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16. Abstract

Two separate studies are reported. The first attempted to determine a sonic boom exposure level below which startle reactions would not occur. Subjects were exposed indoors to six simulated sonic booms having outside overpressures of 50, 30, and 16 N/m^2 (inside sound pressure levels of 74, 71, and 65 dBA). Approximately 20 percent of the subjects gave small-amplitude arm-hand startle responses to the two higher exposure levels, while none responded to the lowest level. In the second study, subjects were exposed indoors to a series of 12 simulated booms in order to assess habituation effects. Outside overpressures were 130 and 50 N/m^2 (indoor sound pressure levels of 81 and 72 dBA). Significant, but not complete, habituation occurred to booms of both levels. Autonomic and eyeblink responses, as well as ratings of subjective annoyance, were obtained in both studies. The final section of the report summarizes the expected behavioral, autonomic, and subjective effects of exposure to various levels of sonic booms.

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BEHAVIORAL, AUTONOMIC, AND SUBJECTIVE REACTIONS TO LOW- AND MODERATE-LEVEL SIMULATED SONIC BOOMS: A REPORT OF TWO EXPERIMENTS AND A GENERAL EVALUATION OF SONIC BOOM STARTLE EFFECTS

Measurable startle reactions of sufficient intensity to evoke arm-hand movements have been found to occur in subjects (*Ss*) exposed indoors to real or simulated sonic booms having outside overpressures as low as 50 to 70 N/m² (indoor sound pressure levels of approximately 72 to 74 dBA).[6 7] These startle reactions tend to occur in 20 to 30 percent of *Ss* who have had little or no previous exposure to sonic booms, with the percentage appearing to diminish with repeated exposure.[6 7] Although total body flexion is seldom, if ever, evident to booms of this level, the startle response does involve arm-hand movements of sufficient magnitude to potentially disrupt performance on tasks requiring precise arm-hand control. These findings are of significance because they suggest that startle reactions can occur to sonic booms having overpressures below the range of overpressures (75 to 175 N/m²) expected along the centerline of the sonic boom carpet of the Concorde SST.[9]

This report presents the results of two separate experiments. The first was conducted to determine an exposure level below which arm-hand startle responses would not occur. The second study was designed to provide further information on habituation of these startle responses to both low- and moderate-level sonic booms. In addition to arm-hand response data, subjective ratings of startle and annoyance and physiological recordings of heart rate, palmar skin conductance, and eyeblink response were obtained in both studies.

Experiment I

I. Method.

A. *Subjects.* Thirty paid male university students, ranging in age from 18 to 29, served as *Ss*. All were right handed, had no reported hearing loss, and had not previously participated in startle or sonic boom experiments.

B. *Apparatus.* The basic simulator consisted of a 4.1- x 3.7- x 2.4-meter testroom, one wall of which formed one of the sides of a hermetically sealed pressure chamber. Complete details of the simulator are given in several previous reports.[3 5 7] In typical usage, the simulated booms are produced by a motor-actuated piston, which generates an N-wave of pressure in the chamber. In the present two studies, it was necessary to introduce certain modifications in order to either hold rise time constant or achieve exceedingly low overpressure levels.

In Experiment I, the simulator's motor-actuated piston was not employed because this mechanism was not capable of faithfully producing the extremely low overpressures with constant rise time that was required. Instead, simulated booms of constant rise time and duration were produced by brief electrical transients, which, after amplification, were led to an Altec Lansing 419A Biflex speaker located in the pressure chamber. Electronic timers were used to control the interval between the two pulses of each N-wave. It should be noted that the piston could have been used to produce the highest overpressure (50 N/m²) used in this experiment. However, although the impulsive stimuli produced by the speaker were quite similar to those produced by the piston, it was decided that slight differences in sound quality warranted using only the speaker for all of the overpressure levels employed. Persons familiar with the sound of sonic booms heard indoors judged the resulting impulsive stimuli 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.

The task apparatus used by the subject (*S*) was a sensitive electromechanical device for measuring small-amplitude arm-hand movements. The tip 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 the rod 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 at the table. Photographs of this device are shown in several previous reports.[6 7]

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 bipotential electrodes attached to the lateral walls of the *S*'s chest with the leads 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 with the leads 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, the onset of the booms was recorded on one channel of the Dynograph by means of a microphone located in the testroom. All recording equipment was located outside the *S*'s testroom.

C. *Procedure.* Ten *Ss* were arbitrarily assigned to each of three exposure levels: 50, 30, and 16 N/m². (These values refer to peak overpressures of the booms as measured outside; i.e., in the pressure chamber.) Mean sound pressure levels inside the testroom were 74, 71, and 65 dBA (fast scale) for the 50-, 30-, and 16-N/m² overpressures, respectively. Mean rise time of the booms was 4 msec and duration was 210 msec.

Following initial instructions, the *S* was instrumented for physiological recording and the task was 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 try to keep the stylus pointed at the small circle. He was instructed to continue doing this until the yellow lights went out. Further, he was not to rest his arm or elbow on the table while holding the stylus. He was told that he might hear certain sounds during the period in which the yellow lights were illuminated. He was, however, 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 1-hour test session was divided into twelve 5-minute periods. During the first 4 minutes of each 5-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 1-hour period and the results will not be reported here.) At the end of the 4 minutes, the yellow signal lights were illuminated and the *S* grasped the pointer of the steadiness tester. Fourteen to twenty-eight seconds after the signal lights were illuminated (these time intervals were randomly determined for each period), either a boom occurred or it did not. Booms were presented in three of the six 5-minute periods in each half-hour; the remaining periods served as controls for expectancy effects. Determination of the periods in which booms occurred was random. Each *S* was given practice on both the steadiness and vigilance tasks prior to the beginning of the experimental session. At the completion of the session, the *S* was exposed to the sound of a .22-caliber pistol shot. The noise level of the shot at the *S*'s location was 103 dBA (fast scale). The purpose of the pistol shot was to provide a reference for evaluating subjective startle to the booms, and the test was conducted in such a way that the *S* had no knowledge that it would be anything other than another boom or control run. Following the pistol shot, subjective ratings of startle and annoyance were obtained. (The subjective scale used is given in Appendix 1.)

D. *Criteria for Defining Startle Responses.* Two levels of startle response to the booms were designated. A minimal response consisted of only an eyeblink reflex, while a more pronounced response involved an arm-hand movement. In order for either of these responses to be considered as a reflex response, its latency had to fall within 20 to 100 msec for the blink response or 90 to 230 msec for the arm-hand response. These ranges were empirically determined from responses to a pistol shot in a comparable previous study.[7] Although *Ss* in the present experiment were also exposed to pistol shots of the same sound pressure level, there were slight differences between the two studies in the range of latencies obtained. In order to enable direct comparisons between the results of the two studies, it was decided to use the pistol shot data from the earlier study in establishing latency ranges. It should be noted that differences between the mean latencies obtained in both studies were not significant for either the eyeblink response ($t=1.27$; $p>.05$) or the arm-hand response ($t=0.11$; $p>.05$).

To be considered a startle reaction, an arm-hand response had to (1) occur in conjunction with an eyeblink reflex, (2) have latencies in both the left-right and up-down planes that fell within the latency ranges obtained from responses to the pistol shot, and (3) have response amplitudes in both planes that exceeded the maximum peak-to-peak amplitude of hand tremor occurring in the 5-second period preceding the boom.

E. *Measurement of the Physiological Response.* Galvanic skin responses to each boom 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 were obtained. The magnitude of heart-rate change was determined by obtaining the difference between the maximum heart rates in the 5-second prestimulus and poststimulus intervals.

II. Results.

A. *Behavioral Response.* Table 1 provides a summary of the eyeblink and arm-hand responses that met the startle criteria. As is evident from the data presented, the only evidence of any startle reactions to the lowest exposure level was in the small percentage of *Ss* showing eyeblink responses. There were no arm-hand responses to this level. Although the 30-N/m^2 level appeared to evoke a greater percentage of startle reactions than the 50-N/m^2 level, chi-square tests revealed the differences between these two levels to be nonsignificant for percent eyeblink response, percent arm-hand response, and arm-hand response amplitude ($p>.05$).

B. *Autonomic Response.* Skin conductance and heart-rate measures are shown in Table 2. The general decline in autonomic level across boom presentations was found to be significant for both prestimulus conductance level ($F=8.99$; $p<.01$) and prestimulus heart rate ($F=3.64$; $p<.01$). There were no significant differences between the exposure groups themselves on any of the physiological measures, and none of the interactions were significant ($p>.05$). It is interesting that heart rate decelerated following the booms and, although the differences between groups were not statistically significant, the magnitude of cardiac deceleration appeared to increase with decreasing exposure levels.

C. *Subjective Data.* Chi-square tests revealed no differences between the groups in their rated annoyance with the booms ($p>.05$). All groups felt that regular exposure to booms of the levels used would be mildly to moderately annoying. Sixty to seventy percent of all *Ss* felt that they would eventually adapt to or become virtually unaware of booms of this level, and the groups did not differ in this respect. Percentages of *Ss* who indicated that the booms startled them were 50, 70, and 90 percent for the 16-, 30-, and 50-N/m^2 overpressure levels, respectively. The differences between the groups, however, were not significant ($p>.05$). Median values assigned to the subjective startle experience evoked by the booms were 15, 33, and 25 for the 16-, 30-, and 50-N/m^2 levels, respectively. These values are with reference to the pistol shot, which was assigned an arbitrary value of 100. The differences between groups were not significant ($p>.05$).

TABLE 1. Eyeblink and Arm-Hand Data for Responses That Met the Startle Criteria

		Eyeblink Data	Arm-Hand Data (Combined Left-Right and Up-Down)	
Overpressure Group (N/m²)	Boom Number	Percentage of Ss Showing Startle Response	Percentage of Ss Showing Startle Response	Mean Response Amplitude (mm)
16	1	10	00	---
	2	20	00	---
	3	10	00	---
	4	00	00	---
	5	20	00	---
	6	00	00	---
	Mean	10	00	---
30	1	80	10	3.25
	2	80	40	2.44
	3	90	30	1.92
	4	90	40	4.12
	5	60	00	----
	6	70	10	8.25
	Mean	78	22	4.00
50	1	50	00	----
	2	80	20	7.87
	3	80	30	2.42
	4	70	10	3.25
	5	60	20	3.75
	6	70	30	0.75
	Mean	68	19	3.61

Experiment II

I. Method.

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

B. *Apparatus.* This study employed the piston of the simulator but modified the N-wave for overpressures greater than 50 N/m² in order to hold rise time approximately constant. To accomplish this, a photocell, whose light source was momentarily interrupted at the points of maximum forward and backward excursion of the piston, was employed. This provided a trigger for the same transient circuit and speaker used in Experiment I. By properly synchronizing the speaker output with the wavefront produced by the piston, it was possible to achieve simulated booms greater than 50 N/m² with nearly equal rise times. Booms were calibrated in the same manner as described in Experiment I.

The task employed and the physiological measures obtained were the same as those in Experiment I.

C. *Procedure.* Ten *Ss* were arbitrarily assigned to each of two exposure levels: 50 and 130 N/m². (As in Experiment I, these values refer to peak overpressures as measured in the pressure chamber and not in the testroom itself.) Sound pressure levels in the testroom were 72 and 81 dBA (fast scale) for the 50- and 130-N/m² levels, respectively. Mean rise time of the 50-N/m² boom was approximately 6 msec; for the 130-N/m² level, rise time was 4 msec. Duration was 210 msec for both levels.

Ss performed both the steadiness task and the vigilance task as in Experiment I. The basic procedure was the same; the major differences were the number of booms presented and the duration of the experiment. Twelve booms were presented during two 40-minute sessions separated by a 5-minute rest pause. Booms were presented in six of the eight 5-minute periods

TABLE 2. Prestimulus and Change Values for Conductance and Heart Rate During Boom Exposure

Physiological Measure	Overpressure Group (N/m^2)	Boom Exposure Number 1	2	3	4	5	6	Mean
Prestimulus Conductance Level (μmho)	16	11.58	11.05	10.62	10.14	9.89	9.86	10.52
	30	11.52	11.09	10.34	10.39	10.20	9.94	10.58
	50	11.81	11.72	11.67	11.06	10.73	11.21	11.37
Conductance Change (μmho)	16	0.28	0.46	0.64	0.54	0.85	0.72	0.58
	30	1.13	1.62	1.34	0.93	0.81	0.94	1.13
	50	0.86	1.00	1.03	0.92	0.86	0.81	0.91
Prestimulus Heart Rate (bpm)	16	79.60	80.50	79.10	77.10	77.10	78.50	78.65
	30	79.60	70.40	70.20	70.90	68.70	68.90	70.95
	50	78.90	81.30	83.30	77.40	77.90	76.10	79.15
Heart-Rate Change (bpm)	16	-3.60	-2.60	-2.20	-0.90	-1.60	-3.80	-2.45
	30	-7.30	-0.50	-1.50	-2.20	-1.20	-0.50	-2.20
	50	0.20	-2.60	-4.80	2.40	0.70	-1.00	-0.58

in each session with the nonboom (control) periods inserted randomly for each *S*. As in Experiment I, *Ss* were exposed to a .22-caliber pistol shot of 103 dBA at the end of the experiment and the subjective questionnaire was administered.

D. *Criteria for Defining Startle Responses.* The same latency ranges employed in Experiment I were used in Experiment II. Likewise, all other criteria for evaluating startle response to the booms were the same.

E. *Measurement of the Physiological Response.* The physiological variables and methods of scoring were the same as described for Experiment I.

II. Results.

A. *Behavioral Response.* A summary of the eyeblink and arm-hand responses that met the startle criteria are shown in Table 3. In comparing responses to the first six booms with responses to the last six booms, sign tests revealed no evidence of habituation of the eyeblink responses in either the 50- or 130-N/m² groups ($p>.05$). For arm-hand responses, sign tests revealed a significant decrease in percent response for both exposure groups ($p<.05$). The effect of repeated boom exposure on response amplitude could not be determined because the number of *Ss* responding to the last six booms was too small to allow adequate statistical comparison.

TABLE 3. Eyeblink and Arm-Hand Data for Responses That Met the Startle Criteria

			Eyeblink Data	Arm-Hand Data	
Overpressure Group (N/m^2)	Boom Number		Percentage of Ss Showing Startle Response	Percentage of Ss Showing Startle Response	Mean Response Amplitude (mm)
	1		40	30	5.17
	2		60	10	4.75
	3		80	30	1.25
	4		70	20	4.25
	5		50	10	1.75
	6		50	30	4.50
		Mean	58	22	3.61
50					
	7		60	10	9.50
	8		50	10	1.25
	9		40	10	9.75
	10		60	0	----
	11		50	0	----
	12		70	10	7.75
		Mean	55	7	7.06
	1		80	70	8.68
	2		90	50	6.45
	3		90	40	7.56
	4		100	60	4.12
	5		100	40	2.31
	6		80	60	2.29
		Mean	90	53	5.23
130					
	7		80	20	4.00
	8		80	30	3.08
	9		80	30	4.75
	10		70	20	2.25
	11		70	10	5.50
	12		80	20	1.87
			77	22	3.57

Since there was evidence of significant habituation effects, evaluations of possible differences between the 50- and 130-N/m^2 groups in frequency or amplitude of startle reactions were made by using only responses to the first six booms. Chi-square tests revealed no differences between the exposure groups in either percent eyeblink or percent arm-hand response ($p>.05$). Likewise, a Mann-Whitney U-test revealed no difference between groups in amplitude of the arm-hand responses ($p>.05$).

B. *Autonomic Response.* Prestimulus and change values for conductance and heart rate are shown in Table 4. Analyses of variances revealed a significant decline across boom exposures for conductance change ($F=5.62$; $p<.01$) and prestimulus heart rate ($F=3.25$; $p<.01$) and a significant difference between the two overpressure levels for heart-rate change ($F=10.56$; $p<.01$). None of the other effects were significant. As in Experiment I, the heart-rate response to the 50-N/m^2 exposure level was one of cardiac deceleration. Cardiac acceleration occurred to the 130-N/m^2 level.

C. *Subjective Data.* Although *Ss* exposed to the higher overpressure level tended to rate the booms as more annoying than did those exposed to the lower lever, a chi-square test revealed the difference between groups to be nonsignificant ($p>.05$). Combining the ratings of both groups gave a mean rating to both exposure levels of "moderately annoying." Seventy percent of the *Ss* exposed to the lower level and 60 percent of those exposed to the higher level felt that they would eventually adapt to or become virtually unaware of the booms. One hundred percent of the *Ss* in each group stated that they were startled by some or all of the booms. With reference to the pistol shot, which had an arbitrary value of 100, the median startle value assigned to the booms by the 50-N/m^2 group was 37.5 while the 130-N/m^2 group assigned a value of 143.5. A chi-square test revealed this difference to be significant ($p<.01$).

Discussion

Experiment I demonstrated that groups exposed indoors to simulated sonic booms having outside overpressures of 30 and 50 N/m^2 (inside dBA levels of 71 and 74) did not differ in the frequency of evoked startle responses. Percent response for the two levels combined was approximately 20 percent for arm-hand responses and 73 percent for eyeblink responses. Reducing the outside overpressure level to 16 N/m^2 (65 dBA inside) resulted in an exposure level that was not sufficient to evoke arm-hand startle responses in any of the *Ss* and that evoked eyeblink responses in only about 10 percent of the *Ss*. The results thus suggest that outside overpressures must be below 30 N/m^2 (71 dBA inside), and possibly as low as 16 N/m^2 (65 dBA inside), in order to insure that measurable startle responses involving arm-hand movements will not occur.

Of more theoretical interest than practical importance was the finding that heart-rate response to the three overpressure levels was that of cardiac deceleration rather than acceleration, with the magnitude of deceleration appearing to increase with decreases in exposure level. Since heart-rate acceleration is the typical cardiac response to startle,[4] this deceleration in heart rate coupled with the relatively small percentage of reactions involving muscular movements suggests that the predominant response to these low exposure levels was more of an orienting, or alerting, response than a startle reaction.[4]

Subjectively, it was judged that repeated exposure to booms of the levels employed would be mildly to moderately annoying, and the groups did not differ in this respect. Sixty to seventy percent of the *Ss* felt that they would eventually adapt to or become virtually unaware of booms of these intensities. Those *Ss* who felt that the booms were subjectively startling evaluated the startle experience as being approximately one-sixth to one-third as startling as the pistol shot to which they were exposed.

Experiment II revealed that exposure to a series of 12 simulated booms resulted in a significant reduction in the frequency of arm-hand startle responses. This was found for both the 130-N/m^2 (81 dBA inside) and 50-N/m^2 (72 dBA inside) overpressure levels. Interestingly enough, the series of 12 boom exposures occurring over a relatively short period of time failed to result in complete habituation of these skeletal-muscular responses. On the basis of the habituation that did occur, it could be hypothesized that prolonged exposure to sonic booms of these levels would undoubtedly result in a further reduction in the number of persons responding with arm-hand movements. It is uncertain whether com-

TABLE 4. Prestimulus and Change Values for Conductance and Heart Rate During Boom Exposure

Physiological Measure	Overpressure Group (N/m^2)	Boom Exposure Number												
		1	2	3	4	5	6	7	8	9	10	11	12	Mean
Prestimulus Conductance Level (μmho)	50	10.44	10.19	10.29	10.25	10.08	9.69	10.24	10.12	10.41	10.29	10.27	10.49	10.23
	130	11.25	10.50	10.23	10.21	9.78	9.80	10.17	10.21	10.44	10.44	10.22	10.38	10.30
Conductance Change (μmho)	50	1.12	1.29	1.18	1.03	0.86	0.91	0.86	0.62	0.67	0.56	0.56	0.36	0.83
	130	1.89	1.08	1.12	1.28	1.29	1.08	1.04	0.89	0.89	0.85	0.95	0.73	1.09
Prestimulus Heart Rate (bpm)	50	75.40	71.10	72.10	72.10	71.70	69.00	66.40	67.60	68.70	64.80	66.90	69.20	69.58
	130	72.60	73.50	73.50	73.30	74.10	74.40	71.90	70.20	71.70	70.70	70.40	68.10	72.03
Heart Rate Change (bpm)	50	-2.60	0.30	-1.10	-2.90	-2.60	0.30	-0.60	-1.40	-1.90	-1.80	-1.50	-6.20	-1.83

plete habituation of this response would ever occur in all individuals even to the lower level employed in this study.

There was no evidence of habituation of minor (eyeblink) startle reactions to either level. This finding is in accordance with the studies reported by Landis and Hunt,[2] in which the eyeblink component of the total startle pattern rarely, if ever, disappeared, even among police marksmen during target practice.

The 130-N/m^2 level used in this experiment evoked more frequent eyeblink and arm-hand responses than did the 50-N/m^2 level. However, the differences in frequency of responses failed to reach significance at the 5-percent level.

Conductance change to the booms and prestimulus heart rate showed some evidence of habituation, but there was no change in prestimulus conductance levels or heart-rate responses across booms. Heart-rate response was that of cardiac acceleration to the higher exposure level and that of deceleration to the lower level.

The exposure groups did not differ in their rated annoyance of the booms and generally felt that frequent exposure to booms of the levels employed would be moderately annoying. As in Experiment I, 60 to 70 percent of the *Ss* felt that they would eventually adapt to and become virtually unaware of booms having levels comparable to those to which they were exposed. Subjects exposed to the 50-N/m^2 booms rated their subjective startle to this level to be about one-third as startling as the pistol shot. Rather surprisingly, the 130-N/m^2 level was rated to be somewhat more startling than the pistol shot. This latter finding must be viewed with some degree of caution, however, since *Ss* were rating their subjective startle experiences. In several previous studies, *Ss* were exposed both to a pistol shot that was comparable in intensity to that employed here and to sonic booms with overpressures approximately equal to the 130-N/m^2 level used in Experiment II. It was found that the actual magnitude of the reflex arm-hand response to the pistol shot was about twice that evoked by the booms.[6 7]

The results of the two experiments reported here, along with the results of several previous studies that used both real and simulated sonic booms,[6 7 8] allow an evaluation of startle effects over a reasonably wide range of exposure levels. A summary of the behavioral, physiological, and subjective data obtained are presented in Table 5. Several general comments concerning these data are in order before the results are discussed. The data on males were obtained by using simulated sonic booms (the same simulator was used in all cases), while the data on females were obtained during a field study in which actual sonic booms were used. All *Ss* were exposed to the sonic booms (simulated or real) while indoors, and the same arm-hand steadiness device was used in all studies. The testrooms used in both the field study and the simulation studies had similar dimensions, and both were of wooden frame construction. Recordings of indoor dBA were taken in all of the studies, but instrumentation problems during the field study resulted in many missed readings of the low- and moderate-level booms. Consequently, indoor overpressures are given in the table for these levels, with dBA values given only for the highest levels. With the exception of data shown for booms in the highest exposure category, all data in the table were obtained on *Ss* exposed to either five or six booms, and the response percentages represent mean values to booms of the intensities shown. Subjects exposed to the boom levels shown for category IV had been exposed to at least five booms on preceding days. Consequently, the response percentages may be somewhat depressed as a result of possible habituation effects. Finally, although the field study employed two age groups, the response percentages shown in the table pertain only to the younger group. This was done in order to make the data of the field study as comparable as possible to the data of the simulator studies, in which only 18- to 29-year-old males were used.

The data in Table 5 have been divided into four exposure categories. These categories are based upon the hypothesis, outlined in a previous study,[8] of a hierarchical pattern of behavioral response to increasing stimulus intensity; that is, there appear to be ranges of exposure levels within which the effects are approximately comparable. Data obtained thus far suggest that with increases in exposure level, there exist certain critical, or "threshold," stimulus levels in which the transition from one level to the next is accompanied by a rather definite change in the extent of skeletal-muscular response. The

TABLE 5. Summary of Data Obtained on Subjects Exposed Indoors to Real and Simulated Sonic Booms

Exposure Category (Levels Producing Similar Effects)	Outside Exposure Level	Inside Exposure Level	Characteristics of Group Studied	Behavioral Effects	Physiological Effects	Subjective Effects	Study (Reference Number)
I	16 N/m^2	65 dBA	Males, 18-29 years	Predominantly orienting responses. Eyeblink responses in 10% of Ss. No evidence of arm-hand movement.	Heart-rate deceleration to booms	Repeated exposure likely to be mildly annoying	Present study (Experiment I)
II	30-50 N/m^2	71-74 dBA	Males, 18-29 years	Mixed pattern of orienting and startle responses. Eyeblink responses in 40-80% ($\bar{X}$ = 60%) of Ss. Arm-hand movements in 10-20% ($\bar{X}$ = 19%) of Ss.	Heart-rate deceleration to booms	Repeated exposure likely to be mildly to moderately annoying	Present study (Experiments I and II), 7
	85-111 N/m^2	29-33 N/m^2	Females, 20-35 and 50-65 years	Eyeblink responses in 30-50% ($\bar{X}$ = 40%) of Ss. Arm-hand movements in 10-25% ($\bar{X}$ = 17%) of Ss. Frequency of startle responses lower among older group. No evidence of gross body responses.	No data	No data	6, 8
III	130-150 N/m^2	81-84 dBA	Males, 18-29 years	Predominant pattern of startle rather than orienting responses. Eyeblink responses in 90% of Ss. Arm-hand movements in 53-62% ($\bar{X}$ = 57%) of Ss.	Heart-rate acceleration to booms	Repeated exposure likely to be moderately annoying	Present study (Experiment II), 7
	170-310 N/m^2	44-69 N/m^2, less than 92 dBA	Females, 20-35 and 50-65 years	Arm-hand movements in approximately 55-70% ($\bar{X}$ = 61%) of Ss. Gross body flexion in 18-28% ($\bar{X}$ = 23%) of Ss. Frequency of startle responses lower among older group.	No data	No data	6,8
IV	340-640 N/m^2	65-130 N/m^2, 92-96 dBA	Females, 20-35 and 50-65 years	Arm-hand movements in 83-100% ($\bar{X}$ = 96%) of Ss. Frequency of startle responses lower among older group.	No data	No data	6

categories in Table 5 represent an attempt to identify those exposure levels associated with a pattern of similar effects.

Category I describes a level in which reflex eyeblink responses occasionally occur, but there is no evidence that the degree of startle elicited is of sufficient magnitude to involve arm-hand movements. The heart rate decelerates to stimuli of this level, and repeated exposure is likely to be only mildly annoying. The indoor sound pressure level associated with this category is at least 65 dBA and less than 71 dBA.

Category II exposure levels evoke a higher percentage of eyeblink responses, and arm-hand movements begin to appear in 10 to 25 percent of the *Ss*. Heart-rate response is still that of deceleration, which suggests that this exposure range generally tends to evoke reactions more appropriately considered alerting, attending, or orienting reactions rather than startle reactions. Continual exposure would probably be mildly to moderately annoying. Indoor sound pressure levels producing these effects apparently range from approximately 71 dBA to less than 81 dBA.

The exposure levels included in category III produce a rather marked increase in the number of *Ss* (53 to 70 percent) showing arm-hand movements. Also, it is to these levels that gross body responses corresponding to the traditional startle pattern[2] begin to appear and heart-rate acceleration occurs. The booms are judged to be moderately annoying. Indoor sound pressure levels are likely to be at least 81 to 84 dBA and probably less than 92 dBA.

Category IV exposure levels represent boom intensities in which the percentage of *Ss* showing arm-hand responses approaches 100 percent. Unfortunately, the high-speed-motion photography used during the field study was not employed on the day these exposure levels occurred, and therefore there are no data on the extent of gross body reactions. However, the frequency of arm-hand movements is approximately the same as that obtained on earlier test days to a reference startle stimulus (.22-caliber pistol shot, 100 dBA).[6] Since most *Ss* who displayed arm-hand movements to the pistol shot also displayed the full startle pattern, it seems reasonable to assume that the frequency of gross body reactions to category IV levels considerably exceeds the frequency shown for category III levels. There are no subjective data available for category IV boom levels, but it is likely that repeated exposure to booms of these levels would be considered quite annoying. Indoor sound pressure levels associated with this category ranged from 92 dBA to 96 dBA.

It is emphasized that Table 5 should be viewed primarily as a guide in predicting the general effects of indoor sonic boom exposure. With the exception of the data presented for category IV, the behavioral, physiological, and subjective data presented in the table represent the typical or mean responses of *Ss* exposed to five or six sonic booms. Percent response to the first boom to which *Ss* are exposed is generally greater than the values shown in the table. Likewise, repeated exposure to booms would be expected to reduce the response percentages shown in Table 5. Both the Experiment II results reported in this paper and the results of the earlier field study[6] suggest that some habituation of the arm-hand startle response occurs to all overpressure levels except perhaps the highest levels. In the field study, there was no convincing evidence of any habituation to booms having outside overpressures of 300 N/m^2 and above among *Ss* with prior exposure to 10 or more booms.

In the studies (including the present experiments) conducted to date,[6,7] the mean magnitude of hand responses to category II, III, and IV boom levels has been found to range from approximately 4.0 to 6.0 mm. This amount of hand movement could disrupt performance on tasks requiring precise arm-hand coordination. It is unlikely that the magnitude of these responses would seriously impair performance on less sensitive psychomotor tasks.[7]

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Appendix 1

Subject No.__________________ Name______________________

Study______________________

Condition____________________

Post-Experimental Questionnaire

Except for the pistol shot, the sounds you heard in the test room were designed to simulate the sounds of sonic booms produced by aircraft flying at supersonic speeds. The following information is needed in order to assess the degree of possible annoyance which could result from exposure to sonic booms of this level.

1. Have you ever heard actual sonic booms? Yes______ No______

2. Did you associate the sounds you heard with sonic booms?

   Yes______ No______

3. If you have heard actual sonic booms, were there any major differences between these simulated booms and real ones as heard <u>indoors</u>? (more or less startling, louder, sharper, etc.)

   ____

4. Suppose that you were regularly exposed 10 to 20 times a day to actual sonic booms of the level of these simulated booms while <u>indoors</u> at home, work, or school. Would you estimate this to be

Not annoying at all	Mildly Annoying	Moderately Annoying	Quite Annoying	Extremely Annoying

   (Place a check on the line nearest the words which best describe your estimated annoyance.)

5. Do you think that you would eventually adapt or become virtually unaware of sounds of this level?

   Yes______ No______

6. (a) Were you startled at all by <u>any</u> of the simulated sonic booms you heard?

   Yes______ No______

(b) If your answer is yes, assume that the pistol shot startled you by an arbitrary value which we will consider to be 100. Try to recall the startle you experienced to the simulated booms and attempt to assign a number to this startle experience which would be in proportion to the amount the pistol shot startled you (e.g., if the booms were twice as startling as the shot, the numerical value would be 200; if they were half as startling, the value would be 50; if one-tenth as startling, the value would be 10; etc.).

Place your number here:__________