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# Aircraft Noise and Children: Longitudinal and Cross-Sectional Evidence on Adaptation to Noise and the Effectiveness of Noise Abatement

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Longitudinal and cross-sectional data on effects of aircraft noise on elementary school children are presented as evidence for the effects of community noise on behavior. To examine the generality of previous laboratory findings in a naturalistic setting, the study assesses the impact of noise on attentional strategies, learned helplessness, performance on cognitive tasks, and blood pressure. Children were tested on the same measures twice, with a 1-year interval between sessions. A previous article reported cross-sectional findings from the first testing session. In the present article, longitudinal data are used to determine whether children *adapt* to the aircraft noise over the 1-year period and to assess the effectiveness of noise abatement interventions introduced in a number of noise-impacted classrooms. Additional cross-sectional data from the original testing session are also presented to provide further information on the utility of noise abatement. In general, there was little evidence for adaption to noise over the 1-year period. Noise abatement had small ameliorative effects on cognitive performance, children's ability to hear their teachers, and school achievement. The implications of the study for understanding the relationship between noise and behavior and resulting policy implications are discussed.

Although prolonged exposure to high-intensity noise can cause temporary and permanent losses of hearing (cf. Kryter, 1970), other general statements about the debilitating effects of routine noise exposure have to be made with considerably less confidence. It is, of course, difficult to isolate the effects of a particular characteristic of a natural environment on the health and behavior of its occupants. Invariably the possibility exists that the people who choose (or are forced) to work or live in a noise-impacted environment are somehow different than those who work or live elsewhere. Moreover, environments that suffer from high levels of noise often have other characteristics (e.g., pollution, poor housing, high levels of population density) that may also deleteriously affect behavior and health.

In a recent article, Cohen, Evans, Krantz, and Stokols (1980) argue that the impact of noise (and other environmental factors) on health and behavior can best be assessed by a methodological strategy that combines the use of laboratory (experimental) and naturalistic studies. Laboratory studies direct our attention to categories of behavior and health that may be affected by noise and establish a causal link between noise and

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these behaviors. Naturalistic research helps to establish whether particular effects found in the laboratory also occur in real-life settings. Cohen et al. (1980) argue that an interplay between these two approaches provides a more complete understanding of the relationship between environmental stressors and behavior and generates the type of data necessary to influence public policy.

Recent laboratory research on the impact of high-intensity noise has directed attention to the possible effects of community and industrial noise on a number of nonauditory systems. For example, noise is associated with alterations in task performance (cf. Broadbent, 1978; Loeb, 1979), decreased sensitivity to others (e.g., 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 can also result in *aftereffects*—deficits in performance and social sensitivity that occur after the noise is terminated (e.g., Glass & Singer, 1972; also see review by Cohen, 1980). The difficulty with this research is that it emphasizes acute rather than long-term noise effects. Thus, its implications for those suffering prolonged exposure in their homes or at work are unknown.

Although investigators have also begun to take a closer look at the nonauditory effects of noise in naturalistic settings (see reviews by Cohen, Glass, & Phillips, 1979; Kryter, 1970; Miller, 1974), methodologically tight studies are rare. This research also tends to be atheoretical and thus difficult to compare with existing laboratory work. Moreover, there are few *longitudinal* studies of people living and/or working under noise. Thus, it is unknown whether prolonged noise exposure results in increasingly deleterious effects or whether those exposed for prolonged periods adapt to noise, with effects disappearing after awhile. Studies comparing measures of health and behavior of the same person before exposure, immediately after exposure begins, and at set intervals for 1 or several years would allow us to determine the long-term course of stress and adaptation. In addition, longitudinal studies in situations in which the environmental stressor is removed or attenuated would make it possible to determine whether there are long-term aftereffects of prolonged noise exposure.

Accordingly, this article reports data from the Los Angeles Noise Project—a longitudinal study of the impact of aircraft noise on elementary school children. The study was designed to examine the course of adaptation and the impact of a noise-abatement intervention on a variety of physiological, cognitive, and motivational measures. 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. (Findings from noise-induced laboratory exposure are discussed more fully in Cohen et al., 1980).

In this study elementary school children living and attending school under the air corridor of a busy metropolitan airport were compared with a matched group of children living in relatively quiet neighborhoods. In an earlier article, Cohen et al. (1980) reported cross-sectional data indicating that children from noisy schools had higher systolic and diastolic blood pressures than those from matched control schools and that this difference was greatest in children with the fewest years of exposure. Noisy-school children were also more likely to fail on a cognitive task and more likely to "give up" before the time to complete the task had elapsed. Finally, children from noisy schools who had lived in the neighborhood less than 2 years were less distractible than their quiet-school counterparts, whereas those children living under noise for more than 4 years were more distractible than those from quiet schools.

As part of a settlement of a law suit brought by the school systems against the airport, money was made available to lower the interior sound levels of many of the schools in the landing corridor. During the summer following the collection of data for the Cohen et al. article, architectural interventions were instituted in 43% of the noisy-school classrooms. These interventions resulted in a substantial decrease in noise levels in treated rooms (data presented later).

Thus, a large number of noisy-school children spent the following school year in noise-abated classrooms. At the end of the school year (1 year after original testing), children who were still enrolled in their schools (noisy and quiet) were retested on the original measures.

This article uses these longitudinal data and some previously unreported cross-sectional data from the first testing session to answer two questions about the long-term impact of aircraft noise on elementary school children. First, do children retested 1 year later continue to show effects found during the first testing session or do they *adapt* to the noise over the 1-year period? Cross-sectional data reported in the earlier article found some evidence for decreasing effects suggestive of physiological (blood pressure) habituation as duration of exposure increased, but failed to indicate adaptation of annoyance, cognitive performance, or helplessness. Second, what are the effects of noise abatement interventions in the classrooms on the various measures of health and behavior? That is, does assignment to a quieter classroom ameliorate the effects of noise?

## Method

### *Overview of the Study*

The subjects were children attending the four noisiest elementary schools in the air corridor of Los Angeles International Airport and three control (quiet) schools with similar (matched on social class and race) student bodies. Peak sound level readings in the noise 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 2½ min. during school hours (Lane & Meecham, 1974). The study focuses on effects occurring *outside* of noise exposure. 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. Students were tested first in the spring of 1977 (T1) and again in the spring of 1978 (T2).

Tasks administered during the test periods were designed to assess feelings of personal control and to determine whether the children employed some common attentional coping strategies. Children were also asked a number of questions about their response to home and classroom noise and had their blood pressures measured. At the time of the first (but not the second) testing session, 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 also collected from school files at the time of the first (but not the second) session.

Data from subjects who were tested at both testing sessions (longitudinal data) were analyzed to determine if noise effects adapted—decreased or disappeared—over the 1-year interval between sessions. Separate analyses (both cross-sectional and longitudinal) were conducted to evaluate the effectiveness of the noise-abatement interventions. The cross-sectional data were collected during the first testing session and compared children who were in noise-abated classrooms with those in noisy (nonabated) rooms as well as those who were from quiet schools. The longitudinal analyses looked at the changes in the response of children who moved from a noisy to a noise-abated classroom in contrast to those children who spent both years in noise-impacted rooms.

This section will provide short descriptions of the experimental tasks and procedures. The reader is referred to Cohen et al. (1980) for additional detail.

### *Matching*

Three control schools (quiet schools) were matched with the experimental schools for grade level, ethnic and racial distribution of children, the percentage of children whose families are receiving assistance under the Aid to Families With Dependent Children program, and the occupations and educational levels of parents. (Detailed data on matching are reported in Cohen et al., 1980). Thus, we were able to compare samples of children attending noisy and quiet schools who were relatively similar in terms of age, social class, and race. A regression analysis procedure (described later) allowed additional control over these factors.

### *Subjects*

The study included children from all noise-impacted third- and fourth- grade classrooms in each noisy school as well as children from an equivalent number of classrooms in quiet schools. To assure that performance differences between children from noisy and quiet schools could not be attributed to noise-induced losses in hearing sensitivity, children failing (either ear) an audiometric pure tone threshold screening (500, 1000, 2000, 4000 Hz at 25 dB) were not included in the study. Six percent of the noisy-school and 7% of the quiet-school children failed the screening.

### *Noise Measures*

*Testing session 1*: Interior sound levels (without children) were measured inside each classroom with Tracoustics Sound Level Meters (SLM S2A). Peak decibel level (A scale) was recorded during 1-hour sessions in both the morning and afternoon. It is important to note that due to limitations in the equipment and duration of the measurement, these measures are presented only to establish *relative* differences between the sound levels of various types of classrooms, not as evidence for sound-level criterion or threshold levels of effects.

*Testing session 2*: Sound levels (again without children) were measured inside each classroom for 1 hour during the morning and 1 hour during the afternoon with Digital Acoustics (DA605), B and K (4426), and General Radio (1945) noise-level analyzers.[1] The machines were calibrated to a pure tone source every other day and were periodically calibrated against one another to ensure intermachine reliability. Microphones were placed approximately 3 feet (.9 m) from the ground in the center of the room. Data available from all machines included peak decibel level (A scale), the decibel level exceeded 33% of the time ($L_{33}$), and the noise level averaged on an energy basis over each hour period ($L_{EQ}$).

## *Parent and Child Questionnaires*

The questionnaire administered to each child assessed his/her perception of classroom and home noise levels. The parent questionnaire (T1 only) also included questions on perception of home noise level as well as queries as to how long the child had been enrolled in his/her school and how long she/he had lived at the present address. Data on school enrollment were also available from school files.

## *Blood Pressure and Health*

Each child's resting blood pressure (systolic and diastolic) was taken each testing day on an SR-2 Physiometrics automated blood pressure recorder.[2] 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 avialable from school files.

## *Helplessness*

Performance on a cognitive task preceded by a success or failure experience was employed 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 (cf. Seligman, 1975). Thus, if noisy-school children are more susceptible to helplessness, they will show greater effects of a failure experience than their quiet-school counterparts. A lack of persistence ("giving up" syndrome) is considered a direct manifestation of helplessness.

*First testing session.* Each child was given a treatment puzzle to assemble after the tester demonstrated the task with another puzzle. One half of the children received an insoluble (failure) puzzle and one half a soluble (success) puzzle. The soluble puzzle was a circle, and the insoluble puzzle was a triangle. After time (2½ min.) 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 min. to solve the second puzzle. Whether the puzzle was solved, how long the solution took, and whether the child "gave up" before the 4 min. had elapsed were used as measures of helplessness.

*Second testing session.* Treatment puzzles were *not* readministered during the second session. Each child was given only the test (square) puzzle to solve. As previously, the child was allowed 4 min. to solve the test puzzle, with the same measures of helplessness assessed as in the earlier testing session.

During T1, a large proportion (34%) of the children assigned to the success condition who received a soluble treatment puzzle failed to solve the treatment puzzle within the 2½ min. allowed. Although the fact that a number of children self-selected themselves into a failure condition makes it difficult to interpret main effects for success–failure and interactions between success–failure and noise, comparisons between the children from noisy and quiet schools, irrespective of (controlling for) their pretreatment, are of primary interest.

## *Distractibility*

It was proposed in our earlier article (Cohen et al., 1980) that children reared in noisy environments become inattentive to acoustic cues (cf. Cohen, Glass, & Singer, 1973; Deutsch, 1964). Since children who are relatively inattentive to acoustic cues should be less affected by an auditory distractor, distractibility was used as a measure of this selective inattention. Subjects performed a crossing out *E*s task under both ambient and distracting conditions. The subject's task was to cross out the *E*s in a 2-page passage from a sixth-grade reader. Each subject worked on a short practice paragraph and then on the task for 2 min. Two versions (different samples of prose) were used.

In a distraction condition, the child worked on one of the versions of the task while a tape recording of a male voice reading a story was presented at a moderate volume over headphones. In the no-distraction condition, the alternative form of the task was completed with headphones on but 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 these scores were adjusted for no-distraction performance. It was expected that children from noisy schools would be less affected by distraction.

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[1] The noise-level analyzers, which were not available to us during the first testing session, were used during the second session because of their increased sensitivity and accuracy and their ability to provide various measures of noise over time, for example, $L_{EQ}$ and $L_{33}$. It is, however, appropriate to again caution the reader that the rather short interval of measurement limits the use of these data to the establishment of *relative* sound levels of classrooms in the various conditions.

[2] 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).

Table 1
*Overview of the Analyses*

| Title of analysis | Sample | Classroom noise condition 1977 (T1) | Classroom noise condition 1978 (T2) | Additional independent variable/conditions |
|---|---|---|---|---|
| I. Attrition bias | T1 | Noise vs. quiet | | Retested at T2?<br>Yes<br>No |
| II. Adaptation to noise | Attrition (T1 & T2) | Noise[a] ——<br>vs.<br>Quiet —— | Noise<br><br>Quiet | None |
| III. Blood pressure: Habituation or attrition? | T1 | Noise vs. quiet | | Migration<br>Not enrolled in school 1 year after T1<br>vs.<br>Enrolled in school 1 year after T1 but not 2 years later<br>vs.<br>Still enrolled 2 years after T1 |
| IV. Noise abatement: Cross-sectional analyses | T1 | Noise vs. abated vs. quiet | | None |
| V. Noise abatement: Longitudinal analyses | Attrition (T1 & T2) | Noise ——<br>vs.<br>Noise —— | Noise<br><br>Abated | None |

[a] The few classrooms that had had noise-abatement work completed prior to T1 are included as noisy classrooms in these analyses. This was done in order to make these analyses comparable to those reported in Cohen et al. (1980) and is justified by the findings reported in this article suggesting little if any effect of abatement.

## *School Achievement*

The scores on the California Test of Basic Skills (California Assessment Program, 1976) reading and math tests (administered during the second and third grades by the school system) were gathered from school files, and the Wepman (1958) auditory discrimination test was administered individually to children in the soundproof van. The Wepman test measures the child's ability to discriminate between pairs of words that differ from each other in either initial or final sound, for example, "sick–thick" or "map–nap."

To roughly equate the effect of the noise and quiet conditions on the aptitude of the children at the time they entered school, analyses of school achievement and auditory discrimination scores included an additional control for the mean cognitive abilities (standardized test administered by school) of the child's class on entering the first grade.

## *Analyzing and Interpreting Data*

The answers to our questions about adaptation to noise and abatement effectiveness each require different blockings (or groupings) of the noise variable and analyses of different subsets of the sample. Table 1 provides an overview of these analyses. It may be useful for readers to refer to this table while reading the results sections of the article.

To avoid confusion about exactly which analysis and/or data set is being employed at any point, we will present two consecutive sets of results and discussions. The first will examine the question of adaptation and the second the question of the effectiveness of the noise-abatement interventions. These sets will be followed by a short section on the overall implications of the study.

The general statistical model (described below) was used in all data analyses reported in this article. Biases in subject attrition (also described below) are important in aiding interpretation of all longitudinal analyses. Attrition bias is not an issue in the interpretation of cross-sectional analyses, which involve only T1 data and thus include the entire T1 sample.

*Statistical analyses.* A regression technique was used in all the analyses reported in this article to allow additional control over the effects of socioeconomic and demographic factors (cf. J. Cohen & Cohen, 1975). All data analyses include controls for the number of children in the child's family, grade in school, months enrolled in school, and race. These control factors, forced into the regression first, are then followed by noise, and then the interaction between noise and months enrolled in school.[3] Additional controls are used in the analyses of

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[3] To avoid confusion, the reader should note that two distinct terms are used to refer to different time frames. T1 and T2 refer, respectively, to the first and second testing sessions, separated by 1 year. The term "months

blood pressure (height and ponderosity), school achievement (cognitive aptitude test), and distractibility (performance under ambient conditions). The primary helplessness analyses include factors for success–failure and the interaction between success–failure and noise. (Those who solved and those who did not solve the success treatment puzzle are treated as separate groups.) Analyses of longitudinal data also include a repeated measure factor (Testing Session 1, Testing Session 2).[4] School achievement analyses were performed with classrooms (nested in noise) rather than with individual children, as the unit of analysis. A more detailed description of the form of each analysis is provided in Cohen et al. (1980).

The various measures were analyzed in predetermined multivariate clusters created on the basis of theoretical consideration.[5] This form of analysis helps to decrease the probability of chance findings that occur when a large number of analyses are necessary (cf. Bock, 1975).

*Interpreting longitudinal analyses: Sample attrition bias.* An effort was made to retest all students who were attending school during the longitudinal follow-up. Sixty-two percent (163: 83 noise and 80 quiet) of the original sample (262: 142 noise and 120 quiet) were retested. Although a slightly higher proportion of quiet-(67%) than noisy-(58%) school children were retested, this difference was not statistically significant, $\chi^2(1) = 1.99, p < .16$.

All data analyses that include data from the second testing session (these are all repeated measures designs) were based on the 163 retested students—the *attrition sample.* Sample attrition (not being retested) may be attributable to either migration or absenteeism. It is our purpose at this point in the article to describe the nature of any self-selection bias in the retest sample; thus, these causes of attrition are not separated.

The purpose of the attrition bias analyses was to determine whether remaining in the study (being retested) was correlated with one or more of the criterion variables in one of the study's conditions (noise or quiet) but not in the other. For example, noisy-school children who were *not* retested had higher blood pressures than those who were retested; whereas being retested was unrelated to blood pressure for quiet-school children. This particular attrition bias resulted in a deflated mean blood pressure for noisy-school children in analyses of the attrition sample. As a result, there is a lessening of the difference between mean blood pressures of noisy- and quiet-school children. It is important to note cases in which the lack of a main effect for noise in the attrition sample is due to selective attrition as opposed to adaptation to noise or problems with measure reliability. To determine whether any such biases occurred, data from the first testing session (all of the original 262 subjects) were analyzed with whether a student was retested (yes/no), and a Retest × Noise interaction added to the standard analysis (see Table 1, I). Note that these analyses are not presented in an attempt to make any conclusions about those who were retested versus those who were not but only to provide information about the nature of the attrition bias that may be useful in interpreting analyses presented later in this article. For this reason, a rather liberal alpha level (.10) was employed, and multivariate analysis is not reported.

A retest bias occurred on a number of the dependent variables. On all of these variables, those in the noise condition who showed the greatest stress during T1 were not present at T2. No such relationship (or in some cases a slight reversal) existed in the quiet group. The variables with Noise × Retest interactions suggesting this pattern were the child's perception that noise made it difficult to hear their teacher, $F(1, 241) = 3.46, p < .06$, and systolic, $F(1, 233) = 8.65, p < .004$, and diastolic, $F(1, 233) = 3.39, p < .07$, blood pressure.

## Adaptation to Noise

### *Results*

To determine whether or not the children adapted to the noise over the 1-year period, data from the attrition sample (those who were tested at both T1 and T2) were analyzed in a repeated measures design, with Testing Sessions 1 and 2 constituting the repeated measure (see Table 1, II). The occurrence of the same difference between noise and quiet schools at both T1 and T2 (main effect for noise) provides evidence for test–retest stability. A diminution of the T1 difference between noise and quiet at T2 (Noise × Testing Session interaction) suggests the possibility of progressive adaptation to the noise stressor. Finally, an increased difference between noise and quiet at T2 (Noise × Testing Session interaction) suggests that increased exposure results in an increased effect of noise.

It is important to note that these analyses include only the attrition sample (163), that is, those who were enrolled and present during the second testing session. Thus, vari-

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enrolled in school" refers independently to the length of time the child was enrolled in school at T1.

[4] Two new variables, sum (T1 + T2) and difference or change score (T1 − T2), were created for each dependent variable. Then separate regression analyses were conducted on each of the new variables. Analyses of the sum score reflect differences between groups, irrespective of the testing session, whereas analyses of change scores reflect differences between testing sessions over groups. The results of these analyses are mathematically equivalent to a standard repeated measures analysis with two levels of the repeated measure (cf. Overall & Klett, 1972).

[5] There are separate clusters for general health, blood pressure, helplessness, and the child questionnaire. The distraction analyses were run as univariates, since each analysis required a unique control factor.

ables that were related to attrition for noisy-school (but not quiet-school) children, including the child's perception of classroom noise and the blood pressure measures, are unlikely to show noise effects in this analysis.

*Children's perceptions of noise.* Main effects of noise for children's reports of how much airplane noise bothered them at home, $F(1, 145) = 3.62, p < .05$, and in the classroom, $F(1, 145) = 15.74, p < .001$, suggest that those attending noisy schools report high levels at both testing sessions. There was no effect on the remaining child questions. The multivariate noise effect was significant, $F(7, 139) = 3.13, p < .004$.

These results are generally consistent with those reported in the original study (analyses including the entire sample of children tested at T1) in which noisy-school children reported noisier classrooms (a variable affected by attrition bias in the present analysis) and said that airplane noise bothered them more in both home and classroom.

*Health measures.* Although neither height nor weight were significantly related to noise in the entire T1 sample, noisy-school children did attend school more often than their quiet-school counterparts. In the present analysis, there was a Noise × Testing Session effect for the percentage of days attending school, $F(1, 120) = 8.00, p < .005$. Although noisy-school children had better attendance during the year of the first testing session (98% attendance for noise group versus 96% for quiet), the attendance of noisy- and quiet-school children was equivalent (94% for both groups) during the following year. The multivariate for the interaction effect of Noise × Testing Session was significant, $F(3, 118) = 3.71, p < .01$.

*Blood pressure.* Although the analysis of the complete T1 sample indicated inflated systolic and diastolic blood pressure for noisy-school children, there were no effects of noise, testing session, or any of the interactions on either systolic or diastolic blood pressure in the present analysis. Longitudinal blood pressure effects were not expected, however, since a relatively high proportion of noisy-school children with high blood pressure were lost to attrition and thus were not included in the present analyses.

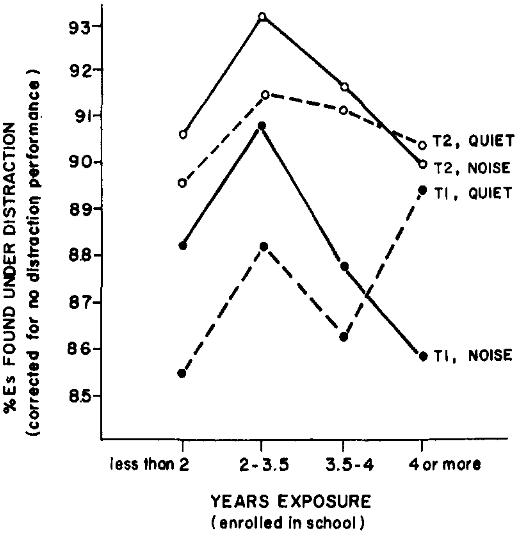

*Figure 1.* Distractibility at T1 and at T2 as a function of school noise level and duration of exposure. (Each period on the number of year's of exposure coordinate represents one quarter (based on quartiles) of the sample. For example, 25% of the sample were enrolled in school for less than 2 years.)

*Distractibility.* In the earlier report of the entire T1 sample (Cohen et al., 1980), an interaction was found between noise and months enrolled in school for the percentage of *E*s found on the distraction task. Children in noisy schools did better than the quiet group on the distraction task during the first 2 years of exposure and worse after 4 years. Quiet- and noisy-school children who had been enrolled between 2 and 4 years, demonstrated equivalent performance. As apparent from the lower half of Figure 1, the attrition sample showed a similar T1 pattern, except that noisy-school children, who had been enrolled for 2–4 years also appeared to be less distractible than their quiet-school counterparts. Examination of the upper half of Figure 1 indicates that the T2 sample continues to show the same pattern of better performance by the noise group on the distraction during the earlier years. In this case, however, performances of the noisy-school and quiet-school groups are rather equivalent after 4 years of enrollment—Noise × Months interaction, $F(1, 141) = 3.66, p < .06$.

*Helplessness.* As in the analysis of the entire T1 sample, there are effects of noise on test puzzle performance that occur irrespective of whether the child received a success (solved or not) or failure treatment. Noisy-school children were more likely to fail the test puzzle than quiet-school children, $F(1, 133) = 5.37$, $p < .02$, and more likely to take longer solving the puzzle, $F(1, 133) = 2.88$, $p < .09$, than quiet-school children—multivariate effect for noise, $F(3, 133) = 1.92$, $p < .12$. Although differences between proportion of children failing and time to solution were stable across the two testing sessions, quiet/noise differences in the percentage of children giving up occurred only at T1—Noise × Testing Session interaction, $F(1, 133) = 3.90$, $p < .05$. The multivariate effect for the Noise × Testing Session interaction was not, however, significant, $F(3, 131) = 1.57$, $p < .20$.

As pointed out in Cohen et al. (1980), an analysis of the proportion of children giving up that includes only those children who failed the test puzzle provides the most direct measure of helplessness. This analysis looks at the degree to which failure is associated with giving up as oppposed to unsuccessful persistence. Although data for the entire T1 sample indicated increased giving up on the part of noisy-school as opposed to quiet-school children, there was neither a noise nor Noise × Testing Session interaction in the present analysis.

Although not directly relevant to problems posed in this article, it is of general interest to examine whether the soluble or insoluble puzzle given at T1 affected performance on the test puzzle administered 1 year later, irrespective of (i.e., controlling for) noise exposure. This comparison provides a rough measure of the duration of the learned helplessness effect. That is, does a failure as opposed to a success pretreatment affect subsequent task performance as much as a year later? As suggested earlier, because of a selection bias created by subjects who were assigned to a soluble puzzle condition who failed to solve their soluble puzzle, there were three levels of the success–failure factor: success group who solved their pretreatment puzzle, success group who failed their pretreatment puzzle, and failure group. At both T1 and T2, children who received a success treatment puzzle and solved that puzzle were more likely to solve, $F(2, 133) = 5.39$, $p < .006$, and faster at solving the test puzzle, $F(2, 133) = 3.16$, $p < .05$, than both those who failed to solve the success treatment puzzle and those who received a failure treatment puzzle. There were no differences between these conditions on the proportion of children giving up; multivariate for success–failure, $F(6, 262) = 2.16$, $p < .05$. These data suggest the possibility of a helplessness effect persisting over a 1-year period, but they are difficult to interpret because of the self-selection problem.

### *Discussion*

In general, the retest data provide strong support for the stability of the effect of noise on annoyance, distractibility, and performance on a moderately difficult task. First, at both testing sessions, noisy-school children were bothered more by aircraft noise than quiet-school children in both the classrooms and homes. Second, the similarity of the T1 and T2 data on the distraction task suggests the relative stability of this unpredicted interaction. Specifically, it suggests that there is some initial increased ability among noise-impacted children for "tuning out" auditory distraction and that this advantage disappears after 4 years of exposure. It was suggested in the earlier article that the children initially attempt to cope with the noise by tuning it out. Later, however, as they find that the strategy is not adequate, they give it up. An alternative explanation is that as duration of exposure increases, the children become more discriminating in terms of the kinds of sounds that they tune out. That is, initially they tune out wide range of acoustic stimuli (including the distractor used in the present study, which is dissimilar to aircraft noise), but later they tune out only sounds that are similar to the aircraft noise.

The present analyses also suggest that noisy-school children were poorer than quiet-school children at solving the test puzzle at both testing sessions. However, the increased "giving up" on the part of the noisy- as opposed to quiet-school children found in the analysis of the entire T1 sample was not found in the present analysis. The lack of such an effect may have occurred because of subject attrition, because the children had had a previous experience with the same puzzle, or because the effect disappeared, that is, adapted out over time. It should be noted that the cross-sectional analysis of the entire T1 sample *did not* indicate a lessening of giving up with increased months of school enrollment. This suggests that the giving up effect does not adapt out over time.

Although the previously reported differences between the noisy- and quiet-school children on systolic and diastolic blood pressure were not found in the analysis of the attrition sample, this result was expected, given the large proportion of noisy-school children with high levels of blood pressure who were not retested. Because of this, the lack of a relationship between noise and blood pressure (at either T1 or T2) in the attrition sample *does not* constitute information for the acceptance or rejection of the hypothesis that the children adapted to noise.

A piece of data that was rather inconsistent with other findings in the original study of the entire T1 sample was that noisy-school children attended school more often than quiet-school children. The present data suggest that this difference did not exist for the data collected at T2. We are unable to explain the difference that occurred at T1 and feel that it may reflect random fluctuation, with T2 reflecting a regression to the mean.

In sum, the data suggest that effects related to living and attending school in a noisy neighborhood are stable over a 1-year period. That is, there is little evidence for adaptation to the noise.

*Blood pressure: Habituation or attrition?* The cross-sectional analysis of the entire T1 sample reported in an earlier article (Cohen et al., 1980) similarly found little evidence for adaptation. In fact, the only data supporting an adaptation hypothesis was the finding that systolic blood pressure differences between noisy- and quiet-school children (noisy-school children had higher blood pressure) were greater during the first few years of school enrollment. A similar pattern also occurred for diastolic pressure, although it did not reach statistical significance. (Figure 2 depicts the results of the T1 sample analysis, as reported in Cohen et al., 1980.) As previously suggested, this effect could be due to noisy-school children adapting to the stressor as the duration of exposure increased. On the other hand, the effect could be due to some kind of subject selection bias. That is, children with noise-induced, elevated blood pressure may have quickly moved out of the noise-impacted neighborhood and thus lessened the mean blood pressure for noisy-school children in the 2 or more years of exposure categories.

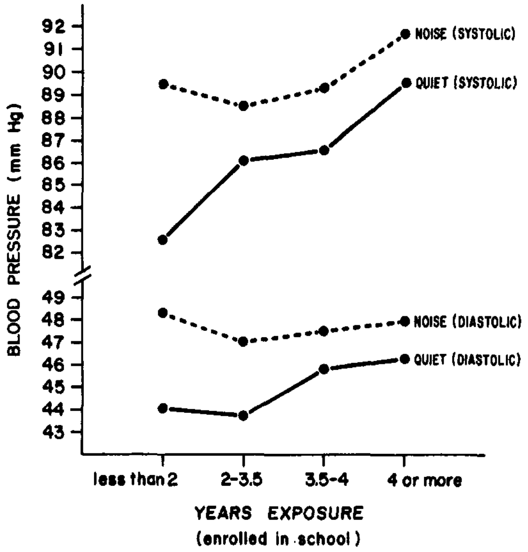

*Figure 2.* Systolic and diastolic blood pressure as a function of school noise level and duration of exposure. Each period on the number of years of exposure coordinate represents one quarter (based on quartiles) of the sample. For example, 25% of the sample were enrolled in school for less than 2 years. (From "Physiological, Motivational, and Cognitive Effects of Aircraft Noise on Children: Moving from the Laboratory to the Field" by Sheldon Cohen, Gary W. Evans, David S. Krantz, and Daniel Stokols, *American Psychologist*, 1980, *35*, 231–243. Copyright 1980 by the American Psychological Association. Reprinted by permission.)

Some longitudinal data on how long specific noisy- and quiet-school children remain enrolled in their schools can help distinguish between these two explanations. The attrition bias analyses reported earlier suggest the possibility that people who move out of noise-impacted neighborhoods are different than those who move out of similar neighborhoods not suffering from noise pollution. Conclusions of this kind cannot, however, be made from the attrition analyses, since a subject assigned to the not-present-during-retesting category may have moved or may have merely been absent during the retesting session. Thus, a second analysis of T1 blood pressure data was conducted to determine whether families of noisy-school children who showed elevated blood pressure were more likely to *move* sometime during the *2* years following the original testing session than families of quiet-school children and of noisy-school children not showing elevated pressure. In this case, unlike the attrition analyses, children who were absent at T2 but still enrolled were categorized as attending school. The retest factor used in the attrition analysis was replaced with a three-level measure of *migration* (not enrolled in school after 1 year/enrolled 1 year later but not after 2 years/still enrolled after 2 years, see Table 1, III).

As in the attrition bias section, we are concerned primarily with the Noise × Migration interaction. This interaction suggests that those children leaving the noise-impacted neighborhood have different scores on blood pressure than those leaving the quiet neighborhood. As depicted in Figure 3, noisy-school students with the highest blood pressures move out of the noise area soon (within 2 years) after the initial testing: $F(2, 229) = 6.80, p < .001$, for systolic, and $F(2, 229) = 3.50, p < .03$, for diastolic. The multivariate interaction effect was significant, $F(4, 456) = 3.84$, $p < .004$. Thus, it appears that selective attrition, *not* adaptation, is responsible for the decrease of the difference between the blood pressure of noisy-school and quiet-school children.

Apparently the families of those noise-group children who showed elevated blood pressure were more likely to move out of the noise-impacted neighborhood than the families of children who did not show elevated blood pressure. It is important to emphasize that these effects occurred with race and social class partialed out of the analyses and that this bias for those with higher blood pressure to move out of the neighborhood occurred only in the noise-impacted area. Some possible explanations for this effect are that (a) parents of children with elevated blood pressure were sensitive to their children's experience of stress and as a consequence moved to a less noisy neighborhood; (b) because of a familial bias (either genetic or environmentally determined), parents of children with noise-induced blood pressure elevations experienced similar stress-related reactions that motivated them to move from the neighborhood; (c) the children's elevated blood pressures were a response not to the noise itself but to their parents' own noise-induced stress, which was motivating the parents to move from the neighborhood; and (d) some unknown third factor is related to mobility, high blood pressure, and living in a noisy neighborhood.[6]

## Noise-Abatement and Noise-Stress Reduction

Do noise-abatement interventions (and their resulting reduction in classroom noise level) decrease or ameliorate the effects of noise in impacted classrooms? Both cross-sectional data collected during the first testing session and longitudinal data looking at changes in the responses of children who moved from noisy to quiet classrooms are relevant to this question. As in the previous section, longitudinal data are based on the attrition (163) sample and, thus, are subject to the attrition bias. The cross-sectional data reported in this section are based on the entire T1 sample (262).

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[6] The explanations that suggest that high blood pressure is the *cause* of the migration from the noisy neighborhoods assume that the child and/or parent perceive that the child is under stress. It is probable that only those children with blood pressures substantially higher than the group mean would fit into this category. Thus, if elevated blood pressure is responsible for increased migration in the noisy neighborhoods, large proportions of those children leaving the noisy neighborhood would have relatively high blood pressures. Analyses of the proportion of children moving from their neighborhoods as a function of whether they attend a noisy or quiet school and whether they have high (80th percentile or above) or low (below the 80th percentile) blood pressure indicate that the proportion of children with high blood pressure who move from the noisy neighborhoods is higher than the proportion of high blood pressure children who move from quiet neighborhoods (Noise × Blood Pressure interactions: for systolic, $F(1, 246) = 5.42, p < .02$; for diastolic, $F(1, 246) = 5.59, p < .02$. Apparently, a relatively large number of noisy-school children who move do have substantially elevated blood pressure.

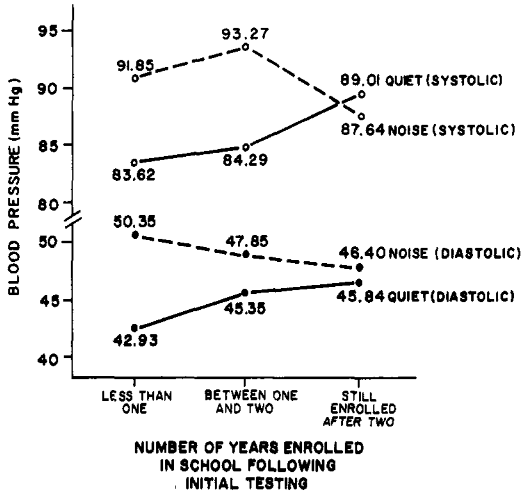

*Figure 3.* Systolic and diastolic blood pressure as a function of school noise level and the number of years enrolled in school following T1.

### *Results: Cross-Sectional Analyses*

Several of the classrooms in noise-impacted schools had been treated with noise-reducing materials several years before the first testing session. Because they were still relatively noisier than quiet comparison classrooms and because of the presumption that the high noise levels in the homes and play areas of noisy-school children were as important as the actual classroom level, these treated classrooms were not separated from other noisy school classrooms in the previous article (Cohen et al., 1980). To evaluate the effectiveness of this treatment and assess the relative impact of a somewhat quieter classroom on the criterion variables, data from the first testing session were reanalyzed, with classrooms categorized as noisy (97 children), abated (45), and quiet (120). The regression analyses on criterion variables are identical to those described previously except that the noise variable had the three levels described above instead of two. (see Table 1, IV).

*Noise measures.* The mean peak noise level for noisy classrooms was 79.06 dB, for abated classrooms it was 63.17 dB, and for quiet classrooms, 56.60 dB. An analysis of variance indicated a significant difference between these means, $F(2, 34) = 38.45$, $p < .001$. Moreover, preplanned contrast indicated significant differences between noise and quiet, $F(1, 34) = 75.06$, $p < .001$; quiet and abated, $F(1, 34) = 16.93$, $p < .0002$; and noise and abated, $F(1, 34) = 45.89$, $p < .0001$, rooms. In general, it was expected that effects on criterion variables would be directly related to average classroom noise levels and therefore, the mean values would fall in the following order: noise, abated, quiet. Preplanned comparisons reported in this section were employed to directly test this hypothesis.

*Child questionnaire.* Although noise had a significant impact on children's self-reports of classroom noise, $F(2, 249) = 2.69$, $p < .07$; airplane disturbance in the classroom $F(2, 249) = 7.4$, $p < .0008$; and airplane disturbance at home, $F(2, 249) = 7.78$, $p < .0005$, all reflected a relatively low level of noise annoyance among quiet-classroom children as compared with noisy- and abated-classroom children, whose means on these questions were nearly identical. The multivariate analysis for the child questionnaire data did not indicate any significant effects.

*Health.* The health cluster analyses indicated Noise × Months Enrolled in School interactions for both height, $F(2, 237) = 2.83$, $p < .06$, and weight, $F(2, 237) = 4.21$, $p < .01$. These interactions were primarily attributable to relatively low mean heights and weights for those in the abated group who had been enrolled in their schools between 2 and 3½ years. There was also a main effect of noise for the percentage of total school days a child was in attendance, with noisy- and abated-group children attending more often (97.5% for noise and 97.2% for abated) than quiet-group children (94.2%), $F(2, 237) = 11.93$, $p < .0001$. Multivariate analyses for both the noise, $F(6, 470) = 1.58$, $p < .15$, and Noise × Months, $F(6, 470) = 1.85$, $p < .09$, effects were marginal.

*Blood pressure.* As is apparent from Table 2, both systolic and diastolic blood pressures appear to vary as a function of noise level, with the highest mean pressure reported for the noise group, followed by a lower blood pressure in the abated group and an even lower pressure in the quiet group. Although the analysis of systolic pressure did not indicate a statistically significant impact of noise, there was a main effect of noise for

Table 2
*Mean Blood Pressures (mm Hg) by Classroom Noise Abatement for Cross-Sectional (T1) Data*

| | Classroom | | |
|---|---|---|---|
| Blood pressure | Quiet | Abated | Noisy |
| Systolic | 86.64 | 88.69 | 90.09 |
| Diastolic | 44.99 | 46.77 | 48.46 |

diastolic pressure, $F(2, 241) = 3.19, p < .04$. The multivariate analysis was not significant.

Preplanned contrasts between the various blood pressure means indicate that for both systolic, $F(1, 235) = 2.61, p < .10$, and diastolic pressure, $F(1, 235) = 5.24, p < .02$, the noise group was different from the quiet group. Comparisons between the quiet group and the abated group indicated marginal differences in both cases—for systolic, $F(1, 235) = 2.21, p < .14$; for diastolic, $F(1, 235) = 3.17, p < .08$. There were no differences between the noise and abated groups for either systolic or diastolic pressure.

*Helplessness.* The percentage of failure on the second helplessness puzzle was also consistent with the expected order. The noise group was more likely to fail the second helplessness puzzle (57% failed) than either the abated group (47% failed) or the quiet group (35% failed), $F(2, 235) = 4.12, p < .02$. There was no difference between noise groups on the time required to solve the second puzzle. Preplanned contrasts comparing proportions of students solving the second puzzle indicate marginal differences between the quiet and abated groups, $F(1, 235) = 3.10, p < .08$, and the noise and abated groups, $F(1, 235) = 2.70, p < .10$, and a significant difference between noise and quiet, $F(1, 235) = 8.03, p < .005$. These data suggest that noise abatement marginally affected puzzle task performance, with children in abated classrooms performing at a higher level than those in nonabated rooms, but not as well as those in quiet rooms.

Both the noise and the abated group "gave up" on the second puzzle (17% for noise, 16% for abated) more often than the quiet group (3%). The multivariate effect for noise did not, however, reach statistical significance. An analysis including only those children who failed the second puzzle indicated that the failures of noise- (29%) and abatement-group (35%) children were associated with giving up more often than were the failures of quiet-group children (7% who failed gave up).

*School achievement.* The achievement tests for reading and math are administered by the school systems during the third but not during the fourth grade. As a result, the scores that were used in the following analyses were recent for third graders (administered at approximately the same time as our own testing) but were 1 year old for fourth graders. Thus, it was expected that noise abatement would affect the achievement scores of third graders who spent a year in their abated classrooms before (and while) taking the test, but not fourth graders, since their classroom assignment at the time that we collected our data was presumably irrelevant to how they performed on a test taken in another classroom 1 year earlier. (Unfortunately, data on the classroom assignment of fourth graders during the year that they were tested were not available.) To test the hypothesis that the achievement scores of third but not fourth graders would be affected by abatement, a Grade × Noise interaction was added to the noise nested in classrooms analysis of the school achievement cluster. Although there were no effects for the noise or Noise × Grade interaction on either reading achievement or auditory discrimination, there was a Grade × Noise interaction for performance on the math achievement test, $F(2, 32) = 3.06, p < .06$; the multivariate for noise was $F(6, 60) = 1.98, p < .08$. As is apparent from Table 3, although grade level did not have a substantial effect on the relative performance of third and fourth graders in quiet schools,

Table 3
*Mean (Adjusted) School Achievement Percentiles for Cross-Sectional (T1) Data as a Function of Classroom Noise Abatement and Grade*

| | Reading | | Math | |
|---|---|---|---|---|
| Classroom | 3rd grade | 4th grade | 3rd grade | 4th grade |
| Noisy | 30.30 | 35.96 | 34.35 | 39.35 |
| Abated | 47.36 | 37.90 | 56.24 | 37.54 |
| Quiet | 37.85 | 39.09 | 36.96 | 42.76 |

third graders in abated classrooms performed substantially better than those in nonabated classrooms, whereas the reverse was true for fourth graders. It is also apparent from Table 3 that there was a similar pattern for reading test scores, although the Grade × Noise interaction for reading did not reach statistical significance.

One anomaly of these data is that math (also reading) achievement performance of the third-grade children from abated classrooms in noisy schools is higher than that of third-grade children from quiet schools. It was noted in a previous article (Cohen et al., 1980) that differences between noisy and quiet schools were affected by a number of variables that could not be controlled for in the present study, including school and district teaching policy, teaching quality, level of federal aid to a school, and school administration. It was also suggested that these factors are probably more important than noise in determining school achievement. These problems are reduced substantially when (as in the analysis above) the noise and abated classrooms are in the same district and often in the same school.

*Distraction.* Analysis of the distraction task data indicated no significant effects.

### *Results: Longitudinal Analyses*

As mentioned earlier, all children from the original sample who were still enrolled in their respective schools were retested 1 year later. The analyses presented below compare those children who were in noisy (nonabated) classrooms during both testings (44 children) with those children who were in noisy rooms during the first testing and abated rooms during the second testing (39 children). Quiet-classroom children were not included in these analyses because of the conceptual problem of evaluating change scores when initial scores are significantly different (see Table 1, V). Only factors for which Noise × Testing Session and/or Noise × Months × Testing Session interactions were significant will be discussed, since at this point we are not concerned with differences between noise/noise and noise/abated groups that occur at both testings (i.e., the main effect for noise) unless an interaction is found.

Table 4
*Mean Classroom Noise Levels for Noisy and Abated-Noise Classrooms at T2*

| | Noise measure | | |
|---|---|---|---|
| Noise level | $L_{EQ}$ | $L_{33}$ | Peak dB (A)[a] |
| Noisy | 70.29 | 55.82 | 91.50 |
| Abated | 62.82 | 49.27 | 71.27 |

[a] Mean peak dB (A) measures at T2 are higher than those recorded at T1. This is because the more sensitive automated equipment used at T2 records peaks that last only a fraction of a second, whereas manual equipment used at T1 required the operator to judge the highest point reached by a fluctuating needle.

*Noise measures.* Before presenting data on the relationship between the noise-abatement work and the children's performance and health, it is important to determine whether the abatement work was effective. Analyses of the differences in the sound levels in classrooms that were sound attenuated versus those that were not sound attenuated suggests that the abatement work had a significant impact on interior sound levels. As apparent from Table 4, on all three measures—$L_{EQ}$: $F(1, 20) = 9.39$, $p < .006$; $L_{33}$: $F(1, 20) = 4.92$, $p < .04$; and peak dB: $F(1, 20) = 24.91$, $p < .0001$—abated rooms have substantially lower sound levels than nonabated rooms.

*Child questionnaire.* Children in the noisy group reported more trouble hearing their teacher during the second testing session, whereas those in abated classrooms reported less difficulty—Noise × Testing Session, $F(1, 48) = 3.98$, $p < .05$. There were no other Noise × Testing Session effects on children's questions and no significant multivariate effects.

There were no significant multivariate or univariate interactions of noise and testing session in any of the remaining clusters; thus, no additional data are reported here. It is important to reiterate that school achievement data were available only at T1, and thus, there were no longitudinal school achievement analyses.

### *Discussion*

The *cross-sectional* comparison of noisy, abated, and quiet classrooms suggests only a minimal impact of the abatement intervention on the criterion variables. Clusters apparently *unaffected* by abatement (those showing no effects or just noisy- versus quiet-school differences) include children's perceptions of noise and noise interference, health factors, and the auditory distraction measure. On the other hand, two important clusters did provide at least marginal support for an ameliorative effect of abatement. First, abatement did have a marginal effect on whether the child was able to solve the moderately difficult test puzzle in the helplessness task, irrespective of whether the child received a soluble or insoluble first puzzle. It is noteworthy, however, that giving up—the measure designed to provide a direct assessment of feelings of helplessness—was affected only by the noisy-school versus quiet-school distinction. Second, although reading achievement and auditory discrimination ability were unaffected by abatement, there was evidence that math achievement was higher for children in abated than in noisy classrooms. This effect seems especially noteworthy, since it occurs, as predicted, only for those children who took the achievement test at the end of the year that was spent in an abated classroom. It is important to consider, however, that unlike all other measures that were administered in a relatively quiet setting, the achievement tests were actually taken in the classroom. Thus, the relative deficit in math performance of the children from the noisy as opposed to noise-abated classrooms may be attributable to noise interfering with test performance rather than to an aftereffect of noise, which we would expect to occur even outside of the noise-impacted environment.

The *longitudinal* data similarly provide little evidence that children who had been enrolled in a noise-impacted school showed improvement in their performance and/or health following a 1- (school) year experience in a noise-abated classroom. In contrast to the cross-sectional analysis, the longitudinal data did not even indicate improvement in ability to solve the moderately difficult puzzle on the part of children in noise-abated rooms. This failure to mimic the cross-sectional findings may be due to an attrition bias or to the marginality of the effect itself. Unfortunately, school achievement data were not available during the second testing session, and there was no opportunity to reevaluate the ameliorative effects of noise abatement on school achievement found in the cross-sectional analyses.

It is clear that the ameliorative effects of classroom noise abatement were not substantial, nor did they cover a wide range of measures. There is evidence, however, that abatement affects behavior in the classroom. Children in abated classrooms reported fewer problems hearing their teachers and performed better on school achievement tests than children in nonabated rooms. It is important to reiterate that unlike other measures in the study, school achievement tests were administered in the (noisy or quiet) classroom. It is thus possible that noise-associated deficits on this measure reflect an effect of noise that occurs *during* rather than after exposure.

We can suggest two possible explanations for the general lack of ameliorative effects of classroom noise abatement. First, it is possible that effects of previous noise exposure are relatively long lasting. That is, it takes more than a 1-year reprieve from the noise for a return to more normal levels of behavior and health. Second, since the children are all exposed to the noise outside of the school—in their homes, on the playground, and so forth—a quieter classroom may not have been a sufficient intervention.

In evaluating these results, it is also important to remember that most of the children attending noisy schools spent previous years in nonabated classrooms. Thus, although abatement interventions were not entirely effective for this population, it is possible that children who start to attend school after the entire school has undergone noise abatement (and are thus always in relatively quiet classrooms) would benefit from the interventions.

## Conclusions and Implications

The data reported in the analyses of the entire T1 sample (Cohen et al., 1980) indicated effects of aircraft noise on cognitive, motivational, and physiological mechanisms that were consistent with effects found in laboratory settings. The data presented in this article established the stability of these effects over time. Moreover, they reinforce our interpretation of the earlier cross-sectional data that children do *not* adapt to noise over time. The analyses of noise-abatement effectiveness indicate that the abatement is partially effective, with the important school achievement measure showing some improvement for children in noise-abated classrooms.

From a policy point of view, these data support the need for noise-abatement work in these kinds of settings but suggest that noise insulation in the classroom may not be enough. It is likely that more effective noise abatement in classrooms (bringing levels closer to those in quiet schools) and decreased noise exposure *outside of school* would have an increased ameliorative impact. Thus, decreasing overall community noise levels by creating buffer zones between airports and other sources of high-intensity noise and the surrounding communities would be one way of providing more adequate protection for community residents.

The data reported in this and the previous article are part of the Los Angeles Noise Project, an ongoing study that is attempting to provide a sound data base regarding the possible links between community noise exposure and various aspects of behavior and health. The consistency of laboratory and field findings is beginning to increase our confidence in a number of deleterious effects of community noise exposure. This project includes an ongoing attempt to replicate this work, with both a second sample of children living in the air corridor and a sample of children attending schools adjacent to highways. The aim is to increase our understanding of the aftereffects of noise, the possible role of adaptation in mediating such effects, and the impact of noise-abatement intervention on noise-related effects. The strategy of studying effects that are closely linked to laboratory findings together with the use of both cross-sectional and longitudinal approaches in the field helps establish both the scientific validity and practical value of work, with implications for social issues. As these converging approaches eliminate alternative explanations for noise-associated effects, the potential for affecting the formation of public policy increases.

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