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A COMPARISON OF THE STARTLE EFFECTS RESULTING FROM EXPOSURE TO TWO LEVELS OF SIMULATED SONIC BOOMS

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16. Abstract

Subjects were exposed indoors to simulated sonic booms having outside overpressures of 50 and 150 N/m^2. Rise times were held constant at 5.5 msecs. In addition to the outside measurements, inside measures of dBlin and dBA were also obtained. Subjects attempted to hold a hand-steadiness device on target during boom exposure and amplitude of the arm-hand startle response was determined. Recordings were also obtained of the skin conductance and heart-rate responses as well as the eye-blink reflex. Although the 50 N/m^2 boom produced slight arm-hand startle responses in a small percentage of subjects, the frequency of these responses was significantly greater to the higher boom level. There was no difference between the levels in amplitude of the response. The predominant autonomic response pattern to the lower exposure level was similar to that obtained for orienting responses, while a startle pattern was obtained for the higher level. The results are compared with the findings of other studies, and the tentative conclusions advanced that sonic booms experienced indoors may cause slight arm-hand startle responses which could have adverse effects on occupational tasks in which arm-hand steadiness is the principal skill required, but that it seems unlikely these responses would significantly impair performance on less sensitive psychomotor tasks.

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I. Introduction.

In a previous study it was found that simulated sonic booms as experienced indoors and having outside overpressures of approximately 50, 100, and 200 N/m² had no adverse effects on tracking performance.[11] On the contrary, the booms appeared to increase task attention and facilitate performance.

Several possible explanations suggest themselves as reasons for the apparent lack of performance disruption produced by the simulated booms. The tracking task employed may have been too insensitive to reveal any slight, momentary startle effect following onset of the booms. Maximum performance disruption following startle is known to occur within the first one or two seconds following stimulation,[5 9 13] and it has been shown that this impairment may be followed by a period of performance facilitation.[9] By integrating tracking error over successive five-second periods, as was done in the previous study, any weak startle reaction which may have occurred could have been masked by the stronger facilitory effect.

A second possibility is that the simulated booms elicited responses more appropriately characterized as alerting or orienting-type responses than as startle reflexes. Thackray[10] has recently differentiated between startle and orienting responses to impulsive stimuli, e.g., sonic booms, and discussed the increasing evidence which suggests the importance of rise time as a significant determinant of the resulting response. Although precise relationships have not as yet been established, in general the faster the rise time the greater the likelihood that a startle reflex (associated with initial performance disruption) rather than an orienting response (associated with heightened attention and performance improvement) will occur. Unfortunately, because of design characteristics of the simulator employed in the previous study, rise times of the booms increased in a manner which was almost proportional to increases in overpressure. For the three levels of overpressure studied (50, 100, and 200 N/m²), the rise times were 6.8, 13.1, and 20.9 msecs. Since the latter two rise times are relatively slow, the increased overpressure levels may have contributed little to the startle qualities of the stimuli and may have, in fact, resulted in approximately equivalent orienting-type responses to all three levels.

The present study was designed to correct the primary deficiencies of the previous study, and thus allow a more adequate assessment of the extent of startle responses occurring to different overpressure levels with rise time controlled. The changes involved a modification of the simulator and the substitution of a different task. With respect to the simulator, the wave front of the simulated booms was modified by sychronizing an acoustic transient from a loudspeaker with the wave front of the primary pressure wave produced by the simulator. Although this technique allowed only limited control over rise time, it was determined that outside overpressures ranging from 50 to 150 N/m² could be produced with a minimum rise time of approximately 5 msecs.

The task employed consisted of a specially constructed device for measuring small-amplitude arm-hand movements. This was the same task used in a recent field study of sonic boom startle effects,[12] and was considered to be far more sensitive in recording slight, short-duration startle responses than the tracking task employed in the Thackray, Touchstone, and Jones study.[11]

Two levels of outside overpressure were studied (50 and 150 N/m²) with rise time held at approximately 5 msecs for each level. These overpressure levels approximate the range of overpressures (75 to 175 N/m²) expected along the centerline of the sonic boom carpet for the Concorde SST[14] and the rise time was virtually the same as the median rise time (6 msecs_ reported for the XB–70 during the Edwards Air Force Base tests.[8]

In addition to studying performance effects, physiological recordings of heart rate, palmar skin conductance, and eye-blink response were obtained. It was hoped that the inclusion of these measures would help to clarify the nature of the total response pattern resulting from exposure to these two boom levels.

II. Method.

A. *Subjects.* Twenty paid, male university students ranging in age from 18 to 29 served as subjects (*S*s). All were right-handed, had no reported hearing loss, and had not participated in previous startle or sonic boom experiments.

B. *Apparatus.* The sonic boom simulator was constructed by Stanford Research Institute and the features of this type of simulator have been fully described by Lukas and Kryter.[3] Essentially, however, it consisted of a 13½ x 12 x 8 foot test room. 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 chamber to create the boom. Overpressure was changed by varying piston travel and duration by changing motor speed. Walls of the test room were of dry-wall construction, the floor was carpeted, and there was acoustical tile on the ceiling. Two 47 x 35 inch windows were located in the test room. One was a conventional glass pane located in the wall forming the pressure chamber. The second window was a one-way mirror located on the opposite wall.

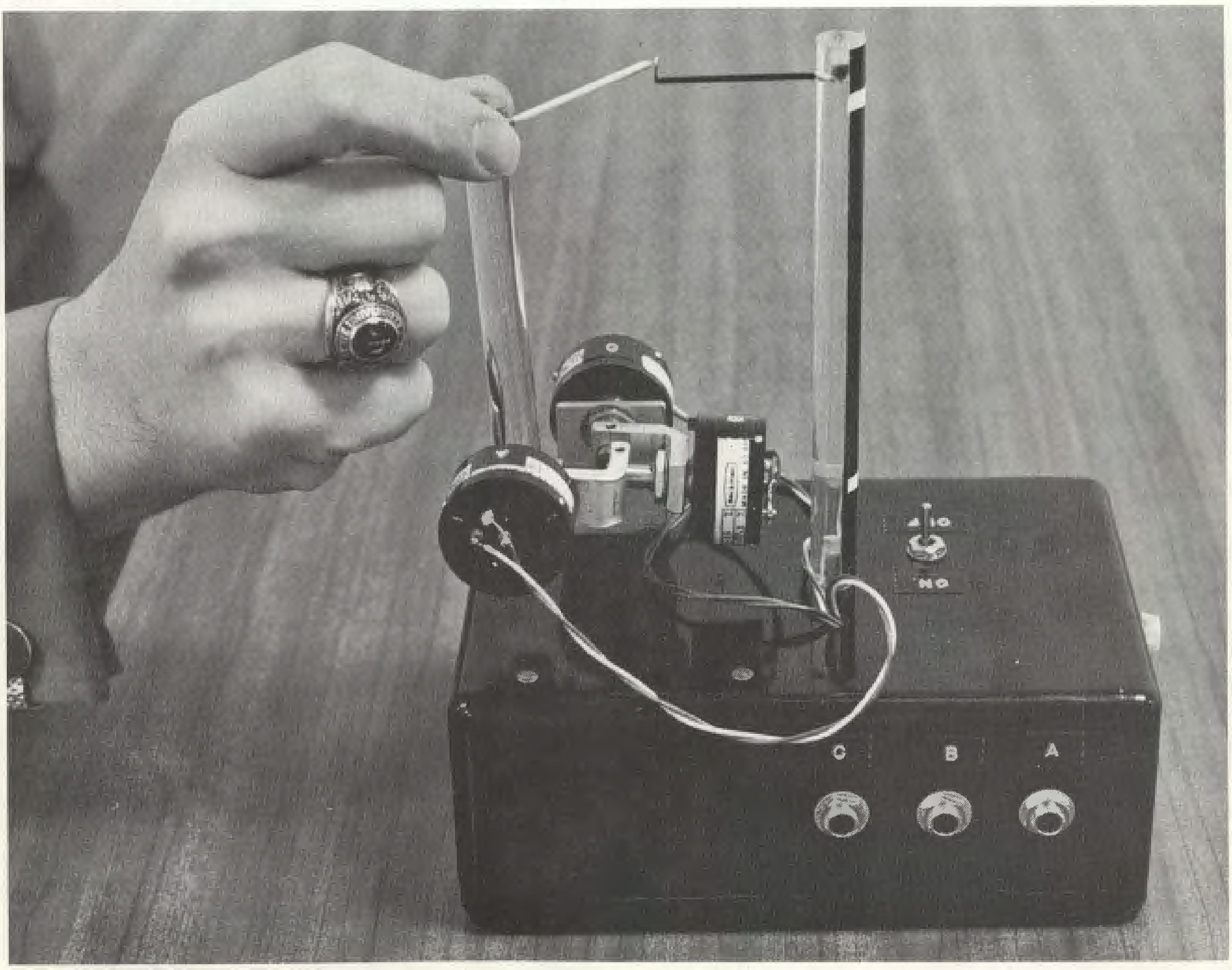

FIGURE 1. The arm-hand steadiness apparatus with pointer held in readiness position.

As noted earlier, because of design characteristics of the simulator, rise times (as defined by time to peak overpressure) increased in a manner which was almost proportional to increases in overpressure. In order to hold rise time approximately constant over varying overpressures, a photocell was employed whose light source was momentarily interrupted at the points of maximum forward and backward excursion of the piston. The electrical transient which resulted from each light interruption was amplified and fed to an Altec Lansing 419A Biflex speaker located in the pressure chamber. By properly synchronizing the speaker output with the wave front produced by the piston, it was possible to achieve simulated sonic booms which differed in overpressure but which had approximately equal rise times. The resulting impulsive stimuli were judged by persons familiar with the sound of sonic booms heard indoors to be quite similar to the booms produced by actual aircraft.

The pressure chamber was calibrated with a Bruel and Kjaer Type 4146 condenser microphone, a Bruel and Kjaer Type 2631 carrier amplifier, and a Honeywell Visicorder. A Hughes storage oscilloscope was used to monitor the booms during the experimental session. Onset of the booms, as well as intervals between booms, was automatically controlled by timers.

The *S*'s task apparatus consisted of a sensitive electro-mechanical device for measuring small-amplitude arm-hand movements. The top of a small rod was aimed at the center of a 5 mm circle, and it was the *S*'s task to try to keep it in that position during each test run. The base of the rod was attached to several potentiometers by means of a gimbal and this, in turn, was mounted on an 18 x 12 x 7 cm plastic instrument case. Outputs from the instrument allowed recordings of both left-right and up-down movements. The steadiness apparatus was placed on a small table and the *S* performed the task while seated. The *S* faced the observation window with his head located 40 inches from the wall of the pressure chamber. A photograph of the steadiness tester is shown in Figure 1.

A Beckman Type R Dynograph recorded the outputs from the steadiness tester. The recorder was calibrated to yield 1 mm of pen deflection for 1 mm of hand movement in either plane. In addition to the performance measures, the Dynograph also recorded the physiological measures. Heart rate was obtained from Beckman biopotential electrodes attached to the lateral walls of the *S*'s chest and the leads were connected to a cardiotachometer coupler. Palmar skin resistance was obtained from zinc-zinc sulphate electrodes attached to the palmar and ventral surfaces of the left hand. Leads were connected to a Fels Model 22A Dermohmmeter, the output of which led to the Dynograph. Beckman miniature biopotential electrodes placed above and below the right eye recorded blinks. In addition to the physiological and performance measures, one channel of the Dynograph also recorded the onset of the booms from a microphone located in the test room. All equipment was located outside the *S*'s test room.

C. *Procedure.* Each *S* was arbitrarily assigned to either the 50 N/m² or 150 N/m² boom condition with ten *S*s in each group. Following initial instructions, the *S* was instrumented for physiological recording and the task explained in detail. He was told that whenever a set of small yellow indicator lights on the table was illuminated, he was to grasp the top of the stylus of the steadiness tester with the thumb and index finger of his right hand and to try to keep it pointed at the small circle. He was instructed to continue doing this until the yellow lights went off. He was further told not to rest his arm or elbow on the table while holding the stylus, and told that he might hear certain sounds during the period that the yellow lights were on. However, he was to attempt to ignore the sounds and continue trying to keep the pointer aimed at the circle. The *S* was given no other information concerning the nature of the sounds, and no *S* was aware that the experiment had anything to do with sonic booms.

The one-hour test session was divided into 12 five-minute periods. During the first four minutes of each five-minute period, the *S* performed an auditory vigilance task similar to that described by Bakan.[1] Essentially, it consisted of the numbers 0 through 9 presented in random order over a ceiling loudspeaker at the rate of one number per second. The *S* responded by pressing a button each time a successive combination of odd-even-odd digits occurred. This task was incorporated simply to maintain a reasonable level of alertness over the one-hour period and, since the results are not relevant to the present study, the data will not be reported here.

At the end of the four minutes, the yellow signal lights were illuminated and the *S* grasped the pointer of the steadiness tester. Fourteen to 28 seconds after the signal lights were illuminated (these time intervals were randomly determined for each period), a boom either occurred or it did not. Booms were presented during three of the six five-minute periods in each half-hour with the remaining periods serving as controls for expectancy effects. Determination of the periods in each half-hour in which booms occurred was random. Each *S* was given practice on each task prior to the beginning of the one-hour session.

At the completion of the session, reaction times to a series of ten 1000 Hz, 60 dBA tones were obtained. Interstimulus intervals were ten seconds. The required response was a movement of the pointer of the steadiness tester away from the center position as rapidly as possible as soon as each tone was heard. In addition to the reaction-time tests, response to a .22 caliber pistol shot was also obtained at the completion of the session. Noise level of the pistol shot at the *S*'s location was 122 dBlin (as measured by a Bruel and Kjaer Type 2204 Impulse Sound Level Meter). This latter test was conducted in such a way that the *S* had no prior knowledge that it would be any thing other than another boom or control run. The purpose of the reaction-time and pistol shot tests was to provide a measure of voluntary response and response to a known startling stimulus in order to evaluate the reaction pattern to the simulated booms.

D. *Criteria for Defining Startle Responses.* Primary criteria for deciding whether an arm-hand response to a sonic boom was an involuntary, reflexive startle response or whether it might be a form of voluntary or reaction-time response were obtained from the latencies of the arm-hand response to the pistol shot. In addition, reflex eye-blink responses were also included in evaluating the total startle response.

Two levels of startle response to the booms were designated. A minimal startle response was said to occur if a given boom evoked an eye-blink reflex whose latency (time from noise onset to the beginning of eye closure) fell within the range of latencies obtained to the pistol shot. In order for an arm-hand response to be considered as a component of a more pronounced startle reaction, it had to meet three criteria:

1. It had to be associated with a blink reflex which met the latency requirement mentioned above.

2. The arm-hand response had to occur in both the left-right and up-down planes with a mean latency which fell within the range of arm-hand latencies obtained to the pistol shot.

3. The amplitude of the arm-hand response in both planes had to exceed the maximum peak-to-peak amplitude of hand tremor occurring in the five-second period preceding the boom.

E. *Measurement of the Physiological Response.* Galvanic skin responses to each boom and to the pistol shot were obtained by measuring the minimum resistance following stimulation and the resistance level immediately prior to each stimulus. These measures were converted to conductance values and difference scores obtained. Magnitude of heart-rate change was determined by taking the difference between the maximum heart rate in the five-second pre-stimulus and post-stimulus intervals. In addition to these autonomic measures, one other measure was obtained for each eye blink falling within the required latency range. The measured amplitude of the blink response was expressed as a percentage of the amplitude of the first voluntary blink to precede it.

F. *Physical Measures of the Simulated Booms.* Table 1 shows the actual mean values of overpressure, dBlin, dBA, rise time and duration for the simulated booms to which the 50 N/m^2 and 150 N/m^2 groups were exposed. As is evident from this table, actual measured overpressures and rise times differed only slightly from the intended values. Overpressures and rise times of the booms inside the test room are not given in the table. Although indoor measures of overpressure and rise time were reported in the previous study,[11] it was subsequently decided that complexities in the waveform resulting from acoustic and vibratory responses of the test room made it virtually impossible to arrive at meaningful, consistent measures of rise time and, to a lesser extent, overpressure. Consequently, indoor measures of dBA (fast scale) and dBlin using an impulse sound level meter were employed.

III. Results.

Behavioral Response

A. *Establishment of Startle Latency Values.* Table 2 shows the behavioral response data ob-

Table 1

Means of the Physical Measurements Obtained Outside the Test Room (Within the Pressure Chamber of the Simulator) and at the S's Location Within the Test Room for the Two Exposure Groups.

Outside Measurements				Inside Measurements	
Overpressure (N/m^2)	Rise Time (msecs)	Duration (msecs)	dBlin[1]	dBlin[1]	dBA[2]
51	5.5	240	128	105	74
151	5.6	240	137.5	111	83

[1]As measured with a Bruel and Kjaer Type 2204 Impulse Sound Level Meter set on Impulse Hold position.

[2]As measured with the same meter, but set to non-impulse mode, fast scale.

Table 2

Mean Values Obtained for the Eye-Blink and Arm-Hand Response to the Pistol Shot.

	Eye-Blink Data		Arm-Hand Data (Combined Left-Right and Up-Down)	
Overpressure Group	Latency (msecs)	Eye-Blink Response Amplitude as Expressed as a Percentage of Voluntary Blink Amplitude	Latency (msecs)	Amplitude Increase (mm)
50 N/m^2	66	131	159	8.00
150 N/m^2	60	81	143	11.61
Combined Groups				
Mean	64	106	152	9.80
Range	20 - 80	20 - 241	90 - 210	3.25 - 22.75

tained to the pistol shot. A median test[7] conducted on the blink amplitude data, and *t* tests of eye-blink latency, arm-hand latency, and arm-hand amplitude increase revealed no differences ($p>.05$) between the two groups on any measure and the data were combined. Both the mean arm-hand latency of 152 msecs and the range of latencies (90 to 210 msecs) were virtually identical to the mean value (150 msecs) and range (100 to 230 msecs) obtained to a pistol shot for comparably aged female *S*s in a previous study.[12] The obtained latency range was also comparable to the range of arm-hand startle latencies (125 to 195 msecs) reported by Landis and Hunt.[2] Mean latency of the eye-blink response was 64 msecs with a range of 20 to 80 msecs. This mean value is somewhat higher than the mean (40 msecs) reported by Landis and Hunt, but differences in technique (high-speed motion photography used by Landis and Hunt vs. electromyography used in the present study) may account for this slight difference.

The latency ranges actually used in scoring eye-blink and arm-hand responses to the simulated booms extended from 20 to100 and 90 to 230 msecs respectively. Note that for each measure 20 msecs were added to the longest latencies obtained to the pistol shot. This was done to minimize measurement error, since accuracy of measurement was only ±20 msecs (0.5 mm on the chart recording). Since the mean response time (230 msecs) to the 1000 Hz tone fell within the range of the arm-hand startle latencies to the pistol shot, there was no way to be absolutely

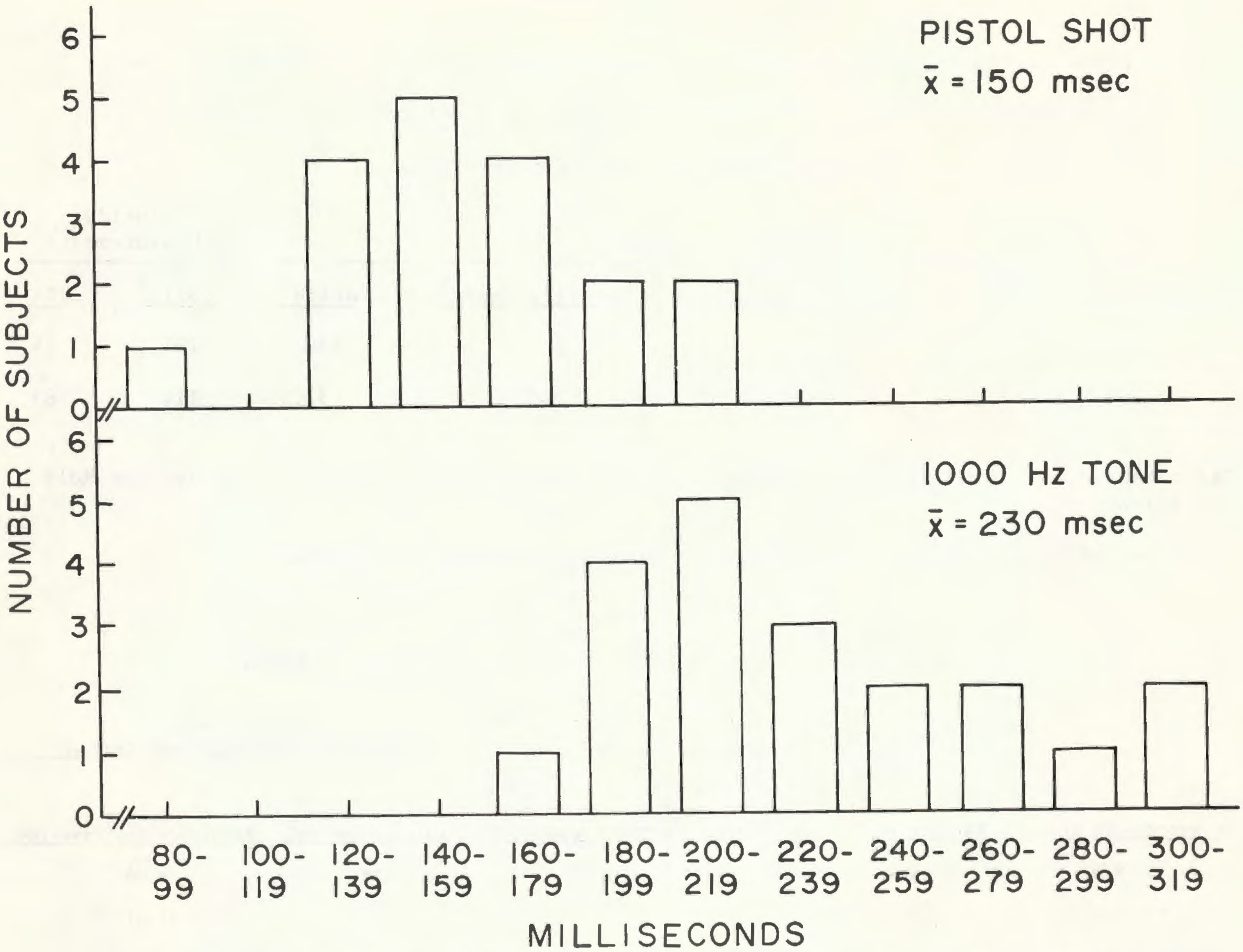

FIGURE 2. Latency distributions of arm-hand response to the pistol shot and to the 1000 Hz tone.

certain that an arm-hand response to the simulated booms was a startle reaction rather than a form of voluntary response. However, the difference between mean response time to the tone and pistol shot was significant ($t=7.34$; $p<.01$) and, as shown in Figure 2, there was relatively little overlap between the distributions. Also, it should be recalled that the criteria for designating an arm-hand response as a startle reaction included not only latency criteria but required that the arm-hand response amplitude exceed the pre-stimulus amplitude, that the response occur in both planes of movement, and that a reflex eye-blink response occur in conjunction with the arm-hand response. With these additional requirements, it was felt that the likelihood of scoring a voluntary response as a startle reaction was minimal.

B. *Behavioral Response to the 50 and 150 N/m² Booms.* Table 3 provides a summary of the eye-blink and arm-hand data for responses which met the startle criteria. The most pronounced differences between the two exposure groups were in the percentages of *S*s showing eye-blink and arm-hand responses to the booms. In order to make statistical comparisons of these differences, Ss were classified according to they showed a startle response to either 0 to 2 or 3 to 6 of the booms presented. The obtained chi squares were 5.49 and 7.50 for the eye-blink and arm-hand responses respectively. Both values were significant ($p.<.05$), indicating a greater frequency of response to the more intense boom level.

To evaluate differences between the groups in eye-blink latency, eye-blink amplitude change, arm-hand latency, and arm-hand amplitude increase, each *S*'s mean response to the six booms was obtained for each measure and Mann-Whitney *U* tests[7] conducted. None of the comparisons

Table 3

Eye-Blink and Arm-Hand Data for Responses Which Met the Startle Criteria.

		Eye-Blink Data			Arm-Hand Data (Combined Left-Right and Up-Down)		
Group	Boom Number	Per Cent Showing Startle Response	Mean Latency (msecs)	Mean Eye-Blink Response Amplitude as Expressed as a Percentage of Voluntary Blink Amplitude	Per Cent Showing Startle Response	Mean Latency (msecs)	Mean Amplitude Increase (mm)
	1	30	73	18	0	---	----
	2	40	70	8	30	173	4.98
50 N/m^2	3	60	75	14	30	160	5.42
	4	50	80	18	10	160	1.25
	5	20	60	14	0	---	----
	6	30	73	18	0	---	----
	Mean	38	72	15	12	164	3.88
	1	90	73	33	80	172	7.21
	2	90	60	86	60	133	8.25
150 N/m^2	3	90	62	85	70	141	5.96
	4	90	62	78	70	151	7.21
	5	90	71	57	50	158	4.25
	6	90	67	46	40	147	6.37
	Mean	90	66	64	62	150	6.54

was significant ($p>.05$), with the exception of eye-blink amplitude change. The obtained U for this measure was 1.0 ($p<.01$).

C. *Habituation Effects.* The data presented in Table 3 suggest little or no habituation effects across the six exposures for either of the two boom levels. The only possible exceptions would appear to be in the percentage of *S*s showing eye-blink and arm-hand responses to the 50 N/m^2 and arm-hand responses to the 150 N/m^2 booms. However, sign tests of the number of responses made by each *S* to the first and last three booms to which each was exposed revealed the differences to be nonsignificant ($p>.05$).

D. *Magnitude of Boom Response Relative to the Pistol Shot.* The group exposed to the 150 N/m^2 boom was used to compare response to the simulated booms with response to the pistol shot. The 50 N/m^2 group was excluded because of the few measurements available on these *S*s. In order to enable comparisons of response to these two stimuli, means of each measure averaged across booms for each *S* were compared with corresponding values obtained to the pistol shot. Significant differences were found for arm- hand amplitude increase ($t=3.57$; $p<.05$) and for per cent change in eye-blink response (sign test, $p<.05$).[7] As an inspection of Tables 2 and 3 will reveal, the greater amplitude changes occurred to the pistol shot. No differences were found for either eye-blink latency ($t=1.97$; $p>.05$) or arm-hand latency ($t=1.69$; $p>.05$).

Autonomic Response

A. *Differences Between Overpressure Groups.* Table 4 shows pre-stimulus and change values for skin conductance and heart rate across the six boom exposures. Analyses of variance revealed no evidence of habituation for either pre-stimulus or change values for heart rate and conductance ($p>.05$). Likewise none of the interaction effects between boom exposures and overpressure groups was significant ($p>.05$). There were significant differences, however, between the overpressure groups on pre-stimulus heart rate ($F=5.17$; $p<.05$), heart-range change ($F=12.86$; $p<.005$), and conductance change ($F=4.74$; $p<.05$). It is interesting to note that the heart-rate response for the 150 N/m^2 group was an increase in rate, while that for the 50 N/m^2 group was a decrease. The higher pre-stimulus heart rate for the 150 N/m^2 group was present even prior to the first boom exposure. This suggests that the difference between the two groups on this measure was the result of a sampling bias and not the result of the experimental conditions.

B. *Comparison With Response to the Pistol Shot.* Except for pre-stimulus heart-rate level which approached significance ($t=1.80$; $p<.10$),

Table 4

Pre-Stimulus and Change Values for Conductance and Heart Rate During Boom Exposure.

Physiological Measure	Exposure Group (N/m^2)	Boom Exposure Number 1	2	3	4	5	6	Mean
Pre-Stimulus Conductance Level (u mhos)	50	11.15	11.15	11.05	11.25	11.40	11.57	11.26
	150	12.53	12.63	12.39	12.01	11.79	11.91	12.21
Conductance Change (μ mhos)	50	0.43	0.45	0.46	0.47	0.44	0.42	0.44
	150	1.58	1.44	1.22	1.31	1.23	1.03	1.30
Pre-Stimulus Heart Rate (bpm)	50	75	76	76	75	77	76	75.8
	150	89	85	86	86	84	84	85.7
Heart-Rate Change (bpm)	50	-2.2	-2.5	-2.2	-1.6	-5.4	-0.7	-2.43
	150	5.2	4.8	2.9	1.2	4.0	2.3	3.40

Table 5

Pre-Stimulus and Change Values for Conductance and Heart Rate

Obtained to the Pistol Shot.

Physiological Measure	Exposure Group (N/m^2)	Mean	Mean of Combined Groups
Pre-Stimuls Conductance Level (μ mhos)	50	12.23	12.23
	150	12.24	
Conductance Change (μ mhos)	50	1.22	1.46
	150	1.70	
Pre-Stimulus Heart Rate (bpm)	50	71.1	74.4
	150	78.4	
Heart-Rate Change (bpm)	50	10.9	11.25
	150	11.6	

t tests revealed no significant differences between the two exposure groups for the pistol-shot data in conductance or heart-rate levels prior to the pistol shot or in magnitude of change to this stimulus ($p>.05$). Mean values for these measures are shown in Table 5. Since no significant differences were obtained, combined means are also shown in the table. Statistical comparisons of mean heart rate and conductance change to the 150 N/m² booms with change in these two measures to the pistol shot revealed a significant difference for heart-rate change ($t=4.59$; $p<.01$), but not for conductance change ($t=1.80$; $p>.05$).

IV. Discussion.

The present study revealed that low-level simulated sonic booms experienced indoors can produce slight arm-hand startle reactions in a small percentage of *S*s. Although these brief startle reactions presumably also occurred to the comparable exposure level (50 N/m² overpressure; 6 msecs rise time) employed in the previous study,[11] they did not produce any apparent performance impairment on the tracking task used. It seems likely that the relative insensitivity of the tracking task to slight startle responses, the infrequency with which they were found to occur in the present study, and the pronounced performance facilitation following boom exposure which was found in the earlier study all tended to obscure the momentary impairment which probably occurred.

Simulated booms having three times the outside overpressure, but with the same rise times, were found to produce arm-hand startle responses which differed from the lower boom level in frequency of occurrence but not in response amplitude. For the eye-blink reflex, the higher boom intensity produced both a greater number of responses and a greater amplitude of response.

It is interesting that similar results for the arm-hand response were also obtained to actual sonic booms experienced indoors during a recent field study of startle effects.[12] Flyovers of supersonic aircraft generated booms having outside overpressures ranging from 60 to 640 N/m² with a mean rise time of 2.5 msecs. Mean arm-hand response amplitude (using the same task used in the present study) was virtually the same in both studies. Although there was evidence in the field study which suggested a slightly greater amplitude of response to the more intense booms, the primary effect of increases in overpressure was an increase in the percentage of *S*s showing startle reactions. Percentages of *S*s exhibiting startle reactions to the 50 and 150 N/m² booms in the present study were almost identical to the percentages obtained for comparable overpressures in the field study.

Taken together, the results of both studies suggest that the indoor stimulus intensities, for the range of boom exposure levels employed, were at or only slightly above the threshold level for evoking startle reactions strong enough to involve arm-hand responses. Higher overpressures levels simply evoked these marginal startle reactions in a greater number of *Ss* than did lower levels, with little or no evidence of a corresponding increase in response amplitude. The startle reactions are considered marginal since, in both the present study and in the field study, arm-hand response to a "standard" startle stimulus (.22 caliber pistol shot) was approximately twice the mean amplitude obtained to the booms.

Autonomic changes noted in the present study would appear to be entirely consistent with the skeletal-muscular responses obtained to the two boom levels. Thus, the heart-rate deceleration associated with the 50 N/m² level suggests that the predominant response was an orienting reaction[10] and this is supported by the relatively few startle reactions involving either eye-blink or arm-hand movements which occurred. On the other hand, heart-rate acceleration, which is associated with the startle reflex,[10] was the typical pattern associated with the 150 N/m² level, and the majority of *S*s responded with eye-blink reflexes and with total startle reactions extensive enough to involve measurable arm-hand responses. Heart-rate acceleration to the pistol shot was significantly greater than to the 150 N/m² boom level and, as has previously been mentioned, this was accompanied by a larger arm-hand response.

Both the present study and the previous field study[12] are in agreement that startle reactions can occur to sonic booms experienced indoors and that these reactions tend to occur with increasing frequency as overpressure increases. While startle reactions involving arm-hand movements of only half a centimeter (the approximate mean amplitude in both studies) could be quite disruptive in skills or occupations requiring precise arm-hand control, it is doubtful that reflex responses of this magnitude would seriously disrupt performance on less sensitive psychomotor tasks, a practical example of which would be automobile driving. Indeed, there is little evidence that real or simulated sonic booms experienced indoors significantly impair such behavior. Lukas and Kryter,[3] for example, found no significant impairment in tracking performance when subjects were exposed to simulated booms having outdoor overpressures of approximately 58 N/m². In a later study by Lukas, Peeler, and Kryter,[4] a slight impairment in tracking performance was found to simulated booms of approximately 120 N/m², but the authors felt that this may have been caused by vibratory responses of the test room acting upon the tracking stylus rather than as the result of a direct startle effect. Rylander, Sorensen, Berglund, and Brodin[6] found that *S*s performing on an automobile-driving simulator indoors and exposed to outdoor sonic boom levels of 40 to 650 N/m² exhibited very little adverse effects. The authors state that ". . . sonic boom exposures of the levels studied here to not significantly influence the muscular performance of persons driving a car when they know that boom exposures might occur, provided that boom levels do not exceed the values studied in this experiment." Indoor overpressures in this study ranged from 20 to 260 N/m². Thus, while the rather long rise times of the 100 and 200 N/m² booms employed in the previous study by Thackray, Touchstone, and Jones[11] may have contributed to the apparent lack of startle effect noted, it is interesting that of the above studies, one of which exposed *S*s to a wide range of overpressure,[6] none found any appreciable evidence of performance impairment on complex psychomotor tasks when *S*s were exposed to sonic booms while indoors.

In conclusion, it is important to emphasize that in virtually all of the studies reviewed here outdoor overpressure has been the primary measure employed to evaluate indoor exposure effects. This is admittedly not the best measure to employ, but it is the only one common to all the above studies. While some of the studies, including the present one, report some measure of indoor exposure level, it is not known which of many possible measures is the most adequate one to use. A comprehensive parametric study to determine the indoor acoustical measure yielding the highest relationship with startle effects has not as yet been conducted and would require a complex simulation facility capable of faithfully producing booms covering a wide range of overpressures and rise times. In spite of the limitation in using only outside overpressure, there is a rather remarkable agreement among the available studies concerning the indoor exposure effects of real and simulated booms, and it is felt that the present evidence can serve as a useful guideline for making initial, practical decisions. Part of the apparent agreement may be due to the fact that in all the studies the test rooms in which *S*s experienced the real or simulated booms were of similar frame or wood-metal construction, with at least one wall of the room directly exposed to the booms. This would also suggest that the observed indoor effects would likely be near the maximal expected.

V. Summary.

Subjects were exposed indoors to simulated sonic booms having outside overpressures of 50 and 150 N/m². Rise times were held constant at 5.5 msecs. In addition to the outside measurements, inside measures of dBlin and dBA were also obtained. Subjects attempted to hold a hand-steadiness device on target during boom exposure and amplitude of the arm-hand startle response was determined. Recordings were also obtained of the skin conductance and heart-rate response as well as the eye-blink reflex. Although the 50 N/m² boom produced slight arm-hand startle responses in a small percentage of the *S*s, the frequency of these responses was significantly greater to the higher boom level. There was no difference between the levels in amplitude of the response. The predominant autonomic response pattern to the lower exposure level was similar to that obtained for orienting responses, while a startle pattern was obtained for the higher level. The results are compared with the findings of other studies, and the tentative conclusions advanced that sonic booms experienced indoors may cause slight arm-hand startle responses which could have adverse effects on occupational tasks in which arm-hand steadiness is the principal skill required, but that it seems unlikely that these responses would significantly impair performance on less sensitive psychomotor tasks.

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32549

Federal Aviation Administration, Office of Aviation Medicine, Civil Aeromedical Institute, Oklahoma City, Oklahoma. **A COMPARISON OF THE STARTLE EFFECTS RESULTING FROM EXPOSURE TO TWO LEVELS OF SIMULATED SONIC BOOMS** by Richard I. Thackray, Robert M. Touchstone, and Joe P. Bailey, December 1973, 11 pp. Report No. **FAA-AM-73-16.**

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Descriptors
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