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Physiological, Motivational, and Cognitive Effects of Aircraft Noise on Children

Moving From the Laboratory to the Field

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ABSTRACT: *A combination of laboratory and field methodologies is suggested as a strategy to increase the influence of psychological research in the formation of public policy. A naturalistic study of the effects of aircraft noise on elementary school children is presented as evidence for the effects of community noise on behavior and as an example of a study that examines the generality of laboratory effects in a naturalistic setting. The study is concerned with the impact of noise on attentional strategies, feelings of personal control, and physiological processes related to health. In general, the results are consistent with laboratory work on physiological response to noise and on uncontrollable noise as a factor in helplessness. Thus children from noisy schools have higher blood pressure than those from matched control (quiet) schools. Noise-school children are also more likely to fail on a cognitive task and are more likely to give up before the time to complete the task has elapsed. The development of attentional strategies predicted from laboratory and previous field research was, on the whole, not found. The implications of the study both for the understanding of the relationship between noise and behavior and for the influencing of public policy are discussed.*

Science's contribution to social policy decisions regarding noise pollution has been primarily limited to the documentation of the impact of high-intensity sound on hearing. Acceptable noise standards used in both national and local statutes are based on research that assesses magnitude of hearing loss at varying intensities and durations of sound. Yet during the last ten years it has become clear that noise can alter nonauditory systems as well as auditory ones. Thus laboratory research has established effects of noise on cognitive, motivational, and general physiological processes. For example, noise is associated with alterations in task performance (cf. Broadbent, 1978; Loeb, 1979), decreased sensitivity to others (e.g., S. Cohen & Lezak, 1977; Mathews & Canon, 1975), and elevation of a number of nonspecific physiological responses (cf. Glass & Singer, 1972; Kryter, 1970). Exposure to noise that is unpredictable and uncontrollable (cannot be escaped or avoided) can also reduce one's perception of control over the environment (e.g., Glass & Singer, 1972; Krantz, Glass, & Snyder, 1974). This loss of control is often accompanied by a depression of mood and a decrease in one's motivation to initiate new responses (Seligman, 1975).

One argument against serious consideration of this evidence when making policy decisions is that it is largely derived from laboratory studies. Since laboratory subjects typically experience a single short period of exposure to high-intensity sound and are aware that their exposure is only temporary, the applicability of these findings to experi-

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ences of chronic noise exposure is questionable. Because of a lack of well-controlled studies of persons routinely living and working under noise, we are unable to say with any certainty if similar effects occur in individuals exposed to noise for prolonged periods.

Our own lack of confidence in the generality of the effects of noise that occurs in laboratory settings translates into a lack of influence in the policymaking process. Legislation restricting noise levels in industrial and community settings usually imposes a heavy economic burden on those responsible for the noise. To convince policymakers that such burdens are justified, there must be substantive evidence that community and/or industrial noise deleteriously affects health and behavior.

Naturalistic studies of the effects of noise that occurs in home, school, or office seem like the obvious alternative to investigations carried out in laboratory settings. However, such studies are correlational. Subjects are not randomly assigned to noisy or quiet settings, and the settings often vary on dimensions other than noise exposure. These problems can be substantially reduced by carefully matching the noise and quiet samples on important dimensions and by statistically controlling for other possible confounds. It is always possible, however, that some unknown factor covaries with exposure to the noise setting and actually causes the effects that the investigator associates with noise. Thus, in isolation, naturalistic studies also provide insufficient evidence for a link between community noise and measures of health and behavior.

It is clear that neither laboratory nor naturalistic studies can in themselves provide what either scientists or politicians would consider convincing evidence for noise-induced effects. What is necessary is an interplay between laboratory and field methodologies. This interplay can take at least two forms. On the one hand, an effect can first be established as reliable within laboratory settings where causal links can be inferred. Then, the robustness of this relationship can be established in a number of naturalistic settings. On the other hand, by first conducting field research, it is possible to isolate important dimensions of a particular problem. At that point, laboratory studies may be useful to rule out plausible alternate explanations often inherent in naturalistic research. Laboratory and field approaches are often pursued to the exclusion of one another, but only by combining these two strategies can we begin to understand the impact of environmental variables in naturalistic settings. Moreover, only when evidence from the laboratory and field converges can a credible scientific case be presented in order to influence public policy.

This emphasis on the interplay between the laboratory and the field is consistent with Campbell and Stanley's (1966) discussion of the inevitable trade-off between well-controlled experimental settings (internal validity) and our ability to generalize across persons and settings (external validity). The laboratory provides the opportunity for an internally valid investigation, but the generality of laboratory findings is severely restricted. Naturalistic studies provide the opportunity to generalize findings to a greater range of persons and settings but often lack the strict control of the laboratory.

The study presented in this article examines the effects of aircraft noise on children. It is particularly concerned with exploring the generality of laboratory work on noise-induced shifts in attentional strategies, feelings of personal control, and nonauditory physiological responses related to health. Our purpose in reporting this study is twofold. First, it is presented as evidence for relationships (or lack of relationships) between aircraft noise exposure and a number of cognitive, motivational, and physiological measures. The article includes short discussions of laboratory and field research in each of the areas of concern. Second, it is presented as an example of an attempt to examine the generality of laboratory effects in a naturalistic setting. In this regard, the study employs an individual testing procedure in a field setting. It uses a matched-group design and attempts to control statistically for a number of possible alternative explanations for correlations between community noise and the various criterion variables.

Overview of the Study

The subjects were children attending the four noisiest elementary schools in the air corridor of Los Angeles International Airport. Peak sound level readings in these schools are as high as 95 dB (A), and the schools are located in an air corridor that has over 300 overflights a day—approximately one flight every 2.5 minutes during school hours (Lane & Meecham, 1974). Three control schools (quiet schools) were matched with the experimental schools for grade level, for ethnic and racial distribution of children, for percentage of children whose families were receiving assistance under the Aid to Families with Dependent Children program, and for the occupations and education levels of parents. Thus we were able to compare samples of children attending noise schools and quiet schools who were relatively similar in terms of age, social class, and race. A statistical technique described later allowed additional control over these factors.

The study focused on effects occurring outside of noise exposure (i.e., aftereffects). Thus all tasks and questionnaires (except the achievement test records gathered from school files) were administered in a quiet setting—a noise-insulated trailer parked directly outside the school. These data were collected during two 45-minute sessions on consecutive days. Three cognitive tasks were administered during the test periods. One was designed to assess feelings of personal control and the others to determine whether the children employed some common attentional coping strategies. A questionnaire concerned with responses to noise and two blood pressure measures were also given during the testing sessions. A parent questionnaire dealing with parent response to noise, mother's and father's level of education, and the number of children in the family was sent home with each child. Scores on standardized reading and math tests and data on absenteeism were collected from school files.

The study included children from all noise-impacted third- and fourth-grade classrooms in each noise school as well as children from an equal number of classrooms in quiet schools. To ensure that performance differences between children from noise schools and those from quiet schools could not be attributed to noise-induced losses in hearing sensitivity, an audiometric pure-tone threshold screening was administered to each child. Children were screened at 25 dB for select speech frequencies (500, 1000, 2000, and 4000 Hz). Children failing to detect 25 dB tones at any one of these frequencies in either ear were not included in the study. Six percent of the noise-school children and 7 percent of the quiet-school children failed the screening. A total of 262 subjects (142 from noise schools and 120 from quiet schools) remained in the study. Individual analyses, however, sometimes contain fewer subjects because of missing data.

Data compiled from the parent questionnaire allowed us to determine the degree of similarity of the prematched noise and quiet samples. Analyses of variance indicated that there were no differences between the samples on the various social class factors. The mean number of children per family was 3.54 in the noise sample and 3.88 in the quiet sample. Levels of parent education were also equivalent, falling between some high school (scaled as 3) and high school graduate (scaled as 4). The mean level of education for fathers was 3.75 for noise-school children and 3.41 for quiet-school children, and for mothers, 3.64 and 3.35, respectively. The racial distributions, however, differed significantly, $\chi^2(3) = 10.5$, $p < .01$, with the noise group containing more blacks (32% vs. 18%) and the quiet group more Chicanos (50% vs. 33%). Noise and quiet samples had nearly equal percentages of whites (32% and 29%, respectively) and of unidentifiable or mixed-race children (3% in each sample).

The two samples also differed on mobility, with children in the quiet sample having lived in their homes longer (a mean of 49.6 months vs. 41.4 months) and attended their schools for longer periods (a mean of 43.2 months vs. 36.0 months) than noise children, $F(1, 270) = 4.8$, $p < .03$, and $F(1, 270) = 12.9$, $p < .001$, respectively. Length of school enrollment was not related to father's education, mother's education, or the number of children in the family. Moreover, the noise and quiet samples were relatively equal on these various social class factors across all durations of exposure. This finding suggests that the decision to continue living in the noise-impacted area was not determined by the parents' socioeconomic status. There were, however, more blacks and whites in the noise group with less than 2 years' exposure than there were in the equivalent quiet group, $\chi^2(4) = 12.04$, $p < .02$. There were no differences in racial distribution for other exposure durations.

Statistical Controls

A regression technique was used to compensate for differences between the noise and quiet samples on racial distribution and mobility (J. Cohen, 1968). In general, the regression analysis allows one to determine the relation between two variables while controlling (covarying or partialing out) for one or more other variables. For example, one can look at the relation between noise level and blood pressure after functionally equating the noise and quiet groups on mobility and race. All data analyses reported in this article include controls for the number of children in the child's family, the grade in school, the number of months enrolled in school (years in residence for the parent questionnaire), and race.[1] These control factors were forced into the regression first, followed by noise and then the Noise × Months Enrolled in School interaction. The interaction indicates whether length of exposure affected the various criterion measures. Additional controls were used in the analyses of blood pressure, school achievement, and selective inattention. The use of these controls is described in appropriate sections. This conservative analysis looks at the effects of noise and the interaction between noise and length of enrollment after functionally equating the noise and quiet groups on grade, race, social class, and mobility, as well as on any additional control factors employed in a particular analysis.

The various measures were analyzed in predetermined multivariate clusters created on the basis of theoretical consideration.[2] This form of analysis helps to decrease the high probability of chance findings that occur when a large number of analyses are necessary (cf. Bock, 1975).

Noise Measures

Interior sound levels (without children) were measured inside each classroom with Tracoustics (SLM S2A) sound level meters. Sound levels were monitored for a 1-hour period in the morning and a 1-hour period in the afternoon. Peak sound levels in terms of dB (A) were recorded for both morning and afternoon sessions. The overall mean peak for classrooms in noise schools was 74 dB and in quiet schools 56 dB. The highest reading in a noise-school classroom was 95 dB, while the highest reading in a quiet school was 68 dB.

The questionnaire administered to each child assessed his or her perception of classroom and home noise levels. The parent questionnaire also included questions on perception of home noise level as well as queries on how long the child had been enrolled in the present school and how long he or she had lived at their present address. Data on school enrollment were also available from school files. Noise contours (compiled by the Los Angeles International Airport) provided approximations of the sound levels outside the homes of noise-school children.

The multivariate F for the effects of noise on the children's noise questionnaire was significant, $F(9, 246) = 3.10$, $p < .002$, thus allowing interpretation of the univariate regressions. Children in noise schools reported that their classrooms were noisier, $F(1, 254) = 5.49$, $p < .02$, and that airplanes bothered them more in the classroom, $F(1, 254) = 14.74$, $p < .001$, than children in quiet schools did. They did not, however, report having more trouble hearing their teacher.

In regard to home noise, children from air-corridor schools were more bothered by airplane noise than their quiet-school counterparts were, $F(1, 254) = 15.75$, $p < .001$. However, noise- and quiet-school children did not differ in ratings of home noise. Neither the multivariate F nor any univariate regression indicated any significant effects for the Noise × Months in School interaction on the children's questionnaire.

The multivariate F for the effects of noise on the parents' noise questionnaire was also significant, $F(2, 221) = 124.2$, $p < .001$. Parents of children from the air-corridor schools indicated both that there were higher levels of noise in the home, $F(1, 232) = 37.33$, $p < .001$, and that they were bothered more by noise, $F(1, 232) = 240.07$, $p < .001$, than the parents of children attending quiet schools indicated. The home noise level reported by the parents of noise-school children increased with the number of years they had lived in their present residence, $F(1, 220) = 3.11$, $p < .08$. This effect must be interpreted carefully, however, since both the univariate and multivariate Fs were only marginally significant.

Effects of Noise

PHYSIOLOGICAL RESPONSE AND HEALTH

Aside from temporary and permanent effects on hearing, previous research provides little convinc-

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[1] Parent education was excluded as a control because data on this factor were not available for a number of children. As mentioned earlier, the noise and quiet samples were closely matched on education. Race was dummy-variable coded (see Overall & Klett, 1972).

[2] There were separate clusters for general health, blood pressure, helplessness, child questionnaire, and parent questionnaire. The selective inattention analyses were run as univariates, since each analysis required a unique control factor.

ing evidence for noise-induced physical disease (cf. S. Cohen, Glass, & Phillips, 1979; Kryter, 1970). It is well established, however, that short-term exposure to relatively high sound levels in laboratory settings can alter physiological processes. Physiological changes produced by noise consist of nonspecific responses typically associated with stress reactions, including increases in electrodermal activity, catecholamine secretions, vasoconstriction of peripheral blood vessels, and diastolic and systolic blood pressure. Because such changes, if extreme, are often considered potentially hazardous to health, many feel that pathogenic effects of prolonged noise exposure are likely. Laboratory evidence that some components of the physiological response to noise do not habituate (Jansen, 1969) lends fuel to this argument, but is difficult to interpret in light of evidence from other laboratories indicating complete habituation (Glass & Singer, 1972).

A number of studies of workers in noisy industries have indicated health problems for those exposed to intense noise levels. Included are respiratory problems, such as sore throat, and allergenic, musculoskeletal, circulatory, neurological, cardiovascular, and digestive disorders (e.g., Anticaglia & Cohen, 1974; A. Cohen, 1973). However, all of the industrial noise studies are subject to serious criticism because of their failure to control for other adverse workplace or job factors, for example, task demands and risks, that often covary with the noisiness of the job (cf. S. Cohen et al., 1979; Kryter, 1970). It is also important to note that several industrial surveys have failed to find a relation between noise and ill health (e.g., Finkle & Poppen, 1948; Glorig, 1971).

There are no existing controlled studies on the impact of noise on nonauditory health in children (Mills, 1975). Recent theoretical work, however, argues that children (along with the old, individuals in institutions, and persons suffering from other sources of stress) may be particularly susceptible to noise-induced illness because they lack the ability to temporarily escape their noisy environments (S. Cohen et al., 1979). It is suggested that this inability to escape at will can cause both an increase in overall duration of noise exposure and an increase in feelings of helplessness. This effect is important, since feelings of helplessness have been implicated as possible causal factors in illness (Seligman, 1975).

Each child's resting blood pressure (systolic and diastolic) was taken on an SR-2 Physiometrics automated blood pressure recorder.[3] To accustom the children to the blood pressure measurement technique, an initial measurement was made at the beginning of the first day of testing. A short explanation of the technique and the concept of blood pressure was given at this time, and questions were solicited and answered. This initial measurement was not recorded. Each child's blood pressure was measured again on the first day and once more on the second day. The blood pressure data are based on the mean systolic and diastolic pressures for these two measurements. The graphic output of the machine was coded after the study was completed, with coders blind to experimental condition. Each child's height and weight were also measured. Absenteeism was used as an indirect measure of health, since absence from school is often attributable to illness. These data were available from school files.

Health measures were separated into two multivariate clusters: general health measures and blood pressure. This procedure was necessary because two of the general health measures—height and ponderosity (weight/height^3)—were required as controls for the blood pressure analyses (cf. Voors et al., 1976). (The ponderosity index was chosen as a measure of obesity because of its high correlation with body fat.) The multivariate F for the effects of noise on the general health cluster was significant, $F(3, 235) = 8.04$, $p < .001$. Although noise-school children were shorter and weighed less than quiet-school children, neither of these differences reached significance, $F(1, 237) = 1.77$, $p < .18$, and $F(1, 237) = 1.07$, $p < .30$, respectively. Surprisingly, noise-school children attended school a higher percentage of the time (97.5% vs. 94.2%) than their quiet-school counterparts did, $F(1, 237) = 21.80$, $p < .001$.

The multivariate F for the effects of noise on systolic and diastolic blood pressure was significant, $F(2, 244) = 2.98$, $p < .05$. As is apparent from Figure 1, children from noise schools had higher blood pressure than their quiet-school counterparts did, with $F(1, 245) = 4.61$, $p < .03$, for

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[3] This instrument is an electronic infrasonic device that records on a rotating paper disc. Measurements were taken with a rubber cuff entirely encircling the upper arm. The reliability of this device for blood pressure measurement in children has been established in previous work (e.g., Voors, Foster, Frerichs, Weber, & Berenson, 1976).

systolic pressure and $F(1, 245) = 4.86$, $p < .03$, for diastolic pressure.[4] Unadjusted means for systolic pressure were 89.68 mm for the noise group and 86.77 mm for the quiet group. Diastolic means were 47.84 mm for the noise group and 45.16 mm for the quiet group. A marginal interaction, $F(1, 244) = 3.30$, $p < .07$, between noise and months in school suggests that systolic pressure differences between noise and quiet groups are greatest during the first few years of school enrollment; differences after this point remain constant. Figure 1 reflects a similar pattern for diastolic pressure. This interaction does not, however, reach even marginal statistical significance.[5]

HELPLESSNESS

Both laboratory and community noise research suggests the possibility that high-intensity noise exposure induces feelings of helplessness. According to Seligman (1975), a psychological state of helplessness frequently results when we continually encounter events (especially aversive ones) that we can do nothing about. The state of helplessness includes a perception of lessened control over one's outcomes, a depression of mood, and a decrease in one's motivation to initiate new responses. Extreme effects of helplessness include fear, anxiety, depression, disease, and even death.

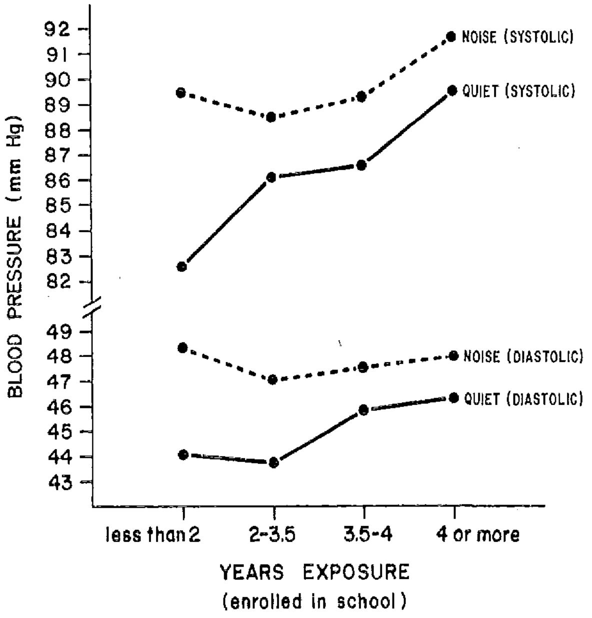

Figure 1. Systolic and diastolic blood pressure as a function of school noise level and duration of exposure. (Each period on the years-exposure coordinate on the figure represents approximately one quarter of the sample. For example, 25% of the sample had been enrolled in the present school less than 2 years.)

A number of researchers have induced helplessness effects in the laboratory by exposing subjects to uncontrollable bursts of noise (Hiroto, 1974; Krantz et al., 1974). Moreover, survey data reporting high levels of annoyance but low levels of complaints from noise-impacted populations have similarly been interpreted as reflecting a helplessnesslike state (Herridge, 1974). This finding, however, is subject to a number of alternative explanations, and thus the helplessness interpretation is only suggestive.

Performance on a cognitive task preceded by a success or failure experience was used in the present study to examine the effect of noise on response to failure and on persistence on a difficult task. Response to failure is a standard measure of susceptibility to helplessness. Thus, if noise-school children were more susceptible to helplessness, they would show greater effects of a failure experience than their quiet-school counterparts would. A lack of persistence (or a "giving-up" syndrome) is considered a direct manifestation of the helpless state.

Each child was given a treatment puzzle to assemble after the tester demonstrated the task with another puzzle. All puzzles were based on the same nine pieces and required the child to fill in a template of a familiar shape. One half of the

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[4] Both the noise-school and quiet-school children have lower mean blood pressures than children of similar ages tested in recent studies (e.g., Voors et al., 1976). It is important to note, however, that it is difficult to compare absolute blood pressure levels across studies, since blood pressure is strongly influenced by environmental and genetic characteristics of the population being studied, the conditions under which measurement occurs, and the measurement device.

[5] To investigate whether elevations in blood pressure occurred equally across races, separate regressions were calculated for whites, blacks, and Chicanos. Since the number of subjects in each of these regressions is small, only very substantial mean differences will reach statistically significant levels. Blacks and Chicanos attending noise schools had higher systolic ($p < .05$ for blacks, $p < .25$ for Chicanos) and diastolic ($p < .25$ for blacks, $p < .10$ for Chicanos) pressure than their quiet-school counterparts did. For whites, there were no main effects of noise, but an interaction between noise and length of school enrollment indicated that an initial inflation of pressure for noise-school children disappeared as length of enrollment increased ($p < .01$ for both systolic and diastolic). These race differences will be pursued in a later paper.

children received an insoluble (failure) puzzle, and one half received a soluble (success) puzzle. The soluble puzzle was a circle, and the insoluble puzzle was a triangle. Each child was allowed to work on the treatment puzzle for 2.5 minutes. After time was up on the first puzzle, the child was given a second, moderately difficult puzzle to solve. The second (test) puzzle was the same—a square—for all (success and failure) children. The child was allowed 4 minutes to solve the second puzzle. Whether or not the puzzle was solved, time to solution and the child's persisting or giving up before the 4 minutes had elapsed were used as measures of helplessness. We expected that children from noisy schools would be more susceptible to a failure (helplessness) manipulation than children from quiet schools would be, and thus would be less likely to solve the puzzle, slower to find the solution, and more likely to give up on the second puzzle following an insoluble (failure) treatment. Moreover, children from noisy schools, irrespective of their success–failure condition, were expected to give up more often than quiet-school children.

A large proportion (34%) of the children assigned to the success condition, and thus receiving a soluble treatment puzzle, failed to solve the treatment puzzle within the 2.5 minutes allowed. Since the puzzles were considered quite simple and had been pilot tested on children of the same age group, this result was quite unexpected. Although the fact that a number of children self-selected themselves into a failure condition makes interpretation of success–failure effects impossible, comparisons between the children from noise schools and those from quiet schools, irrespective of (controlling for) their pretreatment, are still valid.

Except for the first analysis, which includes only those children who worked on soluble treatment puzzles (success condition), the following analyses also include factors for success–failure (those who solved and those who did not solve the success treatment puzzle are treated as separate groups) and the interaction between success–failure and noise. The control factors were forced into the regression first, followed by success–failure (dummy coded), noise, and the Noise × Success and Noise × Months Enrolled interactions. Because of the difficulty in interpreting success–failure effects, they are not discussed. Moreover, since there were no significant interactions between success–failure and school noise level, the reported results are limited to the overall effects of noise.

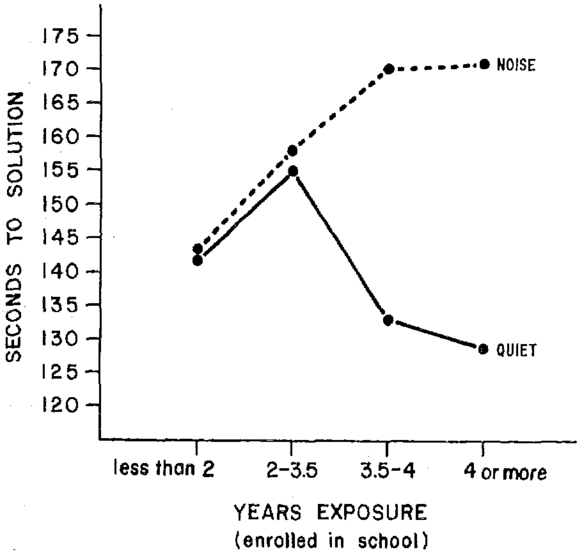

Figure 2. Performance on the second (test) puzzle as a function of school noise level and duration of exposure. (Each period on the years-exposure coordinate on the figure represents approximately one quarter of the sample. For example, 25% of the sample had been enrolled in the present school less than 2 years.)

First, an examination of only those who were assigned to the success treatment condition indicates that children from noise schools were more likely to fail to solve the treatment puzzle (41% failed) than children from quiet schools were (23% failed). This effect, however, was only marginally significant, $F(1, 131) = 3.62$, $p < .07$. Second, there were similar effects of noise on the second puzzle, which occurred irrespective of whether the child received a success (solved or not) or failure treatment. As was the case with the first puzzle, noise-school children were more likely to fail the second puzzle (53% failed) than quiet-school children were (36% failed), $F(1, 246) = 5.99$, $p < .09$, and were more likely to give up, $F(1, 246) = 11.15$, $p < .001$, than their quiet-school counterparts were, multivariate $F(3, 244) = 4.59$, $p < .004$. As is apparent from Figure 2, a marginal interaction between noise and months enrolled in school, $F(1, 243) = 3.27$, $p < .07$, suggests that the longer a child had attended a noise school, the slower he or she was in solving the puzzle. However, the multivariate F for this interaction was not significant.

Although the preceding analyses indicate that children from noise schools are generally less capable of performing a cognitive task (at least puzzle solving) than children from quiet schools are, they provide only suggestive evidence that noise-school children feel or act as if they have less control over their outcomes. The strongest hint that failure on these puzzles on the part of noise-school children is related to helplessness is found in the data indicating that noise-school children were more likely to give up before their allotted time had elapsed than their quiet counterparts were. It is possible, however, that a constant proportion of children who failed on the second puzzle gave up. It would follow that the amount of giving up in the noise condition was inflated by the fact that there was a greater pool of failures. This interpretation suggests that increased giving up under the noise condition cannot necessarily be viewed as a sign of helplessness. A final analysis addresses this point. This analysis, which includes only those children who failed the second puzzle, indicates that the failures of noise-school children were associated with giving up (31% of those who failed gave up) more often than the failures of quiet-school children were (7% of those who failed gave up), $F(1, 103) = 5.85$, $p < .025$. Thus, even though all of these children failed to solve the puzzle, noise-school children were less likely to persist than their quiet-school counterparts were.

ATTENTIONAL PROCESSES DURING NOISE

Human performance studies report that noise often results in a restriction (or focusing) in one's breadth of attention (Broadbent, 1971; Hockey, 1970). Cues irrelevant to task performance are dropped out first, and then, if attention is further restricted, relevant task cues are eliminated. Performance improves under noise when discarded cues are those that are distracting or competing with primary task cues. Performance is adversely affected, however, when a task requires a wide breadth of attention and when focusing results in the neglect of relevant as well as irrelevant cues. Similarly, focusing can have a negative impact on interpersonal behavior when subtle social cues (e.g., another's look of distress) are dropped out, but can improve the quality of an interaction when the discarded cues are merely distracting (S. Cohen & Lezak, 1977).

There is suggestive evidence that an attentional focusing strategy will persist even after noise is terminated. A number of studies have shown post-noise effects on performance and interpersonal behavior (e.g., Donnerstein & Wilson, 1976; Glass & Singer, 1972). These aftereffects of noise are consistent with what one would expect to occur when one uses a focusing strategy (S. Cohen, 1978). As yet, however, there is no direct evidence that attentional focusing occurs following exposure to noise in either the laboratory or the field.[6]

Selective inattention. A strategy that is similar (and possibly identical) to attentional focusing has been proposed by Deutsch (1964) to account for the effect of community noise on the verbal abilities of children. Deutsch suggests that children reared in noisy environments become inattentive to acoustic cues. That is, they tune out their acoustic environment. (This could be viewed as their focusing their attention on other aspects of their environment.) Children who tune out their noisy environments are not likely to distinguish between speech-relevant and speech-irrelevant sounds. Thus, they lack experience with appropriate speech cues and generally show an inability to recognize relevant sounds and their referents. The inability to discriminate sound is presumed to account, in part, for subsequent problems in learning to read. Although recent research suggests that children living and attending school in noisy neighborhoods are poorer at making auditory discriminations and in reading (Bronzaft & McCarthy, 1975; S. Cohen, Glass, & Singer, 1973), there is no direct evidence for the selective inattention mechanism. An alternative explanation is that noise masks parent and teacher speech, similarly resulting in a lack of experience with appropriate speech cues and, as a consequence, in reading deficits.

The present study attempts to assess the relation between environmental noise level and the selective inattention strategy in order (a) to determine the generality of noise-induced shifts in attention that occur in laboratory settings and (b) to test Deutsch's (1964) hypothesis. In line with

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[6] The only study on the impact of chronic noise exposure on attentional focusing resulted in rather ambiguous findings, with children from noisy homes (as reported by parents) exhibiting general performance deficits but no focusing strategy (Heft, 1979). A replication of the incidental memory task used in the Heft study was administered in the present study. Errors in administering the task, however, made the data uninterpretable.

the testing of the Deutsch hypothesis, the relation of the above-mentioned variables to auditory discrimination and reading achievement is also assessed.

Because children who are relatively inattentive to acoustic cues should be less affected by an auditory distractor, distractibility was used as a measure of selective inattention. Under both ambient and distracting conditions, the subjects performed a task consisting of crossing out the *e*'s in a two-page passage from a sixth-grade reader. They were instructed to move from left to right and from top to bottom of the page, as if they were reading, and to go as fast as they could without missing any *e*'s. Each subject worked on a short practice paragraph and then on the task for 2 minutes. Two versions (different samples of prose) were used.

In the distraction condition, the child worked on one of the versions of the task while a tape recording of a male voice read a story at a moderate volume. In the no-distraction condition, the alternative form of the task was completed under ambient sound conditions. The distraction and no-distraction tasks were administered on different testing days. Both the order of alternative versions of the task and the experimental conditions were counterbalanced. The criterion measure was performance (percentage of *e*'s found) on the distraction task after the scores were adjusted for no-distraction performance. It was expected that the children from noise schools would be less affected by distraction than the children from quiet schools. Since selective inattention is a strategy that develops over time, it was also predicted that this tuning-out strategy would increase with increased exposure (S. Cohen et al., 1973).

Separate analyses examined the number of lines completed under distraction and the percentage of *e*'s in the completed lines that were found under distraction. No-distraction performance (number of lines in the first analysis and percentage of *e*'s in the second) was added as an additional control variable in order to equate the children on their ability to perform the task under quiet conditions. There were no differences between the noise group and the quiet group (nor was there an interaction) on the number of lines completed under distraction. There was, however, a significant interaction between noise–quiet and months enrolled in school, $F(1, 237) = 5.05$, $p < .03$, for the percentage-of-*e*'s-found measure. As is apparent from Figure 3, the children in noise schools did better than the quiet group on the distraction task during the first 2 years of exposure and did worse after 4 years of exposure. Contrary to earlier evidence, this finding suggests that as the length of noise exposure increases, children are more, rather than less, disturbed by auditory distractors. One possible explanation for this effect is that at first, the children attempt (somewhat successfully) to cope with noise by tuning it out. Later, however, as they find that the strategy is not adequate, they give up. This interpretation is consistent with the helplessness data.

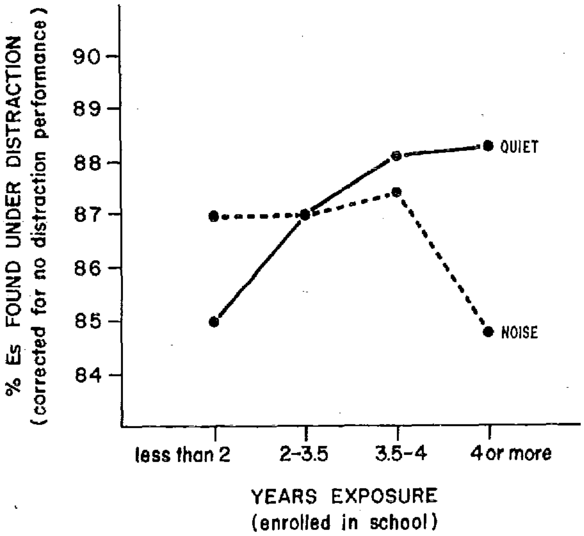

Figure 3. Distractibility as a function of school noise level and duration of exposure. (Each period on the years-exposure coordinate on the figure represents approximately one quarter of the sample. For example, 25% of the sample had been enrolled in the present school less than 2 years.)

As suggested earlier, reading deficits in children from noisy neighborhoods have been attributed to noise-impacted children's selective filtering out of acoustic cues. Auditory discrimination and reading achievement were assessed in an attempt to replicate previous work and to determine whether there was an association between these measures and the children's attentional strategies. Standardized reading and math tests (administered during the second and third grades by the school system) were gathered from school files, and the Wepman Auditory Discrimination Test (Wepman, Note 1) was administered individually to children in the soundproof van. The Wepman test consists of 40 pairs of words, some of which differ from each other in either initial or final sound, for example, *sick–thick* or *map–nap*. The pairs of words are recorded on tape and presented to each child through earphones. The child is instructed to report if the two words in each pair are the same or different. Control word pairs, in which the words are the same, allow for the elimination of children who have problems with same–different judgments or who are not attending to the task.

In order to roughly equate the noise and quiet conditions on the aptitude of the children at the time they entered school, the analyses of school achievement and auditory discrimination scores included an additional control for the mean cognitive abilities of the child's class on entering the first grade. None of the multivariate or univariate analyses were significant for this cluster. Math, reading, and auditory discrimination were all unrelated to both noise and the Noise × Months Enrolled in School interaction.

Further analyses (Pearson correlations) suggest that the children who were better at auditory discriminations were also better on both the reading test, $r(231) = .19$, $p < .05$, and the math test, $r(231) = .18$, $p < .05$. There were, however, no significant relations between these variables and the selective inattention measure. The same analyses, including only noise-school children, and correlations partialing out control variables for both the entire sample and the noise sample yielded similar results. In summary, there is no evidence that aircraft noise affects reading and math skills, or that these skills are related to a selective inattention strategy.

Classroom as the unit of analysis. Since noise would be likely to have an impact on school achievement by affecting behavior in the classroom, a second analysis of the school achievement cluster was performed with classroom, rather than individual child, as the unit of analysis. This covariance analysis treated the control factors as covariates and months enrolled in school, noise, and classrooms (nested in noise) as independent variables. This analysis is considerably more conservative than the previous analysis because the degrees of freedom in the denominator are based on the number of classrooms (37) rather than on the number of children (262). The results for the school achievement cluster were the same.

The classroom analysis was not used for the other clusters, since those measures were not achievement oriented and thus were presumed not to be classroom mediated. The subjects were also tested individually, not in the classroom. Even using this ultraconservative technique, however, a reanalysis of the other clusters indicates very similar results for the parent-questionnaire, blood pressure, and helplessness clusters. Differences between the noise group and the quiet group on the child-questionnaire and selective inattention clusters, which were significant in the previous analysis, did not reach statistical significance with classroom used as the unit of analysis.

QUIET HOMES AND NOISY SCHOOLS

To determine whether or not living in a relatively quiet home (at least in terms of aircraft noise) would lessen the impact of school noise, we isolated the children living in the 20 quietest homes in the noise sample, that is, in homes with contour levels of less than 68 in terms of the Community Noise Equivalency Level (CNEL).[7] These children were then compared (using the regression techniques described earlier) with the remainder of the noise sample and with the entire quiet sample.[8] In no case was there a difference between these quiet-home children and the remaining children of the noise sample. In a number of cases, however, even this small group of 20 showed the effects of noise reported earlier. Thus the noise-sample children from quiet homes were less likely to solve the first helplessness task puzzles than the quiet-sample controls were, $F(1, 132) = 3.04$, $p < .10$. The longer a child had attended a noisy school, the less likely he or she was to solve either the first puzzle, $F(1, 130) = 4.06$, $p < .05$, or the second puzzle, $F(1, 240) = 2.07$, $p < .15$. Moreover, children from quiet homes but noisy schools were more likely to fail, $F(1, 244) = 6.20$, $p < .01$, and to give up, $F(1, 244) = 11.95$, $p < .001$, on the second puzzle than children from quiet schools were, multivariate $F(3, 244) = 4.71$, $p < .003$. Further, their failures on the second puzzle were associated with giving up more often than the failures of quiet-school children were, $F(1, 102) = 6.27$,

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[7] CNEL is a measure of community noise giving more weight to noise occurring between 1900 and 2200 hours and the most weight to noise occurring between 2200 and 0700 hours (cf. Peterson & Gross, 1972).

[8] Noise was dummy coded. The two contrasts discussed in this section were used to determine the impact of noise. This is a conservative technique of doing the contrasts, since the error term for the entire sample is used in calculating the F.

$p < .025$. Noise-school children from quiet homes also had both higher systolic blood pressure, $F(1, 240) = 3.59$, $p < .06$, and higher diastolic blood pressure, $F(1, 240) = 5.32$, $p < .02$, than children from quieter schools did, multivariate $F(2, 239) = 2.84$, $p < .06$. There were no effects, however, on the selective inattention task (crossing out *e*'s under distraction condition), as reported for the entire sample.

These analyses suggest that living in a relatively quiet neighborhood did not lessen the cumulative impact of exposure to noise at school. The reason may be that the noise experienced during school attendance is sufficient to create noise effects.

Air Pollution

A possible alternative explanation for differences between the noise and quiet samples is air pollution levels. Such an alternative is very unlikely. Sulfur dioxide was minimal at all the school sites, never exceeding the California standard (South Coast Air Quality Management District, Note 2; State of California, Note 3). Ozone and nitrogen dioxide standards were exceeded, but maximum levels were slightly higher at the control schools than at the airport schools. The maximum 1-hour rates in any school area for ozone (.21 parts per million) and NO_2 (.60 ppm) were below levels that generally show any effects on human behavior or health (Morrow, 1975; National Academy of Sciences, Note 4). Maximum carbon monoxide was slightly higher in the airport schools (30 vs. 27, 22 ppm), but average values were identical (6 ppm). The differences in maximum values of 8 ppm are negligible, and human effects from CO concentrations of less than 40 ppm are extremely rare (National Air Pollution Control Administration, 1970). Note that we have used maximum values in arguing against an air pollution alternative, thus presenting a very conservative counterargument. Average values in all cases were considerably below established standards.

Conclusions

In general, the evidence presented in this article is consistent with laboratory work on physiological response to noise and on uncontrollable noise as a factor in helplessness. Thus children from noisy schools have higher blood pressure and are more likely to give up on a task than children from quiet schools are. The development of attentional strategies predicted from laboratory work and previous field research was, on the whole, not found. Contrary to prediction, increased years of exposure led to children's being more distractible rather than less. However, a general deficit in task performance on the puzzle task and increased distractibility do seem to support the more general hypothesis that prolonged noise exposure affects cognitive processes.

These data are most interesting, however, because of the tentative answers they provide concerning questions of adaptation to noise over time. One interpretation of the data is that they indicate some habituation of physiological stress response but show no signs of adaptation of cognitive and motivational effects. In fact, in a number of cases, increased length of exposure resulted in an increased negative impact of noise. First, the only evidence for an adaptation effect is provided by the systolic blood pressure data. On that measure, the greatest difference between the noise and quiet groups occurred during the first 2 years of exposure. As length of exposure increased, these differences leveled out but still remained substantial. Perceptions of noise and noise annoyance did not adapt. Thus children from noise schools and their parents reported more noise and being more bothered by noise. Parents, in fact, reported higher levels of noise as their length of residence in the noisy area increased. Neither the cognitive deficits on the helplessness puzzles (which actually increased over time) nor the giving-up syndrome of the children from noise schools lessened with increased length of exposure. Finally, although noise-school children were initially less affected by an auditory distractor, increased length of exposure (beyond 4 years) seemed to result in greater distractibility. Thus the preponderance of evidence suggests a lack of successful adaptation over time. The above interpretation, however, is only tentative. Although length-of-exposure differences may be due to increased exposure to noise, they may also be attributable to some unknown factors that differentiate between children who continue to live in the air corridor and those who move, or to some combination of exposure and these factors.

It should be noted that the failure of the present study to replicate the previously reported relation between community noise and reading ability (Bronzaft & McCarthy, 1975; S. Cohen et al.,

1973) may be attributable to an experimental design insensitive to noise-induced differences in school achievement. In both of the earlier studies, all the students attended the same school. Moreover, in the Cohen et al. study, students from both noisy and quiet apartments were taught in the same classrooms by the same teachers. In the present study, noise-sample children and quiet-sample children attended different schools, were in different classrooms, and had different teachers. It is likely that these factors add substantial error variance to the equation, making the detection of a small effect of noise quite difficult.

Can we conclude that community noise has effects that are similar to noise-induced effects reported in the laboratory literature? The similarity of our results to those reported in laboratory settings is striking. However, we still must be cautious. Replications of these results in other settings and with other populations are required before definitive conclusions are possible. To this end, our own research program includes an ongoing replication of this study, with a population exposed to traffic noise, as well as plans to collect longitudinal data on the children attending airport schools.

What conclusions can we make in regard to public policy? From a policy point of view, these data are valuable but not sufficient. At least 8 million people in this country are exposed to aircraft noise (U.S. Environmental Protection Agency, 1974), and the vast majority of noise-impacted communities have racial and social class compositions more similar to the composition of the present sample than to that of the general population (U.S. Environmental Protection Agency, Note 5). In combination with the laboratory noise literature, these data clearly suggest lending additional weight to the possible impact of aircraft noise on psychological adjustment and on nonauditory aspects of health. Replications of these results, however, would substantially increase their potential influence in the realms of both science and social policy.

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