form, while the two instructional sets were presented in ABAB form. Each S took part in only one session per day, a session consisting of judgments of a set of forty stimuli.

TABLE 1

ORDER OF EXPERIMENTAL CONDITIONS FOR EACH SUBJECT GROUP

	Session (Day)			
Group	1	2	3	4
A	FH	FD	NH	ND
B	NH	ND	FH	FD
C	FD	FH	ND	NH
D	ND	NH	FD	FH

F = Far Range (5500-10,000 ft.) H = Fractionation (Halving distance)

N = Near Range (500-5000 ft.) D = Multiplication (Doubling distance)

Prior to a halving session Ss received these instructions: "You will first see the target in a stationary position. The target will then move toward you. Your task is to say "Stop" when the target has reached a point that seems to be half the distance of its original position." Instructions prior to a doubling session were essentially the same, differing only in that S was told that the target would move away from him and that he must stop the target at a point twice its original position. All Ss received the same list of stimuli in each of the range conditions.

RESULTS

Geometric means were used to summarize half-distance or twice-distance judgments to each stimulus. Table 2 contains geometric mean responses to each condition.

Psychophysical Analyses

Construction of a psychophysical function from fractionation data involved two operations: (a) obtaining a response function relating half and twice distance judgments to distance; and (b) constructing the psychophysical function by interpolating successive ratios along the response function (Torgerson, 1958).

Response functions--Figures 1 through 4 show the geometric means of Table 2 plotted with the distance stimulus values in logarithmic and linear coordinates. Figures 1 and 2 contain the near range conditions. Figures 3 and 4 show corresponding plots of the far range data. For the ND condition the stimulus distance is shown along the abscissa while the distance judged twice as far is on the ordinate. The halving data is shown with the stimulus values on the ordinate while the distance judged one half as far is on the abscissa. Halving and doubling functions for a stimulus range are shown on the same plot with axes reversed as a check on the internal validity of the scaling procedure (Torgerson, 1958). Both sets of judgments should lie on the same line. For the near range conditions the correspondence was good, especially on the log-log plot. The far range response functions were quite different.

The data were shown in both linear (Figures 1 and 3) and log-log (Figures 2 and 4) coordinates. With the exception of the FD results, both transformations provided an adequate linear representation of the data. Consequently the linear and power functions shown in Table 3 were fit (least squares criterion) to the data of Table 2 and used to obtain the psychophysical functions reported below. All fitted functions accounted for more than 95% of the variance of the dependent measure.

For these response functions, a power exponent close to 1.0 (in conjunction with a good linear fit with slope $\neq$ 1.0) is an indication that the error of judgment was proportionately constant across the stimulus range. Exponents below 1.0 suggest that percent error of underestimation increased across the stimulus range.

TABLE 2

DISTANCE STIMULI AND GEOMETRIC MEAN OF

64 RESPONSES FOR EACH FRACTIONATION CONDITION

FAR RANGE			NEAR RANGE		
Target Distance	Halving (FH)	Doubling (FD)	Target Distance	Halving (NH)	Doubling (ND)
5500	2242	10330	500	259	1214
5900	2470	10930	650	323	1605
6300	2672	11660	830	416	1864
6700	2680	12050	1100	541	2525
7200	2853	12860	1400	666	3186
7700	3175	13630	1800	805	3758
8200	3286	13370	2300	1105	4943
8800	3530	15660	3000	1419	6407
9400	3788	16170	3900	1765	8472
1000	3821	16230	5000	2158	11045

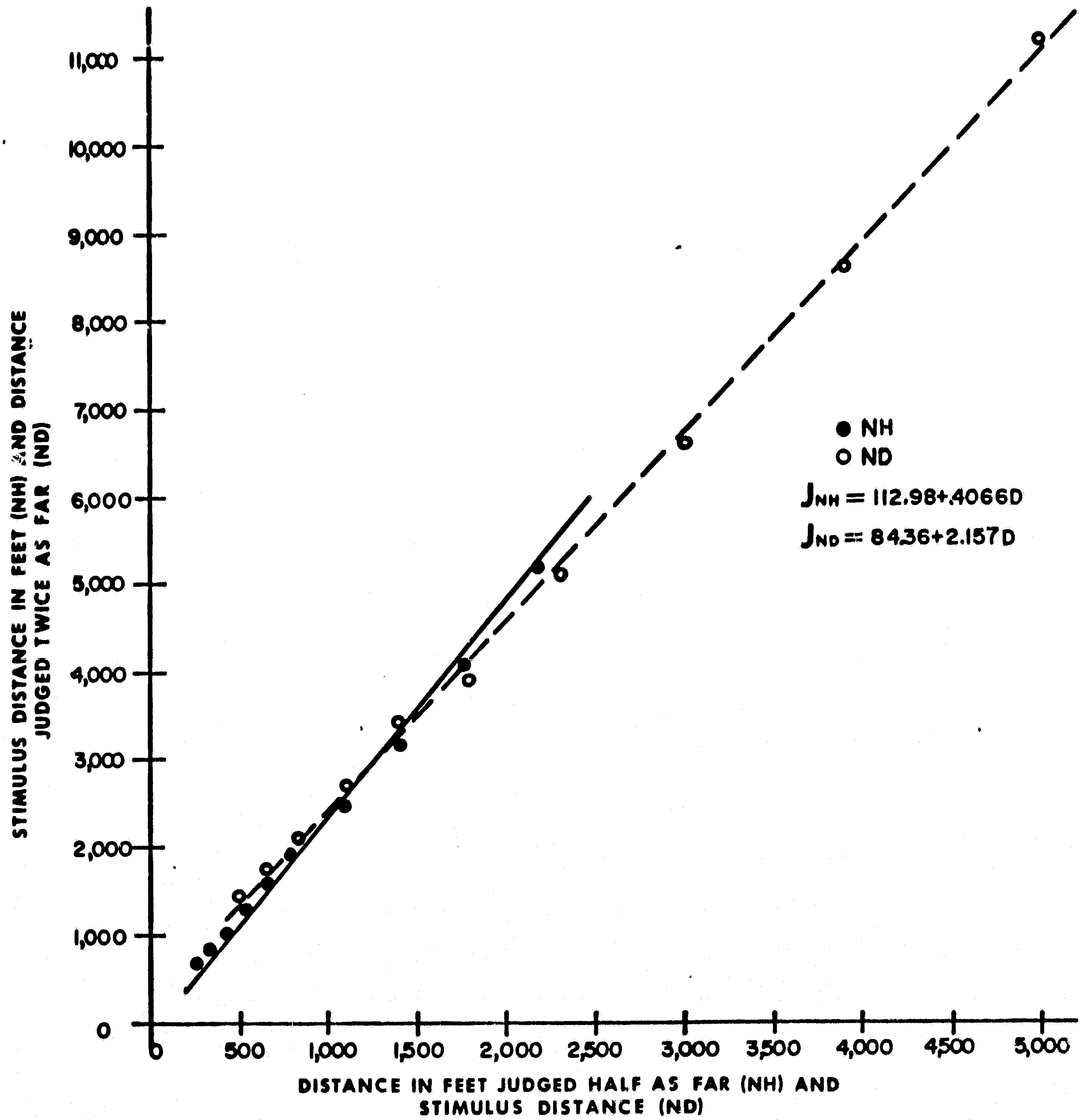

Figure 1. Near Range response functions. Linear co-ordinates. Each point is the geometric mean of 64 responses. Unfilled circles are doubling data. Filled circles are halving data. Axes are reversed for halving data.

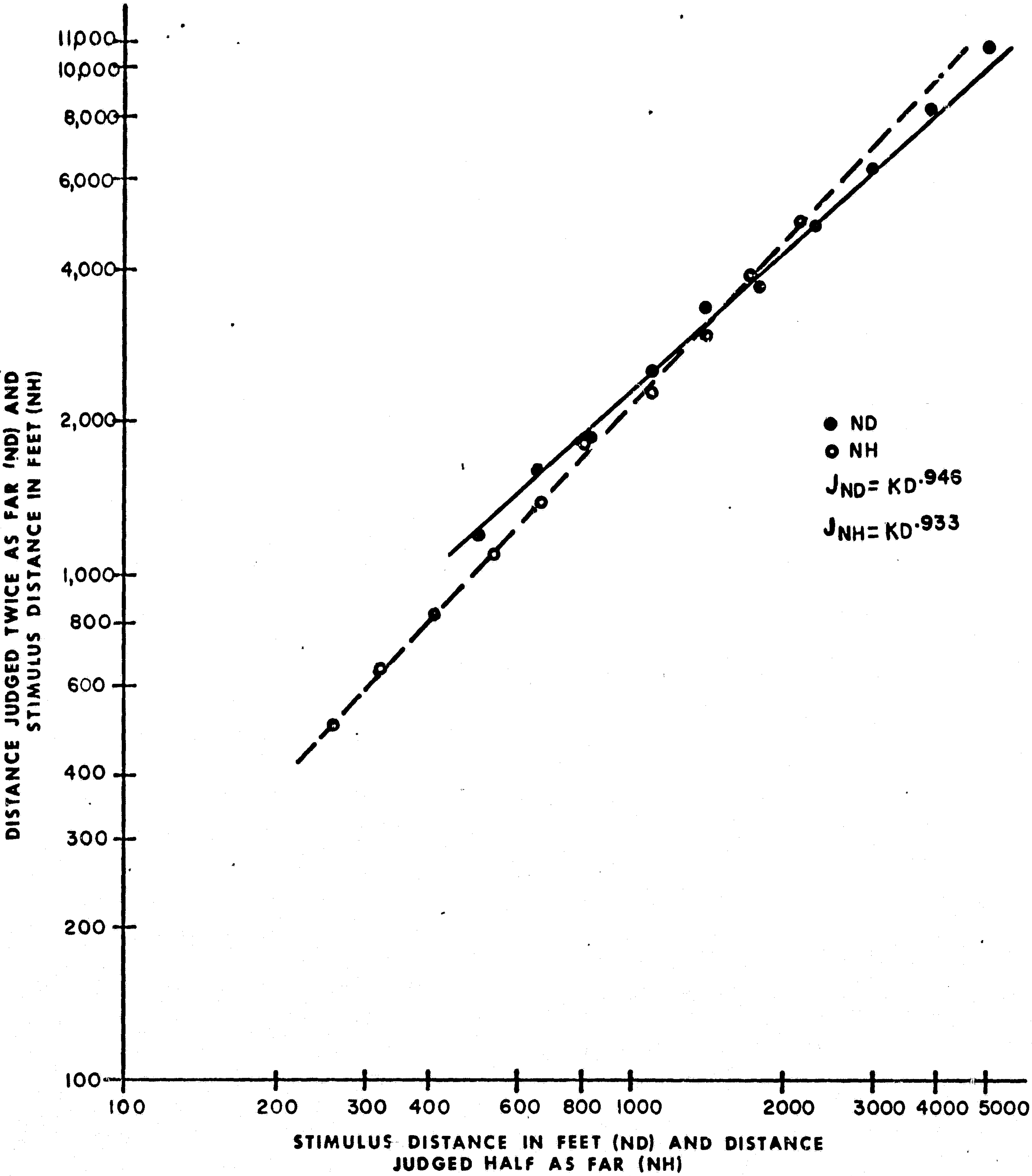

Figure 2. Response functions for Near Range. Log-log co-ordinates. Each point is the geometric mean of 64 responses. Axes are reversed for halving data.

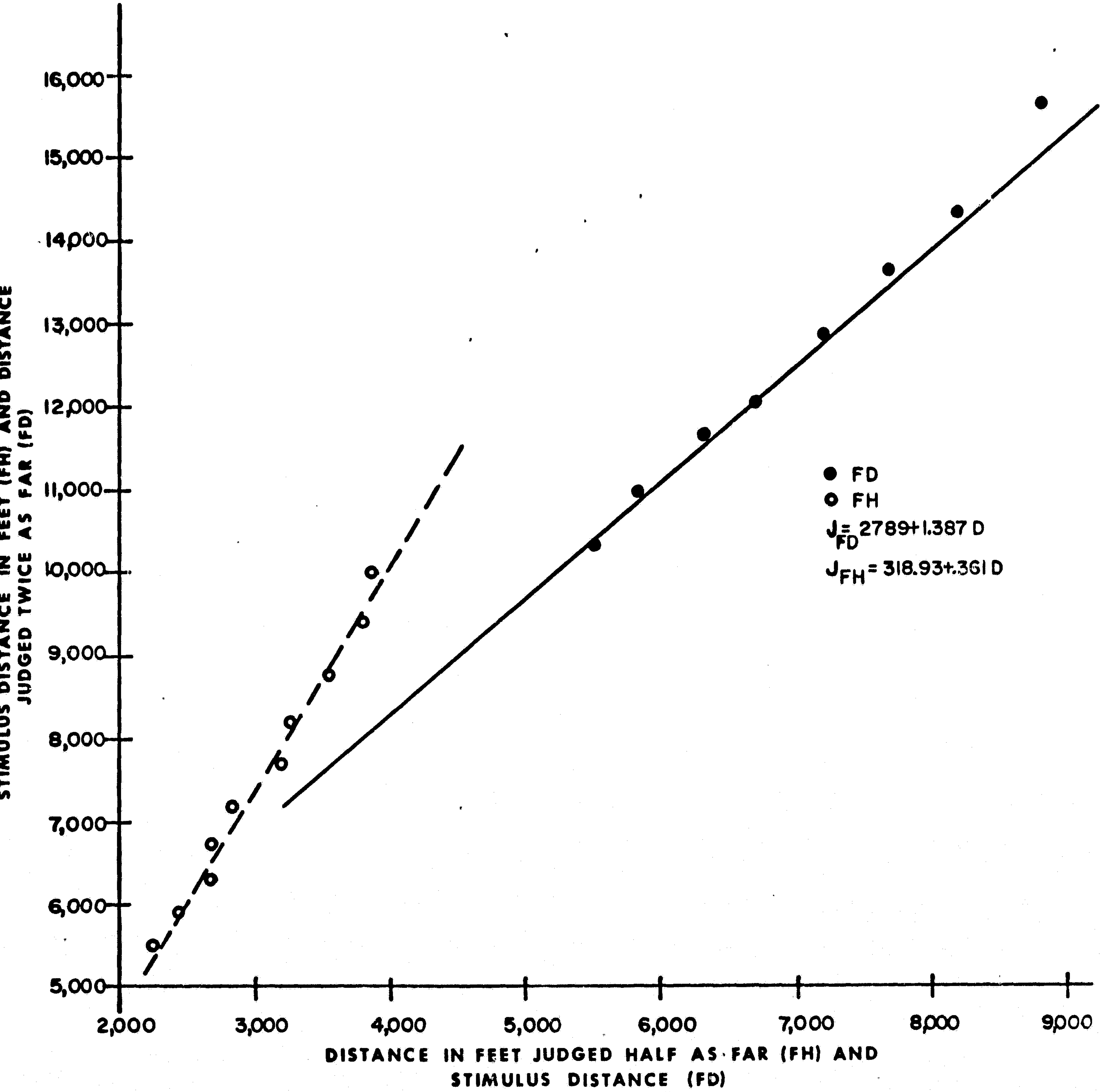

Figure 3. Response functions for Far Range. Linear co-ordinates Each point is the geometric mean of 64 responses. FD, distance judged twice as far, is on the ordinate. FH, distance judged half as far, is on the abscissa.

N

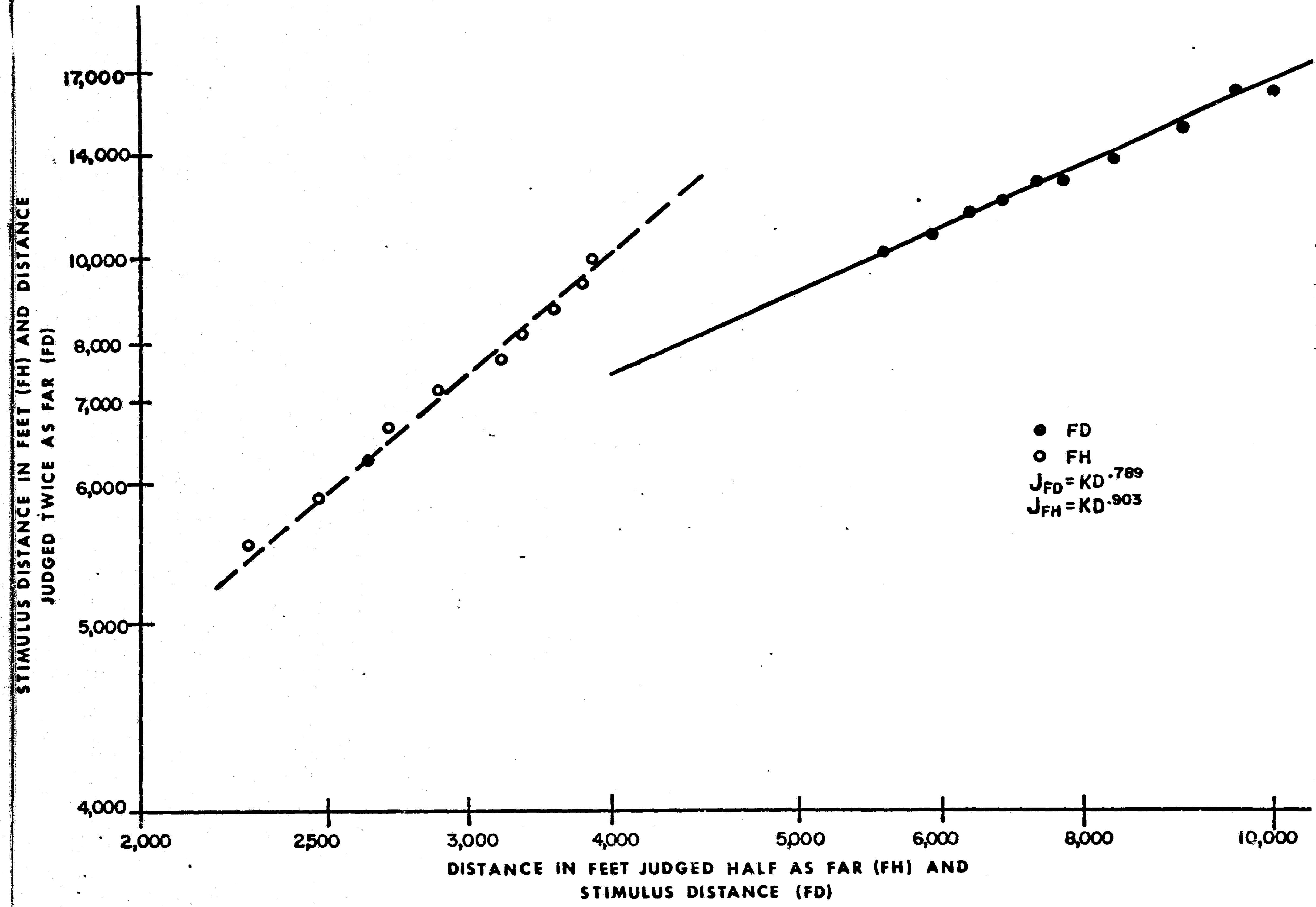

Figure 4. Response functions for Far Range judgments. Logarithmic co-ordinates. Each point is the geometric mean of 64 responses. FD, distance judged twice as far, is on the ordinate. FH, distance judged half as far, is on abscissa.

Differences in performance due to particular group or session are observed in Table 4. Power functions were obtained relating judged half or twice distance to stimulus distance for each session (day) of each condition. The exponents of these functions are shown in Table 4 classified by condition, session, and subject group. Inspection of the Table indicated that: (a) there was no consistent effect of sessions on either group or condition exponents even though the average exponent for session 1 was slightly less than the average for the other sessions; (b) exponents for the FD condition were less than those for the other conditions; and (c) group average exponents were nearly identical.

TABLE 3

RESPONSE FUNCTIONS RELATING JUDGED HALF AND TWICE DISTANCE TO STIMULUS DISTANCE

Condition	Function
NH	J = 112.98 + .4066(D)
ND	J = 84.36 + 2.157(D)
FH	J = 318.93 + .3610(D)
FD	J = 2789 + 1.387(D)
NH	log J = -.1089 + .933(log D)
ND	log J = +.5238 + .946(log D)
FH	log J = -.0177 + .903(log D)
FD	log J = +1.0640 + .789(log D)

J is the predicted judgment
D is the stimulus distance

TABLE 4

POWER EXPONENTS FOR RESPONSE FUNCTIONS

FOR EACH SESSION, GROUP, AND CONDITION.

Functions fit to Geometric Mean of 16 or 64 Responses

Condition	Session 1	2	3	4	All Sessions
FD	.720	.840	.760	.82	.789
FH	.860	.859	.795	1.090	.903
NH	.920	.906	.952	.932	.933
ND	.860	1.002	1.064	.850	.946
Overall Mean					.887
Group					**Group Means**
A	.860	.840	.952	.850	.876
B	.920	1.002	.785	.820	.884
C	.720	.859	1.064	.932	.894
D	.860	.906	.760	1.090	.904
Session Means	.840	.902	.893	.924	
Overall Mean					.890

Psychophysical Functions--A psychophysical function relates a subjective magnitude to a physical magnitude. The functions so far reported have related two sets of physical magnitudes and we have referred to them as response functions. Torgerson (1958) has described the procedure for obtaining psychophysical functions from response functions. Psychophysical power functions were constructed for each of the eight response functions of Table 3. Their exponents are shown in Table 5.

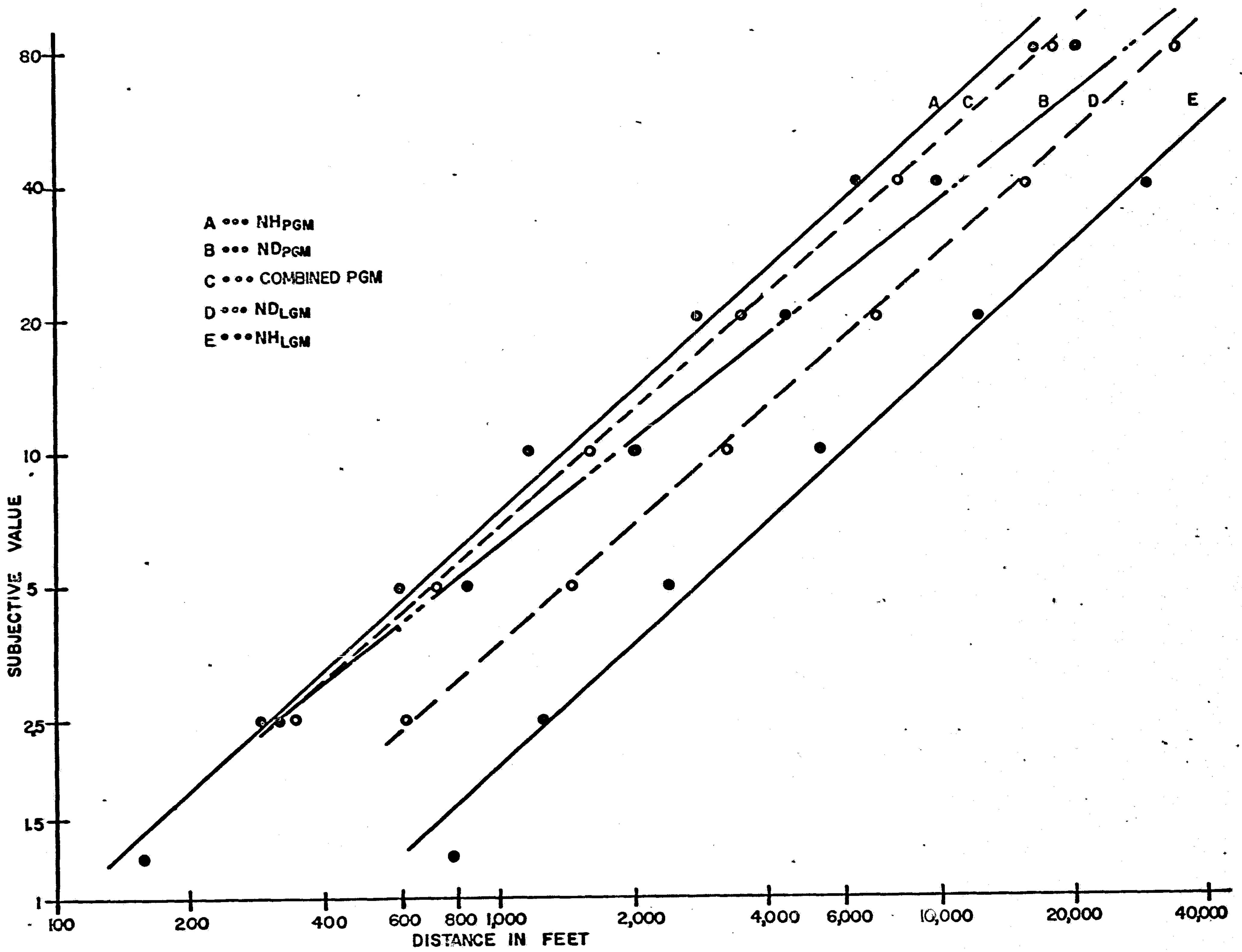

Figure 5. Psychophysical functions for Near Range. For clarity, curves are arbitrarily spaced along the abscissa. NH and ND refer to halving and doubling conditions respectively. The subscripts refer to the response function used to derive the psychophysical function. PGM indicates that the response function was a Power function fit to the Geometric Mean of responses. L indicates a linear fit.

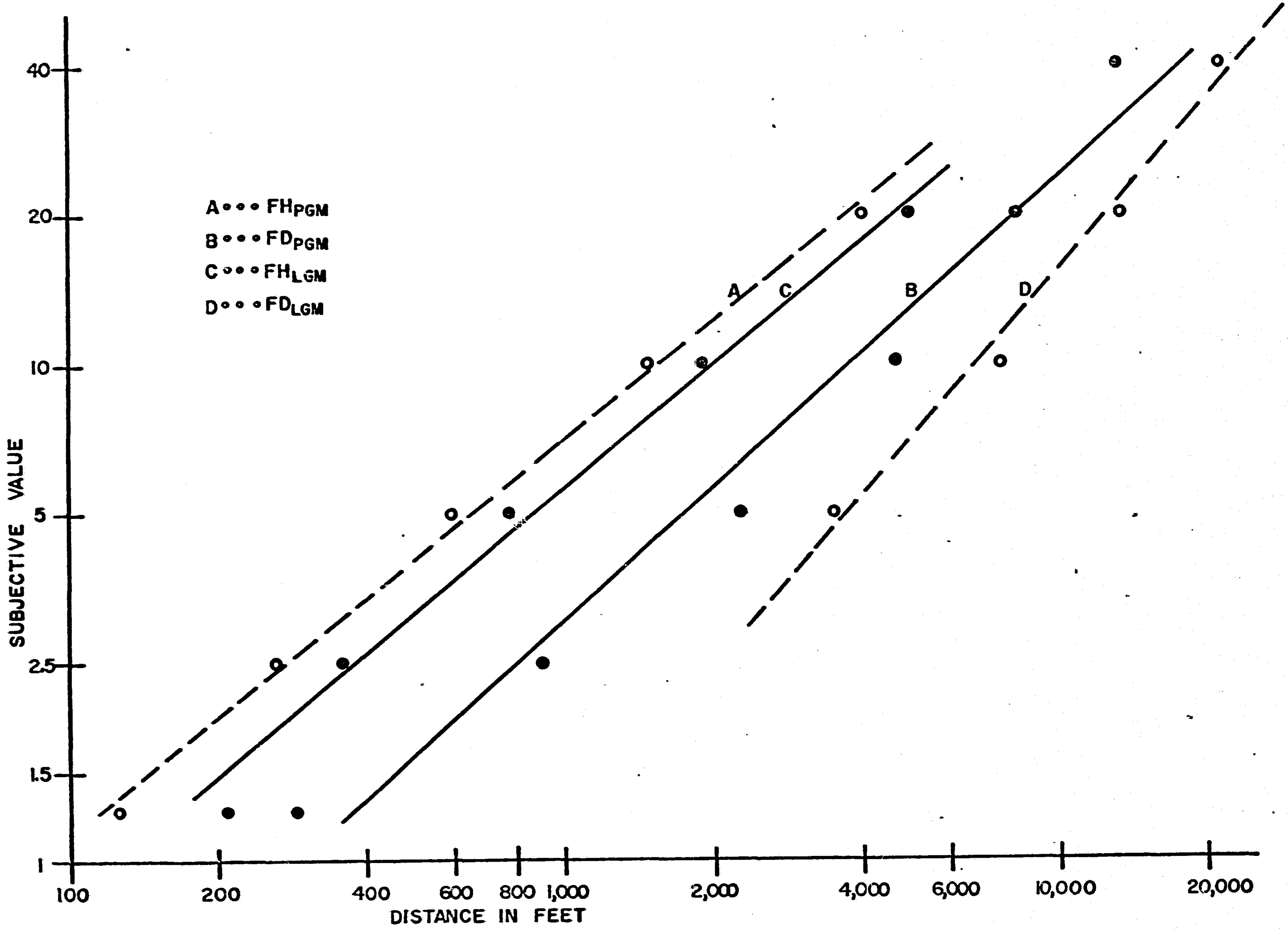

Figure 6. Psychophysical functions for the Far Range conditions. For clarity, curves have been arbitrarily spaced along the abscissa. FH and FD refer to halving and doubling conditions respectively. The subscripts refer to the response function used to derive the curves shown here. PGM indicates a Power function fit to the Geometric Mean of the responses. L indicates a linear fit.

TABLE 5

PSYCHOPHYSICAL POWER FUNCTION EXPONENTS FOR DISTANCE

DERIVED FROM THE RESPONSE FUNCTIONS OF TABLE 3

Condition	Linear Response Function	Power Response Function
FD	1.136	.897
FH	.852	.798
ND	.866	.854
NH	.901	.894

The psychophysical functions are shown in Figures 5 (NR) and 6 (FR). (The plots were spread along the abscissa for clarity.) Only points lying within the distance range of the simulator were included.

The acceptability of Stevens' Power Law in psychophysical theory has rested primarily on the consistent empirical finding that plots of scale values (subjective magnitudes) vs. physical mangitudes tend to fall on a straight line in log-log oc-ordinates when appropriate ratio scaling procedures are used. The trends of the data points in Figures 5 and 6 are clearly curved although the power functions do not do too much violence to the data for most of the conditions. Especially in Figure 5. Note that all halving functions were concave to the abscissa while the doubling functions were convex.

Error Analyses

Median per cent error was computed in the manner described by Arnoult, Brown, Vincent, and Tees (1968) for each condition and stimulus. Figures 7, 8, 9, and 10 contain these results. The results from the nine Ss with previous experience were shown separately and marked

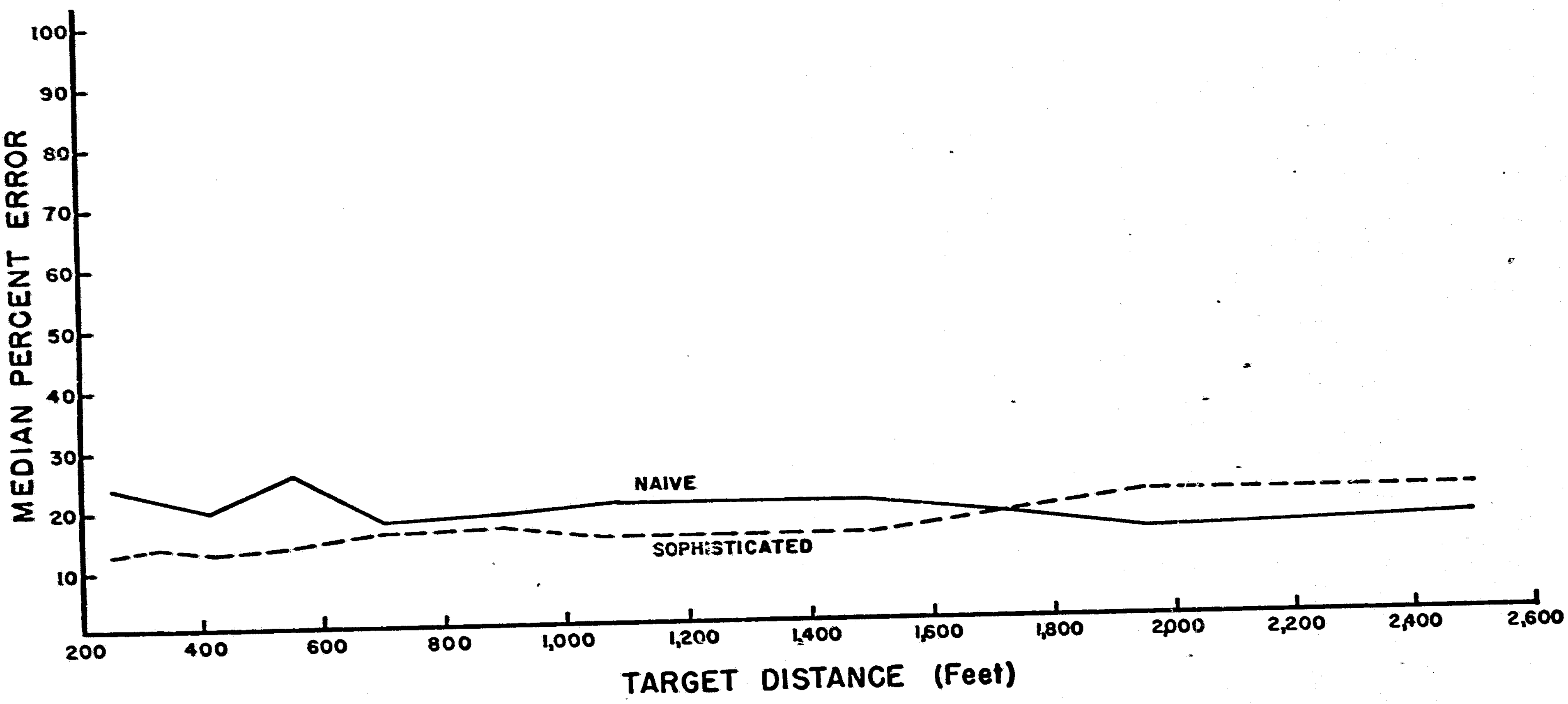

Figure 7. Median per cent error in halving of distance over the Near Range.

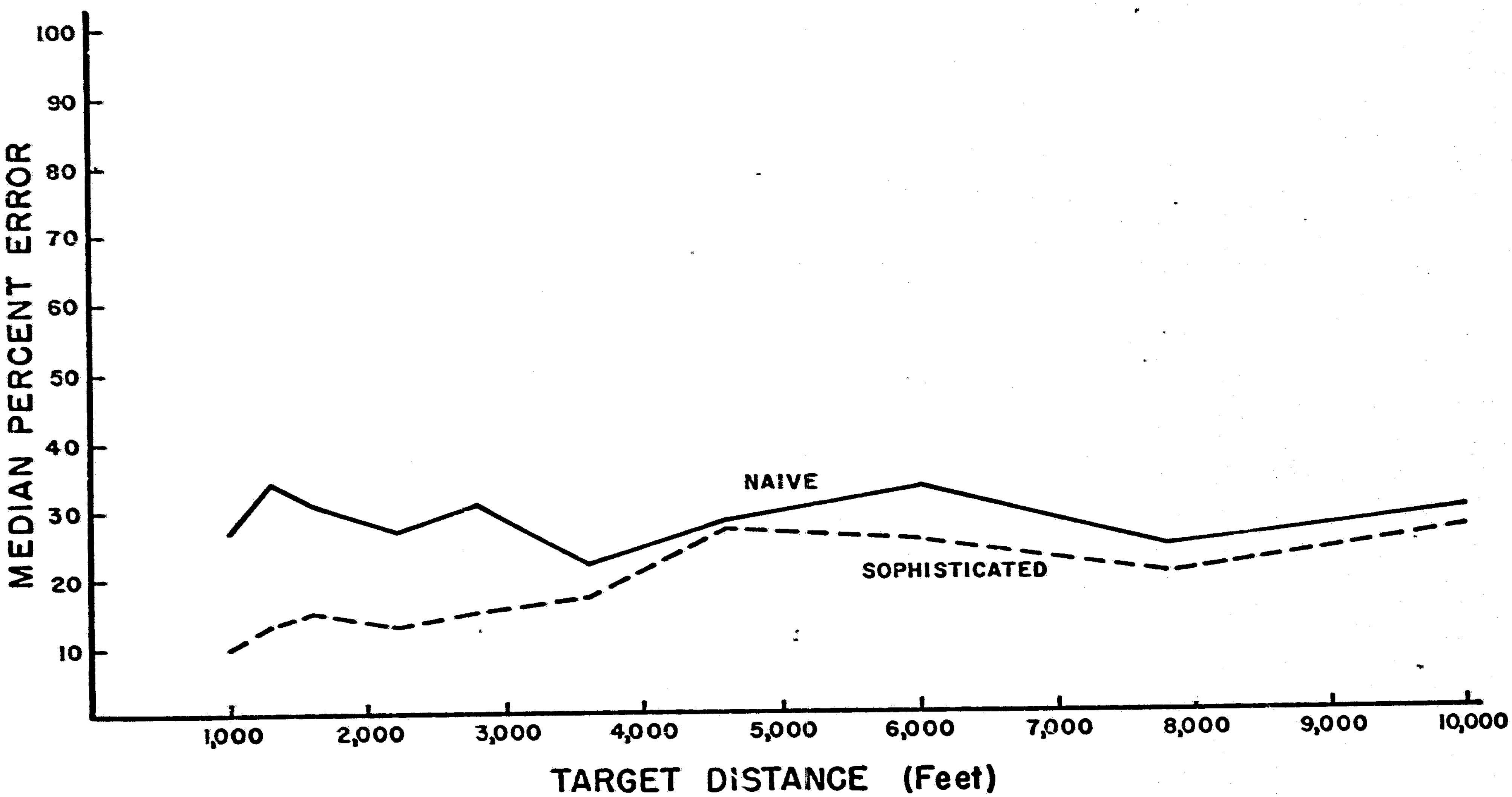

Figure 8. Median per cent error in doubling of distance over the Near Range.

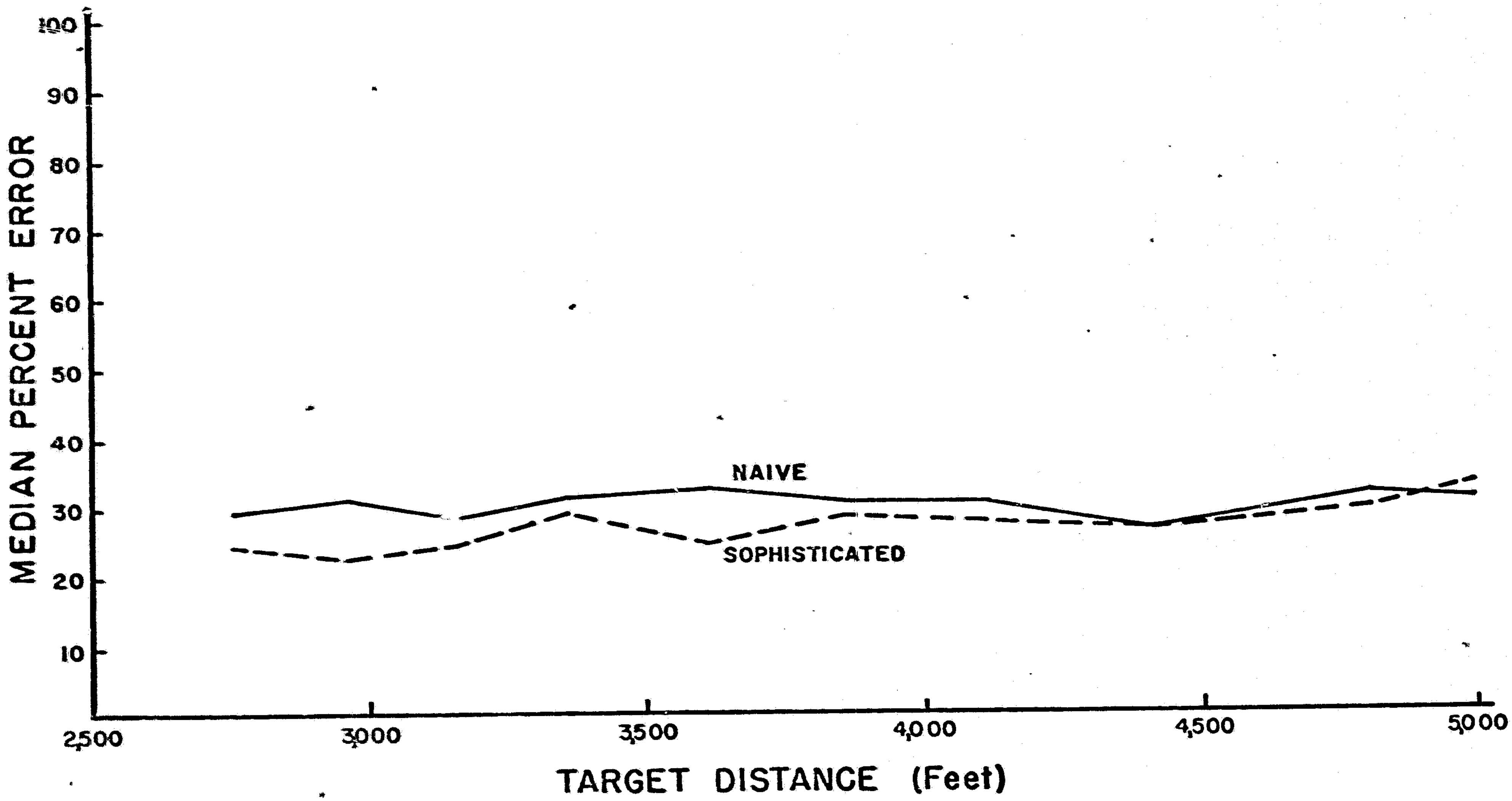

Figure 9. Median per cent error in halving of distance over the Far Range.

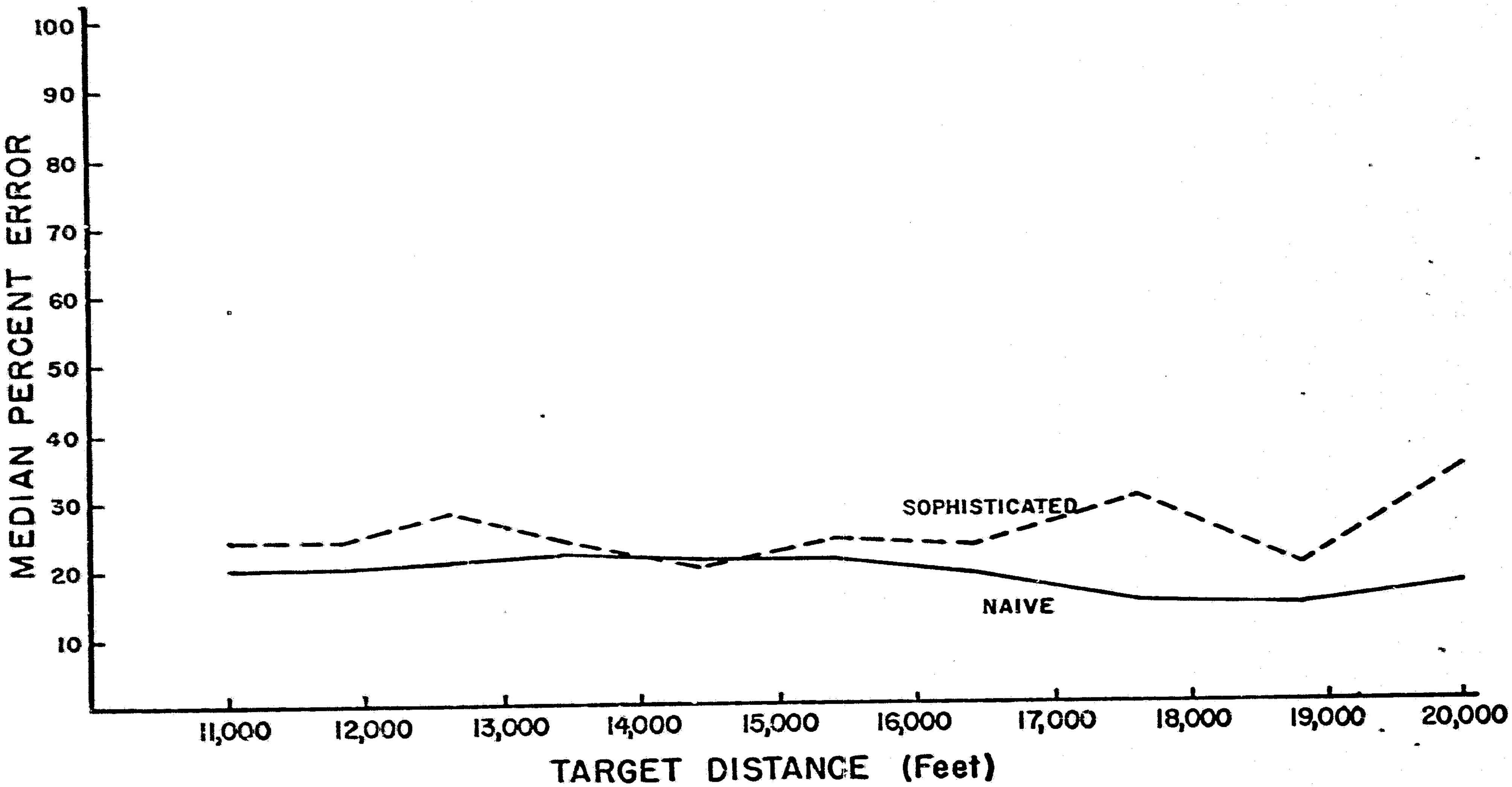

Figure 10. Median per cent error in doubling of distance over the Far Range.

'sophisticated' while the seven new Ss were labelled 'naive.' The target distance for each figure was either one-half or twice the stimulus distance. Figures 7 - 10 depict three findings: (a) There was no real change in median per cent error as a function of target distance within a range and condition; (b) There were no consistent differences between naive and sophisticated Ss; and (c) Median per cent error varied between 10% and 40%. The median value for all Ss, for all distances, and all conditions was 22%.

Median per cent error as used in the above analyses was an absolute measure that ignored the direction of error. A frequency count of the number of over- and under-estimations was made for each target distance in each condition. Correlations were computed between the frequency of over- and under-estimation and target distance and are presented in Table 6.

TABLE 6

RANK ORDER CORRELATION COEFFICIENTS BETWEEN TARGET DISTANCE AND FREQUENCY OF OVER- AND UNDER-ESTIMATION OF THE TARGET DISTANCE

Condition	Under-estimations	Over-estimations
FD	+.736*	-.61
FH	+.43	-.43
NH	+.903*	-.76*
ND	+.75*	-.77*

*significant at 5% level

The correlations shown in Table 6, taken together with Figures 7 through 10, indicated the the magnitude of error was constant across distance and conditions. However, there was a tendency for the errors that were made to change from over-estimates to under-estimates (with the exception of the FH condition).

While the trend was for increasing errors of under-estimation, there were differences in the nature of the changes in each condition. In the ND condition the majority of the responses to each stimulus were over-estimates. However, the size of the majority decreased from 72% to 53% as distance increased. In the NH condition, under-estimates increased from 39% to 72% of the responses as the distance increased. In the FH condition, under-estimates made up from 65% to 76% of the responses to each stimulus with no significant change over distance. In the FD condition, under-estimates increased from 63% to 83% of the responses to distance as distance increased. It must be noted, however, that due to limitations of the simulator it was not possible to over-estimate the 20,000 ft. target distance of the FD condition.

DISCUSSION

The results of this study supported previous findings that a power function relating subjective distance to objective distance has an exponent slightly less than 1.0. Visual performance under conditions simulating the visual aspects of outer space was very similar to visual performance on the earth's surface. Since retinal image size is the dominant distance cue retained in the Simulator, these results support Kunnapas' (1968) findings with regard to the importance of retinal size in distance judgment.

A notable feature of the data was the differences between results from the FD condition and the other three tasks. There are several possible reasons for these differences: (a) The target appeared phenomenally different at the distances employed in the FD condition; it had lost most of its shape and object characteristics and appeared as a pin point of light. (b) As was noted earlier, it was not possible to extend the target beyond 20,000 ft., which potentially restricted S's choice of responses to the 10,000 ft. stimulus. (c) Detection of real movement at or near 20,000 ft. was extremely difficult; Ss often thought that the target continued to recede after it had reached its stopping point at 20,000 ft. and may not have been able to discriminate between real movement and autokinetic movement (Royce, et. al., 1966) when making final adjustments at these ranges.

If the FD results are not interpreted as procedural artifacts, then they suggest that somewhere past 10,000 ft. (for the Apollo target) the configuration of distance cues available to Ss was changed or that Ss altered their interpretation of these cues. One such change might be a loss in usefulness of the binocular cues and retinal size cues, requiring reliance upon apparent brightness alone. This possible shift in processing is perhaps reflected also in the results of Vincent, Brown, Markley, and Arnoult (1968a) who reported data for full range (150 to 20,000 ft.) magnitude estimations that were dramatically concave downward in log-log co-ordinates and needed a constant of 300 ft. added to the distance variable to obtain a good fit for a power function with an exponent of 0.48. (In the present study, no attempt was made to fit modified power functions by adding constants to either variable.) Psychophysical functions for apparent brightness of a point source have been previously reported to have exponents of around .5 (Stevens, 1961).

There were consistent differences between halving and doubling response functions. Several of the psychophysical functions appear to deviate consistently from the simple power functions forced upon them in these analyses. The differences in the far range data can be attributed to the problems with the FD condition. The other distortions might be an indication that halving and doubling are not manifestations of the same judgmental process. However, the pattern of shifts between over- and under-estimations found in the error analyses suggest instead that the source of the distortions is simply a tendency for the S to overshoot the distance that appeared either one-half or twice as far. Perhaps if the target had been under the S's manual control and they had been able to adjust it back and forth, some of the problems and judgmental errors reported here could have been avoided.

With regard to the near and far range locations and the psychophysical function, there seemed to be no effects except for those in the FD condition. It is probable that, for whatever reason, the range beyond 10,000 to 12,000 ft. (using the Apollo target) is not going to produce a function that is an extension of scales for apparent distance developed over the nearer ranges.

The results concerning judgmental error suggested that for group data, per cent error is fairly constant across distance. Gibson and Bergman (1955) have previously reported that for judgments of the distance of a target on a grassy field both percentage error (6 to 10% on the average) and direction of error were independent of distance. The present error analyses also indicated that Ss' median per cent error was perhaps slightly higher in fractionation than it was in the best of the verbal estimation conditions reported previously (Arnoult, Brown, Vincent, and Tees, 1968). However, the variability of these data is such that a statistical test would not reveal a difference.

Results from the several studies now completed in this laboratory (Arnoult, Brown, Vincent, and Tees, 1968; Vincent, et. al., 1968a, 1968b) now indicate that even under the best of conditions a judgment of a single distance will likely be in error by something between 10% and 30%. This amount of error was consistently found for different range locations, stimuli within ranges, range sizes, and methods of response. There were indications that direction of error was dependent upon distance although this may be confounded by the response task. The results concerning various methods of responding suggest that as long as Ss can make some sort of comparative or relative judgment there is little difference in performance between verbal and non-verbal response modes.

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