EFFECTS OF IONIZING RADIATION UPON HUMAN PSYCHOMOTOR SKILLS

SCHOOL OF AVIATION MEDICINE
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The realization of nuclear propulsion for manned aircraft depends in part on the availability of knowledge about the effects of low-level ionizing radiation upon the psychologic capabilities of those who will fly and maintain them. For obvious reasons the satisfaction of this requirement can at best be little more than approximated through lower animal research. On the other hand, ethical and moral considerations inherent in our culture preclude the development of such knowledge as a primary objective of human experimentation. Thus, the problem of how to obtain relevant and reliable information has been most vexing.

A partial solution to this problem was offered six years ago by the director and staff of the M. D. Anderson Hospital and Tumor Clinic of Houston, Tex. (1). This group had long been interested in the comparative value of radiotherapy and chemotherapy for generalized neoplastic disease, and it foresaw no valid criticism of an incidental and collateral study of behavioral changes, if any, that might arise subsequent to the routine application of radiotherapy. All parties realized, of course, that the scientific orderliness of such a study and the applicability of its results might be somewhat diluted by the necessity for placing responsibility for selection of patients and prescription of doses entirely in medical hands. Nevertheless, the studies which finally resulted from this unique arrangement proved reasonably sound. They are reported here because of their useful implications for the Air Force and because they constitute the only known body of human data on this subject.[1]

Two sets of observations will be reported. The first set is concerned with the question whether a given air dose will have a greater effect when delivered in a single exposure than when delivered in a series of fractional exposures, while the second can be considered analogous to a straightforward dose-response study involving relatively high exposure levels. If the results seem trivial now, one should recall that no hindsight was possible six years ago when the studies were begun.

FIRST STUDY

The first study was organized around the therapeutic circumstance that some patients were treated with whole-body doses delivered in single exposures, while others were given equivalent total exposures in five equal increments separated by intervals of 1 hour. Psychomotor performance data obtained from both types of patients made it possible to test a hypothesis about the way in which exposure effects become modified by temporal dispersion.

Subjects

Subjects were adult males usually in advanced stages of neoplastic disease that was not amenable to surgical intervention or localized radiation therapy. Their ages ranged from 19 to 76 years.

Tasks

Three well-known perceptual-motor tasks served as criteria of treatment effects. The USAF SAM Complex Coordination Test (CM 701 D), shown in figure 1, required the subject to coordinate the movements of a stick and rudder bar in order to match successive positions of three red lights with three green

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[1] The clinical aspects of the radiotheraphy studies are published elsewhere (1, 2).

lights. The USAF SAM Two-Hand Coordination Test (CM 101 E), shown in figure 2, required the subject to turn two lathe-like crank handles in order to keep a cursor positioned on an eccentrically moving target. The USAF SAM Rotary Pursuit Test (CM 803B), shown in figure 3, required the subject to follow a rotating target with a stylus.

Radiation

Three exposure levels were available for study: 15, 25, and 50 r, as measured in air at the position of a plane which bisected the patient. Each level was reached either by a single exposure or by five equal fractional exposures separated by an interval of 1 hour. Delivery was accomplished by a 400 kvp General Electric

FIGURE 1

The USAF SAM Complex Coordination Test (CM 701 D).

x-ray machine with Thoraeus III filtration having a half-value layer equivalent to 4.1 mm. of copper. At the target distance of 300 cm., the output was approximately 0.95 r/min. One large field was employed, the patient being treated in a lateral position with left and right sides alternated in proximity to the target. Air-wall ionization chambers (Farmer) were placed on the patient's skin during exposure in order to measure entrance and exit doses (3).

Procedure

At approximately 0800 hours on the day of exposure, each subject was given formal test instructions and a standardized amount of preliminary practice on the three testing devices. Practice sessions were 2 minutes for the Complex Coordination and Two-Hand Coordination Tests, and 100 seconds (five 20-second trials separated by 10-second rests) for the Rotary Pursuit Test. Following practice, the prescribed treatments were begun. One hour later the psychomotor testing sessions were resumed, and they were repeated thereafter at 2-hour intervals until six posttreatment sessions had been completed. Two testing sessions 8 hours apart were completed on the day following treatment. Additional testing was done on some of the subjects, but these data are not considered in the present study. Single-exposure subjects and multiple-exposure subjects within a given total exposure group were treated alike except that the latter alternated between testing sessions and fractional treatment sessions until the five exposures had been accomplished.

Results

Indexes of two somewhat related dimensions of performance were subjected to statistical analysis. The first index was simply the total

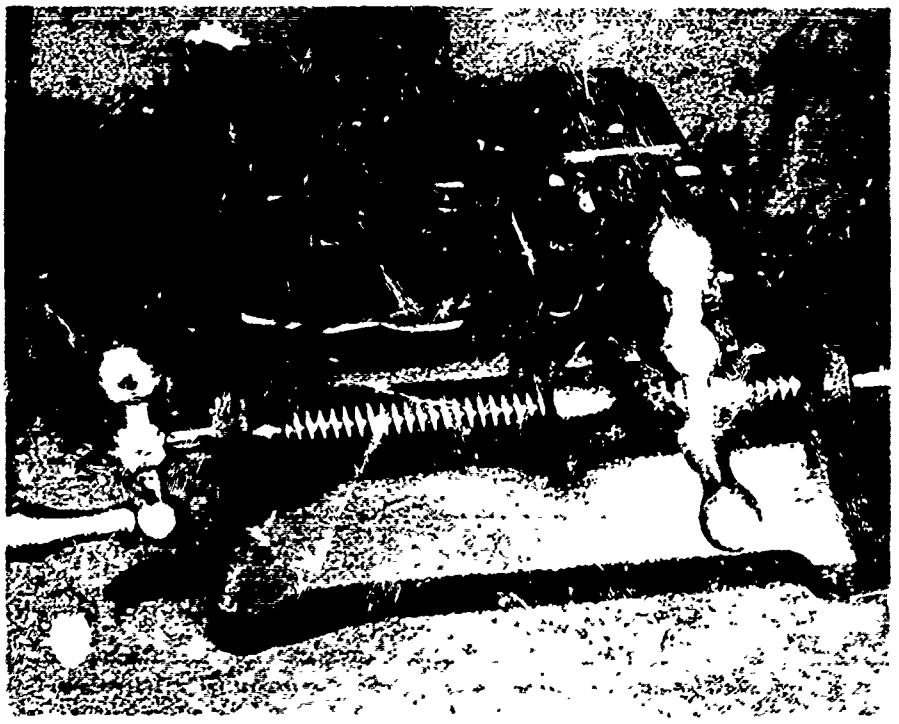

FIGURE 2

The USAF SAM Two-Hand Coordination Test (CM 101 B).

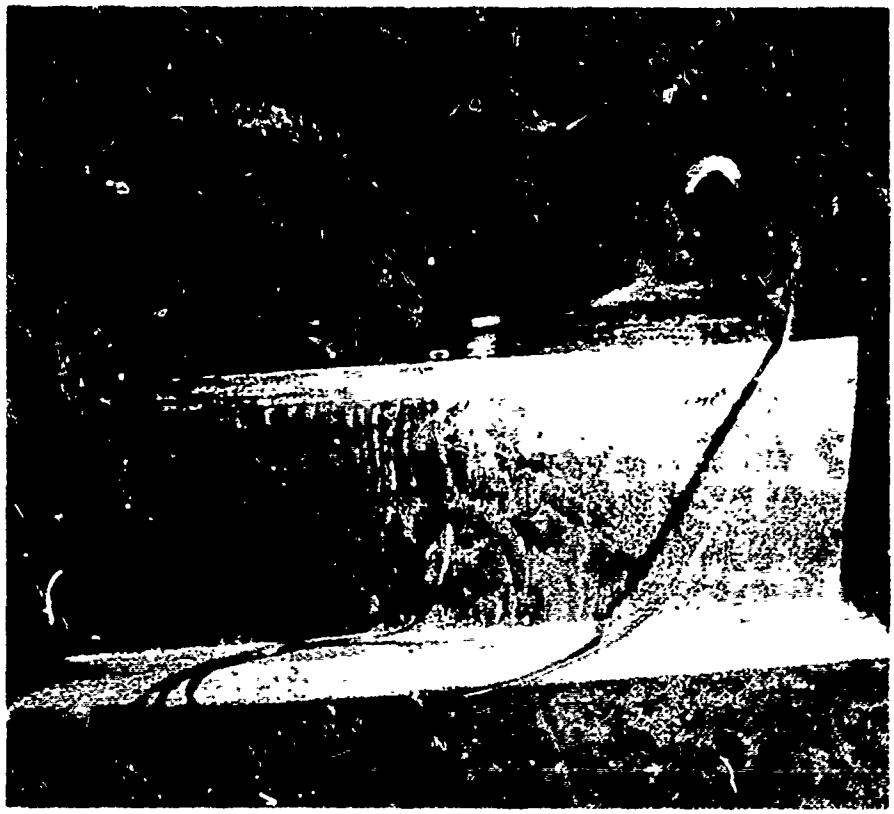

FIGURE 3

The USAF SAM Rotary Pursuit Test (CM 808 B).

TABLE I

Analyses of adjusted variance of over-all achievement levels

Source	df	Complex Coordination		Two-Hand Coordination		Rotary Pursuit	
		s^2	F	s^2	F	s^2	F
Doses	2	.827	<1.00	5,491	<1.00	256.38	<1.00
Methods	1	.477	<1.00	124	<1.00	1.85	<1.00
D x M	2	.737	<1.00	13,067	1.07	148.68	<1.00
Error	70*	2.538		12,234		1,285.82	
Total	75*						

* Reduced by 2 df for regression of posttreatment scores (y) upon pretreatment scores (x) and chronologic age (z). Regression and correlation values are:

For Complex Coordination, b_1 = 1.4928, and b_2 = −.0271. $R_{y.xz}$ = .78; r_{xz} = −.24, r_{xy} = −.39; r_{zy} = .76.

For Two-Hand Coordination: b_1 = 1.031, and b_2 = −3.7782. $R_{y.xz}$ = .83; r_{xz} = −.33; r_{xy} = −.50; r_{zy} = .79.

For Rotary Pursuit: b_1 = 1.1944, and b_2 = −1.6498. $R_{y.xz}$ = .74; r_{xz} = −.16; r_{xy} = −.47; r_{zy} = .74.

score achieved during the posttreatment testing sessions or during any portion thereof that seemed worthy of closer scrutiny. The second index consisted of the tangent of the angle defined by the abscissa of the performance curve and the linear regression of scores upon abscissa values (trials). This was a measure of the linear component of learning rate. Whenever appropriate, each index was adjusted for multiple regression upon chronologic age and pretreatment performance levels before the final analysis of the posttreatment variation was performed. This had the general effect of (a) reducing the contribution of these factors, and of factors correlated with them (such as type and severity of disease), to posttreatment variation, and (b) increasing the precision with which final tests of significance could be made. What remained for the final analysis was the variation attributable to the main experimental effects, their interaction, and the residual differences between subjects.

The analysis of Complex Coordination Test results given in table I shows clearly that treatment levels and treatment methods do not contribute significantly, either singly or jointly, to the total adjusted variation. The negligible main effects and their uncorrelated status are easily appreciated in figure 4, which shows the adjusted mean scores for each combination of treatment level and treatment method. Comparable analyses were made for each posttreatment trial separately, and for the linear component of the regression of scores upon the eight-trial sequence, but without significant results.

The results of the Two-Hand Coordination Test resemble closely those of the previous test. As shown in figure 5, neither the level of exposure nor the methods of delivery had a discernible effect upon performance, whether viewed in terms of achievement level or (not shown here) in terms of rate of progress.

The results of the Rotary Pursuit Test are much like the previous ones with respect to the over-all performance level, as shown in figure 6. However, there is a bare suggestion in the analysis of the linear regression component of

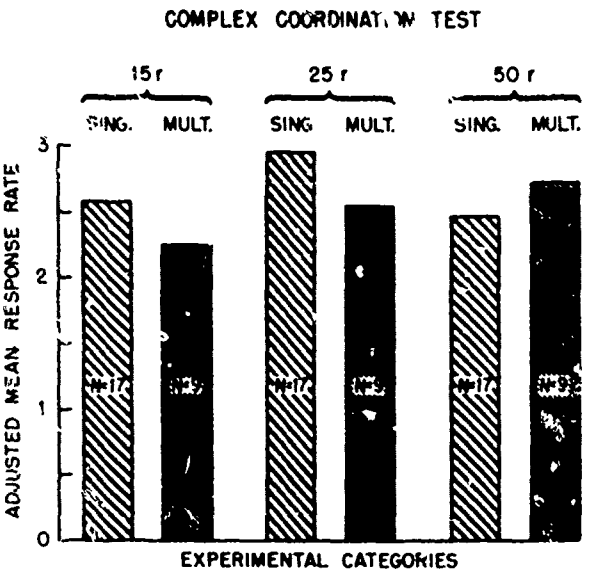

FIGURE 4

Adjusted subclass mean response rates for Complex Coordination.

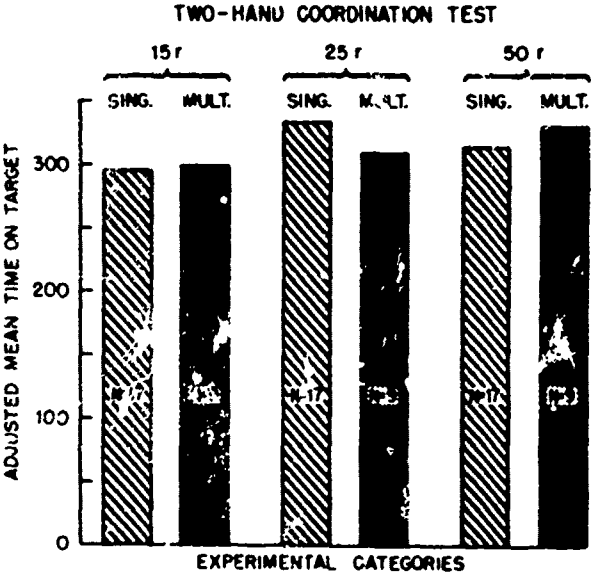

FIGURE 5

Adjusted subclass mean time-on scores for Two-Hand Coordination.

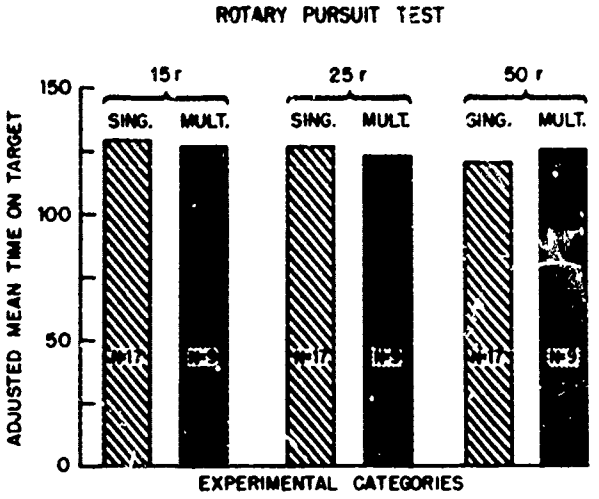

FIGURE 6

Adjusted subclass mean time-on scores for Rotary Pursuit.

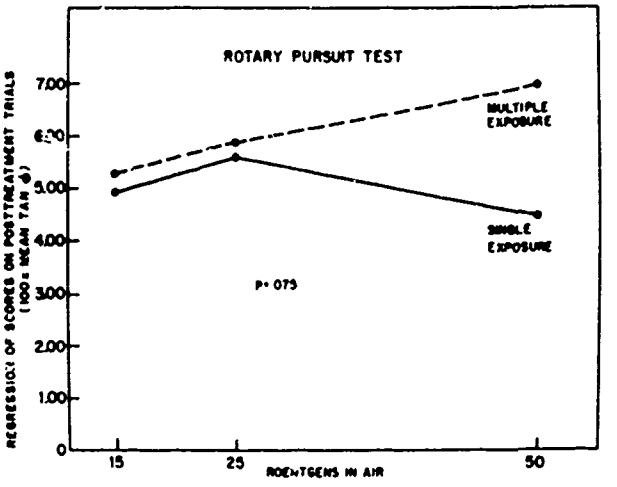

FIGURE 7

Interaction of exposure level and exposure method for Rotary Pursuit.

TABLE II

Analysis of variance of the linear component of scores by trials for Rotary Pursuit

Source	df	Mean square	F	P
Doses	2	6.1888	<1.00	
Methods	1	20.9941	2.05	.165
D x M	2	28.6785	2.79	.075
Error	70*	10.2589		
Total	75*			

* Reduced by 2 df for regression of posttreatment scores (y) upon pretreatment scores (x) and chronological age (z).

$R_{y.xz} = .43$; $r_{xz} = -.16$; $r_{zy} = -.42$; $r_{xy} = .11$; $b_1 = .0043$; $b_2 = -.0900$.

the trial means, shown in table II, that the effects of exposure level and method of delivery may be correlated; that is, the effects of treatment methods may not be the same for all exposure levels. The plot of subclass means in figure 7 suggests that single exposures to a given dose level attenuate the rate of the subjects' progress somewhat more than fractional exposures to the same level, particularly at the higher exposure levels. Although this is consistent with fact and theory concerning interexposure repair of tissue damage, one must recall from the analysis in table II that there is no satisfactory degree of assurance that this finding is real. It is mentioned here because of its speculative merit and because it is a rare oasis in a veritable desert of negative results.

Discussion

With the exception of one faint suggestion, which is probably not real, the data considered thus far do not contain the slightest hint that psychomotor performance was affected by the independent variables under investigation. It is possible, of course, that protracted observation might have revealed important differences, particularly in subsequent rates of progress, but this possibility is generally denied in the study to follow. When viewed in terms of the crew in the nuclear-powered vehicle, these results do not necessarily provide complete grounds for complacency, for it must be recalled that our subjects, although human, were seriously diseased at the time of study. And it must also be recalled that psychomotor coordination is only one of many processes which underlie aircrew job proficiency.

SECOND STUDY

During the course of the medical staffs' evaluation of the therapeutic value of whole-body x-irradiation, it was deemed clinically sound to prescribe single doses higher than

those which prevailed during the period of the first study. As a consequence, psychomotor studies were performed after the administration of single doses as high as 200 r, and for a longer period of time.

Subjects

As before, subjects were adult males whose participation in the study was governed by the medical staff as previously described. Ages ranged from 23 to 76 years.

Tasks

The psychomotor tasks were the same as those described in the previous study.

Radiation

As before, patients were exposed in a lateral position with left and right sides alternated in proximity to the target. For approximately half the subjects, mostly those receiving below 75 r, the treatment was delivered as previously described. For the remainder, treatment was accomplished by a General Electric Maxitron operated at 250 kvp with a Thoraeus III filter providing half-value layer equivalent to about 3 mm. of coper. Output was about 3.8 r/min. Nine exposure levels, ranging from 0 through 200 r. in 25-r steps, were sampled. Each subject received his prescribed exposure in a single session.

Procedure

Beginning at approximately 0800 hours each day for 4 days prior to exposure, each subject was allowed a practice session on each testing device. Practice sessions both before and after exposure were 4 minutes for Complex Coordination and Two-Hand Coordination, and 300 seconds (fifteen 20-seconds trials separated by 10-second rests) for Rotary Pursuit. Exposure occurred on the morning of the fifth day. One hour later the first posttreatment testing session was held, and this was repeated each day at approximately the same time for 9 days thereafter. All subjects, including controls, were treated essentially alike except for the amount of radiation to which they were exposed.

Results

Analyses of variation in posttreatment achievement levels for Complex Coordination and Two-Hand Coordination were based upon the forty 1-minute performance samples obtained from each subject (10 days × 4 min./day), while that for Rotary Pursuit was based upon the thirty 100-second performance samples from each subject (10 days × 300/sec./day). The scores of all subjects in each performance sample were adjusted for their multiple regression upon chronologic age and pretreatment levels, and the residual variation of all scores was then analyzed.

The outcomes for all testing devices are fully exemplified by the analysis of adjusted variation for Rotary Pursuit, as shown in table III. The highly significant variation attributable to "Days" and "Trials/day" results from the fact that significant amounts of learning occurred both within each day and from day to day. All radiation groups are essentially alike in this respect, as shown by the interaction values, and there is no evidence of radiation impairment. The radiation group means for the entire posttreatment sequence are shown in figure 8 for Complex Coordination, figure 9 for Two-Hand Coordination, and figure 10 for Rotary Pursuit.

TABLE III

Analysis of variance of adjusted posttreatment achievement levels for Rotary Pursuit

Source	df	Mean square	F	P
Groups (doses)	7	23,086	<1.00	ns
Ss treated alike	57	40,466		
Days	9	75,218	68.07	<.001
D x G	63	1,229	1.11	ns
Ss x D	513	1,105		
Trials/day	2	16,353	19.17	<.001
T x G	14	1,039	1.22	ns
Ss x T	114	853		
T x D	18	121	<1.00	
T x D x G	126	272	1.14	ns
Ss x T x D	1,026	238		
Total	1,949*			

* Reduced by 60 df for regression coefficients, as follows: Ss treated alike (-2), Ss x D (-18), Ss x T (-4), and Ss x T x D (-36).

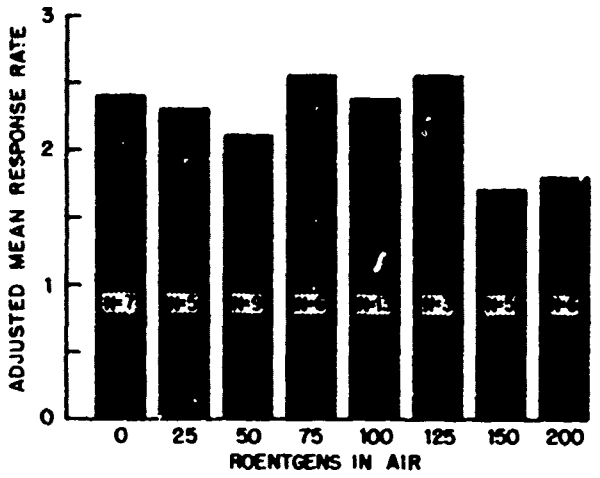

FIGURE 8

Dose-response function for Complex Coordination.

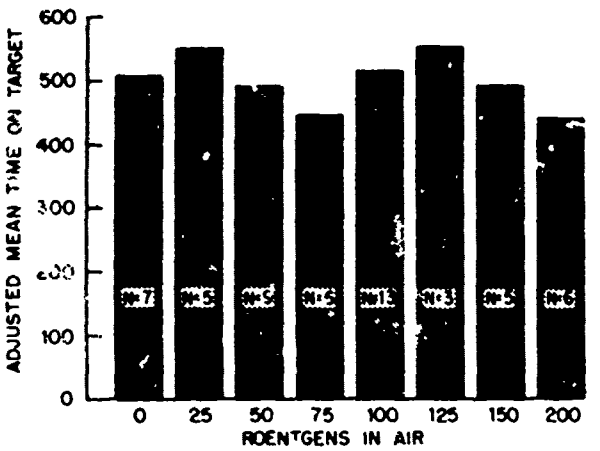

FIGURE 9

Dose-response function for Two-Hand Coordination.

The data from each testing device were further analyzed in terms of the linear component of the regression of scores upon post-treatment trials, both within days and from day to day, but none of the analyses implicated radiation exposure as a significant source of variation. Comparable analyses were made in terms of the quadratic component of these regressions; that is, a regression coefficient was computed for each subject, then the total variation of the coefficients was partitioned

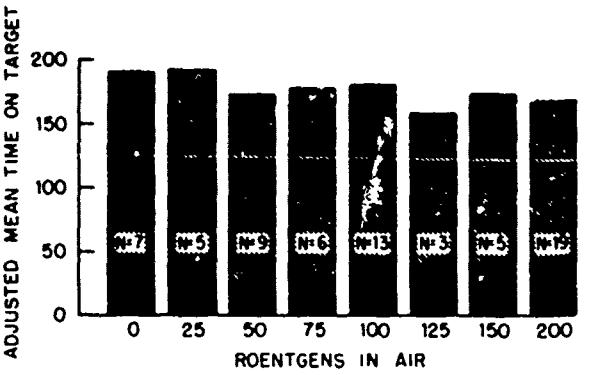

FIGURE 10

Dose-response function for Rotary Pursuit.

TABLE IV

Analysis of variance of quadratic component of scores by days for Complex Coordination

Source	df	Mean square	F	P
Between radiation groups	8	.00282061	3.33	<.01
Within groups	58	.00084699		
Total	66			

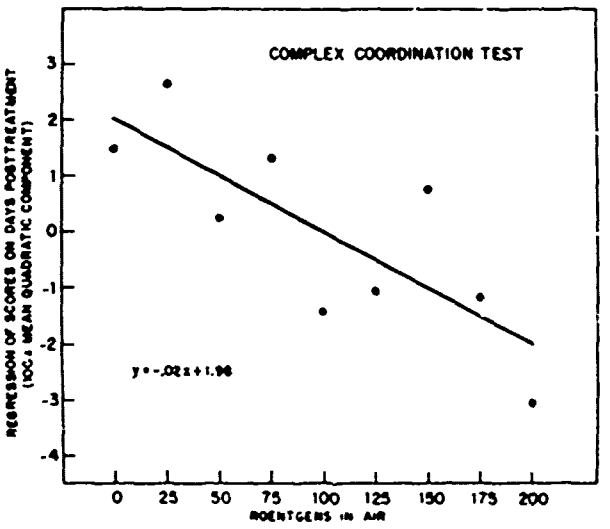

FIGURE 11

Change in quadratic component of performance sequence as a function of exposure level.

with respect to "Between groups" and "Within groups" sources in order to provide a test of significance of exposure effect. The results of these analyses were negative for Two-Hand Coordination and Rotary Pursuit, but those for Complex Coordination were positive, as shown in table IV. A plot of the mean quadratic coefficients against exposure values, shown in figure 11, suggests, despite the several inversions, that the quadratic component of performance over the 10-day period becomes more negative the more intense the radiation exposure. Another way of putting this is to say that the more intense the exposure, the more likely it is that performance will be falling, rather than rising, toward the end of the 10-day period of measurement.

Discussion

With the possible exception of the quadratic component of the 10-day performance sequence, there is no evidence that exposure to ionizing radiation has affected the psychomotor skills in question. Whether this exception is a true radiation effect is debatable. It could just as well have been a disease effect, for we must presume that the prescribed exposure intensity bore some relationship to the severity of the disease. This confoundment, of course, was unavoidable. What we may have in this analysis of the curvature aspect of performance sequence is some combination of radiation effect and the general debilitating effect of the disease. In any event, the absolute magnitude of change from group to group seems too slight to be of any practical significance.

One further point requires clarification. The radiation variable in these analyses was expressed in terms of air dosimetry because the more urgent objective of the studies was some empiric basis for deciding what behavioral risks might be invited by exposure to various possible radiation fields. However, what the subject was exposed to and what he actually absorbed are not necessarily identical, the latter being a complex function of backscatter, the size and weight of the body and the absorption coefficient of the various tissues. If one computes an integral body dose more representative of the quantity actually absorbed, it turns out on the average to be a linear function of the air dose. Thus, it is clear that an air dose index would misclassify very few subjects with respect to the quantity absorbed. This would suggest that our results would remain unchanged if analyzed in terms of integral body dose. Checks performed thus far show that this is in fact the case.

Finally, it seems important to re-emphasize that the application of these results to developmental and operational problems should be made with cautious regard for the medical status of the subjects we studied and for the limited relevance of experimental criteria.

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