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Cardiovascular and Behavioral Effects of Community Noise

Evidence from field studies of schoolchildren supports laboratory findings that high-intensity noise adversely affects physical health and psychological functioning

Over seventy million Americans live in neighborhoods with noise levels that interfere with communication and cause annoyance and dissatisfaction (USEPA 1974). Sources of this noise include aircraft overflights, traffic, construction and industrial machinery, as well as the sounds of neighbors, children, and pets. Are high levels of community noise detrimental to residents' health and well-being? This is a question we are only beginning to answer.

The potentially deleterious impact of high-intensity noise on hearing has been widely accepted by scientists and policymakers alike. Acceptable noise standards used in both national and local statutes are based on data that establish the relationship between the intensity and duration of noise and temporary or permanent losses of hearing (Kryter 1970). Research completed during the last ten years indicates that noise can affect nonauditory, as well as auditory, systems. For example, accumulating evidence suggests that prolonged exposure to high-intensity noise is as-

sociated with increased risk of cardiovascular pathology and disturbing psychological symptoms (Cohen and Weinstein 1981). Moreover, increased levels of community noise have been repeatedly associated with residents' greater dissatisfaction and annoyance (Borsky 1980). But despite numerous studies of the possible harmful effects of routine exposure to noise on aspects of health and behavior other than hearing loss and annoyance, inferences concerning these other effects are generally considered tenuous.

It is difficult to reach firm conclusions based solely on naturalistic studies of the effects of community noise. Inevitably, the possibility exists that people who choose (or are forced) to work or live in a noise-affected area are somehow different from 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 population density) that may also affect health and behavior (cf. Krantz et al., in press).

Laboratory research provides another source of data from which to speculate about the effects of routine exposure to noise. This research suggests that high-intensity noise can affect at least three types of nonauditory processes. First, exposure to noise can lead to a narrowed focus of attention. This decrease in breadth of attention presumably occurs either as a reaction to a noise-induced increase in arousal (Broadbent 1971) or as a strategy to decrease the amount of information being processed when the presence of noise taxes processing capacity (Cohen 1978). A narrowed focus of attention during noise expo-

sure is assumed to have detrimental effects on performance of complex tasks, i.e., those requiring a wide range of attention, but not on tasks that are simple or intermediate in complexity.

A second effect of exposure to noise—at least to unpredictable or uncontrollable noise—is a reduction in perception of control over the environment (e.g., Glass and Singer 1972; Krantz et al. 1974). This loss of control is often accompanied by a depressed mood and decreased motivation to initiate new responses (Seligman 1975). It has also been associated with "aftereffects"—deficits in performance that occur after the noise stimulus is terminated.

A third effect is an alteration in physiological arousal characteristic of a generalized stress reaction (Kryter 1970; Welch and Welch 1970). This effect includes increased blood pressure, elevated skin conductance levels, and increased excretion of hormones indicative of sympathetic nervous system activity. There is also evidence that prolonged exposure to noise can produce long-term changes in cardiovascular function in animal subjects. Particularly notable in this regard is research by Peterson and colleagues (Peterson 1979; Peterson et al. 1981) demonstrating that monkeys subjected to noise levels found in industrial settings for several months developed pronounced (i.e., more than 20%) and lasting blood pressure elevations. However, as most of these reactions in humans have been documented in laboratory studies involving short-term exposure to relatively high sound levels, the implications of human laboratory research for those suffering prolonged expo-

sure at home or at work are questionable.

The respective shortcomings of laboratory and field research on nonauditory effects of noise can be overcome by a strategy that combines experimental and naturalistic studies. Laboratory studies serve to direct our attention to categories of behavior and health that may be affected by noise, and to establish a causal link between noise and changes in these categories. Naturalistic research helps to establish whether particular effects found in the laboratory also occur in real-life settings. Accordingly, this article will review research on the cardiovascular and behavioral effects of noise on humans with particular emphasis on health-related cardiovascular responses, noise-induced shifts in attention, and feelings of personal control. In conjunction with this review, we will report results of a collaborative longitudinal study, the Los Angeles Noise Project, designed to examine the course of adaptation to noise and the impact of noise abatement on a variety of physiological and psychological processes (Cohen et al. 1980, 1981).

Noise and health

Is noise harmful to the human body? Many would argue that, outside of the effects of high-intensity sound on hearing (see Kryter 1970; Miller 1974), there is little convincing evidence for a causal link between noise and physical disorders. However, several noise-induced physiological changes have been reported in laboratory research, and such changes, if extreme, are often considered potentially hazardous to health.

Epidemiological research in industrial and community settings also suggests evidence of deleterious effects on health. A recent review of the foreign industrial noise literature by Welch (ms.) indicates that there is increased prevalence of certain nonauditory diseases (e.g., cardiovascular disorders, gastrointestinal complaints, infectious disease) among people who have been exposed at work to sound levels of 85 db(A) or greater for at least three to five years. Welch concludes that these conditions may result in a doubling of risk of cardiovascular disease. Moreover, the morbidity associated with exposure to relatively high intensities of

sound increases with advanced age and years of employment for both men and women. Disease tends to be more widespread among those exposed to sound that is unpredictable or intermittent, compared to periodic or continuous noise. Both absenteeism and accident rates are also markedly higher for those working in intense noise as compared with unexposed workers or workers wearing ear protection (Cohen 1976). Unfortunately, many of these studies do not control for relevant confounding factors such as education, income, and job demands. It is also important to note that several industrial surveys failed to find a relationship between noise and ill health (Finkle and Poppen 1948; Glorig 1971).

The strongest case for routine industrial noise affecting health derives from research on cardiovascular problems (Cohen and Weinstein 1981; Welch, ms.). Impaired regulation of blood pressure (including especially hypertension) is the best documented of these effects. For example, more than fifteen studies report that the prevalence of hypertension is increased by at least 60% among workers chronically exposed to sound levels over 85 db (cf. Welch, ms.). Additional concomitants of prolonged exposure to intense industrial noise include other clinical cardiac symptoms (e.g., arrhythmia) and vascular disorders. The impressive amount of data linking cardiovascular disorders to exposure to high noise levels at work must, nevertheless, be viewed with caution. All the studies suffer from the methodological problems associated with correlational field research, and many do not include adequate control groups.

The effects of community noise on cardiovascular problems have also been examined. In a series of studies conducted in the neighborhoods adjacent to an airport in Amsterdam, Knipschild (1977) reports that residents in areas with high levels of aircraft noise were more likely to be under medical treatment for heart trouble and hypertension, more likely (especially among women) to be taking drugs for cardiovascular problems, and more likely to have high blood pressure and other cardiac abnormalities than an unexposed population. While these differences could not be explained by age, sex, smoking

habits, or obesity, the noisy and quiet areas did differ in socioeconomic status. Another study in the same report (Knipschild 1977), not subject to this alternative explanation, indicates that increases in the purchase of cardiovascular drugs were positively correlated with the number of aircraft overflights at night. Similarly, a Russian study (Karagodina et al. 1969) suggests that children (9–13 years old) in noise-affected areas around nine airports show blood pressure abnormalities, higher pulse rate lability, cardiac insufficiency, and local and general vascular changes. Unfortunately, the report does not provide any information on the nature of the control population or any details of the measurement procedures.

Studies of the effects of traffic noise on cardiovascular measures are less consistent. A German investigation of children in the seventh through tenth grades (Karsdorf and Klappach 1968) reports higher systolic and diastolic blood pressure for children from noise-affected schools, while a Dutch study (Knipschild and Salle 1979) found no evidence for increased risk of cardiovascular disease in middle-aged housewives living on streets with high levels of traffic noise as compared with their neighbors living on quieter streets. Despite inconsistencies, the studies of community noise do suggest that it is associated with increases in the incidence of cardiovascular disease and factors related to risk of cardiovascular pathology.

One striking aspect of these data is the evidence that children as well as adults show noise-associated cardiovascular effects. In fact, there is reason to suspect that exposure to high-intensity noise is a greater threat to children than to adults. Physiological development may be disrupted by unusual demands of external stressors. As we will describe below, children may also be psychologically less able to deal with a continuous stressor because of a limited repertoire of coping strategies or because they lack the opportunity to control or manipulate their environment (Cohen et al. 1979). During the formative years of childhood, noise may have a particularly detrimental effect on learning or cognitive development.

A number of years ago, it was theorized that young children contin-

uously exposed to noise adopt an attentional strategy of "tuning out" their acoustic environment (Deutsch 1964). Moreover, it was suggested that this strategy, while successful in the sense of helping the children cope with the noise, has the adverse effect of causing children reared in noisy environments to become inattentive to acoustic cues. Children who tune out noisy environments are not likely to distinguish between speech-relevant and speech-irrelevant sounds. Thus, they will lack experience with appropriate speech cues and generally have difficulty recognizing relevant sounds and their referents. Such a disregard of acoustic cues is presumed to account, in part, for subsequent problems in learning to read.

Recent research suggests that children living and attending school in noisy neighborhoods are poorer at making auditory discriminations even when tested in quiet settings. For example, Cohen and colleagues (1973) studied children in the third through fifth grades who lived in apartment buildings built on bridges spanning a busy expressway. When tested in a quiet setting, children living in noisier apartments demonstrated poorer auditory discrimination and reading ability than those living in quieter apartments. The magnitude of the correlation between noise and auditory discrimination increased with the length of residence. Differences in race and social class, and hearing losses, were ruled out as possible alternative explanations. Similarly, Moch-Sibony (in press) compared children from a quiet (soundproofed) elementary school in the air corridor of Orly Airport near Paris to children in a nearby noisy (without soundproofing) school. The groups were matched on socioeconomic grounds. Results indicated that children from the noisy school showed poorer auditory discrimination, but there were no differences between schools in reading achievement.

A third study of four-and-a-half to six-and-a-half year old children from homes described by their parents as either noisy or quiet indicates that when tested in quiet settings, children from noisy homes did worse on both a matching and incidental memory task than those from quieter homes (Heft 1979). Analyses controlled for age, preschool experience, and income level of parents. It should be noted,

however, that lay assessments of noise level do not usually correlate highly with objective noise measures (Kryter 1970).

These results may be termed aftereffects, since task performance was measured outside the stressful environment. However, Bronzaft and McCarthy (1975) tested children in their respective noisy and quiet classrooms. Children in classrooms on the side of a school facing train tracks performed less well on a reading achievement test than children in classrooms on the quiet side of the building.

Although the evidence suggests that children living and attending school in noisy environments are poorer at making auditory discriminations and at reading, there is no explicit data that this is attributable to the selective inattention mechanism. Another equally plausible explanation is that noise masks parent and teacher speech, similarly resulting in the child's lack of experience with appropriate speech cues and, as a consequence, reading deficits. Clearly, more research is needed to evaluate these various hypotheses.

Laboratory research on personal control over aversive stimuli (Glass and Singer 1972) suggests some possible long-term effects of exposure to noise. The majority of this work deals with the role of control in offsetting adverse physiological and behavioral effects during short-term exposure to laboratory stress (e.g., Krantz et al. 1974). Seligman (1975) suggests that individuals who continually encounter environmental events (especially aversive events) that they can do nothing about display motivational, cognitive, and emotional disturbances. This psychological state, called learned helplessness, results because individuals perceive themselves as incapable of exerting control over the environment.

Closely related to the work on learned helplessness is Glass and Singer's (1972) research on the effects of noise on poststimulation performance. These and other authors (e.g., Rotton et al. 1978; Sherrod et al. 1977) report that subjects exposed to uncontrollable noise that is unrelated to an ongoing task do less well on poststimulation tasks than do subjects who perceive that they can terminate

the noise at will. These effects were observed on poststimulation tasks as diverse as proofreading and tests measuring tolerance for frustration. Although various plausible explanations for these aftereffects have been suggested (see Cohen 1980 for review), both Seligman (1975) and Glass and Singer (1972) assert that subjects unable to control or predict noise learn that there is little they can do to affect the stressor. This presumably results in lowered motivation and poorer performance on subsequent poststimulation tasks.

There is inferential data to suggest that those experiencing chronic exposure to noise in real-life settings often perceive the noise as uncontrollable and show effects similar to helplessness. Consider, for example, data reported by Herridge (1974) indicating that those living in "noise slums" were more likely to be admitted to a mental hospital than those living in less noisy areas. Even though they were apparently disturbed by noise, residents of the noisy areas were less likely to complain about aircraft noise than residents of control areas. Herridge suggests that the mental distress of those experiencing prolonged exposure to noise was due more to feelings of helplessness than to noise per se. However, the questionable demographic comparability of noisy and less noisy areas in this study, and the low base rate of complaints from both areas, restricts our confidence in this interpretation.

Although these data on the relationship between noise and helplessness are only suggestive, two studies supply direct evidence that environmental stress (noise or high levels of residential density) can adversely affect children's behavior. Moch-Sibony's (in press) study reports that children from a noisy school in an airport corridor were less tolerant of frustration than their counterparts in a quiet school. A well-controlled set of experiments by Rodin (1976) demonstrates that living in chronic high density can result in feelings of helplessness among children. Although helplessness is associated with environmental stress in both these studies, our interpretation of this research must be restricted since the studies are cross-sectional in design. A study with good controls examining the effects of noise stress on helplessness would advance our understanding of

the cognitive and motivational processes affected by chronic noise exposure.

The Los Angeles Noise Project

The evidence reviewed above suggests that cardiovascular changes, noise-induced shifts in attention, and changes in feelings of personal control may result from chronic exposure to noise. Although investigators have begun to take a closer look at the nonauditory effects of noise in naturalistic settings, methodologically tight studies are rare. And because this research tends to be atheoretical, comparisons with laboratory work are difficult. Moreover, there are few longitudinal studies of people living and/or working under noise. Thus it is unknown whether prolonged exposure to noise results in increasingly deleterious effects, or whether those exposed for prolonged periods adapt to noise, with effects eventually disappearing.

Studies comparing measures of health and behavior of the same person before exposure, immediately after exposure begins, and at set intervals for one to several years would allow us to determine the long-term
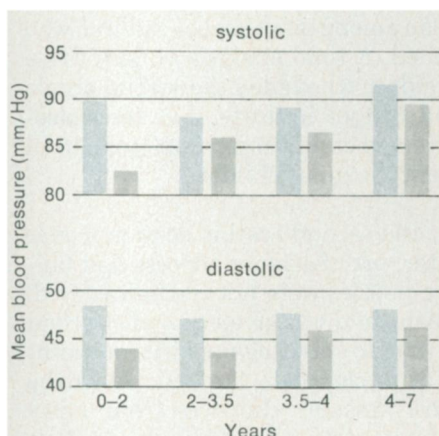
course of stress and adaptation. In addition, longitudinal studies in situations in which the environmental stressor is removed or attenuated would make it possible to determine whether there are long-term aftereffects of prolonged exposure to noise. Accordingly, we conducted a controlled longitudinal study of the impact of aircraft noise on elementary schoolchildren—the Los Angeles Noise Project. The study examined the course of adaptation and the impact of noise abatement on blood pressure, attentional processes, and feelings of personal control (see Cohen et al. 1980 and 1981 for a fuller report of this study).

The subjects were children (initially in the third and fourth grades) living and attending schools in the air corridor of Los Angeles International Airport, and children of similar socioeconomic condition, age, and race living and attending schools in quiet Los Angeles neighborhoods. Children with hearing losses were excluded from the study, and relevant demographic factors were further controlled statistically. In the noisy schools, subject to approximately one overflight every two-and-a-half minutes during school hours, peak sound level readings were as high as 95 db(A) (Lane and Meecham 1974). The study focused on effects occurring outside noise exposure; thus all tests, except school achievement tests given in classrooms, were administered in the quiet setting of a soundproof van.

As part of the settlement of a lawsuit brought by the school systems against the airport, the interior sound levels of many of the schools in the air corridor were lowered following the first testing session of the study. Thus a large number of noise-affected children spent the following year in quieter classrooms, while others remained in noisy classrooms. One year after original testing, children who were still enrolled in their schools were retested to determine whether effects of noise would persist after they were assigned to quieter classrooms. Longitudinal data from subjects in noisy classrooms at both sessions were compared to those from children in quiet classrooms at both testing sessions to determine whether noise effects decreased or disappeared over the one-year interval between sessions.

In addition to the noise-abatement work done in the schools between the testing sessions, a number of classrooms had been treated with noise-reducing materials several years before the first session. Separate cross-sectional analyses were therefore conducted to evaluate the effectiveness of this earlier noise abatement. In our discussion below we will first consider the nature and persistence of noise effects and then discuss the results of abatement.

The effects of noise on blood pressure were quite clear in the data from the first session (Fig. 1). Children attending noisy schools had higher systolic and diastolic pressures than their counterparts in quiet schools. Moreover, the pattern of pressures suggests that this effect was greatest during the first two years in a noisy school, with the differences remaining consistently smaller after that point. It should be noted, however, that while these blood pressure differences were statistically reliable, the levels for children attending noisy schools do not as a group exceed normative

Figure 1. Children in noisy schools (*color*) have higher blood pressure than those in quiet schools (*gray*), although the difference lessens after the first two years of school enrollment. This decrease occurs because children with the highest blood pressures move out of the noisy neighborhoods. Each time period represents the length of enrollment of one-quarter of the sample in the schools under investigation. For example, 25% of the children had been enrolled in the schools less than two years. (After Cohen et al. 1980.)

Figure 2. Children with the highest blood pressures measured remain less than two years in noisy schools, perhaps because their parents also react to the stress of noise with elevated blood pressures, and move to quieter neighborhoods. Because of this, our data do not enable us to determine whether children in noisy schools (*color*) become accustomed to noise or continue to show higher blood pressure than children in quiet schools (*gray*). Each time period represents the number of years the students remained enrolled after the first testing session. (After Cohen et al. 1981.)

levels for children of similar ages (e.g., Voors et al. 1976). The long-term health consequences, if any, of these elevations of blood pressure in children remain unknown.

The greater difference during the first few years of school enrollment could be due to noise-affected children becoming habituated to the stressor, or it could be due to some kind of subject selection bias. That is, children with noise-induced blood pressure elevations may have quickly moved out of the noisy neighborhood and thus lowered the mean blood pressure for children who remained exposed for two or more years.

Additional longitudinal data on how long specific children remain enrolled in their noise-affected or quiet schools helped distinguish between these two explanations (Fig. 2). A reanalysis of blood pressure data from the first session revealed that students with the highest blood pressures in the noisy schools did indeed leave soon (within two years) after the initial testing. In the quiet schools, the trend was reversed and children with the lower blood pressures tended to leave. Thus it seems that selective attrition, *not* adaptation, is responsible for the decrease in the difference between the blood pressure of children in noisy and quiet schools. Data from an independent replication sample of third graders are consistent with the results discussed above. Children who had attended noisy schools for two years or less had higher blood pressure levels, but those who had been exposed to noise for longer periods did not. Our data, therefore, do not enable us to determine whether noise-affected children with increased blood pressure become habituated to the stressor over time.

It is important to emphasize that race and social class were controlled for in these analyses. Some possible (and admittedly speculative) explanations for this intriguing effect among noise-affected children are (1) 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; (2) 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
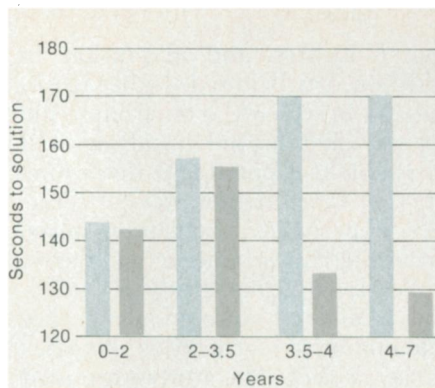

Figure 3. Children from noisy schools (*color*) were less successful at solving puzzles than their counterparts from quiet schools (*gray*), and were more likely to give up before the time to work on the puzzle ended. Each time period indicates how long one-quarter of the sample had been enrolled in the schools. (After Cohen et al. 1980.)

motivated them to move from the neighborhood; (3) the children's elevated blood pressures were a response not to the noise itself but to their parents' own noise-induced stress, which motivated the parents to move from the neighborhood; and (4) some unknown additional factor is related to mobility, higher blood pressure, and living in a noisy neighborhood.

Although we cannot be certain any of these explanations is correct, there is recent related evidence that children of hypertensive parents show elevated cardiovascular response to stress (Baer et al. 1980; Falkner et al. 1979; Obrist et al., in press). This reinforces the notion that parents of children with elevated blood pressure may be suffering from cardiovascular disorder. We have no ready explanation for the opposite tendency for children with lower blood pressures to leave the quiet schools after several years.

Cognitive and motivational effects

To determine whether children in noisy schools behave as though they have less control over their environment, the Los Angeles Noise Project tested students with a cognitive task after an experience of success or failure. A lack of persistence after failure is considered a direct manifestation of learned helplessness. Each child was given a puzzle to assemble after the tester demonstrated the task with another puzzle. Half the children received an insoluble (failure) puzzle, and half a soluble (success) puzzle.

After time was up on the first puzzle, the child was given a second, moderately difficult puzzle to solve. The second puzzle was the same for all children, and each child was allowed four minutes to solve it. The time required to solve the puzzle and whether the child gave up before the four minutes had elapsed were used as measures of helplessness. Unexpectedly, a large proportion of the children receiving a soluble first puzzle failed to solve it within the time allowed. We therefore confined ourselves to comparing children from noisy and quiet schools, irrespective of whether they received success or failure puzzles.

Children from noisy schools were more likely to fail to solve the success puzzle than children from quiet schools. And regardless of whether they first received a success (solved or not) or failure puzzle, noise-affected children were more likely to fail the second puzzle, and more likely to give up, than quiet school children. Moreover, as is apparent in Figure 3, the longer the child attended a noisy school, the slower he or she was in solving the puzzle.

The strongest indication that the failure of noise-affected children to solve these puzzles is related to helplessness per se would be data indicating that giving up before the allotted time elapsed was more likely among children from noisy schools who failed to solve the second puzzle than among quiet school children who failed. A final analysis of only those children who failed the second puzzle did in fact indicate that the noise-affected children gave up more often than the quiet children.

At the second testing session a year later, pretreatment success and failure puzzles were not readministered. Each child was given only the second puzzle to solve, again with four minutes to complete the task. As at the first session, children from noisy schools were less likely to solve the test puzzle than children from quiet schools, and more likely to take longer solving it. However, in the second session noise-affected children were not more likely to give up than children from quiet schools. This effect may have disappeared simply because of elapsed time, because of subject attrition, or because the children had had a previous experience with the

same puzzle. It should be noted that the data from the first session did not indicate a lessening of giving up with increased years of school enrollment, thus suggesting that the passage of time alone does not account for this difference between the two sessions. In sum, performance deficits among children from noisy schools seem to persist over a one-year period. However, it is unclear whether the poorer performance of noise-affected children can be interpreted as learned helplessness.

Earlier it was proposed that selective inattention may result from chronic exposure to noise. Since children who are relatively inattentive to acoustic cues should be less affected by an auditory distractor, we used distractibility to measure selective inattention. Subjects were instructed to cross out the *e*'s in a two-page passage from a sixth-grade reader. The children performed the task once while a tape-recorded male voice read a story at moderate volume, and once under ambient sound conditions. We expected that children from noisy schools would be less affected by distraction. Since selective inattention is a strategy that develops over time, we also predicted that this "tuning out" strategy would increase with exposure (Cohen et al. 1973).

Data from the first testing session (Fig. 4) indicate that children in noisy schools did better than the quiet group on the distraction task during the first two years of exposure to noise, and unexpectedly worse after four years. The second testing session produced similar data, except that children enrolled in noisy schools for two to four years also appeared to be less distractible than their counterparts from quiet schools. Contrary to earlier evidence, these findings suggest 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 the noise by tuning it out. Later, as they find that the strategy is not adequate, they give it up. This interpretation is consistent with the helplessness data. Alternatively, it is possible that as the duration of exposure increases, the children become more discriminating in terms of the
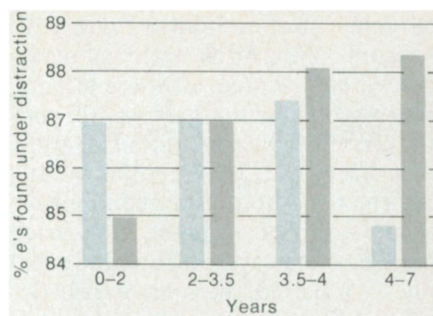

Figure 4. Contrary to our expectations, distractibility increases with length of exposure to noise. In this experiment, children from noisy (*color*) and quiet (*gray*) schools were asked to cross out *e*'s in a textbook passage, once while a recorded voice read an unrelated story, and once without distraction. The scores have been statistically corrected to reflect performance under conditions of no distraction. Children in noisy schools may give up trying to ignore noise when they realize they cannot control it. Or, perhaps, they become more selective in "tuning out" and are more distracted by sounds other than aircraft noise—the usual stressor. One-quarter of the sample had been enrolled in the schools for each time period. (After Cohen et al. 1980.)

kinds of sounds that they tune out. That is, initially they tune out a wide range of acoustic stimuli (including the distractor used in the present study) but later tune out only aircraft sounds.

Auditory discrimination and reading achievement were assessed in an attempt to replicate previous work and to establish whether there is an association between these skills and the children's attentional strategies. We used the results of standardized reading and math tests administered during the second and third grades by the school system, and of an auditory discrimination test (Wepman 1958) we gave individually to children in the soundproof van. We found that math, reading, and auditory discrimination were all unrelated to exposure to noise and to duration of the exposure. Further correlational analyses suggested that those children who were better at auditory discriminations were also better on both the reading ($r = 0.19$) and math ($r = 0.18$) tests; however, there were no significant relationships between these variables and the selective inattention measure.

It should be noted that this study may have failed to replicate the previously reported relationship between

community noise and reading ability (Bronzaft and McCarthy 1975; Cohen et al. 1973) because of an experimental design insensitive to noise-induced differences in school achievement. In both the earlier studies, all students attended the same school. Moreover, in the study by Cohen and colleagues, students from both noisy and quiet apartments were taught in the same classrooms by the same teachers. The children in the present study attended different schools, were in different classrooms, and had different teachers.

Noise abatement

Does noise abatement, and the resulting reduction in classroom noise levels, decrease the effects of noise? To answer this question, we examined both cross-sectional data collected during the first testing session (comparing children in noise-abated classrooms to their peers in noisy rooms and in quiet schools) and longitudinal data (looking at changes in response of children moved from noisy to quiet classrooms, in contrast to children who remained in noisy rooms). To examine effects of abatement in the first session, we categorized classrooms as noisy, abated, and quiet. The mean peak noise level for noisy classrooms was 79 db(A); for abated, 63 db(A); and for quiet classrooms, 57 db(A). Analyses comparing children in these classrooms suggested only a minimal impact of the abatement on the criterion variables. Factors apparently unaffected by abatement include children's perceptions of noise and noise interference, their blood pressure, and their reactions to auditory distraction. On the other hand, abatement seems to provide at least marginal improvement in two factors.

First, it had a slight effect on whether or not children were able to solve the moderately difficult test puzzle in the helplessness task, irrespective of whether they had 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 distinction of noisy versus quiet school. Second, children in noise-abated classrooms also had higher math achievement than their peers in noisy classrooms, though reading achievement and auditory discrimination ability were

unaffected by abatement. It is important to consider, however, that unlike all other tests which 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 outside the noisy environment.

The longitudinal data similarly provide little evidence that children who had been enrolled in a noisy school improve in their performance and/or health after a school year in a noise-abated classroom, even though interior sound levels were substantially reduced. In contrast to the cross-sectional analysis, the longitudinal data did not even indicate that children in noise-abated rooms became better able to solve the moderately difficult puzzle. This failure to mimic the cross-sectional findings may be due to attrition or to the marginality of the effect itself. Unfortunately, school achievement data were not available during the second testing session, and thus there was no opportunity to reevaluate the effects of noise abatement on school achievement found in the cross-sectional analyses.

The evidence for ameliorative effects of classroom noise abatement was not substantial, nor did it cover a wide range of variables. School achievement test performance, however, was affected by the sound attenuation. This improvement probably reflects a remediation of the effects that occur during noise, rather than after exposure.

Implications and future directions

The data from our study of aircraft noise indicate that chronic exposure to the noise resulting from aircraft overflights affects a variety of cognitive, motivational, and physiological processes in a manner generally consistent with previous laboratory findings on the nonauditory effects of noise and other stressors. Blood pressure was relatively higher in noise-affected children, they did less well with puzzle-solving and math, and they were less distractible during the early—but not later—years of exposure. With the exception of math achievement scores, all these effects occurred outside noise exposure, and may therefore be considered aftereffects. Moreover, they cannot be attributed to confounding economic or social variables or to hearing loss. Since the effects were also stable over a one-year period, there was very little evidence that children adapted to the noise stressor over time.

Although this article has discussed how the physical intensity of sound affects health and behavior, it is also important to note that noise is a psychological concept. The meaning of noise to the individual and the context in which noise occurs play important roles in determining its effects (Cohen and Weinstein 1981; Krantz et al., in press; Lazarus 1966). Recently completed analyses of data from the Los Angeles Noise Project have revealed that after controlling for the physical intensity of noise, the child's ratings of noise annoyance predict a variety of dependent measures. For example, diastolic blood pressure is relatively higher among children who rate classroom noise as more bothersome. In addition, noise levels at home and school have an interactive effect, with school noise abatement making less of a difference on blood pressures of children from the noisier homes in the airport community.

Pending replication of these results in other settings, it is difficult to draw definitive conclusions about the clinical or policy significance of these data. However, our findings do support the need for noise abatement in noisy settings, and they also suggest that short-term protection by sound insulation in the classroom may not be enough. This relative ineffectiveness may be because the effects of exposure to noise are long lasting; it takes more than a one-year reprieve from the noise for a return to more normal levels of behavior and health. In addition, since children are also exposed to noise outside school, a quieter classroom may not have sufficiently reduced the level of noise in their lives. This view is supported by some evidence that abatement was more effective for children living in quieter homes. 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.

Finally, in evaluating the abatement results, we should remember that most of the children attending noisy schools spent previous years in non-abated classrooms. Thus while noise abatement was 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 who are therefore always in relatively quiet classrooms) would benefit from the abatement.

A research 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, has important benefits. In particular, it helps establish the scientific validity and practical value of work with potential implications for social issues. The research reviewed in this article clearly suggests the impact of community noise on psychological adjustment and on nonauditory aspects (particularly cardiovascular) of health. As converging laboratory and naturalistic approaches eliminate alternative explanations for noise-associated effects, the potential for affecting the formation of public policy increases.

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