NASA CONTRACTOR REPORT

NASA CR-1522

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EFFECTS OF SONIC BOOMS AND SUBSONIC JET FLYOVER NOISE ON SKELETAL MUSCLE TENSION AND A PACED TRACING TASK

by Jerome S. Lukas, Donald J. Peeler, and Karl D. Kryter

Prepared by
STANFORD RESEARCH INSTITUTE
Menlo Park, Calif.
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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • FEBRUARY 1970

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ABSTRACT

Electrical activity in the trapezius muscle of the shoulder in twelve subjects was monitored while they were: (1) performing a paced tracing task in the presence of occasional simulated indoor sonic booms of 2.5 pounds per square foot (as measured outdoors), (2) performing a paced tracing task in the presence of occasional subsonic jet flyover noise of 100 PNdB (perceived noisiness in dB), (3) performing the tracing task under quiet conditions, (4) seated at rest in the presence of occasional simulated indoor sonic booms. A measure of time-on-track during a paced tracing task was obtained. A group of three subjects (males, 31 to 44 years of age) was tested under each of the four conditions.

Simulated sonic booms increased the electromyographic activity in the group who performed the tracing task as well as in the group who heard booms while seated at rest. In addition, the booms were found to degrade tracing performance during the five test sessions. Flyover noises did not affect tracing performance nor result in electromyographic responses of the magnitude found as a result of the sonic booms. The control group, which performed the tracing task without any booms or flyover noises, did not show any significant change in performance or change in muscle tension throughout four test sessions.

The results are considered tentative because of the small number of subjects involved in the tests. It is also to be noted that vibration of the subject or the tracing apparatus as a direct result of the simulated boom, rather than its audible effect, is perhaps a significant factor in the results obtained.

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EFFECTS OF SONIC BOOMS AND SUBSONIC JET FLYOVER NOISE ON SKELETAL MUSCLE TENSION AND A PACED TRACING TASK

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I INTRODUCTION

A. Background

An earlier study of college students (Ref. 1) showed that a rapid but brief increase in activity of the trapezius muscle occurred in response to simulated sonic booms. After 36 stimulations the amplitude of the electromyographic activity was reduced relative to its initial levels, but not to the level of a control group which had not been stimulated by booms. In addition, when sonic booms and the resultant muscle activity occurred coincidentally with acquisition of skill on a self-paced tracing task, attainment of speed on the task was hindered, but the attainment of accuracy was facilitated. Exposure to sonic booms before acquisition of skill on the task did not hinder the attainment of normal tracking speed but did hinder the attainment of accuracy.

The exact meaning and significance of these results is not clear. The results obtained by other investigators are also not particularly helpful in understanding the effects of noise, particularly impulsive, upon psychomotor task performance. In some experiments, most of which involved young adults as subjects and mental or motor tasks for which the subjects themselves set the pace at which the tasks were performed, the general effect of the noise was negligible or was to increase the number of errors made and also to increase the amount of work accomplished (Refs, 2, 3, 4, 5, 6). Data obtained by Teichner et al. (Ref. 7) indicated that, at least while learning a visual discrimination task, a sudden change in the noise environment, either an increase or decrease in level, had a significant depressing effect upon the rate at which the task was learned.

It would appear likely from a consideration of these previous studies that the sonic boom might have the most negative effects, if it has any, upon the acquisition and performance of a paced task that requires a high degree of visual-hand coordination. Accordingly, the tests to be described below were designed as a pilot study to further explore the performance and skeletal muscular activity of a subject while performing such a task. Data were recorded as a function of exposure to a sonic boom and to a less-sudden noise (the flyover noise from a subsonic jet aircraft).

B. Objectives

The objectives of the study were to determine:

1. The extent and duration of the skeletal muscle response to sonic booms and subsonic jet aircraft noise in people other than college students.

2. The effects of simulated sonic booms and subsonic jet aircraft noise on a paced-tracing tasks.

II METHOD

A. Subjects

Male, professional and technical laboratory personnel, aged 31 to 44 years were subjects. All had normal hearing, and were free of physical disabilities which might affect the experimental results.

B. Stimuli

Sonic booms, generated by a simulator described in detail in Ref. 1, had an intensity of about 2.5 psf (as measured outdoors), a duration of about 270 ms, and an effective rise time of about 10 ms.

The second test noise was an indoor recording of the noise from a KC135B jet aircraft flying directly over a typical house at about a 500 foot altitude. It was presented, after appropriate attenuation, through a high fidelity loudspeaker directly above the subjects' heads. The fly-over noise had an intensity of 100 PNdB as measured in the test room, and a duration of 5.0 seconds. The intensity of the flyover noise increased at a rate of about 20 dB per second for about 2.5 seconds and decreased in intensity at the same rate. Tape loops made from the original recording of flyover noise were placed on a tape loop play-back device, which was controlled by sensing a translucent portion of the tape loop. This technique assured that a flyover noise of given duration and intensity would be presented to the subjects exactly as required.

C. Apparatus

The tracing apparatus was designed to simulate tasks requiring fine eye-hand coordination; it is described in greater detail in Ref. 1. For the purposes of this study the apparatus was modified so that the subject's movement about the outermost group of tracks (see Figure 1) was paced by lights which appeared in sequence, once every five seconds, in each of the corners of the board. The subject began the task with his stylus on the start line shown in Figure 1. When the lights in quadrant 1 were turned on he was instructed to move along the designated track at a rate such that when the lights in quadrant 2 turned on five seconds later (simultaneously the lights in quadrant 1 were extinguished) his stylus

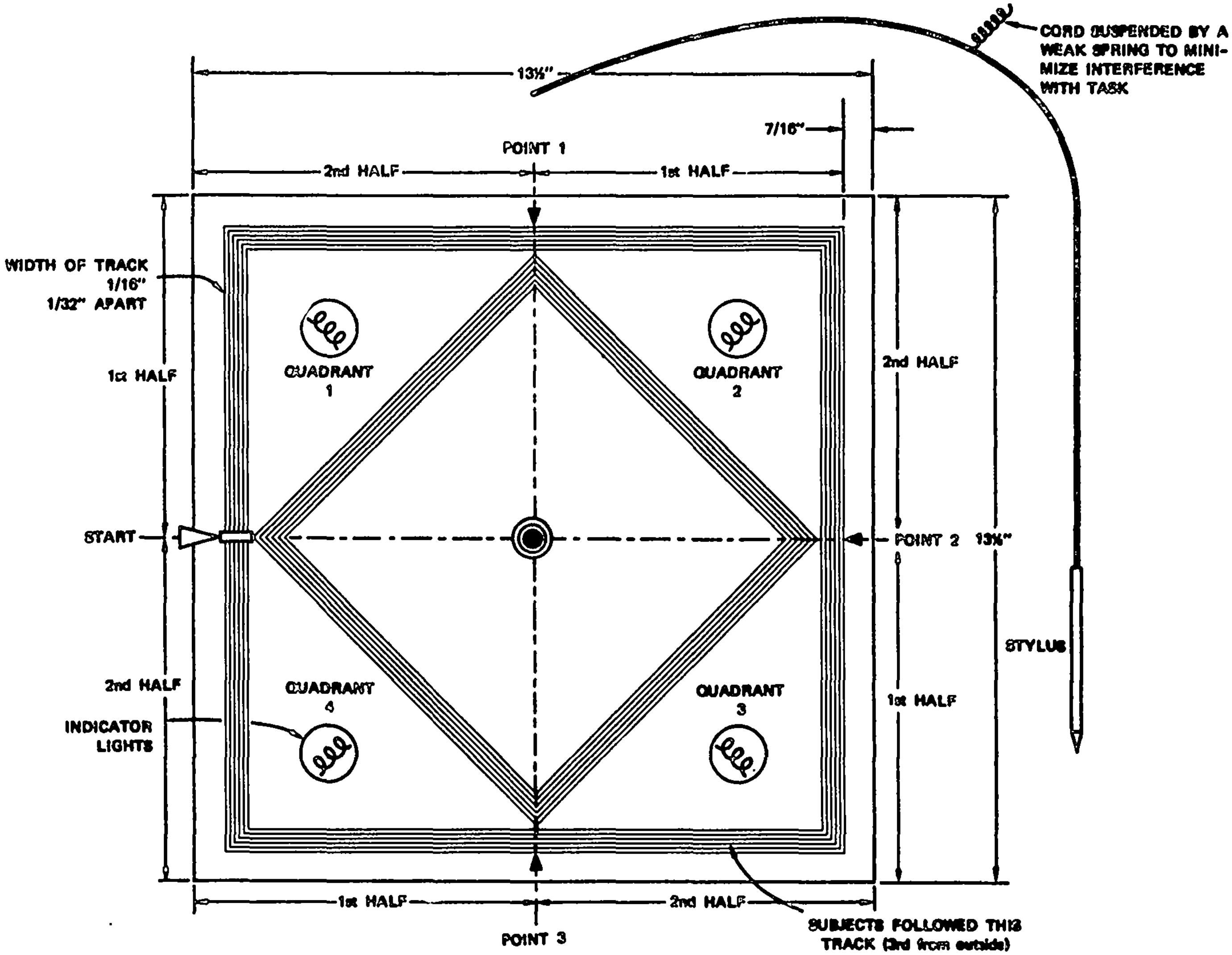

FIGURE 1 SCHEMATIC OF PACED TRACING APPARATUS

was to be at point 1. Without stop he was to move through quadrant 2, so that 5 seconds later, that is when the lights in quadrant 3 were turned on, he would be at point 2, and so on about the board until he returned to the start line. There he would wait until the lights in quadrant 1 were turned on, at which time he was to move about the board again, as indicated above. If for some reason the subject was ahead of the pace, he was instructed to hold his stylus above the point and wait for the light in the next quadrant. If he was behind the pace, he was told to lift his stylus and move rapidly to the appropriate point and begin tracing from that point.

Once around the board was called a trial. Trials of twenty seconds each were separated by rest periods of about five seconds, and eight trials constituted a run. Runs were divided by rest periods of 2 or 3 minutes, and a session consisted of eight runs. On any day the subjects were tested during a single session of about 50 minutes duration.

D. Response Measures

Time-on-track (TOT) was the performance measure obtained. It was recorded by means of two digital counters with accuracies of ± 1 ms. Booms were scheduled to occur when the subject was at or near the midpoint (i.e., the corners) of any quadrant; the two counters were used to measure time-on-track (TOT) before and after the boom.

It was anticipated that the effects of booms, being of about 0.27 second duration, were likely to be confined to performance during the half-quadrant (see Figure 1) immediately following the boom, but the effects of the flyover noises, being of about 5.0 seconds duration, were likely to be seen throughout the quadrant coincidental with the flyover. Accordingly, the effects of booms on the tracing task were assessed by comparing the sum of times-on-track (TOT) of the half quadrant during which the boom occurred with (1) the sum of TOT obtained for that half quadrant during a control session (to be later identified as E 1), or (2) the sum obtained on a comparable half quadrant of the run in question but during the tracing of which no boom occurred. Similarly, the effects of the flyover noise were assessed by comparing the sum of the TOT's of the two halves of the quadrant during which flyover noise occurred with (1) the sum of TOT's obtained for those two halves during session E 1, or (2) the sum obtained on a comparable two halves during the run in question but during the tracing of which no flyover noise occurred.

That tracing performance was approximately equal on the two halves of the quadrants is shown in Table I. The data in Table I were obtained when the subjects were not exposed to booms or flyover noise.

Table I

NUMBER AND PERCENTAGE OF TRIALS IN WHICH TIME-ON-TRACK OF DIFFERENT DURATIONS WERE OBTAINED FOR THE FIRST AND SECOND HALVES OF FOUR QUADRANTS (No Sonic Booms or Flyover Noises Were Present)

Quadrant Halves	Number (N) and Percent	Time-on-Track Interval (seconds)*			
		2.50 - 2.26	2.25 - 1.76	1.75 - 1.26	1.25 - 0.75
First	N	242	169	64	6
	%	(50.3)	(35.1)	(13.3)	(1.2)
Second	N	214	200	56	11
	%	(44.5)	(41.6)	(11.6)	(2.3)

X^2 = 6.327, 3 df (degrees of freedom), $0.10 > p > 0.05$, N.S. (not significant)

* The truncated distribution of times-on-track precluded use of parametric statistics. Consequently, the range of possible times-on-track was divided into the intervals shown, and the frequency of measures (times-on-track) in each interval was tallied to develop this and the tables which follow.

E. Comparability of Groups

The numbers and percentages of occurrences of TOT's in the different intervals listed in Table II show that the four groups of subjects were approximately equal to each other, on the average, with respect to performance on the tracing task. The relevant TOT for group 4 is for full quadrants rather than halves and, therefore, the intervals for group 4 have twice the duration of that used for scoring the performance of groups 1, 2, and 3. As will be outlined below, groups 1, 2, and 3 were used in evaluating the effects of booms, and group 4 the effects of flyover noise. (See scoring procedures described in Section D above.)

Table II

NUMBER AND PERCENTAGE OF TRIALS IN WHICH DIFFERENT DURATIONS OF TIME-ON-TRACK WERE OBTAINED DURING THE SECOND HALVES OF FOUR QUADRANTS FOR GROUPS 1, 2, AND 3 AND DURING FULL QUADRANTS FOR GROUP 4
(No Sonic Booms or Flyover Noises Were Present)

Group	Number (N) and Percent	Time-on-Track Interval (seconds)			
		2.5 - 2.26	2.25 - 1.76	1.75 - 1.26	1.25 - 0.75
1	N	41	36	16	2
	%	(43.2)	(37.9)	(16.8)	(2.1)
2	N	87	84	16	5
	%	(45.3)	(43.8)	(8.3)	(2.6)
3	N	78	76	36	2
	%	(40.6)	(39.6)	(18.8)	(1.0
		5.0 - 4.51	4.50 - 3.51	3.50 - 2.51	2.50 - 1.50
4	N	39	47	10	0
	%	(40.6)	(49.0)	(10.4)	(0.0)

$X^2 = 14.949$, 9 df, N.S.

F. Muscle Action Potentials

Bipolar electromyographic (EMG) activity in the trapezius muscle was recorded on a Honeywell Visicorder. The trapezius muscle, which is located in the shoulder, was used in order to minimize "cross talk" found in muscles in the non-active forearm homologous to those in the arm used for tracing, and the contralateral trapezius was used to eliminate artifacts due to movement of the arm and shoulder used in the task. In fact, to minimize movement in the non-used arm and shoulder, that arm rested on a rubber pad and the electrical leads coming from that shoulder were taped to the subject's wrist. The raw EMG signal was integrated over one-half second intervals and the results recorded on the Visicorder by a pulse whose amplitude was proportional to the energy generated by the muscle during the interval.

G. Procedure

Five sessions of about one hour each were devoted to training of each of twelve subjects. During these training sessions one of the experimenters was in the test room with the subject monitoring his performance, and providing instructions as described in C, above. In addition, during the rest periods, the subject was informed about his performance with respect to TOT. Occasionally during the experimental tests, the subjects were similarly monitored to assure that their performance was up to standard.

On the basis of the performance of the subjects during the last training sessions, the subjects were divided into four groups such that the median TOT of the four groups were approximately equal. That the matching procedure was effective is demonstrated by the performance data and the supporting insignificant Chi-square (X^2) presented in Table II, which compares the time-on-track (TOT) frequency in 4 scoring intervals, obtained by the four groups on the sixth day (session E 1) of testing. The data, in the table, are a random selection of TOTs obtained during the second halves of the quadrants (group 1-3) or complete quadrants (group 4), and correspond to portions of the quadrants when the effects of noise are anticipated. It should be noted that TOT of less than about 0.75 second, or 1.50 seconds in the case of group 4, was not obtained, except in rare instances of equipment malfunction when times of zero (0) were obtained. These spurious data were eliminated from consideration, and times of less than 0.75 second are not included in the tables of this report.

The conditions for testing the four groups were: (1) Boom and Tracing, (2) Tracing Only, (3) Boom Only, and (4) Flyover Noise and Tracing. After the five training sessions data taking commenced; the groups were tested for an additional five sessions under the conditions indicated in Table III.

Eight simulated sonic booms and flyovers were presented during each of the required sessions (E 2, E 3, E 4, and E 5). They were presented at random with the restrictions: (1) that for any group at least one stimulus be presented in each of the quadrants, (2) that for any subject within a group two stimuli occur during two successive quadrants, and (3) that two stimuli occur during the rest periods between runs but two stimuli should not occur during the same rest period. The order of stimulation for each subject for each of the sessions was different, with counterbalancing between subjects within a group, insofar as possible. Counterbalancing was used to preclude possible biases in the data due to several stimuli occurring during the first or last circuits of the runs.

Table III

EXPERIMENTAL DESIGN

Group	Training Sessions					Experimental Test Sessions				
	1	2	3	4	5	E 1	E 2	E 3	E 4	E 5
1 Boom + tracing task	Tracing* EMG†	Tracing EMG	Tracing EMG	Tracing EMG	Tracing EMG	Tracing EMG	Tracing EMG Booms‡	Tracing EMG Booms	Tracing EMG Booms	Tracing EMG Booms
2 Tracing task only	Tracing EMG	Tracing EMG	Tracing EMG	Tracing EMG	Tracing EMG	Tracing EMG	Tracing EMG	Tracing EMG	Tracing EMG	Tracing EMG Booms
3§ Boom only	Tracing EMG	Tracing EMG	Tracing EMG	Tracing EMG	Tracing EMG	Tracing EMG	EMG Booms	EMG Booms	EMG Booms	EMG Booms
4 Flyover + tracing task	Tracing EMG	Tracing EMG	Tracing EMG	Tracing EMG	Tracing EMG	Tracing EMG	Tracing EMG Flyovers**	Tracing EMG Flyovers	Tracing EMG Flyovers	Tracing EMG Flyovers

* Time on track performance measure.

† Electromyographic activity-measure of "startle" response.

‡ Boom intensity = 2.5 psf, duration = 270 ms, effective rise time = 10 ms, as measured outdoors.

§ During sessions E 2, E 3, E 4, and E 5, Group 3 read light materials such as newspapers and magazines.

** Flyover intensity = 125 PNdB, duration = 5 seconds, as measured outdoors.

To be sure, the subjects were not told at any time whether they would be stimulated, but in order to maintain motivation, they were informed that session 5 was the last of the training sessions.

III RESULTS

A. Electromyographic Response to Sonic Booms and Flyover Noise

That more pronounced EMG startle responses were obtained to sonic booms than flyover noise is shown in Figure 2. Because of differences in baseline muscle tone the mean integrated muscular activity level for each subject over two one-half second periods before and two one-half second periods after any stimulation was subtracted from the mean level obtained during that stimulation, and these individual change scores were averaged to obtain the mean difference scores of the groups. Increases in muscular activity were coincidental with the onset and duration of the sonic booms (as indicated by Visicorder traces) and, insofar as the output of the muscular activity integrator was concerned, lasted a maximum of one second. Thus, for booms, the integrator output over one second (or two pulses) was averaged to obtain a measure of muscular response during booms. With respect to the response to flyovers, the muscular response was not as clear cut, since the responses did not occur with a regularity similar to that found for booms, nor were the observed EMG changes uniformly coincidental with some amplitude or time aspect of the flyover trace. Thus, the integrator output over a five second interval, or ten pulses (equal to the duration of the flyover noise) was averaged to obtain the muscular response during flyovers.

With respect to Figure 2, it should be noted that during session E 1, before any stimuli were presented, the responses of the four groups were similar, i.e., the four data points are spread over a range of about one unit. Thereafter, however, the groups (1 and 3) who heard booms show a continuing increase in muscle tension. In contrast, groups 2 and 4 maintained relatively constant levels of muscular tension throughout sessions E 1 to E 4, varying a maximum of about 0.6 units from session E 1 levels. The large increase (about 3.7 units) in muscular tension observed in group 2 during session E 5 relative to the level of session E 4 appears to be attributable to the incidence of booms which were absent prior to session E 5. However, an explanation for the 2.8 unit increase shown for group 3 during session E 5 relative to the level during session E 4 is not readily available. Between sessions E 1 and E 4 the muscular responses of group 3 increased slightly more than 1 unit and insofar as session E 3 and 4 are concerned, appeared to have leveled off. Thus, only a small

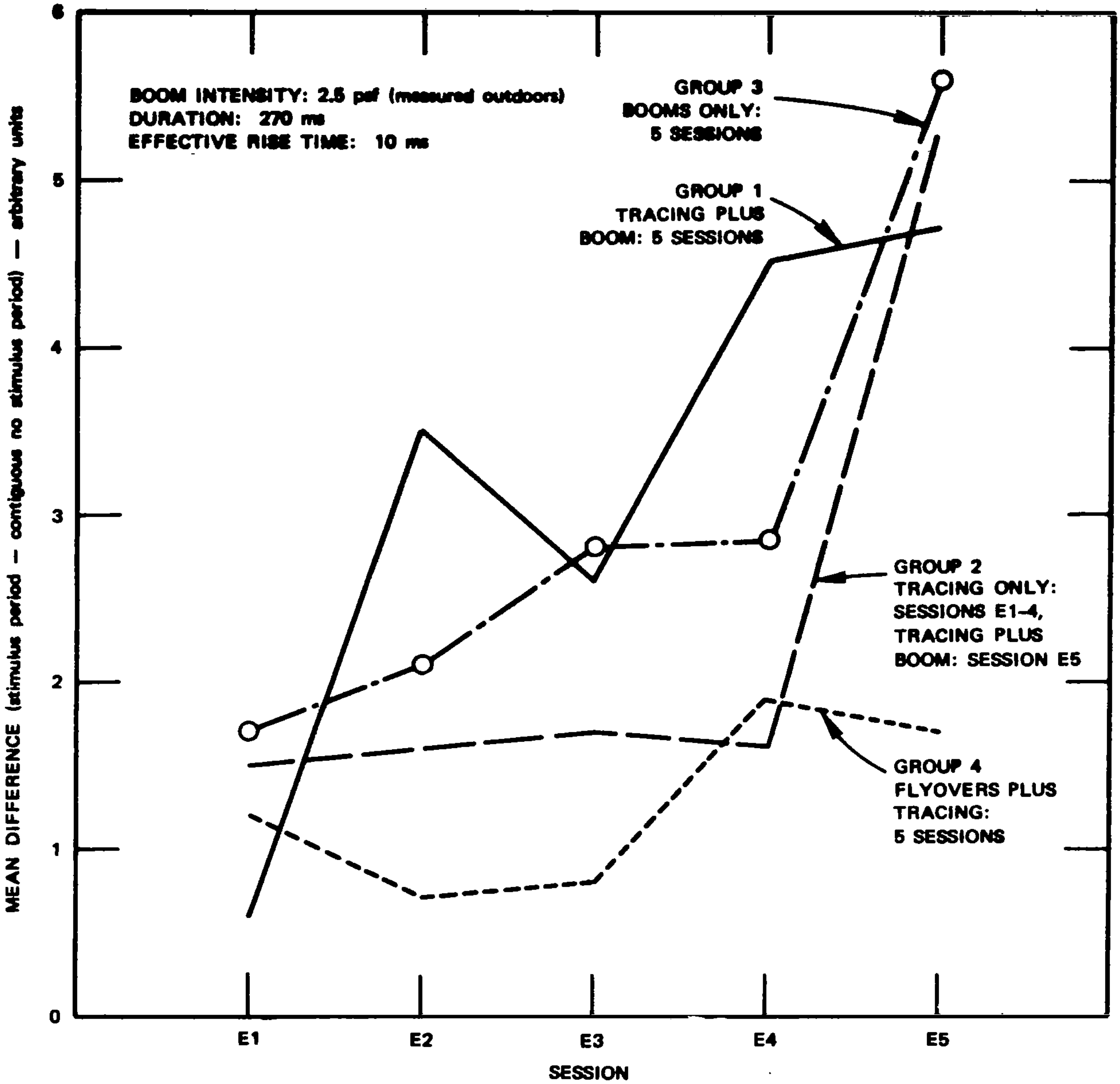

FIGURE 2 NORMALIZED ELECTROMYOGRAPHIC RESPONSE IN TRAPEZIUS MUSCLE TO SIMULATED SONIC BOOMS AND JET FLYOVER NOISE DURING A TRACING TASK

increase in muscular response of about one-half unit might have been expected in group 3 between sessions E 4 and E 5, not the 2.8 units observed.

In line with the findings of Davis, et al. (Ref. 8, p 25), who report increases in muscular responses as being proportional to base line muscular potentials, the base line levels of the subjects in Group 3 during session E 4 and E 5 were compared. It was found that the mean base line potentials of Group 3 during session E 4 were higher than those during session E 5 (10.99 mm versus 8.44 mm). Clearly, the data presented here are at variance with those of Davis et al., cited above.

Statistically, the group differences illustrated in Figure 2 were found to be significant, as is shown in the analysis of variance summary presented in Table IV.

Table IV

SUMMARY ANALYSIS OF VARIANCE OF ELECTROMYOGRAPHIC RESPONSES TO NOISE DURING A PACED TRACING TASK

Source of Variance	Mean Square Variance	df	F	Significance Level
Groups	86.3134	3	16.3914	$p < 0.01$
Sessions	281.5899	4	53.4754	$p < 0.01$
Groups x session (interaction)	50.7159	12	9.6312	$p < 0.01$
Errors (within)	5.2658	1218		
Total	6.7968	1237	1.2907	$p < 0.01$

Changes in muscular activity to booms and flyovers occurring during the rest periods (shown in Figure 3) are consistent with those observed during the performance periods, that is, the groups (1 and 3) stimulated by booms tended to have greater muscular responses than did the group (4) which heard the jet flyover noise or the group (2) which did not hear any noise during session E 1 to E 4. In Figure 3, however, it should also be noted that groups 1, 2, and 4 showed muscular responses of greater variability than was the case during the performance trials. This difference is attributable largely to the fact that during the rest periods there was

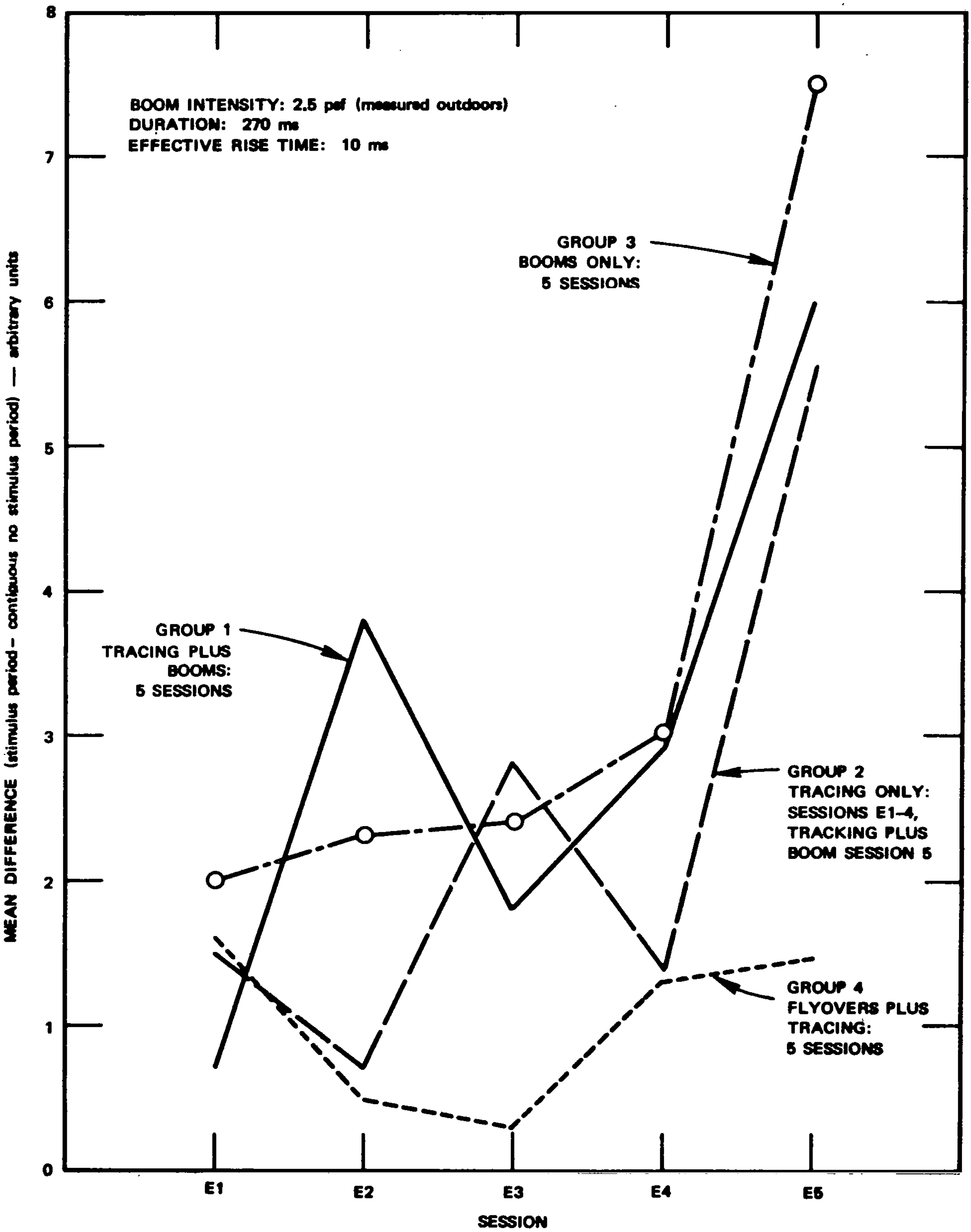

FIGURE 3 NORMALIZED ELECTROMYOGRAPHIC RESPONSE IN TRAPEZIUS MUSCLE TO SIMULATED SONIC BOOMS AND JET FLYOVER NOISE DURING REST PERIODS

more body movement due, for example, to subjects shifting in their seats, stretching, and so forth, than during the performance periods when activity was confined to the tracing task. It may also be that the startle responses to booms during rest periods were accompanied by gross body movement. Unfortunately the test room did not have a viewing port nor did the experimenter observe the subjects directly during the rest periods which included booms, so that evidence as to how much body movement accompanied the booms is not available.

On the basis of the findings of Davis, et al. (Ref. 8) greater electromyographic responses to stimuli are to be expected when muscular potentials are higher, that is when extraneous movements may or are occurring. Consistent with this reasoning, the responses of group 3, who were unable to distinguish between the rest and performance periods but read throughout the session, show the same slowly increasing change in EMG response level between sessions E 1 and E 4 as was seen during the "performance" periods (see Figure 2). That the variability of responses during the rest period is probably due to the extraneous motor activity that occurred during the rest periods and not exclusively due to booms is also evident in the responses of Group 2. Group 2, who heard no booms during sessions E 1 and E 4, showed a range of about 2 units in muscular activity during the rest periods of the first four sessions compared to a range of about 0.2 of a unit during the performance periods of the same sessions.

The results of the statistical analysis of the data illustrated in Figure 3, are presented as an Analysis of Variance Summary in Table V.

Table V

SUMMARY ANALYSIS OF VARIANCE OF THE ELECTROMYOGRAPHIC RESPONSES TO NOISE DURING THE REST PERIODS

Source of Variance	Mean Square Variance	df	F	Significance Level
Groups	37.2500	3	6.4457	$p < 0.01$
Sessions	118.7629	4	20.5508	$p < 0.01$
Group x session (interaction)	26.1935	12	4.5325	$p < 0.01$
Error (within)	5.7790	343		
Total	7.9657	362	1.3784	$p < 0.01$

B. Effects of Startle to Noise on Performance

1. Group 1--Tracing Task with Sonic Booms

Since electromyographic startle responses to booms were closely related in time with the occurrence of the booms, it might be anticipated that the effects of startle on tracing performance should be correlated in time with the startle response. The data show this to be the case. Table VI permits comparison of the TOT obtained during the first-half of quadrants with the TOT obtained during the second-half of quadrants of only those quadrants in which booms occurred. (Booms, it will be recalled, occurred when the subject had traced through about half of the quadrant. Thus, the effect of startle is likely to be seen during his performance on the second half of the quadrant.) The effect of startle was an increase (from 4.1 percent to 17.8 percent) in the number of trials in which TOT was in the 0.75-1.25 second interval, and a decrease in the number of trials in which TOT was in the 1.26 to 2.25 second interval.

Table VI

NUMBER AND PERCENTAGE OF TRIALS IN WHICH TIME-ON-TRACK OF DIFFERENT DURATIONS WERE OBTAINED DURING BOOMS WITH GROUP 1

Quadrant Segment	Number (N) and Percent	Time-on-Track Interval (seconds)			
		2.50 - 2.26	2.25 - 1.76	1.75 - 1.26	1.25 - 0.75
First half	N	29	24	17	3
	%	(39.7)	(32.9)	(23.3)	(4.1)
Second half	N	30	20	10	13
	%	(41.1)	(27.4)	(13.7)	(17.8)

$X^2 = 8.445$, 3 df, $0.05 > p > 0.025$

That no systematic differences in performance on the first and second halves of quadrants without booms occurring is shown in Figure 4. It is sufficient to note here that the startle response did not affect performance negatively during quadrants subsequent to those in which booms occurred, i.e., about 2.5 seconds later. Mean performance on trials

16

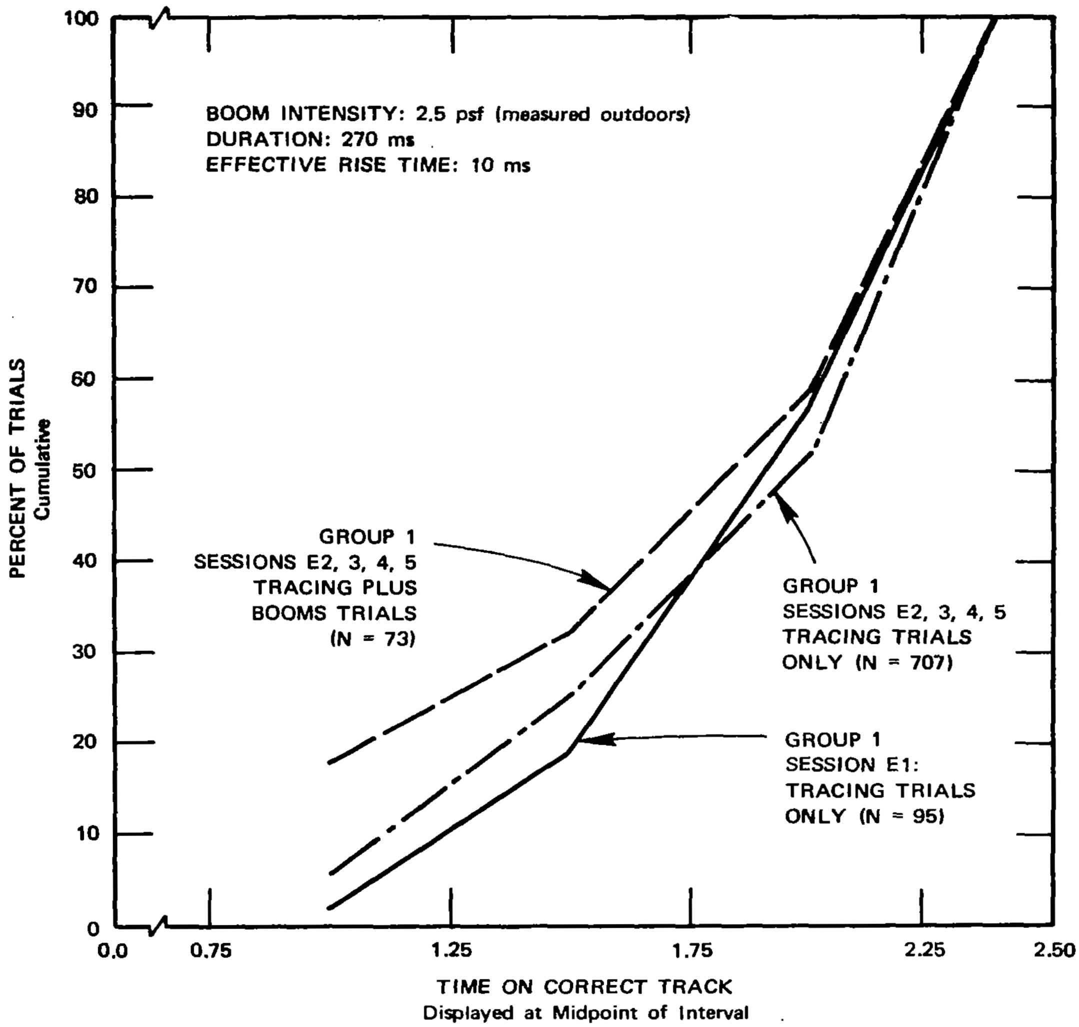

FIGURE 4 EFFECT OF SIMULATED SONIC BOOMS ON TRACING PERFORMANCE DURING SPECIFIC TRIALS CONTAINING BOOMS

in which booms occurred during two successive quadrants was analysed using a "fixed effects" model of the Analysis of Variance.* The results of this analysis, illustrated in Figure 5, indicate that booms occurring in one quadrant had little negative effect on performance during subsequent

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* Hays (Ref. 9, pp 378-380) suggests that the assumptions of the Analysis of Variance violated in this case have little effect upon the F and the inferences made. In addition, to assume that differences in means not variances were the reason for the statistically significant effect, an F_{max} test (Ref. 10, pp 191-195) showed statistically insignificant differences (F_{max} = 2.598, k = 4, n = 12, N. S.) between the four half-quadrant variances.

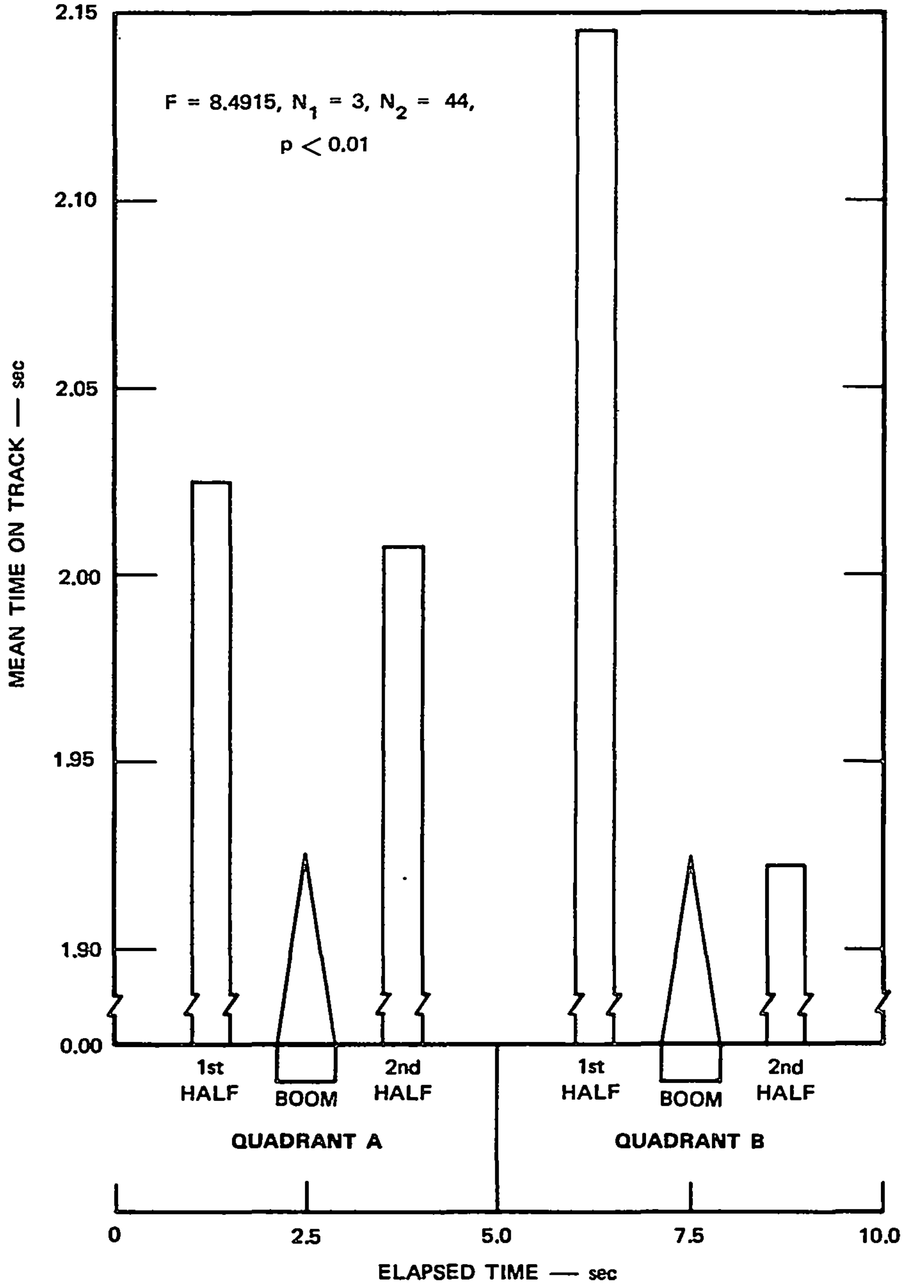

FIGURE 5 EFFECT OF SONIC BOOMS OCCURRING IN THE LATTER HALF OF ONE QUADRANT ON PACED TRACING PERFORMANCE IN THE FIRST HALF OF THE SUBSEQUENT QUADRANT

quadrants. If anything, an improvement in performance is suggested. This is not unlike the results of Broadbent (Ref. 2), Woodhead (Refs. 11 and 12), and others which show that immediately following an intermittant noise there is a decrease in performance and then, for a brief period a subsequent improvement in performance.

The slight increase (about 8 percentage points on the average) in the number of trials having relatively short TOT (times of 0.75 to 1.75 seconds) during sessions E 2, E 3, E 4, and E 5 without booms compared to the percentage of trials in which similar TOTs were obtained during session E 1, suggests that booms have a slight but statistically insignificant effect on tracing performance during trials in which booms did not occur. This finding is illustrated in Figure 5, and the statistical analyses are shown in Table VII.

A statistically significant effect due to sessions was found. Surprisingly, the subjects did not adapt to booms, but, as was found with respect the electromyographic response (Figure 2), the subjects of group 1 showed progressively poorer performance between sessions E 1 and E 5. A small initial improvement in tracing performance during the first session with booms (E 2) can be seen in Figure 6, but thereafter the group showed an increasing percentage of scores in the 0.75 to 1.75 second interval, clearly indicating a degradation of average performance. The overlap of performance during session E 5 into that of session E 4 and E 3 probably is of little importance since it is due to the absence in session E 5 of tracing times in the 1.25-1.75 second interval, as is shown in Table VIII. That the effect of the sessions was probably due to booms and not to motivational factors associated with prolonged practice on a motor task, will be demonstrated below by comparison of the performance of group 1 with that of group 2.

2. Group 2--Tracing Task Only

In Group 2 no statistically significant changes in tracing performance were found between sessions E 1 to E 4, during which booms did not occur; the supporting statistical data are summarized in Table IX. In addition, when booms did occur during session E 5 a suggestive, but statistically insignificant (see Table X) decrease of TOT was noted and is illustrated as the left-most line in Figure 7. Finally, note also in Figure 7 that after four sessions of consisting only of tracing trials, the onset of booms resulted in a slight improvement in performance in trials in which the boom did not occur (Curve labeled Session E 5: Tracing Trials only).

Table VII

NUMBER AND PERCENTAGE OF TRIALS IN WHICH DIFFERENT DURATIONS OF TIME-ON-TRACK WERE OBTAINED DURING COMBINATIONS OF FIVE SESSIONS WITH AND WITHOUT BOOMS WITH GROUP 1

Sessions	Conditions	Number (N) and Percent	Time-on-Track (seconds)			
			2.50 - 2.26	2.25 - 1.76	1.75 - 1.26	1.25 - 0.75
E_1	Tracing task	N %	41 (43.2)	36 (37.9)	16 (16.8)	2 (2.1)
[A] E_2, E_3, E_4, E_5	Tracing task No boom trials	N %	337 (47.7)	185 (26.2)	145 (20.5)	40 (5.7)
[B] E_2, E_3, E_4, E_5	Tracing task + Boom trials	N %	30 (41.1)	20 (27.4)	10 (13.7)	13 (17.8)

$X^2_{(E_1 \text{ vs. } [A])} = 7.120$, 3 df, N.S.

$X^2_{(E_1 \text{ vs. } [B])} = 13.070$, 3 df, $0.005 > p > 0.001$.

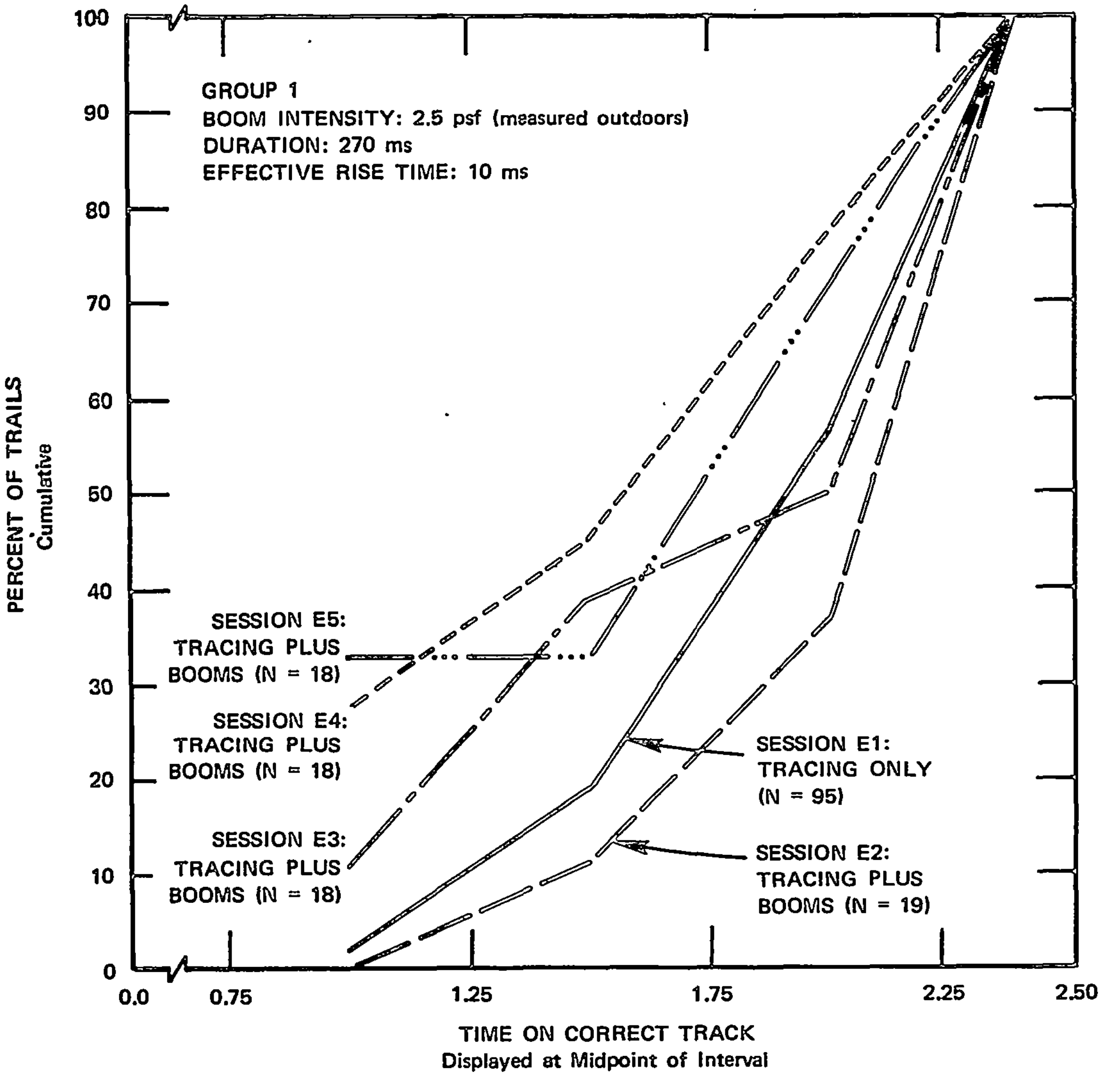

FIGURE 6 EFFECT OF SIMULATED SONIC BOOMS ON PACED TRACING PERFORMANCE DURING FIVE SESSIONS

3. Boom versus No-Booms--Groups 1 and 2

On the basis of the evidence presented to this point, it appears that sonic booms resulted in electromyographic startle responses which progressively increased in amplitude throughout the four test sessions, and that degradation of tracing performance was related to increases in startle response amplitudes. That skill level on the task did little to alter the effects of muscular tension responses on the task is illustrated in Figure 8, which compares the performance of Groups 1 and 2 during the session in which booms were first heard. (Each subject of Group 2 practiced the task during session E 2 to E 4, and thus had 256 more practice trials than the subjects of Group 1 before hearing the first boom during

Table VIII

NUMBER AND PERCENTAGE OF TRIALS IN WHICH DIFFERENT DURATIONS OF TIME-ON-TRACK WERE OBTAINED DURING FIVE SESSIONS WITH GROUP 1

Session	Condition	Number (N) and Percent	Time-on-Track Interval (seconds)			
			2.50 - 2.26	2.25 - 1.76	1.75 - 1.26	1.25 - 0.75
E 1	Tracing task	N %	41 (43.2)	36 (37.9)	16 (16.8)	2 (2.1)
E 2	Tracing task + Boom trials	N %	12 (63.2)	5 (26.3)	2 (10.5)	0 (0.0)
E 3	Tracing task + Boom trials	N %	9 (50.0)	2 (11.1)	5 (27.8)	2 (11.1)
E 4	Tracing task + Boom trials	N %	4 (22.2)	6 (33.3)	3 (16.7)	5 (27.8)
E 5	Tracing task + Boom trials	N %	5 (27.8)	7 (38.9)	0 (0.0)	6 (33.3)

$X^2 = 37.697$, 4 df, $p < 0.001$

Table IX

NUMBER AND PERCENTAGE OF TRIALS IN WHICH TIME ON TRACK OF DIFFERENT DURATIONS WERE OBTAINED DURING SESSIONS E 1 TO E 4 WITH GROUP 2

Session	Condition	Number (N) and Percent	Time-on-Track Intervals (seconds)			
			2.50 - 2.26	2.25 - 1.76	1.75 - 1.26	1.25 - 0.76
E 1	Tracing task	N	87	84	16	5
		%	(54.3)	(43.8)	(8.3)	(2.6)
E 2	Tracing task	N	91	78	19	4
		%	(47.4)	(40.6)	(9.9)	(2.1)
E 3	Tracing task	N	91	78	22	1
		%	(47.4)	(40.6)	(11.5)	(0.5)
E 4	Tracing task	N	86	89	29	1
		%	(42.0)	(43.4)	(14.1)	(0.5)

$X^2 = 9.206$, 9 df, N.S.

Table X

NUMBER AND PERCENTAGE OF TRIALS IN WHICH TIME-ON-TRACK OF DIFFERENT DURATIONS WERE OBTAINED DURING SESSIONS WITH AND WITHOUT SONIC BOOMS WITH GROUP 2

Session	Condition	Number (N) and Percent	Time-on-Track Intervals (seconds)			
			2.50 - 2.26	2.25 - 1.76	1.75 - 1.26	1.25 - 0.76
E 1, E 2, E 3, E 4	Tracing task	N %	355 (45.5)	329 (42.1)	86 (11.0)	11 (2.4)
E 5	Tracing task + Boom trials	N %	4 (23.5)	10 (58.8)	2 (11.8)	1 (5.9)

$X^2 = 5.093$, 3 df, N.S.

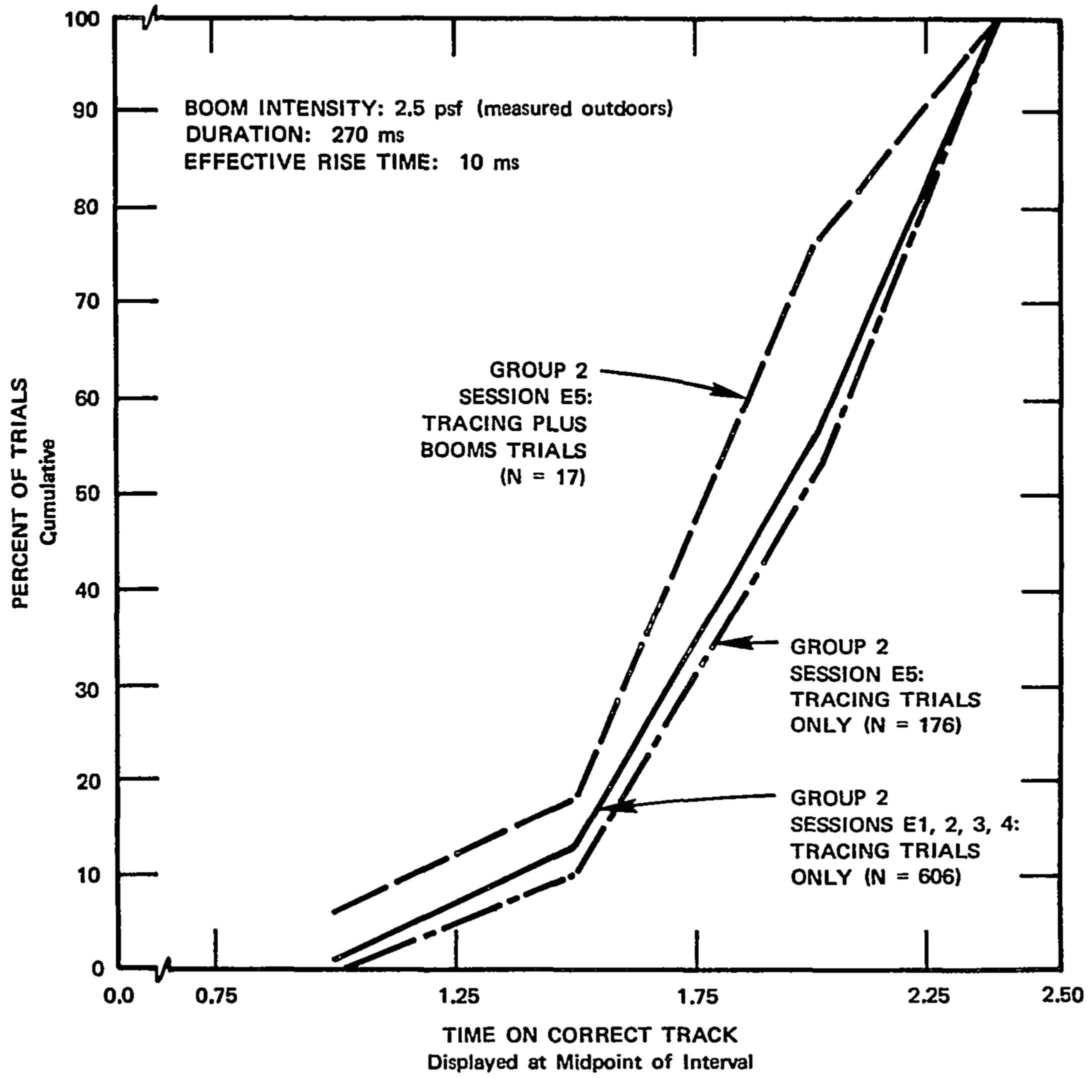

FIGURE 7 EFFECT OF SIMULATED SONIC BOOMS ON PERFORMANCE ON A WELL PRACTICED TRACING TASK

session E 5.) It can be seen that the effect of startle to booms is relatively small (the median TOT of Group 2 decreased about 0.25 second, and that of Group 1 about 0.06 second) and statistically insignificant (see Table XI). Note, however, that the effect, regardless of its statistical significance, appears to be greater on the well practiced task, and related to the magnitude of the muscular startle response: Group 2 showed an average electromyographic response of about 5.3 units to booms during session E 5, while Group 1 showed an average response of about 3.5 units to booms during session E 2 (see Figure 2).

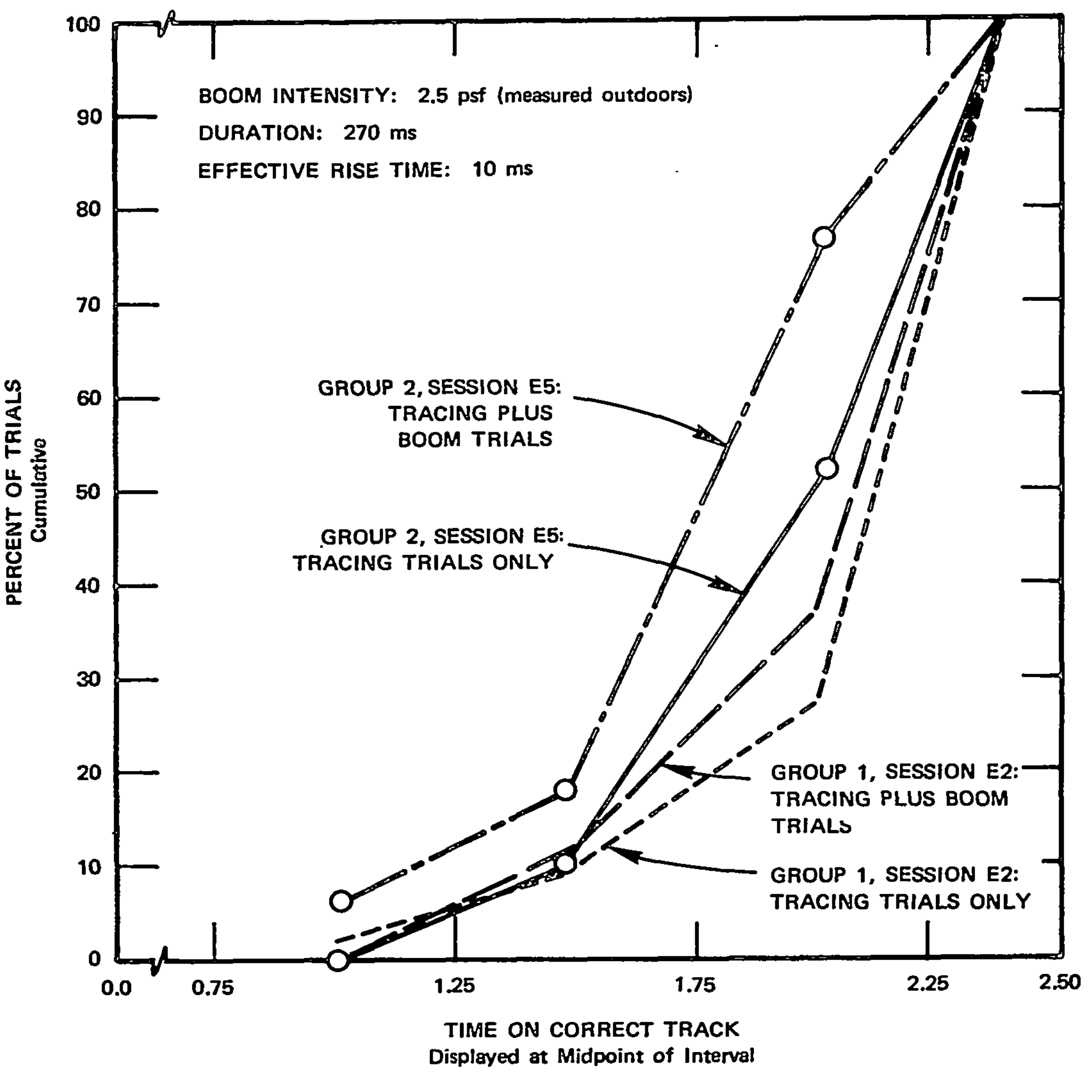

FIGURE 8 EFFECT OF SIMULATED SONIC BOOMS ON THE PERFORMANCE OF A PACED TRACING TASK WITH DIFFERENT AMOUNTS OF PRACTICE

4. Group 4--Tracing Task with Flyover Noise

Group 4 had relatively small EMG increases (an average of 1.3 units) to flyover noises during session E 2 to E 5 compared, for example, to the responses of group 1 to booms (an average of 3.8 units). In light of this relatively small startle response, it might be anticipated that the flyover noise would have little effect on the tracing performance of group 4. Indeed, group 4 showed statistically insignificant changes in tracing performance during session E 1 without flyover noise compared to the trials with noise of sessions E 2 to E 5, as is demonstrated in Table XII. In Figure 9 the performance of group 4 during session E 1 and sessions E 2 to E 5, during trials with and without flyover noise, are plotted to

Table XI

NUMBER AND PERCENTAGE OF TRIALS IN WHICH DIFFERENT DURATIONS OF TIME-ON-TRACK WERE OBTAINED DURING SESSIONS IN WHICH BOOMS WERE FIRST PRESENTED TO GROUPS 1 AND 2

Group	Session	Condition	Number (N) and Percent	Time-on-Track Interval (seconds) 2.50 - 2.26	2.25 - 1.76	1.75 - 1.26	1.25 - 0.75
1*	E 2	Tracing trials	N	122	31	10	4
			%	(73.1)	(18.6)	(6.0)	(2.4
	E 2	Tracing + Boom trials	N	12	5	2	0
			%	(63.2)	(26.3)	(10.5)	(0.0)
2†	E 5	Tracing trials	N	84	75	17	0
			%	(47.7)	(42.6)	(9.6)	(0.0)
	E 5	Tracing + Boom trials	N	4	10	2	1
			%	(23.5)	(58.8)	(11.8)	(5.9)

* X^2 = 1.693, 3 df, N.S.

† X^2 = 3.016, 3 df, N.S.--Hays (9, pp 592-7, and Ref. 10 10, p 107) indicates that, in cases of more than 2 degrees of freedom, a maximum of 20 percent of the cells can have expected frequencies of about one without significant effect upon the computed Chi-Square. In this study when this rule was not met, rather than combining TOT intervals, the Chi-Square was computed without regard to the cells with expected frequencies of less than one, but the Chi-Square significance table was entered with the initial degree of freedom. Effectively it is assumed that the expected and observed frequencies in the cells in question were zero. The result of this procedure is that a larger computer Chi-Square value is required to attain a given level of significance than would be the case if the TOT intervals were combined and the significance table entered with the resultant reduced number of degrees of freedom.

Table XII

NUMBER AND PERCENTAGE OF TRIALS IN WHICH DIFFERENT DURATIONS OF TIME-ON-TRACK WERE OBTAINED DURING FIVE SESSIONS WITH GROUP 4

Session	Condition	Number (N) and Percent	Time-on-Track Intervals (seconds)			
			5.00 - 4.51	4.50 - 3.51	3.50 - 2.51	2.50 - 1.51*
E 1	Tracing task	N %	39 (40.6)	47 (49.0)	10 (10.4)	0 (0.0)
E 2	Tracing task + Flyover trials	N %	7 (39.0)	10 (55.6)	1 (5.6)	0 (0.0)
E 3	Tracing task + Flyover trials	N %	6 (33.3)	7 (39.0)	5 (27.8)	0 (0.0)
E 4	Tracing task + Flyover trials	N %	9 (50.0)	9 (50.0)	0 (0.0)	0 (0.0)
E 5	Tracing task + Flyover trials	N %	4 (22.2)	12 (66.7)	22 (11.1)	0 (0.0)

X^2 = 10.897, 12 df, N.S.

* See note at the bottom of Table XI.

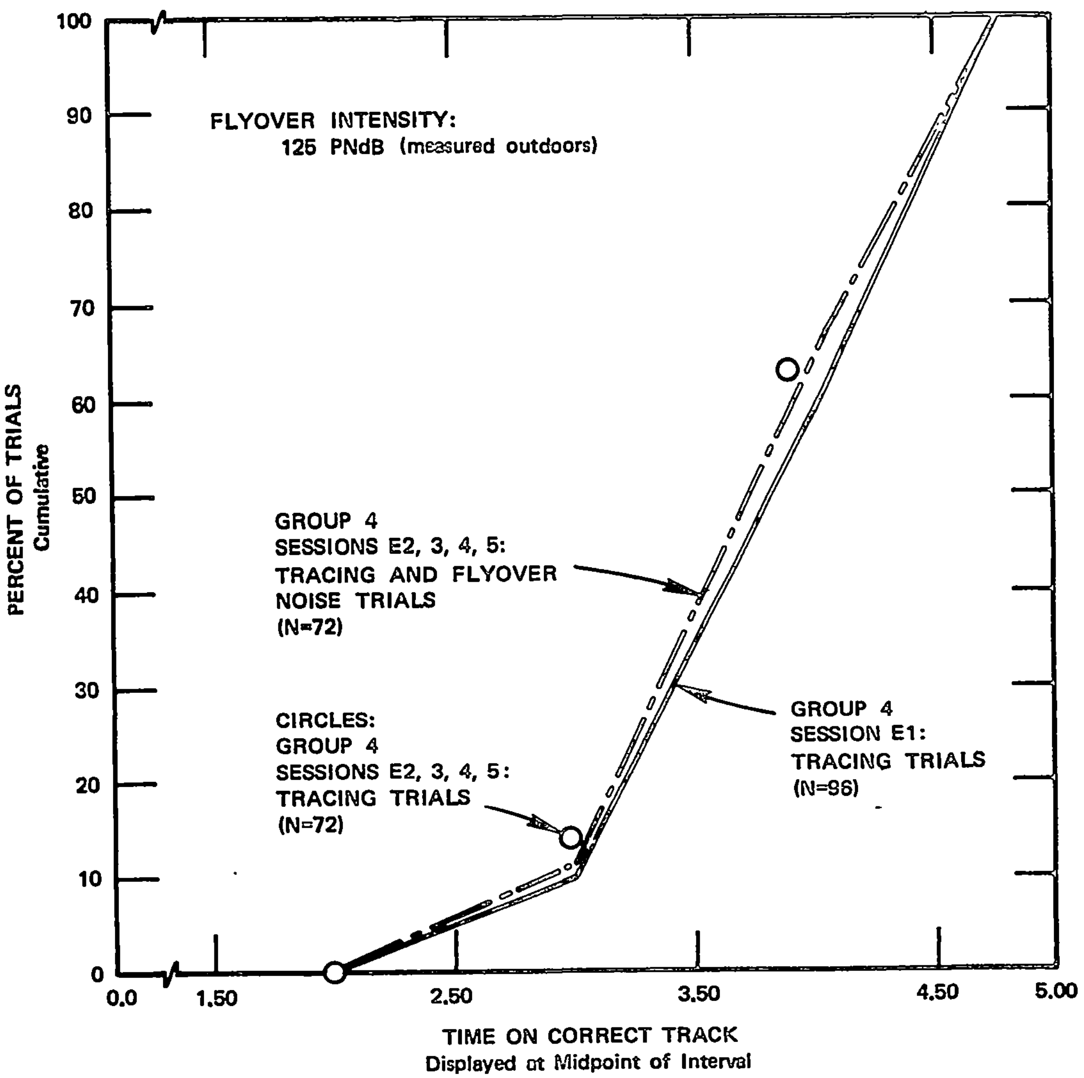

FIGURE 9 EFFECT OF SUBSONIC JET FLYOVER NOISE ON A PACED TRACING TASK

illustrate the small changes in TOT observed. It is clear from the figure that statistically significant differences are unlikely to be found. That such was the case is shown in Table XIII.

5. Booms Versus Flyover--Groups 1 and 4

In contrast to the detrimental effect of sonic booms on tracing performance, flyovers did not degrade tracing performance. Figure 10 illustrates the relative effects of booms and flyovers on TOT during the specific trials containing the stimuli as compared to trials in the same sessions which did not contain noise. Clearly, flyovers had little effect on

Table XIII

NUMBER AND PERCENTAGE OF TRIALS IN WHICH DIFFERENT DURATIONS OF TIME-ON-TRACK WERE OBTAINED DURING COMBINATIONS OF FIVE SESSIONS WITH AND WITHOUT FLYOVER NOISE WITH GROUP 4

Session	Condition	Number (N) and Percent	Time-on-Track Intervals (seconds)			
			5.00 - 4.51	4.50 - 3.51	3.50 - 2.51	2.50 - 1.51*
E 1	Tracing task	N %	39 (40.6)	47 (49.0)	10 (10.4)	0 (0.0)
E 2, E 3, E 4, E 5	Tracing task No flyover noise trials	N %	27 (37.5)	35 (48.6)	10 (13.9)	0 (0.0)
E 2, E 3, E 4, E 5	Tracing task + Flyover noise trials	N %	26 (36.1)	38 (52.8)	8 (11.1)	0 (0.0)

X^2 = 0.849, 6 df, N.S.

* See note at bottom of Table XI.

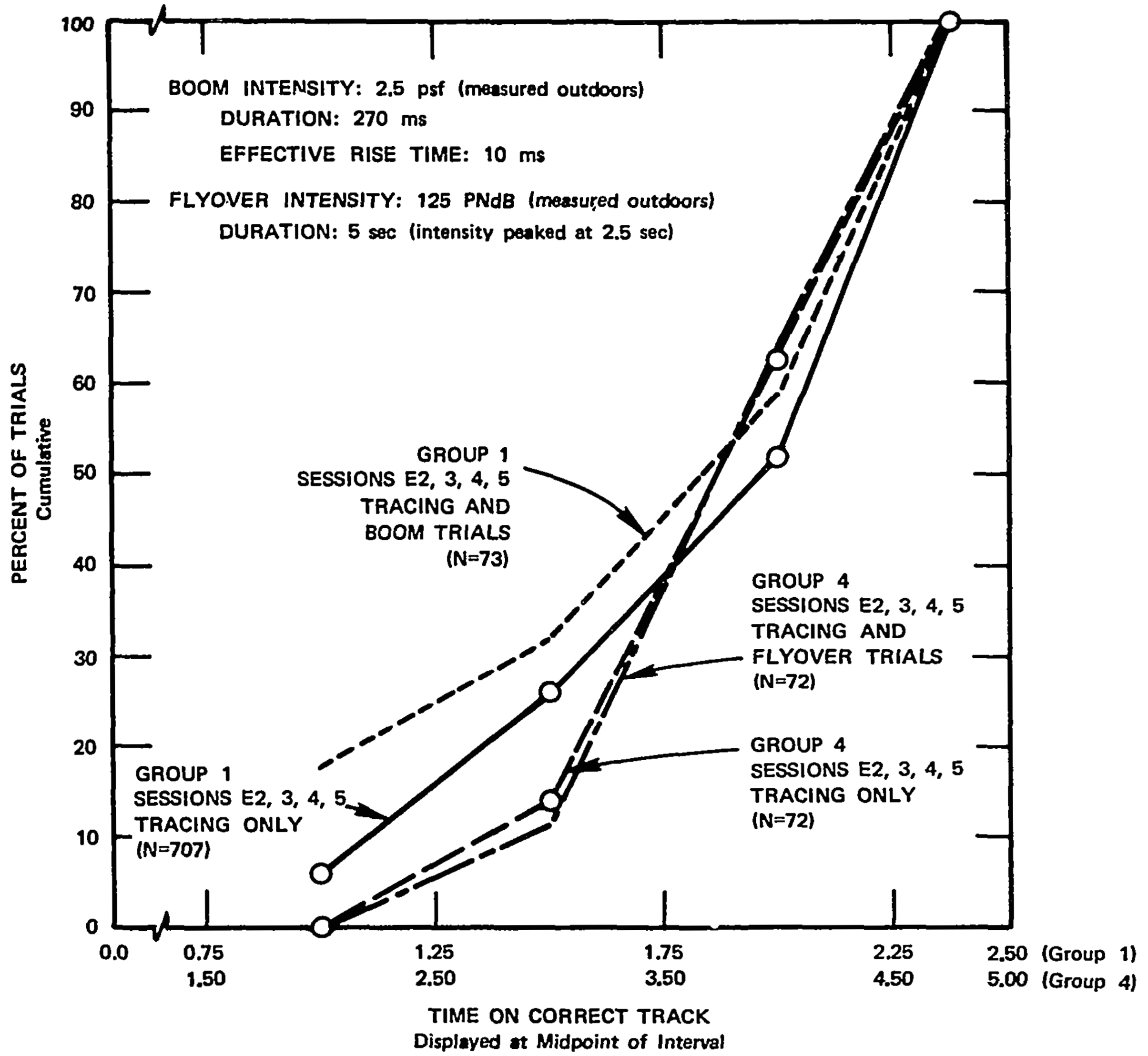

FIGURE 10 EFFECT OF SIMULATED SONIC BOOMS AND SUBSONIC JET FLYOVER NOISE ON A PACED TRACING TASK

performance (see Table XIII), while booms primarily resulted in an increase of the number of trials in which TOTs of 0.75 to 1.25 were obtained.

With respect to performance during session E 1, the results were essentially the same for Group 4 since no differences were found between session E 1 and E 2, E 3, E 4, and E 5 (see Figure 9). However, for group 1, comparing the TOTs on boom trials during sessions E 2, E 3, E 4, and E 5 with those obtained during session E 1 (no boom trials) makes the effect of booms more apparent since during session E 1 only 2.1 percent of the obtained TOTs were in the 0.75 to 1.25 second interval (see Figure 6 and Table VII).

IV DISCUSSION

The finding that sonic booms resulted in both an electromyographic startle response and a decrement in tracing performance may seem inconsistent with the negligible effects of the subsonic jet flyover noise. Two explanations suggest themselves: (1) the slower increase in level of the aircraft noise compared to the sonic boom caused less of a startle response in the subjects and therefore had less of an effect on muscle tension or performance; and (2) the vibration of the test room by the sonic boom caused the test subjects to shake somewhat, thereby causing slight adjustments in muscle activity. (This effect could, of course, be entirely normal mechanical-body interactions and in no way involve any psychological or physiological startle responses.)

In addition to audible and subaudible components (the frequency spectrum of booms peaks at about 5 Hz), sonic booms produce a perceptible shaking of the floors of the room. The shaking has peak accelerations of about 0.25 g and a frequency of about 3 Hz (Ref. 1), which is near the 4 Hz vibration frequency reported by Clark, et al. (Ref 13) as the predominant body resonance frequency, as well as being near one of two frequencies at which people appear least tolerant of vibration (Ref 14.). Thus, the electromyographic startle response to booms might simply reflect a response (voluntary or involuntary) on the part of the subjects to the vibration associated with the booms. Hence, Group 3, which was not engaged in the tracing task but simply read, responded to the booms with startle responses of increasing amplitude during the four sessions in which booms were presented. It is important to note in this regard that Group 3, which could not discriminate between "rest" and "performance" periods, responded similarly in these periods. In contrast, Group 1, which heard booms and performed the tracing task and was aware of the rest periods, showed more variability in response to booms during the rest periods than during performance when engagement with the tracing task required continuous effort to counteract the effects of booms.

It should be noted that the EMG response as measured in this study is a relative one, being the difference between the levels before and during stimuli or, for the non stimulated group, brief periods corresponding to pre- and post-stimulus periods. It is entirely possible that the general increase in EMG noted particularly in the boom groups from session 1 through session 5 was due to the subject's becoming more relaxed and having lower resting EMG levels; i.e., the absolute muscular tension to the booms due to vibration did not change from the first to the last session, but rather the general (pre-boom) level of muscle tension in the subjects to the test situation declined in successive test sessions. It is unfortunate that the measurement technique used in this study did not permit measurement of the absolute level of background muscular potentials since, if the explanation is correct, it would be hypothesized that the potentials of group 1 would be higher than those of group 3.

Clearly, final specification of the relative contributions of the vibratory and acoustic components of sonic booms to changes in startle, as measured electromyographically, and to changes in psychomoter performance, must await further experimental evidence.

V CONCLUSIONS

The periodic presence of subsonic jet aircraft flyover noise at a level of 100 PNdB had no significant effect on skeletal muscle tension or on the time-on-track of a well practiced, paced visual tracing task.

The periodic presence of the noise and vibration indoors from a simulated sonic boom of an outdoor intensity of 2.5 psf caused a significant increase in skeletal muscle tension and a decrease in the accuracy of tracing. The number of short-time on-track periods was increased relative to the number of long-time on-track periods.

It is suggested that the effects noted for the simulated sonic boom conditions may have been due to mechanical vibrations of the body in response to floor vibrations caused by the booms and not the result of physiological or psychological startle responses.

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NASA-Langley, 1970 — 5 CR-1522