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16. Abstract

Subjects were exposed to four simulated "indoor" sonic booms over an approximate thirty-minute period. The overpressure levels were 1.0, 2.0 and 4.0 psf (as measured "outdoors") with durations of 295 milliseconds. Subjects performed a two-dimensional compensatory tracking task during the exposure period and continuous recordings were obtained of heart rate and skin conductance. No evidence of performance impairment was found for any of the overpressure levels. Rather, performance improved significantly following boom stimulation along with heart-rate deceleration and skin conductance increase. The obtained pattern suggests that the simulated booms may have elicited more of an orienting or alerting response than a startle reflex. The results are discussed in terms of the possible importance of rise time as a determinant of the physiological and performance effects which may be produced by sonic booms. Since faster rise times of the simulated booms might have increased loudness sufficiently to change these results considerably, care should be taken to avoid drawing unwarranted conclusions, relative to general sonic boom effects, on the basis of these findings alone.

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THE EFFECTS OF SIMULATED SONIC BOOMS ON TRACKING PERFORMANCE AND AUTONOMIC RESPONSE

I. Introduction.

There is evidence that the startle resulting from a sudden, high-intensity sound may produce a transitory, but significant impairment in performance.[18 19 21 22] Since sonic booms are often reported to be "startling",[1 6 13 20] one might expect these stimuli as well to produce a temporary impairment in performance. As yet, however, very few relevant studies have been conducted. Part of this is due to the difficulty involved in conducting controlled field studies using actual booms, and part with the problems inherent in constructing adequate simulators to study sonic boom effects in the laboratory.

Of the laboratory studies which have been reported, the results suggest that some impairment in performance may be produced by sonic booms on certain tasks and/or with booms of sufficient overpressure level. However, impairment is not invariably found and in some cases performance improves with exposure to sonic booms. Woodhead,[23] for example, studied the indoor effects of simulated sonic booms having outdoor peak overpressures of 0.80, 1.42, and 2.53 pounds per square foot (psf). The 2.53 psf level produced a significant increase in omissions, but not errors, on a symbol-matching task during the 30-sec. post-stimulus period. (The task was one which required the matching of a series of continuously moving symbols against a row of stationary ones). Neither of the other two levels had a significant effect on performance. There were wide individual differences, with 33 subjects out of the 108 improving their performance following stimulation and 21 showing no change whatsoever.

Other studies have examined the effects of sonic booms as heard indoors on motor coordination.[10 11] Both studies were conducted with the same indoor boom simulator and both employed the same task (a stylus tracing task involving fine eye-hand coordination). Simulated booms having overpressures of 1.2 psf (as measured "outdoors"), durations of 100 msecs., and rise times of 10 msecs. were used in the first study, while booms having overpressures, durations, and effective rise times of 2.5 psf, 270 msecs., and 10 msecs. respectively were employed in the second.

The results of the first study suggested a slight impairment in performance upon initial exposure to the booms, but an improvement in performance with repeated presentations of the stimuli. These effects were not statistically significant, however. The second study examined performance immediately following boom presentations and found some evidence for a slight decrement followed by a period of performance improvement. The decrement was confined to the initial 2.5-sec. period subsequent to the booms. In contrast to the findings of the earlier study, repeated exposure to the booms was found to result in progressively poorer performance. Because of the small number of subjects, however, the authors consider their findings quite tentative.

The present study was conducted in order to provide further information on the effects of sonic booms on psychomotor performance and autonomic activity, including recovery patterns following stimulation and the effects of boom repetition. Stimuli were produced by an indoor sonic boom simulator with overpressure levels chosen to include both the expected and extreme values which Kryter[7] has indicated would likely be produced by an SST-type aircraft flying at cruising altitude. According to Kryter, within an area 12.5 miles on either side of the flight track, approximately 98 per cent of the sonic booms would have overpressures falling between 1.5–2.0 psf, with the remaining 2 per cent reaching 4 psf or higher or 1 psf or lower. Values for the duration of the "N-waves" of the simulated booms were also selected to be representative of the durations of the booms which might be produced by an SST-type aircraft and were based upon data collected during the XB-70 flights conducted at Edwards Air Force Base.[17] Durations of the booms produced by this aircraft (which approximates the proposed SST in size) ranged from 260 to 320 msecs.

Because of design characteristics of the simulator, rise times of the simulated sonic booms increased in a manner which was almost proportional to increases in overpressure. Thus, rise times of the simulated booms employed ranged from approximately 7 msecs. for a 1 psf boom to 21 msecs. for a 4 psf boom. Although these values are considerably higher than the median rise time of 6 msecs. for the Edwards XB-70 tests,[8] they nevertheless fall within the range of values which were reported for this particular aircraft during those tests.[17]

The task and general design employed in the present study were the same as that used in an earlier one concerned with the recovery of motor performance and autonomic activity following an unexpected burst of 115 dB sound pressure level random noise.[18] This was done to enable direct comparison of the known effects of a startling stimulus on performance and autonomic response with the effects produced by the simulated booms. The only major differences between the two studies were in the nature of the auditory stimuli employed and in the number of stimuli presented. (Each subject received four stimuli in the present study while only two were used in the previous one.)

II. Method.

Subjects. Forty paid male college students between the ages of 18 and 25 served as subjects *(Ss)*. All were right-handed, had no reported hearing loss, and had not participated in the earlier startle study.

Apparatus. The sonic boom simulator was constructed by Stanford Research Institute and has been described in detail elsewhere.[10] Essentially, it was a simulator designed primarily to study the effects of sonic booms, as experienced indoors, on sleep. Consequently, the test room was built to approximate the dimensions (13½′ × 12′ × 8′) of a bedroom in a "typical" frame house. Standard housing construction was employed with drywall interior surfaces. There were two windows in the room, with one being a one-way mirror used for *S* observation. A two-foot diameter piston was coupled to a hermetically-sealed pressure chamber, one side of which formed one of the walls of the test room. Activating a "one-shot" clutch resulted in the rotation of a cam through 360° causing a forward and backward motion of the piston. This generated an N-wave of pressure in the sealed chamber to create the boom. Changing the cam offset varied the peak overpressure level of the boom, and levels ranging from 1.0 to 9.0 psf could be achieved in this manner. (It should be noted that, unless otherwise specified, the values stated for all boom parameters refer to values as measured "outdoors" (in the pressure chamber) and not to levels occurring in the room.) Duration of the boom could be varied from 100 to 300 msecs. by changing the rpm of the DC motor. As noted earlier, because of the manner in which overpressure levels were varied in the simulator, it was not possible to manipulate rise time of the booms independently of overpressure levels. Thus, increases in cam offset, resulting in longer piston travel, yielded an increase in rise time of the boom which was approximately proportional to the overpressure level.

The pressure chamber was calibrated with a Bruel and Kjaer type 4146 condenser microphone, a Bruel and Kjaer type 2631 carrier amplifier, and a Consolidated Electrodynamics Corporation, Model 5–124 recording oscillograph. In addition to the oscillograph, the booms were also recorded during the experimental sessions on a Consolidated Electrodynamics Corporation, Model VR3700 tape system.

A console containing the oscilloscope display for a two-dimensional compensatory tracking task was located in the center of the test room. The spot on the oscilloscope was driven in a random manner by means of a cam function generator which constantly varied the voltages to the horizontal and vertical deflection plates of the oscilloscope. *S's* task was to attempt to keep the spot continuously at the center of the oscilloscope by means of a small control stick located at his right hand. Minimal muscular effort was required to move the stick, and an excursion of approximately 1 in. in any direction from center was sufficient to move the spot to the edge of the scope. Voltages defining the position of the target on the oscilloscope (i.e., the algebraic sum of the function generator and control stick voltages) were fed to a PACE TR-20 analog computer and the output voltages (absolute horizontal and vertical error) were separately integrated by Beckman Type 9873B resetting integrator couplers. The entire tracking task was essentially a slightly modified version of one previously described by Pearson.[12]

Onset of the booms, as well as the intervals between booms, was automatically controlled by a series of electric timers. These timers were also used to program and control the duration of the training trials, the inter-trial rest periods, and the onset of a warning light which occurred prior to each training trial.

A Beckman Type R Dynograph recorded the physiological variables as well as the integrated tracking error. Beckman biopotential electrodes were attached to the lateral walls of *S's* chest and the leads connected to a Beckman Type 9857 cardiotachometer coupler. Skin resistance was obtained from two Fels zinc-zinc sulphate electrodes leading to a Fels Model 22A Dermohmmeter. One electrode was attached to the palmar surface of the left hand and the other to the ventral surface of the left wrist. Current density was 22.3 microamps/cm.[2] The output of the Dermohmmeter led to another channel of the recorder.

All equipment, with the exception of that used by the *S* in performing the task, was located outside the test room. Figures 1 and 2 show details of the boom generating apparatus and the interior of the test room respectively.

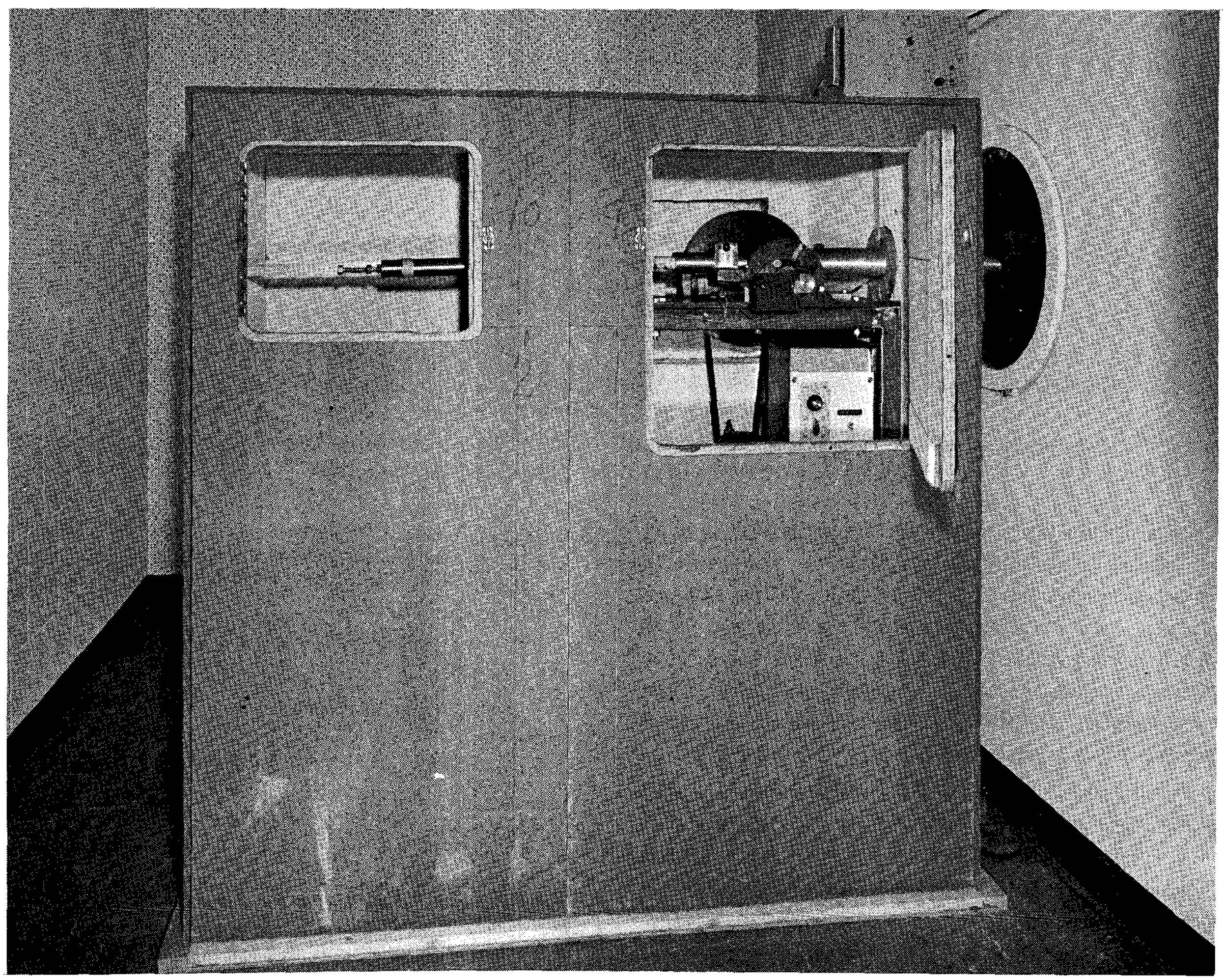

FIGURE 1. Exterior view of the pressure chamber of the sonic boom simulator showing details of the boom generating apparatus.

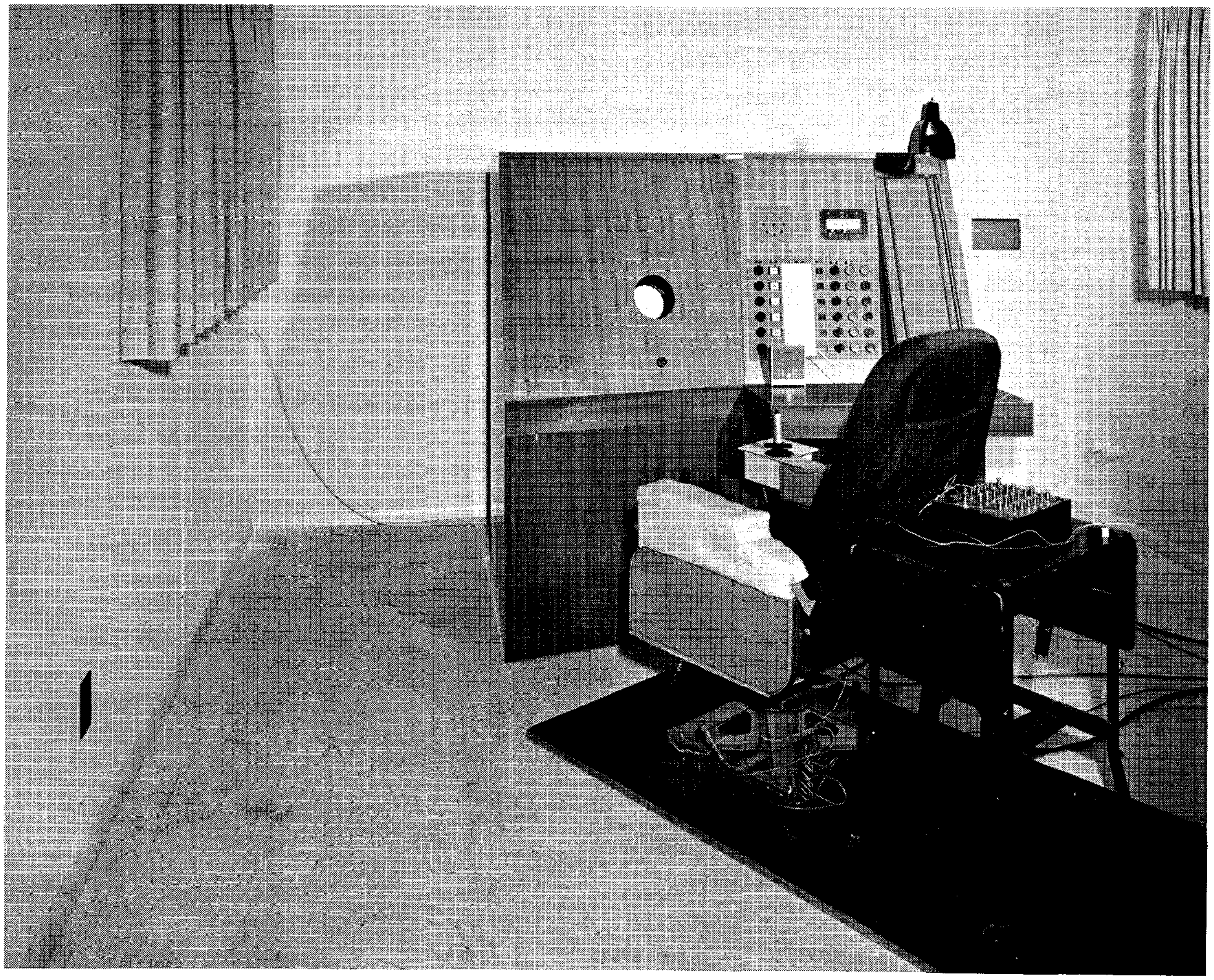

FIGURE 2. Interior view of the test room. The displays to the right on the console were not used in the experiment. The left wall forms one of the walls of the pressure chamber.

Procedure. Subjects were assigned to one of the three experimental groups or the control group on a simple rotational basis. The experimental groups will be subsequently referred to as the 1, 2, and 4 psf groups, although the actual obtained overpressures departed slightly from these values. Table 1 shows the obtained mean overpressures as well as the corresponding durations and rise times of the booms as measured in the pressure chamber. Also shown are the mean "indoor" values obtained for each of the three groups. These latter values were obtained with the microphone suspended in the test room at *S's* head level. As would be expected, there was considerable attenuation of the booms as recorded in the test room. It is interesting to note that there was also a relative increase in the rise

TABLE 1.—Mean overpressure, rise time, and duration of the booms administered to the 1, 2, and 4 psf groups as measured in the pressure chamber and in the test room.

Location	Group	Actual Peak Over-pressure (in psf)	Rise Time (in msecs.)	Duration (in msecs.)
Pressure Chamber	1 psf	1.0	6.8	299.5
	2 psf	2.1	13.1	286.9
	4 psf	3.9	20.9	302.2
Test Room	1 psf	0.13	12.1	283.6
	2 psf	0.23	18.0	295.6
	4 psf	0.40	23.7	301.3

times of the booms in the test room. Boom duration was relatively unchanged by the test room.

After being seated in the test room, *S* was played a tape which explained that the purpose of the experiment was to investigate physiological changes associated with prolonged performance on a perceptual-motor task. Electrodes were then attached and the task explained in detail. Briefly, the instructions informed *S* that the first or training phase would consist of a series of 2-min. trials with 35-sec. rest periods between them. His task was to try to keep the moving spot on the oscilloscope as close to center as possible during the trials. He was informed that a small red warning light would be illuminated 5 sec. prior to the beginning of each trial. Fifteen training trials were then administered.

Following completion of training, *S* was allowed a 10-min. rest period. He was then informed that the next phase of the experiment would be similar to the training phase just completed except that he would have to perform the task without any rest periods for 35 to 40 min. (The actual length of this period was 26 min.) In addition, *Ss* in each of the experimental groups were told that during this period they might hear certain sounds which were not present during the training period. However, it was emphasized that their task was to try to maintain consistent tracking performance regardless of any sounds or noises they heard. (No indication was given regarding the nature of the sounds and no *S* was aware that the experiment had anything to do with sonic booms.) Two minutes after the test phase began, the first boom was presented. This was followed by three more booms each separated by a 6-min. period. Upon completion of this phase, electrodes were removed and *S* completed a post-experimental questionnaire.

Scoring of Test- and Training-Phase Data. Scoring of the physiological and performance data was essentially the same as employed in the earlier study,[18] i.e., the 1-min. periods following each boom were divided into 12 5-sec. intervals. Total tracking error (sum of the horizontal and vertical integrator resets) in each interval was then determined for each *S*. Skin resistance was measured at the end of each interval and the values converted to conductance. To determine the magnitude and course of heart-rate change following stimulation, the maximum heart rate (single fastest beat as measured from the cardiotachometer recording) was obtained for each interval.

Response to the booms was evaluated in terms of change from pre-stimulus levels. In order to make the pre- and post-stimulus units comparable, the 1-min. period preceding each boom was also divided into 12 5-sec. intervals. The number of integrator resets and the maximum heart rate in each of the 12 intervals were obtained and means computed for each *S*. Levels of skin conductance prior to each boom were found by taking the mean of the conductance level measured 1-min. before stimulus presentation and the level at the moment of stimulation. Change scores for each variable were obtained by taking the difference between the pre-stimulus values for a given boom and the values in each of the 12 5-sec. intervals folowing that particular boom.

All of the physiological and performance data for the control group were scored in the same way as the data for the experimental groups. While the control group received no boom or other auditory stimulus, the "pre- and post-stimulus" periods analyzed were those corresponding in time of occurrence to comparable periods analyzed for the experimental groups.

III. Results.

Tables 2, 3, and 4 show the mean values for tracking error, maximum heart rate, and conductance level during the 1-min. period prior to each boom. Repeated-measures analyses of variance conducted on these data revealed no significant differences between groups on any of the variables ($p > .05$). There were, however, significant pre-stimulus differences between the

TABLE 2.—Mean tracking error during the one-minute period prior to each boom. Values are expressed in terms of number of integrator resets per five-second interval.

Groups	Booms			
	1	2	3	4
1 psf	8.36	9.73	11.12	11.61
2 psf	8.70	10.71	10.61	10.61
4 psf	8.24	9.41	9.54	9.77
Control	6.22	8.32	8.29	7.89
Means	7.88	9.54	9.89	9.97

TABLE 3.—Mean maximum heart rate in beats per minute during the one-minute period prior to each boom.

Groups	Booms 1	2	3	4
1 psf	74.9	77.4	76.5	75.3
2 psf	74.3	75.6	75.8	77.1
4 psf	72.0	74.0	73.6	75.6
Control	70.6	73.1	71.1	74.3
Means	73.0	75.0	74.3	75.6

TABLE 4.—Mean conductance level in micromhos during the one-minute period prior to each boom.

Groups	Booms 1	2	3	4
1 psf	11.88	10.81	10.84	11.43
2 psf	11.54	10.69	10.77	10.69
4 psf	9.41	9.39	9.30	9.32
Control	11.75	10.81	10.84	10.75
Means	11.14	10.43	10.44	10.55

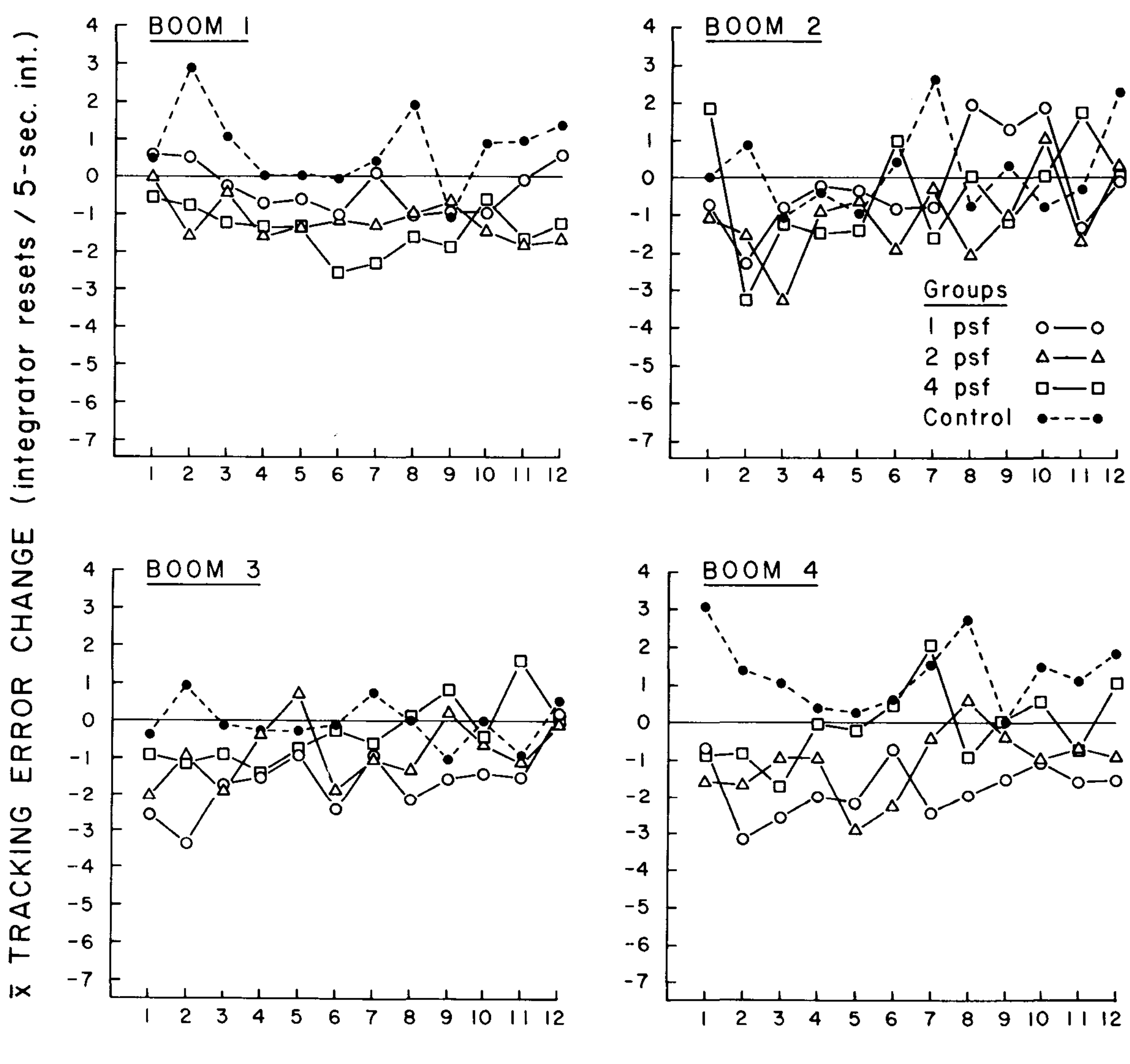

FIGURE 3. Relative change in tracking error for each group during the one-minute period following each boom.

booms. The F-values for tracking error, maximum heart rate, and conductance level were 15.73 (df=3/36, $p<.01$), 6.59 (df=3/36, $p<.01$), and 10.18 (df=3/36, $p<.01$) respectively. There were no significant boom x group interactions. The significant differences between the pre-stimulus levels of the four booms appear to reflect progressive changes which are not unlike those reported in the previous startle study and which suggest fatigue effects resulting from the rather demanding visual task.

Change scores for tracking error during the 12 5-sec. intervals in the minute following each boom are shown in Figure 3. (In this figure, as well as in the subsequent figures, positive values always represent increases in the variable relative to the pre-stimulus value.) Examination of Figure 3 suggests that the initial effect of the booms was to produce an apparent improvement in tracking performance followed by a gradual return to pre-stimulus levels. A p x q x r repeated-measure analysis of variance[24] performed on these data revealed significant differences between groups (F=7.37, df=3/36, $p<.01$) and periods

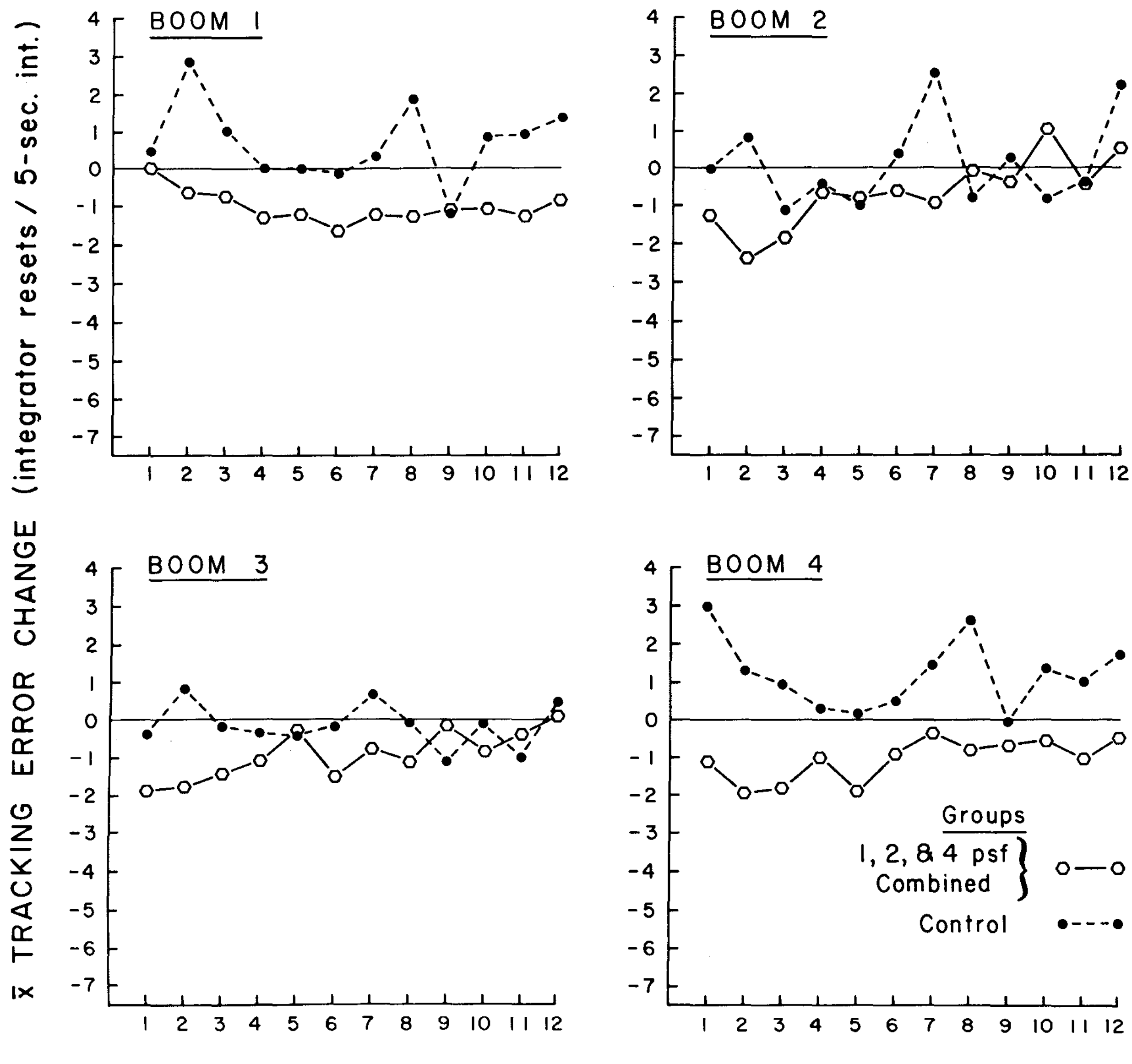

FIGURE 4. Comparison of the combined overpressure groups with the control group with respect to relative change in tracking error following boom stimulation.

($F=2.27$, df=11/396, $p<.05$). There were no significant differences between booms ($p>.05$) and no significant interactions ($p>.05$). Newman-Keuls tests[24] revealed the control group to differ significantly from the 1, 2, and 4 psf groups ($p<.05$), but interestingly enough, the experimental groups did not differ significantly among themselves. Comparisons were also made of the differences between periods. Only the difference betweeen period 3 and period 12 was significant at the .05 level using the Newman-Keuls test. Since there were no significant differences between the experimental groups, the data were combined and plotted along with the control group. These data, as shown in Figure 4, rather clearly reveal the general improvement in performance immediately following boom stimulation which tends to diminish toward the end of the 1-min. period.

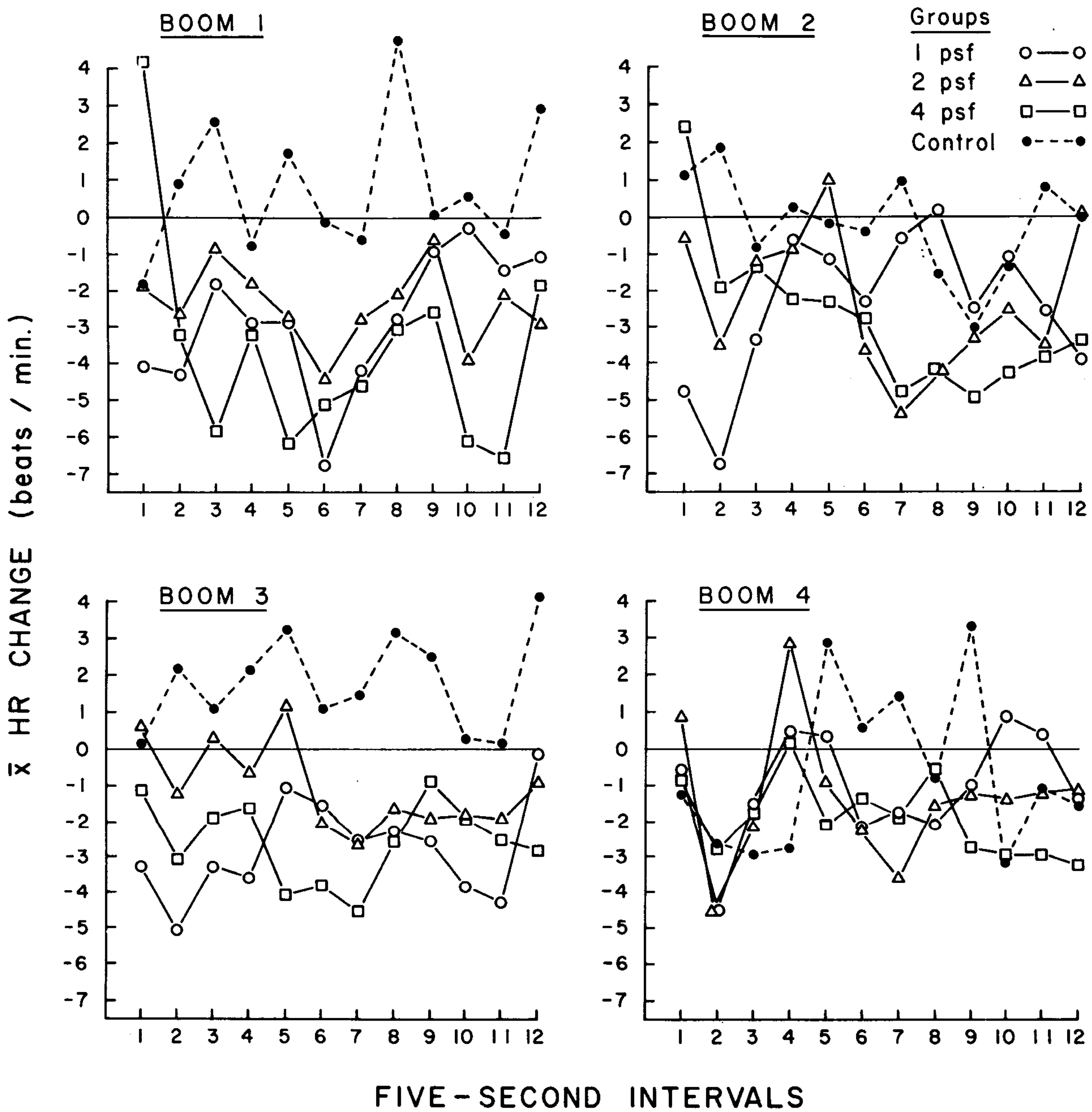

FIGURE 5. Relative change in heart rate for each group during the one-minute period following each boom.

The pattern of heart-rate charge following boom stimulation is shown in Figure 5. The general effect displayed by the experimental groups in this figure is one of heart-rate deceleration which reaches its peak about 10 sec. following stimulation. This is followed by oscillations which are generally below the pre-stimulus level for the remainder of the minute. However, while the analysis of variance revealed significant differences between groups ($F=3.04$, $df=3/36$, $p<.05$), there was no evidence of significant differences between the post-stimulus periods ($F=1.44$, $df=11/396$, $p>.05$). There were also no significant differences between booms ($F<1.00$) and none of the interactions were significant. Multiple comparisons using Newman-Keuls tests revealed that, while each of the three experimental groups differed from the control at the 10 per cent level, only the difference between the 4 psf group and the control was significant at the 5 per cent level. There were no significant differences among the experimental groups them-

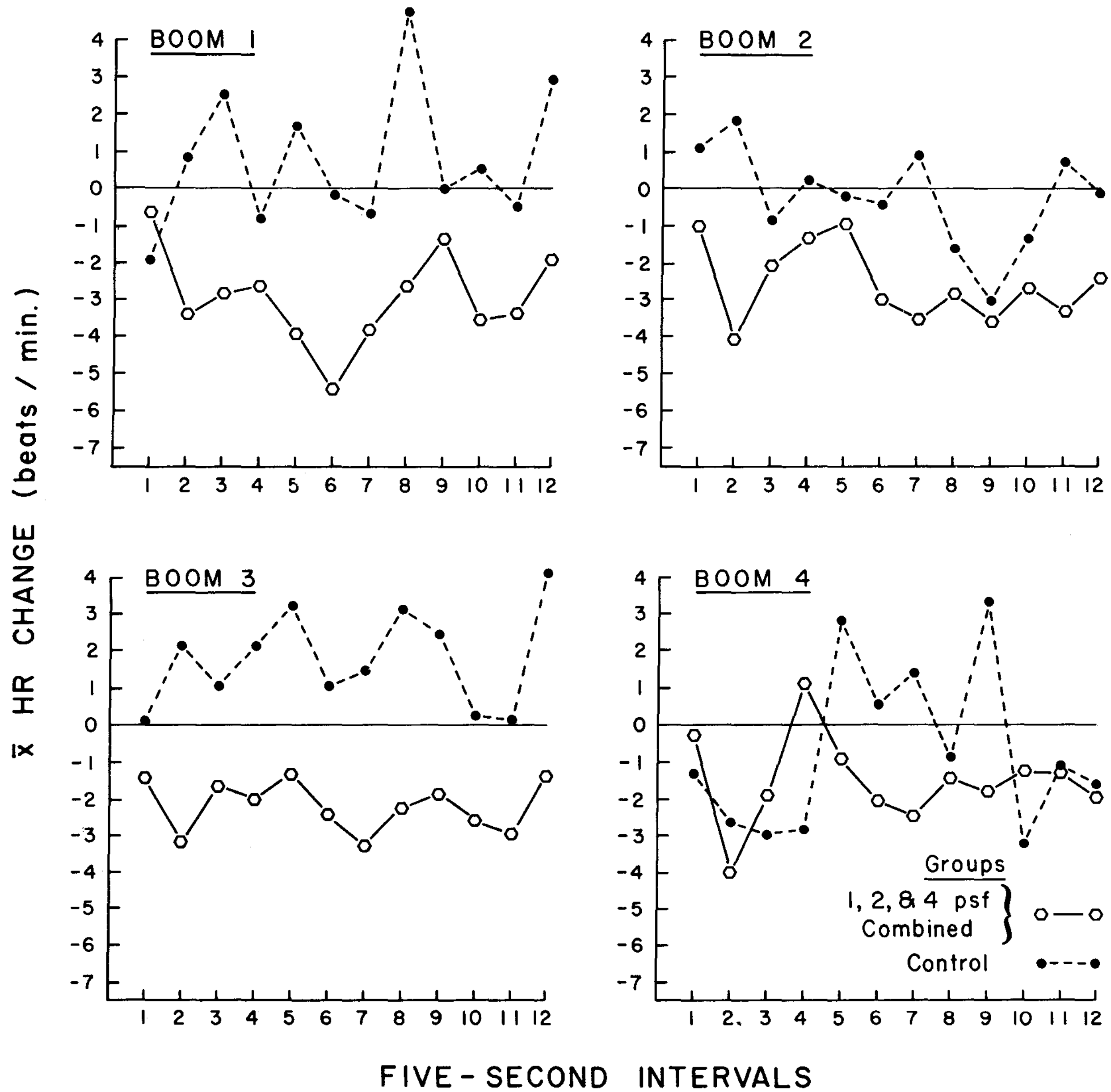

FIGURE 6. Comparison of the combined overpressure groups with the control group with respect to relative change in heart rate following boom stimulation.

selves. Because of the similarity between the patterns displayed by the three experimental groups and because the experimental groups were shown not to differ among themselves, it would appear reasonable to assume that the overall effect of the boom stimulations was a general heart-rate deceleration for all three groups, but that subject variability within the 1 and 2 psf groups may have been sufficiently great to mask the boom effect. Consequently, it seemed appropriate to test the combined experimental groups against the control. A Scheffé test for multiple comparisons[2] yielded a significant difference ($p<.10$) between the average of the 1, 2, and 4 psf groups and the control. (Since this is a conservative test, Scheffé[2] suggests employing the 10 per cent rather than the 5 per cent level.) As was done with the tracking data, the heart-rate data for the experimental groups were combined and, along with the control data, are shown in Figure 6.

Figure 7 displays the change in skin conductance following boom stimulation. The expected effect of such stimuli would be an initial increase in conductance with a gradual return to pre-stimulus levels. It is readily apparent that this is the nature of the patterns shown in the figure. Interestingly enough, the greatest change appears to occur in the 2 psf group. In the analysis of variance, significant differences were found between groups ($F=9.25$, $df=3/36$, $p<.01$), booms ($F=2.92$, $df=3/108$, $p<.05$), periods ($F=28.35$, $df=11/396$, $p<.01$), and the period x group interaction ($F=6.71$, $df=33/396$, $p<.01$). None of the other interactions approached significance at the .05 level. Multiple comparisons of the experimental and control group means were again made to clarify the nature of the between-groups effect. Newman-Keuls tests revealed each of the three experimental groups to differ significantly from the control ($p<.05$) and the 2 psf group to differ significantly ($p<.05$) from both the 1 and the 4 psf groups. The latter two groups did not differ significantly from each other.

The significantly greater conductance change obtained for the 2 psf group is interesting in view of the fact that this group gave no evidence of differing from the other two groups in terms of either heart-rate response or change in tracking error. This suggests that the increased conductance change might have been due to a difference in sudomotor responsiveness of this group rather than to any peculiar characteristic of the 2 psf stimulus. To test this hypothesis, the three experimental groups were compared with regard to their conductance change to the red warning light which occurred at the beginning of the test phase and prior to any boom presentations. Mean change in conductance for the three groups was 0.41, 0.74, and 0.24 micromhos (μmhos) for the 1, 2, and 4 psf groups respectively. A single-classification analysis of variance conducted on these data yielded an F-value of 3.00 ($df=2/25$) which exceeded the 10 per cent level, but was not significant at the 5 per cent. Consequently, although the mean for the 2 psf group was in the predicted direction, the data provide only suggestive support for the hypothesis that the 2 psf group was a more autonomically reactive group per se.

Since a significant F-value was obtained for the differences between booms, Newman-Keuls tests were conducted on the mean conductance values for each boom. These values were 0.40, 0.66, 0.44, and 0.47 μmhos for the first, second, third, and fourth booms respectively. The second boom was found to differ significantly from the first ($p<.05$), but there were no other significant differences among the means.

Because of the significant period x group interaction, tests were conducted on the simple effects of periods for each of the four groups.[24] Significant decreases in conductance over the 12 periods were obtained for the 1 psf ($F=16.07$, $df=11/396$, $p<.01$), the 2 psf ($F=28.59$, $df=11/396$, $p<.01$) and the 4 psf ($F=2.91$, $df=11/396$, $p<.01$) groups. As would be expected, the obtained F-value for the control group was nonsignificant ($F<1.0$).

Since the 2 psf group differed significantly from the 1 and 4 psf groups, the data were not combined as was done with the heart rate and tracking data. It should also be pointed out that the abrupt increase in conductance shown in Figure 7 in the control group data was the result of one *S*. This *S's* conductance changed from 12.41 to 16.93 μmhos during the eighth 5-sec. interval of the 4th boom. The reason for this shift is unknown, but may have been caused by a gross shift in body position.

The results of the subjective rating scale administered to the experimental *Ss* at the close of the test session are shown in Table 5. It can

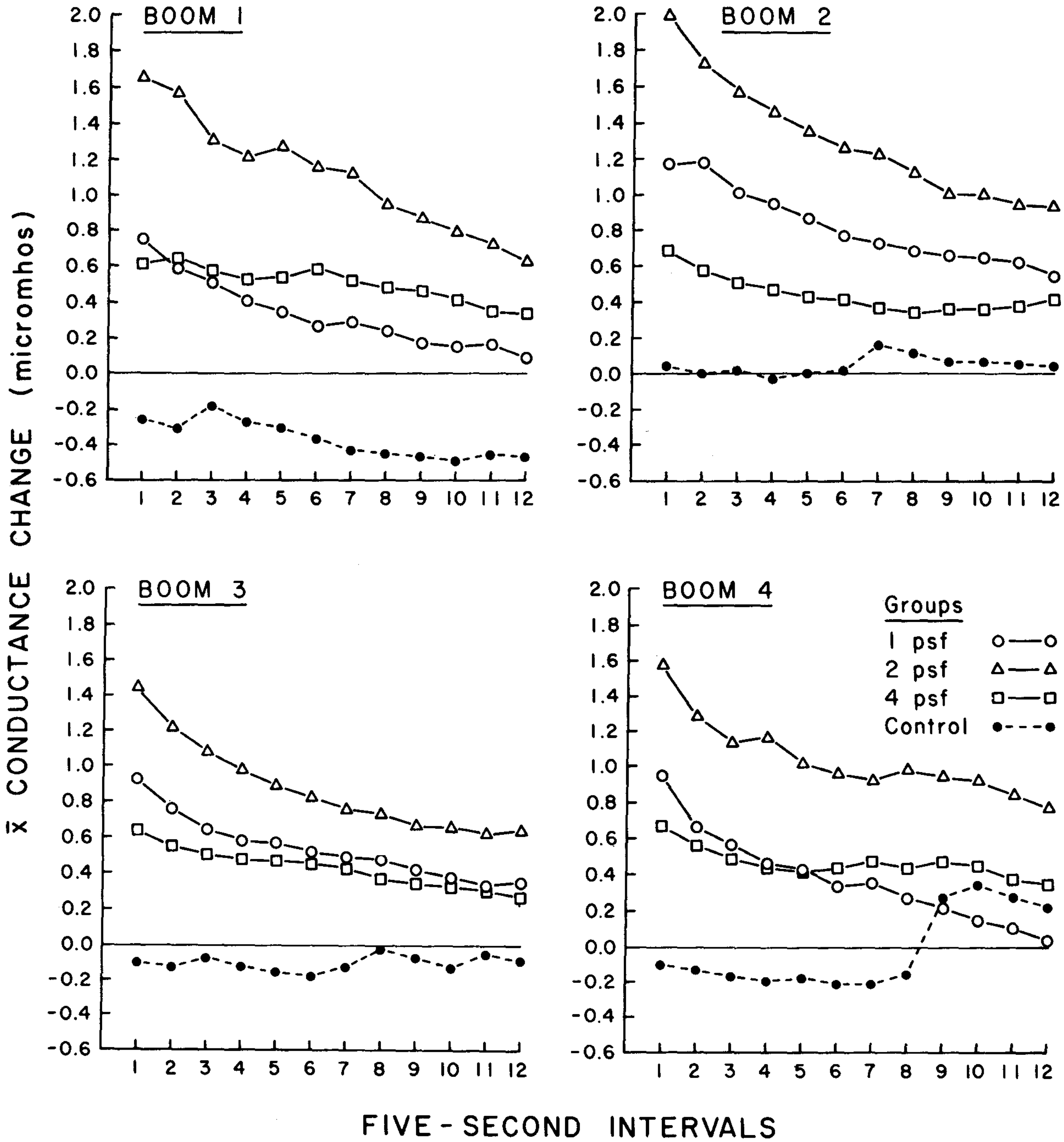

FIGURE 7. Relative change in palmar skin conductance for each group during the one-minute period following each boom.

be seen that there is a tendency for each successive boom to be rated somewhat less "startling" than its predecessor. (The values were derived from a five-point scale with end points consisting of "not startled at all" (scale value of 1) to "extremely startled" (scale value of 5).) Friedman two-way analyses of variance[16] conducted on each overpressure group revealed the differences between booms to be significant for the 1 and 2 psf groups ($p<.05$), but not for the 4 psf group ($p>.03$). The data in Table 5 suggest that the 2 and 4 psf groups might have been more startled by the booms than was the 1 psf group. However, Kruskal-Wallis analyses of variance[16] re-

TABLE 5.—Mean ratings of "startle" to the four booms. A rating of 1.0 signifies "not startled at all," while a rating of 5.0 would signify "extremely startled."

Groups	Booms				Means
	1	2	3	4	
1 psf	2.8	1.9	1.8	1.7	2.0
2 psf	3.5	2.7	2.6	2.3	2.8
4 psf	3.0	2.7	2.6	2.4	2.7
Means	3.1	2.4	2.3	2.1	

vealed no significant differences ($p>.05$) between the ratings of the three groups for each boom. Because the nature of the task required that ratings be obtained at the completion of the experiment rather than after each boom, the rating data should be viewed as suggestive rather than conclusive.

IV. Discussion.

The results of the present study clearly indicate an improvement in performance following exposure to the simulated sonic booms. This improvement reached its maximum approximately 15 sec. after the booms occurred, with a gradual return to pre-stimulus performance levels during the 1-min. period following boom presentations.

While no evidence of impairment, especially with the 4 psf boom, was a somewhat surprising finding, it should be recalled that neither Lukas and Kryter[10] nor Lukas, Peeler, and Kryter[11] found much evidence of impairment in psychomotor performance following simulated booms, with both studies reporting some evidence of performance improvement. The Lukas, Peeler, and Kryter study, which was the more comprehensive of the two, found the impairment to be confined to the 2.5-sec. period immediately after boom presentation. Following this, there was a period of performance facilitation. It is interesting to note that the authors of the above study feel that the impairment, although appearing to be the result of a muscular (startle) reflex, may well have been caused by the mechanical vibration of the room (and the subject as well) resulting from the boom stimulus and causing the stylus used in the tracing task to move momentarily off target. Since the boom simulation facility used in the present study was patterned after the one used by Lukas, Peeler, and Kryter, it is probable that similar levels of room vibration were present in both studies. However, the tracking task used in the present study would seemingly be much less susceptible to the influence of mechanical vibration, and it would appear quite unlikely that a slight vibration of the room would result in any detectable increase in performance error.

If the explanation offered by Lukas, Peeler, and Kryter to account for their impairment is correct, then their finding of subsequent performance facilitation would agree with the findings of the present study, and would suggest that differences between the studies with reard to initial impairment may simply be a reflection of differences between the tasks in their sensitivity to vibration.

In considering the nature of the "startle" response, if any, which was elicited by the simulated sonic booms, it is of interest to compare the response patterns obtained in this study with those obtained in the previous study by Thackray and Touchstone.[18] In the earlier one, the initial unexpected burst of 115 dB random noise resulted in a significant increase in tracking error lasting from 10–15 seconds. During the remainder of the 1-min. post-stimulus period, performance fluctuated about the pre-stimulus level. The heart-rate response was rather clearly diphasic and consisted of an initial significant acceleration during the first 5-sec. interval after stimulation followed by a rather abrupt deceleration. The pattern of heart-rate change during the first 15–20 sec. appeared to mirror the recovery pattern obtained for tracking performance. A second presentation of the noise stimulus 15 min. after the first produced similar patterns of heart-rate and performance change. As would be expected, palmar skin conductance increased significantly to both presentations of the stimuli.

In the present study, heart rate showed both initial and sustained *deceleration* and, as already noted, performance *improved*. Surprisingly, there were no differences between the three overpressure groups in magnitude of heart-rate and performance change, although there was a difference between the 2 psf group and the other two groups in magnitude of conductance change. However, since the finding of a significantly greater conductance change in the 2 psf group clearly departs from the results obtained for heart rate and tracking, it would appear that the most parsimonious explanation for this discrepancy is that the 2 psf group probably differed by chance from the 1 and 4 psf groups in sudomotor reactivity.

It is evident that the "startle" evoked by the stimuli employed in the two studies resulted in quite different response patterns. The initial pattern of heart-rate acceleration and performance impairment found in the Thackray and Touchstone study suggests that at least part of the classic startle pattern[9] was elicited by the stimuli. However, the pattern produced by the simulated sonic booms reveals little or no evidence of a true startle response, but rather suggests an orienting or alerting response followed by a period of heightened attention to the task. Initial heart-rate deceleration is known to be a principle component of the orienting reflex,[4] and there is evidence that sustained reduction in heart rate reflects a state of heightened attention.[5]

Since orienting responses are more likely to occur to acoustic stimuli of low intensity, with defensive (or startle) responses occurring to higher intensities,[14] the differences in obtained patterns may have been the result of differences in "intensity levels" of the stimuli employed in the two studies. There is evidence that such differences did exist. Thus, although *Ss* in both the present study and the previous one rated the stimuli employed as "startling," the range of mean ratings given to the booms ("mildly startled" to "moderately startled") was less than the range of mean ratings to the random noise ("quite startled" to "extremely startled"). Also, *Ss* were observed through a one-way window during the boom presentations and, except for an occasional slight orientation of the head toward the source of the sound, there were no observable body responses. This was in contrast to the earlier study in which body jerks were the rule rather than the exception. Lastly, there is evidence of greater change in skin conductance to the noise stimuli presented in the previous study than to the simulated sonic booms. Mean change (2.49 μmhos) to the random noise stimulus was significantly greater than the mean change (1.00 μmhos) of the combined 1, 2, and 4 psf groups ($t=4.93$, $df=58$, $p<.001$). A comparison of conductance levels immediately prior to the above stimuli in both studies yielded no significant differences ($t=0.47$, $p>.05$).

The results obtained in this study would suggest that the response to sonic booms might be more appropriately characterized as an alerting or orienting response than as a classical startle response. However, in terms of generalizing from these results, the question must be asked "Is the type of response obtained to the simulated booms employed in this study representative of the typical response which would be generallly expected to occur to sonic booms produced by aircraft under field conditions?"

In answering this question several factors need to be considered. One factor is the judged realism of the simulated booms. *Ss* who had previously heard sonic booms under indoor conditions were asked to evaluate the booms at the completion of the experiment. A majority of these *Ss* felt that the simulated booms sounded similar to real ones they had heard. Because many of these *Ss* had been exposed to the Oklahoma City sonic boom tests conducted in 1964, reasonable reliance can probably be placed on these judgments. *Ss* did comment, however, on the booms originating from one wall of the room whereas there was less directionality associated with real sonic booms they had experienced indoors. Also, the duration of the simulated booms (N-waves) appeared longer than ones with which they were familiar. This, of course, was the result of attempting to simulate the longer duration of the booms produced by an SST-type aircraft. Interestingly enough, only three *Ss* reported the simulated booms to be less startling than ones they had heard, although this evaluation must be viewed with considerable caution because of the time factor involved in the comparisons.

The other factor relates to spectral energy characteristics of the simulated booms. As Kryter[6] has noted, the maximal energy of sonic booms is largely concentrated in the frequency regions usually considered subaudible, with a rapid decline in energy at the higher frequencies. Power spectral density function analyses of the simulated booms as measured in the test room revealed that the simulated booms also displayed maximal energy in the subaudible range with a peak at approximately 3 Hz. There was a decline in energy at frequencies above this value with energy down 45 dB at 1000 Hz. However, as was indicated earlier, the rise times of both the 2 and 4 psf booms employed in the present study were considerably longer than the median rise time obtained for the XB-70 aircraft during the Edwards tests.[8] Faster rise times of the simulated booms would have increased the spectral energy in the frequencies above 200 Hz and presumably increased their loudness.[15 25] Whether reduction in rise times of the 2 and 4 psf booms to this level (6 msecs.) would have increased loudness sufficiently to have produced startle reflexes and/or impairment in tracking performance is not known. Evidence from animal research would suggest that rise times of acoustic stimuli are significant determinants of the resulting behavioral response, with startle responses occurring only if the rise times are sufficiently short.[3] The simulator employed is capable of modifications to achieve greater control over the effective rise time. Research incorporating such modifications is currently being planned in order to obtain needed information relative to the importance of this variable in influencing the type of response produced by sonic booms. Until such information is available, some degree of caution should be exercised in generalizing from the results of this study, especially with regard to the 2 and 4 psf booms, to booms of comparable levels occurring under field conditions.

Finally, no evidence of adaptation to the four booms was found for either the physiological responses or performance change. Skin conductance response did show a significant change with the second boom, but this was in the nature of an increase rather than a decrease. There is no ready explanation for this discrepant result. With regard to the subjective responses, all three overpressure groups rated each successive boom as less startling than its predecessor. These differences were significant for the 1 and 2 psf groups, but not for the 4 psf group. However, as noted earlier, *Ss* were continuously tracking during the test period and ratings had to be obtained at the completion of the experiment rather than after each boom. Because of this, greater reliance should probably be placed in the physiological and performance data than in the subjective responses in terms of evaluating possible adaptation effects.

V. Conclusions.

While the results of the present study revealed a facilitative effect of the simulated indoor sonic booms on psychomotor performance, it should be emphasized that care must be taken to avoid drawing unwarranted conclusions, relative to general sonic boom effects, on the basis of these findings alone. As previously mentioned, the use of faster rise times might have changed the results considerably. Also, the present study was only concerned with one aspect of behavior (visual-motor coordination) and did not consider the possible effects of booms on other behaviors or on sleep disturbance. Lastly, the study was in no way concerned with annoyance levels of sonic booms, and there is ample evidence that booms having overpressures within the range of values employed in this study are considered by sizable segments of the population to be unacceptable.[7 8 17]

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