Mathematical Analysis of Peripheral Visual Response Time and Associated Effects of Hypoxia

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In previous studies (Kobrick, 1965, 1971, 1972, 1974, 1975; Kobrick and Appleton, 1971; Kobrick and Dusek, 1970; Kobrick and Sutton, 1970), it was shown that response time (RT) to the occurrence of a visual flash stimulus increased in direct relation to the degree of its peripheral placement in the visual field. It was shown also that these increases in RT differed for various sectors of the visual field, such that the largest increases were associated with stimuli along the vertical meridian, and the smallest with those along the horizontal meridian. In addition, it was demonstrated that hypoxic exposure during the performance of this task resulted in further systematic RT increases for all stimulus positions in direct relation to the degree of hypoxia.

These studies all employed the same configuration of stimulus positions, consisting of 48 lights angularly displaced 12°, 38°, 64° and 90° from center on each of 12 radial meridians spaced at 30° angular intervals about the visual field (0°, 30°, 60°, 90°, 120°, 150°, 180°, 210°, 240°, 270°, 300°, 330°). (See Figure 1.)

Insert Figure 1 about here

These studies also involved the manipulation of other stimulus conditions, including contrast and relative brightness, frequency of stimulus occurrence, and length of task performance. Since these latter conditions by themselves were found to have little effect upon RT performance, it was concluded that peripheral stimulus location and hypoxic exposure were the principal variables producing the RT impairments observed. Since the treatment values of stimulus location and hypoxic exposure were the same in all of the studies, and the other stimulus conditions were ineffective, the data of these studies were combined to provide a more authoritative analysis of peripheral visual response and associated hypoxia exposure effects. This paper reports the results of a polynomial regression analysis of the combined performance data.

Method

The data of four studies (Kobrick, 1974, 1975; Kobrick and Dusek, 1970; Kobrick and Appleton, 1971) were selected for the present analysis because they comprised complete sets of RT's in all 48 cells of the data matrix described above for each of four hypoxia treatment levels (20.93% O_2: 0 ft altitude; 12.8% O_2: 13,000 ft altitude; 11.8% O_2: 15,000 ft altitude; 10.9% O_2: 17,000 ft altitude). The accumulated data represent the RT values for 43 individual subjects in each hypoxia condition.

In order to determine first that the main effects observed in the previous separate studies were also significant for the involved data when combined, three separate one-way analyses of variance were conducted: (1) for peripheral stimulus locations combined across all field meridians and hypoxia conditions; (2) for field meridians combined across all peripheral stimulus locations and hypoxia conditions; (3) for hypoxia conditions combined across all visual stimuli. All three main effects proved to be highly significant ($P < .001$) ($F(1) = 67.54$, df = 3, 188; $F(2) = 2.55$, df = 11, 180; $F(3) = 7.72$, df = 3, 188). Therefore, it was concluded that a more intensive anlaysis of the trends involved in the main effects was justified.

Group mean RTs were first calculated for each stimulus position across all meridians for each hypoxia condition, and a polynomial regression analysis was then performed separately for the group means of each hypoxia condition. The curves of best fit for each were obtained by the following third degree polynomial equations:

0 ft: $$y = .0000097x^3 - .0009x^2 + .0284x + .4613 \quad (1)$$

13,000 ft: $$y = .0000057x^3 - .00028x^2 + .0074x + .9593 \quad (2)$$

15,000 ft: $$y = .0000088x^3 - .00077x^2 + .0261x + .8314 \quad (3)$$

17,000 ft: $$y = .000009x^3 - .00059x^2 + .0034x + 2.0503 \quad (4)$$

Grand mean: $$y = .0000084x^3 - .0063x^2 + .0162x + 1.0778 \quad (5)$$

The curves of best fit representing Equations 1-5 are shown in Figure 2, in which the group mean values for each hypoxia condition are plotted separately, along with a best-fit curve for the RT grand means for each peripheral stimulus position.

Insert Figure 2 about here

It is clear that the curves fit the empirical data points remarkably well;

this is supported by associated coefficients of determination of 1.00 for each of the curves shown.

The same polynomial regression analysis was also performed separately for the peripheral stimulus locations averaged across all hypoxia conditions for each meridian. The equations of best fit (6-17) for the 12 meridians (0°-330°) are the following:

0°: $y = .0000001x^3 + .000099x^2 - .00613x + 1.18565$ (6)

30°: $y = .0000102x^3 - .001190x^2 + .04279x + .76392$ (7)

60°: $y = .0000013x^3 + .000910x^2 - .03725x + 1.45714$ (8)

90°: $y = -.0000045x^3 + .001480x^2 - .05705x + 1.76262$ (9)

120°: $y = .0000115x^3 - .000888x^2 + .02532x + .99046$ (10)

150°: $y = .0000077x^3 - .000577x^2 + .01340x + 1.14254$ (11)

180°: $y = .0000039x^3 - .000295x^2 + .00219x + 1.33345$ (12)

210°: $y = .0000117x^3 + .001843x^2 - .06389x + 1.62549$ (13)

240°: $y = .0000237x^3 - .002562x^2 + .07536x + .80722$ (14)

270°: $y = .0000262x^3 - .002564x^2 + .07565x + .52685$ (15)

300°: $y = .0000196x^3 - .002134x^2 + .06782x + .57841$ (16)

330°: $y = .0000094x^3 - .00130x^2 + .03674x + .91216$ (17)

The curves of best fit to the empirical data points are presented in Figures 3 and 4, in which the respective meridians are plotted in general spatial relationship to their positions in the visual field (Figure 3 - upper visual field; Figure 4 - lower visual field).

Insert Figures 3 and 4 about here

The data points for each meridian were fitted virtually exactly by third-degree polynomial equations, with associated coefficients of determination of 1.00 in all cases.

Thus, it appears from the foregoing analysis that visual response to the occurrence of a flash stimulus becomes progressively impaired in a simple power-function relationship to peripheral excursion of the stimulus. The impairment for all visual field meridians is also expressible by the same third-degree polynomial relationship, but the magnitude of impairment varies for different zones as expressed by the equation coefficients. The greatest impairments occur around the superior and inferior vertical meridians, and the least impairments are found around the horizontal meridians. It is important to remember the simple nature of the stimulus involved, which nevertheless resulted in sizable peripheral impairments; more complex stimulus configurations should, thus, be expected to produce even larger impairments.

The effect of hypoxia appears to be an increase in impairment in direct relation to severity, but almost completely isomorphic to the performance seen under normoxic conditions. Thus, hypoxic stress does not seem to change the functional relationships between central and peripheral response, but only to shift the entire function in proportion to the magnitude of stress involved.

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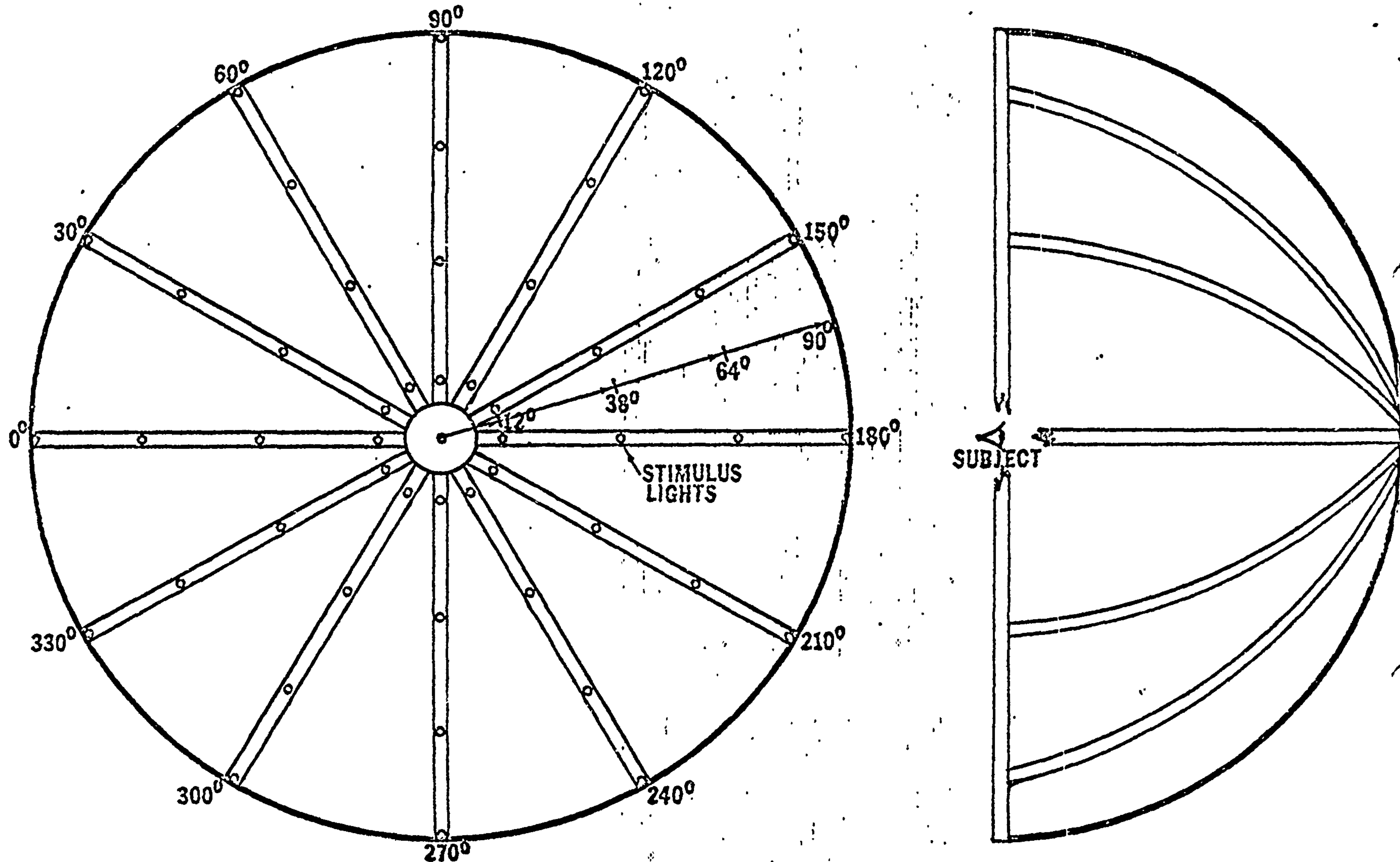
Figure Captions

Figure 1. Diagram of the stimulus configuration.

Figure 2. Curves of best fit for mean response time by peripheral stimulus location for each hypoxia condition.

Figure 3. Curves of best fit for mean response time by peripheral stimulus location for the upper visual field meridians.

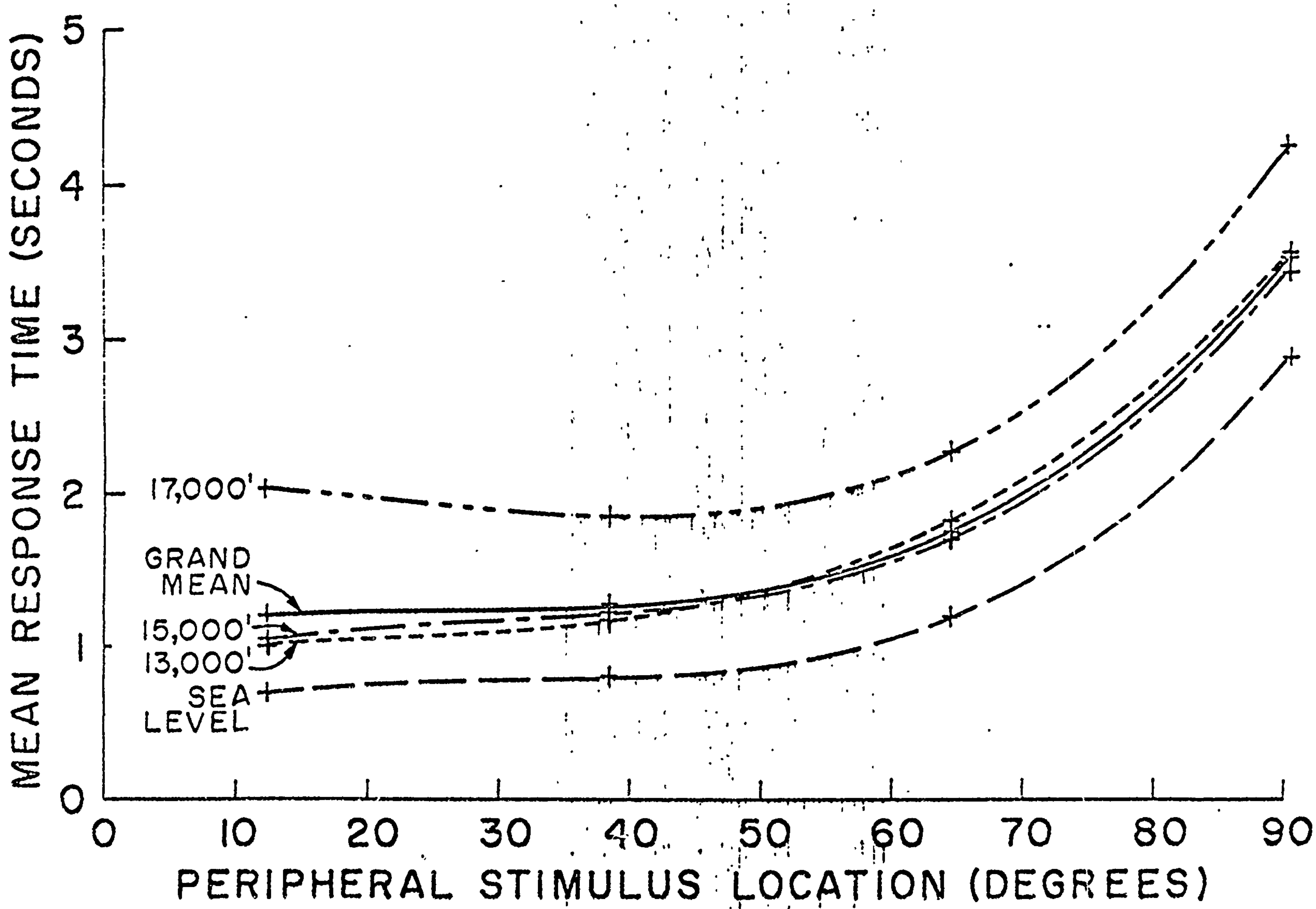
Figure 4. Curves of best fit for mean response time by peripheral stimulus location for the lower visual field meridians.



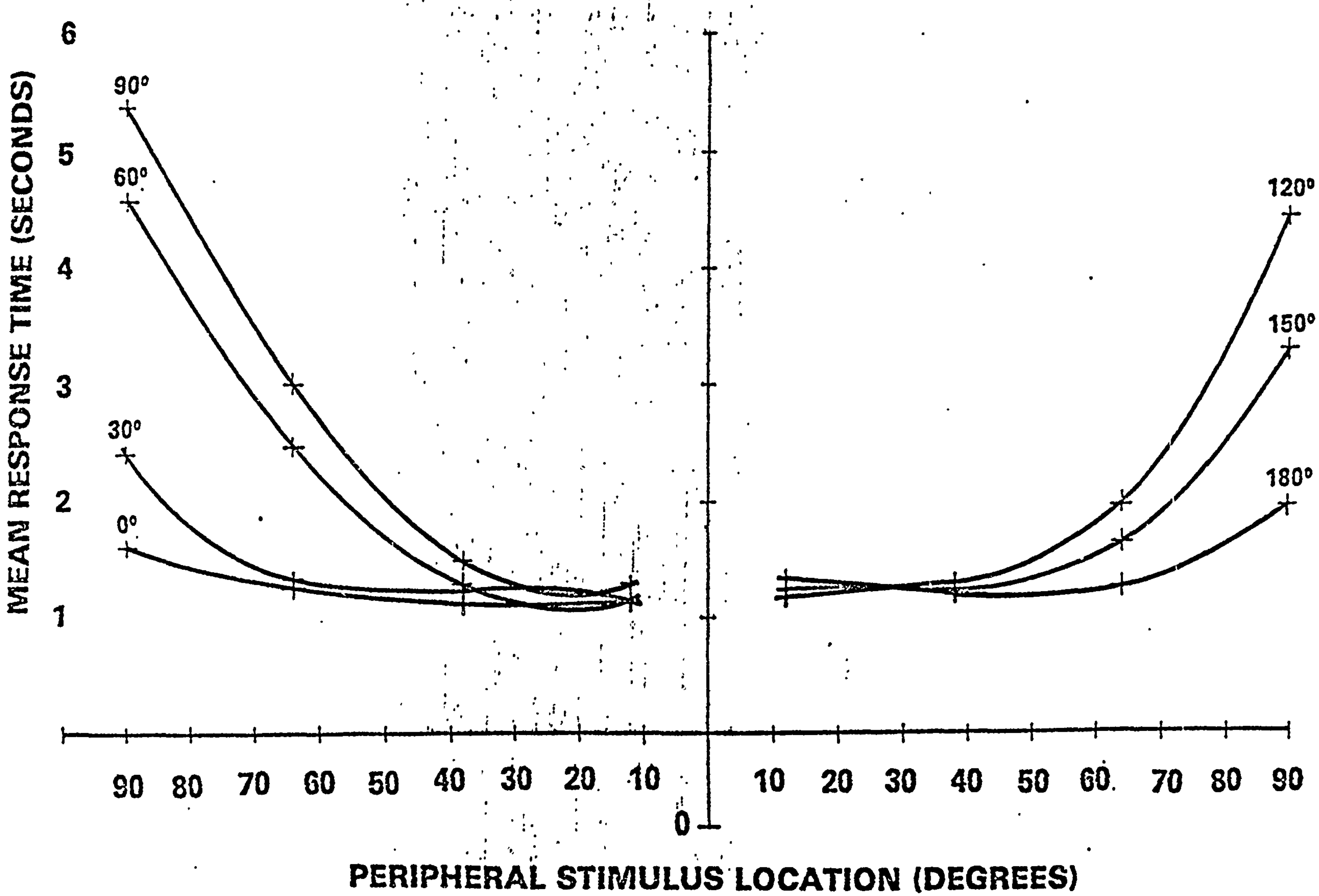
PLAN VIEW

SIDE VIEW

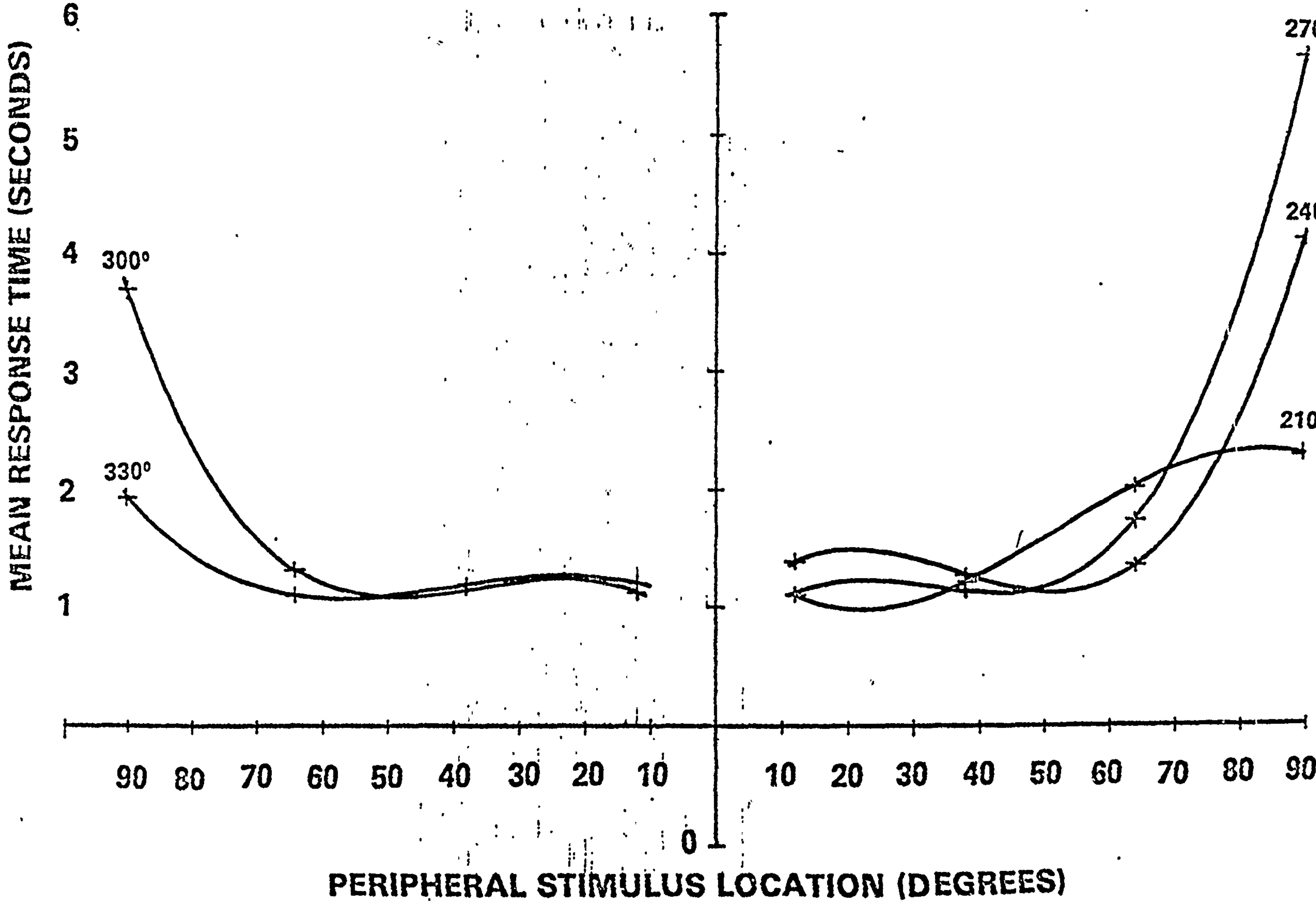
KOBRICK. FIGURE 1.



KOBRICK - FIGURE 2.



KOBRICK - FIGURE 3



KOBRICK - FIGURE 4.

Abstract

A polynomial regression analysis was performed on the combined data of four previous studies (43 subjects) on the effects of four levels of hypoxia (O_2 concentrations of 20.93%, 12.8%, 11.8%, and 10.9%, respectively) on response time (RT) to visual flash stimuli distributed in 48 locations about the visual field. The relationship of RT to peripheral stimulus location could be described in all instances by third-degree polynomial power functions, which differed only with respect to meridional location of the stimuli in the visual field. The main effect of hypoxia exposure was elevation of the RT impairment in direct relation to severity, but without changing the functional relationships involved from those observed for normoxic performance.

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