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By Robert J. Vincent, Bill R. Brown, and Malcolm D. Arnoult

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MAGNITUDE ESTIMATION OF PERCEIVED DISTANCE OVER VARIOUS DISTANCE RANGES

By Robert J. Vincent, Bill R. Brown, and Malcolm D. Arnoult

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SUMMARY

Three groups of Os made magnitude estimation judgments of the apparent distance of a stationary space vehicle under conditions simulating outer space. Psychophysical functions for three stimulus ranges were obtained. The exponents for the "near" and "far" stimulus ranges were nearly 1.0. The power function exponent for the "full" range group was 0.48. The psychophysical scales are compared to JND scales obtained in previous research. The results indicate that in all ranges investigated the power law is an appropriate description of the relationship between perceived and objective distance, but that distance range and the location of the range are important determinants of the psychophysical scale.

INTRODUCTION

There have been few investigations concerned with scaling perceived distance as a function of objective distance. Results thus far indicate that to a first approximation, perceived distance (R_D) tends to grow as a power function of physical distance (I_D), or

$$R_D = I_D{}^n. \qquad (1)$$

The constant normally included is omitted since its value depends only upon the choice of unit. Of singular importance for scaling purposes is the value of the exponent (n), since it is considered to be unique to a given continuum (Stevens (1957)). When log R_D is plotted against log I_D, the exponent is the slope of the straight line. In other words,

$$\log R_D = n \log I_D. \qquad (2)$$

Distance scaling provides an excellent example of the need for conservative application of the psychophysical power law. Gilinsky (1951), for example, required two Os to bisect each one of fourteen distances between 8 ft. and 200 ft. on a large flat lawn. Her results are well described by a power function with a slope of 0.87. The exponent was estimated by the present authors from an analysis of median judgments fitted by least squares.

In one phase of a larger study Gruber (1954) employed 20 Os whose task was to make half-distance judgments of six distance pairs, the stimuli being either 10 cm. or 15 cm. triangles viewed at distances between 6.4 ft. and 14.4 ft. Mean distance judgments plotted as a straight line against objective distance in log-log coordinates, the function having a slope of n = 1.02 as determined by least squares.

Kunnapas (1960) scaled distance over three objective ranges and found that as the stimulus range increased, the exponent (n) decreased in an orderly fashion. Pairs of 18 in. squares were presented to each O, 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.

There is thus the indication that perceived distance has in common with other continua the disquieting feature of being susceptible to modifications in experimental procedure. The present study attempts to provide additional information about the "range effect".

SYMBOLS

R_D = perceived distance

I_D = objective target distance

I_{D_o} = constant (300 ft.)

n = exponent (slope)

JND = number of JNDs relative to 150 ft.

O = observers

METHOD

Observers.--Thirty-three Os volunteered to participate in this research. Each O had 20/20 vision or better (corrected, if necessary) as determined from an examination conducted by an optometrist. No O had participated in similar research, and none was told of the intent of the study. Three experimental groups were formed from the pool of volunteers in a non-systematic manner.

Apparatus.--Distance judgments were made in the NASA-TCU Space Vision Simulator. A report describing this apparatus is in preparation.[1] The opto-mechanical simulator 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.

Procedure.--Each O was run separately and was read the same instructions:

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[1] M. D. Arnoult, R. T. Vincent, B. R. [illegible] and R. H. Hensleigh: Description of the NASA-TCU Space Vision Simulator. Contract Report, Project NAS 2-1481. (in progress)

"I am going to show you a spacecraft at various distances. Your task is to tell how far away it appears by assigning numbers to the distances. The first time that you see the target it will be at a distance you are to call "10". Thereafter, you are to assign numbers proportional to your subjective impression of this first distance. For example, if the target appears to be twice as far away as the first target, assign to it a number of "20". If it appears to be 1/5th as far, call it "2", and so forth. I do not want you to restrict your response range. Use numbers as large or as small as you feel are necessary, including those less than "1" (fractions or decimals) if you feel they are appropriate."

Three distance ranges were investigated:

(a) "Full range": 150 ft. to 20,000 ft. The target was presented at seven distances within the range chosen so as to approximate a geometric series. The mid-point of the stimulus range, 1750 ft., was selected as the standard and was identified with the number "10" only once at the beginning of each session.

(b) "Far range": 5500 ft. 10,000 ft. Ten stimuli were presented at approximately equal logarithmic intervals within this range. The standard was at 7200 ft.

(c) "Near range": 500 ft. to 5000 ft. Ten stimuli were shown at approximately equal logarithmic intervals, with a standard at 1800 ft.

In all three experimental groups the targets were presented in irregular order in four separate series. An intertrial interval of 10 sec. was required to change distances. During this time a shutter occluded the visual scene.

Separate groups of 11 <u>O</u>s scaled the "full" and "far" ranges, and 10 <u>O</u>s scaled the "near" range. The data from one <u>O</u> had to be disregarded since he failed to follow the instructions.

RESULTS

The geometric means of the first two of four responses to each stimulus, averaged across Os, are plotted in the log-log coordinates of Figs. 1-3. Scale values for the "far" (Fig. 2) and "near" (Fig. 3) distance ranges conform to the simplified power function

$$R_D = I_D^{1.0}. \tag{3}$$

For these ranges, then, perceived distance is directly related to physical distance. The curves were fitted by least squares.

A distinctively curvilinear function was obtained for the "full" range results (Fig. 1), and is of the form

$$R_D = (I_D - I_{D_o})^{0.48}. \tag{4}$$

Here, perceived distance grows approximately as the square root of objective distance. The curve was fitted by the procedure devised by Ekman (1961). I_{D_o} is a constant value (300 ft.) which is subtracted from each stimulus value to produce a linear function. For several other continua the constant has been considered as the "effective" threshold (Stevens, 1959; Scharf and Stevens, 1960), but the term "threshold" seems not to be an appropriate label for the constant in the present study.

Table I compares the interquartile ranges of responses for all Os across all comparison stimuli, showing the number of JNDs involved in each stimulus range, and the exponent for each stimulus range. The JND data are from a study

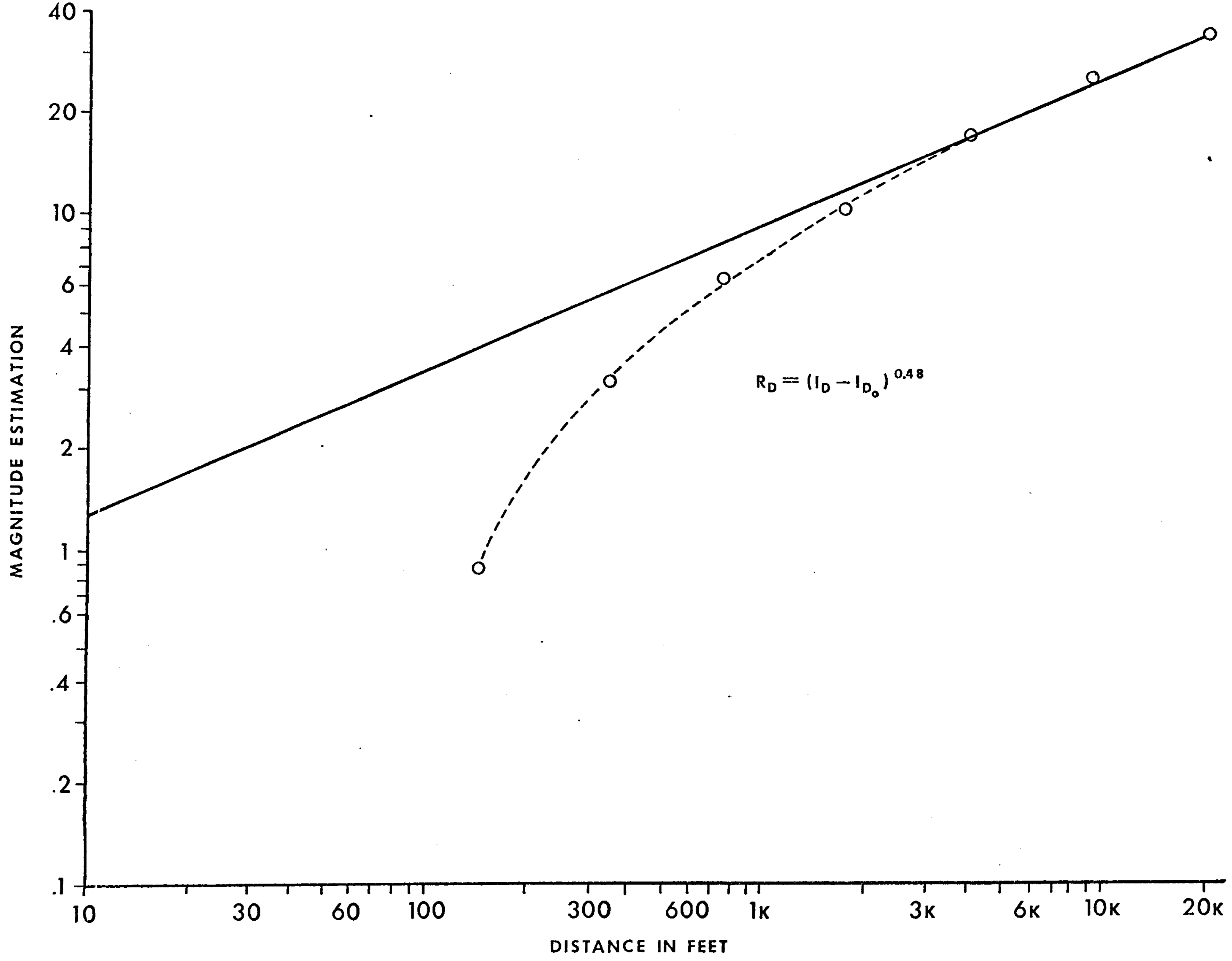

Figure 1: Psychophysical function for distance (full range).

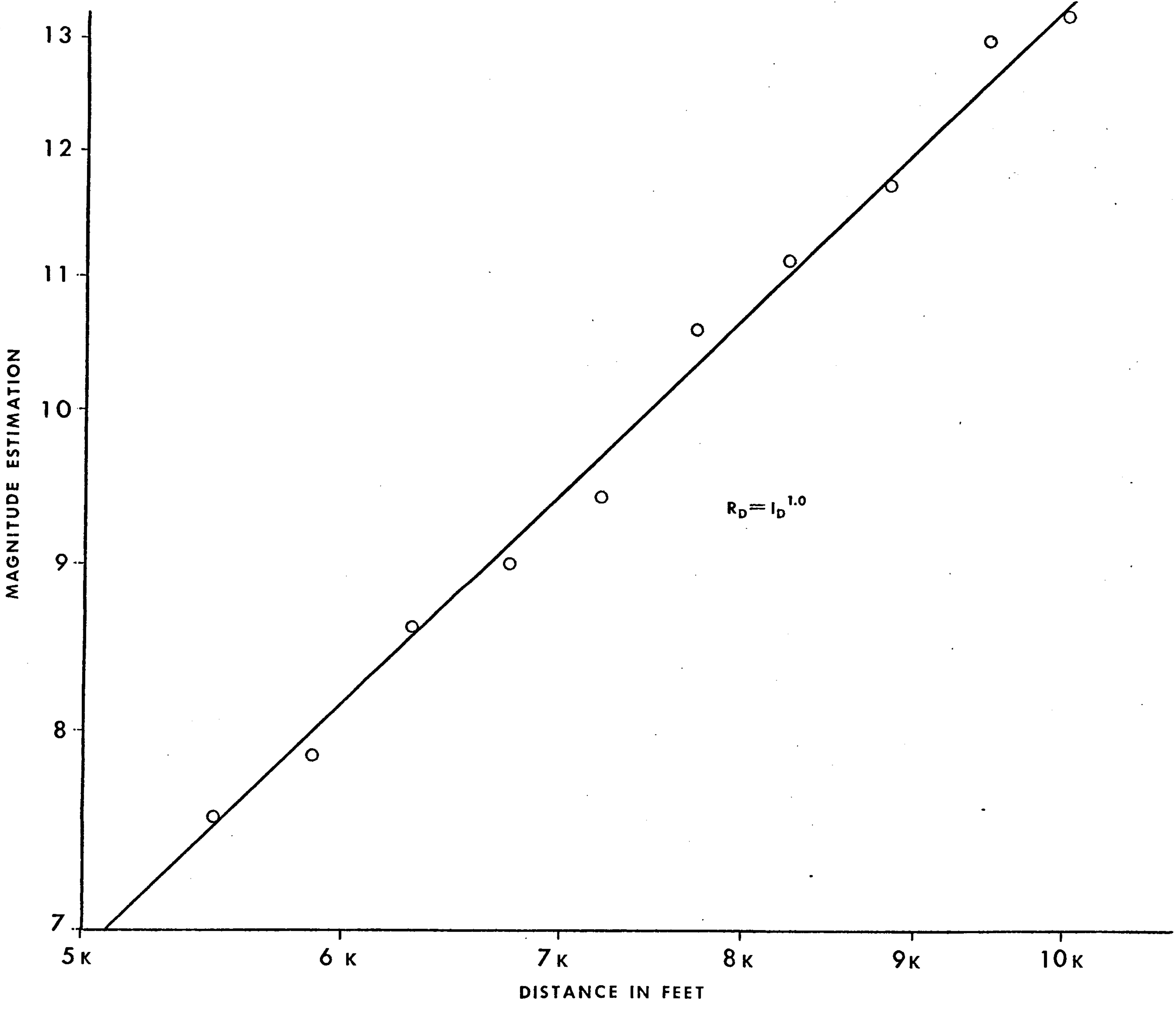

Figure 2: Psychophysical function for distance (far range).

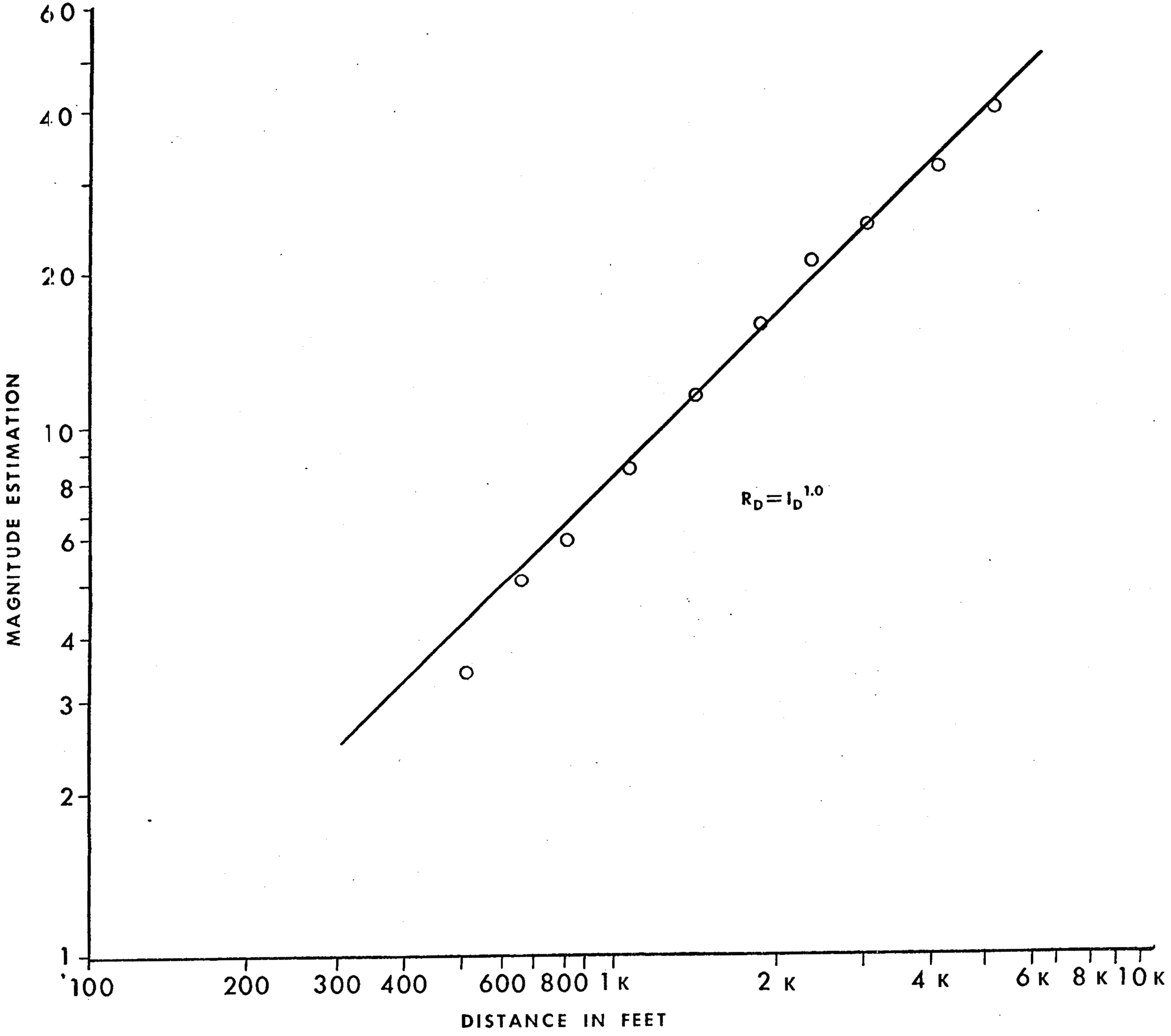

Figure 3: Psychophysical function for distance (near range).

TABLE I

STIMULUS RANGE, RESPONSE RANGE, AND EXPONENTS FOR THREE GROUPS OF OBSERVERS

Stimulus Range	Interquartile Range		No. of JNDs	Exponent
	Q1	Q3		
Full range 150-20,000 ft.	4	20.5	190	0.48
Far range 5500-10,000 ft.	9	12	17	1.00
Near range 500-5000 ft.	7	25	90	1.08

TABLE II

EXPONENTS OF GROUP PSYCHOPHYSICAL FUNCTIONS OBTAINED FROM MEDIANS OF RESPONSES 1 AND 2, 3 AND 4, AND 1 THROUGH 4

Stimulus Range	Exponent	Responses
Full range 150-20,000 ft.	0.48	1&2
	0.50	3&4
	0.49	1-4
Far range 5500-10,000 ft.	0.83	1&2
	0.69	3&4
	0.77	1-4
Near range 500-5000 ft.	1.04	1&2
	0.87	3&4
	0.96	1-4

by Vincent, Brown, and Arnoult.[2] The response ranges are shown not to be directly linked to stimulus ranges. Rather, the response ranges appear to reflect an interaction of both stimulus range and the location of the stimulus range along the stimulus continuum. The Os judging the "far" range produced the least amount of response dispersion while those involved with the "full" and "near" ranges offered considerably more and relatively comparable amounts.

Table II summarizes the results for each of three response measures: (a)the first two responses to each comparison stimulus; (b) the second two responses; (c) all four responses. In this analysis medians rather than geometric means were obtained.

It is readily apparent that continued exposure to the comparison stimuli tends to be associated with a lower exponent, at least in the case of the "far" and "near" distance ranges. Scale values are thus shown to be relative both to the standard and, eventually, to the remaining comparison stimuli within each group. Moreover, the data suggest that care should be taken in determining which measure of central tendency is chosen. Note the difference in slopes for the "far" range when geometric means and then medians are used in the analysis.

Considering the near-points of the "full" and "near" ranges sufficiently similar as to be equal, it follows that as the stimulus range increases, the exponent describing the corresponding distance scale decreases, a trend noted by Kunnapas (1960). This relationship also holds when the near-point is markedly

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[2] Vincent, R. J.; Brown, B. R. ; and Arnoult, M. D.: Distance Discrimination in a Simulated Space Environment. Contract Report, Project NAS 2-1481 (in progress).

displaced (to 5500 ft. in the "far" range). However, the results do not accord well with Kunnapas' (1960) contention that as the ratio of the maximal stimulus in the range to the minimal stimulus increases, the exponent will decrease.

An adjunctive explanation of the "range effect" is provided by Figs. 4-6, in which magnitude estimates are plotted against a summated JND function in semi-log coordinates. The resulting linear functions imply that discriminative sensitivity plays a part in the specificity of psychophysical scales, since equal response ratios seem to be derived from equal discrimination differences. It should be recalled that for prothetic continua (Stevens, 1957) such as loudness, brightness, and perceived distance, the magnitude of the JND increases with an increase in stimulus intensity. Here it would be an increase in physical distance. Therefore, the number of JNDs within a range are specific both to the extent of the range as well as to the location of that range on the stimulus continuum. The functions were fitted by least squares, and the empirically determined equations (5-7) are noted in Table III. The JND scale was

TABLE III

PSYCHOPHYSICAL FUNCTIONS FOR PERCEIVED DISTANCE (R_D)

(1) $R_D = I_D^{n}$

(2) $\log R_D = n \log I_D$

(3) $R_D = I_D^{1.0}$

(4) $R_D = (I_D - I_{D_0})^{0.48}$

(5) $\log R_D = .008\ (\mathrm{JND}) + .079$

(6) $\log R_D = .016\ (\mathrm{JND}) - 1.654$

(7) $\log R_D = .012\ (\mathrm{JND}) - .253$

obtained by an iterative procedure.[2]

DISCUSSION

The results indicate that in all ranges investigated the power law is an appropriate description of the relationship between perceived and objective distance, but that distance range and the location of the range are important determinants of the psychophysical scale.

The role of stimulus range has been demonstrated by a number of authors concerned with subjective length of lines, subjective area, apparent distance, brightness, loudness, heavinesss, and numerosity (Engen and Levy, 1958; Schickman, 1960; Stevens, 1958; Björkman and Strangert, 1960; Kunnapas, 1960; Strangert, 1961; and Ekman and Sjöberg, 1964). In each instance, the exponent of the scale decreased as stimulus range increased. Kunnapas (1960) mentioned that his Os tended to apply a relatively constant response range regardless of the stimulus (distance) range, which would immediately lead to a decrease in the value of the exponent as stimulus range increased.

Such an explanation seems to account for the decrease in slope as one proceeds from the "near" to the "full" distance range in the present study. The response ranges (in terms of overall interquartile ranges) were quite comparable. Moreover, the functions relating scale values to the summated JND data support such a position. There, the slope decreased with increased stimulus range, indicating that the rate at which estimates increase diminishes as the number of discriminable points grows.

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[2] Vincent, Brown, and Arnoult: ibid.

As for the "far" distance range, the response range was substantially smaller than in the other conditions. This reflects, at least in part, the difficulty encountered in discriminating differences at these distances. It will be recalled that the slope of the function relating magnitude estimates to the JND scale was largest in this instance, suggesting that <u>O</u>s were in fact functioning with limited discriminative ability.

In short, the overall extent of the stimulus range alone does not determine the psychophysical scale; one must also consider the number of perceptively different stimuli within the range. If this combination of factors plays the same role in other continua, and Vincent (1967) has recently demonstrated that it does for softness and apparent distance of a tone, the stability of the scales of perceived intensity is possibly nothing more than an artifact of using only extensive stimulus ranges. The alleged invariance of the power law to changes in experimental conditions is thus shown to be doubtful.

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Texas Christian University,
Fort Worth, Texas, 76129, October 20, 1967.

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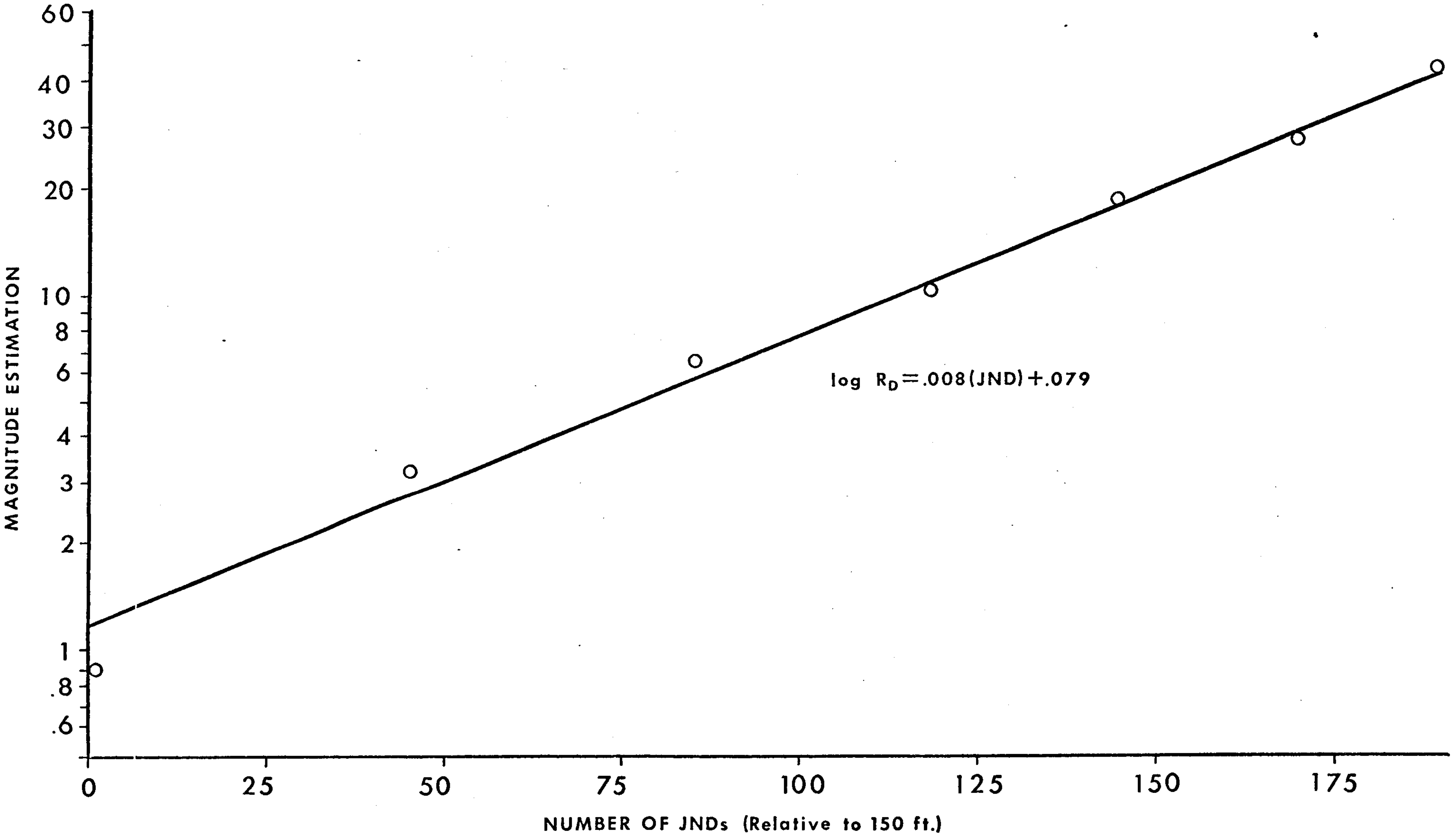

Figure 4: The relationship between magnitude and JND scales for distance (full range).

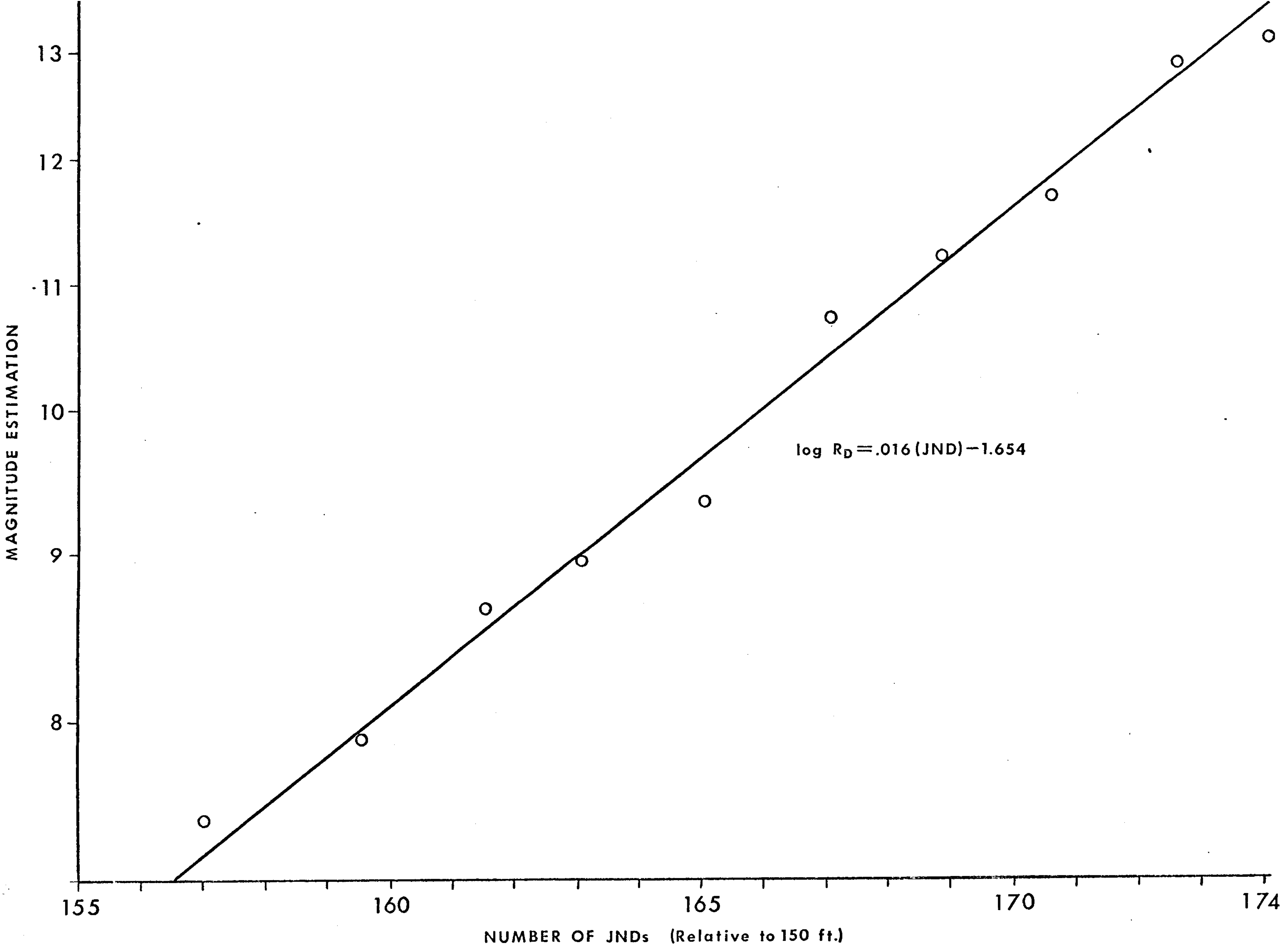

Figure 5: The relationship between magnitude and JND scales for distance (far range).

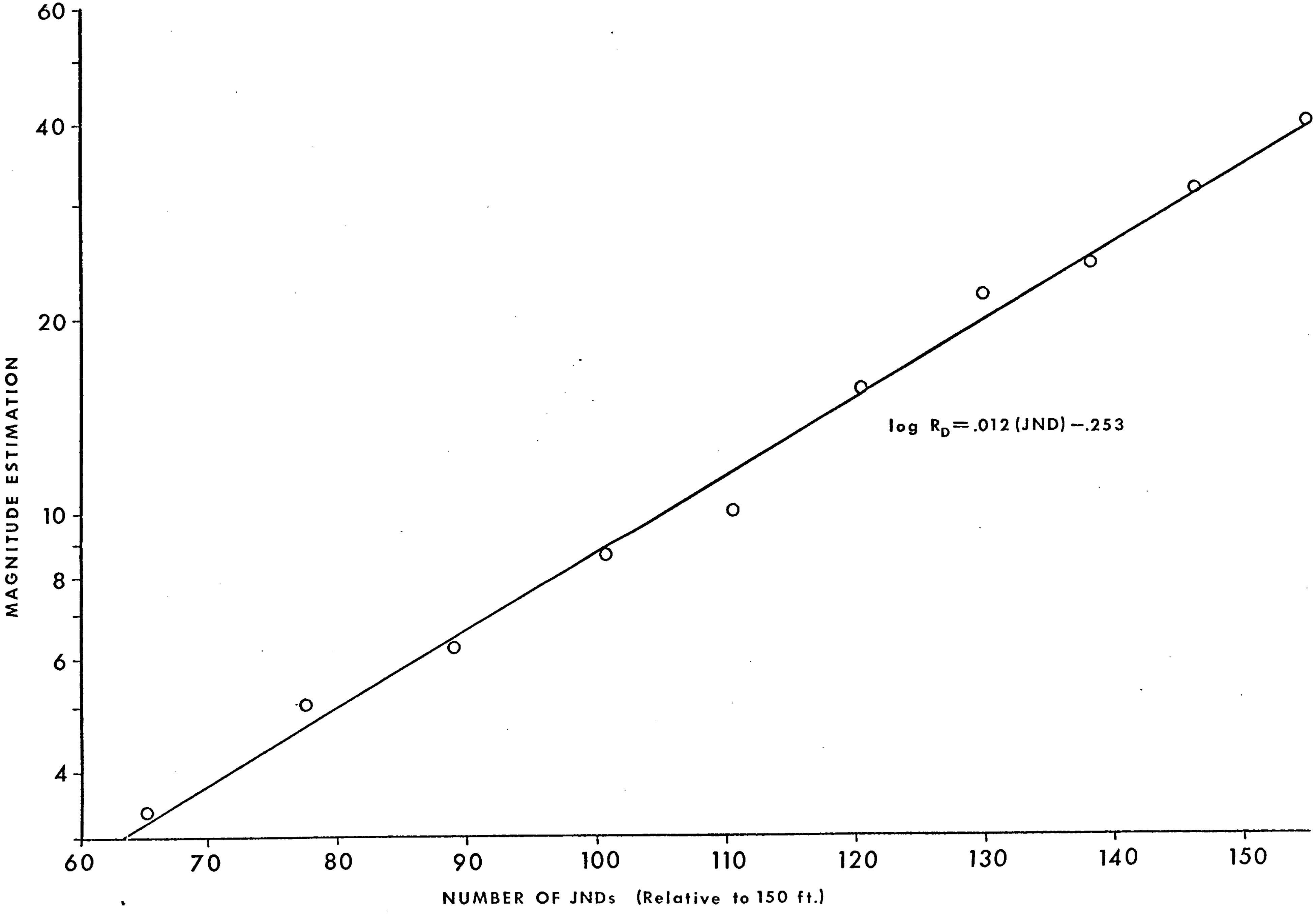

Figure 6: The relationship between magnitude and JND scales for distance (near range).

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