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Apartment Noise, Auditory Discrimination, and Reading Ability in Children[1,2]

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This study examined the relationship between a child's auditory and verbal skills and the noisiness of his home. Expressway traffic was the principal source of noise. Initial decibel measurements in a high-rise housing development permitted use of floor level as an index of noise intensity in the apartments. Children living on the lower floors of 32-story buildings showed greater impairment of auditory discrimination and reading achievement than children living in higher-floor apartments. Auditory discrimination appeared to mediate an association between noise and reading deficits, and length of residence in the building affected the magnitude of the correlation between noise and auditory discrimination. Additional analyses ruled out explanations of the auditory discrimination effects in terms of social class variables and physiological damage. Partialling out social class did, however, somewhat reduce the magnitude of the relationship between noise and reading deficits. Results were interpreted as documenting the existence of long-term behavioral aftereffects in spite of noise adaptation. Demonstration of postnoise consequences in a real-life setting supplement laboratory research showing the stressful impact of noise on behavior.

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[2] We thank the parents and children of the Bridge Apartments who so graciously cooperated in the study. We also owe a debt of gratitude to Mr. Reuben Silver of New York University who consulted and assisted in all phases of noise measurement. Thanks also go to Mrs. Anita Jacobs for administering the audiometric threshold tests.

Laboratory-produced noise has few direct effects on behavior; people adapt to noise (Kryter, 1970). But noise and other stressors—at least where they are unpredictable and uncontrollable—do have aftereffects which appear relatively soon after stimulation is terminated (Glass & Singer, 1972a,b). Degradation in task performance, along with lowered frustration tolerance and impaired ability to resolve cognitive conflict, have been the aftereffects most often observed in previous research. Other more or less immediate consequences of noise exposure, for example, verbal learning deficits, have been alleged to occur (Cohen, 1969), but there is as yet little systematic evidence to support this allegation.

Studies of the delayed effects of noise stress are more equivocal. Some investigators report negative behavioral effects under certain conditions (cf., Rodda, 1967), whereas others indicate that noise has little impact on later behavior (cf., Kryter, 1970). On the other hand, several field studies clearly document the existence of delayed consequences of stressors other than noise. Grinker and Spiegel (1945), for example, report that soldiers who were relatively calm during combat manifested severe attacks of anxiety months later and miles removed from the scene of battle. The individual showed adaptive behavior during the stressful period, yet continued exposure to the stressor produced cumulative effects which appeared only after stimulation had ceased. It is as if the individual did not experience the maximal impact of the stressor until he was no longer required to cope with it; only then did behavioral effects of the event become evident.

A principal purpose of this paper is to report systematic data in support of an hypothesized association between noise stress and subsequent behavior. More specifically, we will present evidence suggesting that a child's ability to learn verbal skills is in part related to the noisiness of his home environment and how long he has resided there. Penetration of traffic sounds into the home was selected as our exemplar of noise stress because previous surveys report that roadway traffic is a major source of noise disturbance (McKennell & Hunt, 1966). It seemed reasonable to assume, therefore, that learning deficits might also covary with exposure to chronic traffic noise.

Cognitive variables such as unpredictability of noise and perceptions of uncontrollability over noise offset were critical in producing behavioral aftereffects in previous laboratory experiments (Glass & Singer, 1972a). Unlike this earlier research, we were unable to manipulate these variables in the particular field setting selected for study. We simply assumed that subjects were unable to do anything about intermittent traffic noise and then proceeded to examine the relationship between verbal skills and apartment noisiness. Prior research had in fact shown that decibel level contributes to the production of noise aftereffects (Glass, Singer & Friedman, 1969, Expt I). The cognitive context in which noise occurs is often more important than sheer magnitude of stimulation, but physical parameters may still play a role in the occurrence of aftereffect phenomena (cf., Glass & Singer, 1972a).

Two general lines of thought led to the research described in this paper. The first stems from the speculations of Deutsch (1964) that a child reared in a noisy environment eventually becomes inattentive to acoustic cues which, in turn, leads to impaired auditory discrimination. In tuning out his noisy environment, a child is not likely to distinguish between speech relevant and speech irrelevant sounds. He will, therefore, lack experience with appropriate speech cues and show general inability to recognize relevant sounds and their referents. The inability to discriminate sounds is presumed to account, in part, for subsequent problems in learning to read. A child who cannot readily discriminate basic speech sounds faces a difficult task in learning to associate these sounds with their appropriate signs. Deutsch reports correlational data consistent with a hypothesized relationship between auditory discrimination and reading.

A second fact which motivated the present study was the desire to extend previous research in several new directions simultaneously. First, we wished to examine the possibility that noise aftereffects include complex learning deficits as well as simple performance degradations. Second, we wished to test the notion that prolonged exposure to noise may be related to delayed aftereffects in the form of impaired reading performance. Third, we were convinced of the value of moving into the field in order to test real-life counterparts of the aftereffects observed in the laboratory. The study reported here was undertaken for all of these reasons, as well as for the purpose of examining some of Deutsch's theoretical notions.

To give an overview of the research, elementary school children living in four 32-floor apartment buildings that span a heavily traveled expressway were tested for auditory discrimination, reading level, and related task performances. Noise from the expressway raised the ambient level at the adjacent bases of the apartment buildings to approximately 84 dBA. The noise level decreased within the buildings as one moved from lower to higher floors. The floor of each subject's apartment was therefore taken as an index of noisiness of his home environment. The other major independent variable was length of time a child had lived in his apartment. It was expected that positive correlations would be obtained between floor and auditory discrimination, and between the latter variable and percentile scores on a standardized test of reading achievement. It was also expected that the former association would be greater the longer subjects had lived in their apartments. Indeed, it was anticipated that the correlation would decline substantially when length of residence was below some critical number of years. The rationale for this prediction is that the longer a child is exposed to uncontrollable noise, the more he learns to "filter" both relevant and irrelevant sounds out of awareness. This progressive inattentiveness to acoustic cues could well lead to greater impairment of auditory discrimination, hence to deficits in reading ability.

METHOD

Subjects

Subjects consisted of 73 second-, third-, fourth-, and fifth-grade elementary school children whose parents gave permission to the school principal for their inclusion in the study. The names of these children were obtained from a school listing.

Eighteen cases were eliminated for the following reasons: (a) four because they could barely speak English; (b) eight because they no longer lived in the apartment buildings of interest; (c) two because they were absent on one or more days of testing; (d) one because he was emotionally disturbed and testing seemed inadvisable; and (e) three because they had shown hearing deficits on an audiometric threshold test. The final sample consisted of 54 cases—29 boys and 25 girls.

Setting of the Study

All children in the sample lived in the Bridge Apartments built in 1964 on bridges spanning Interstate 95 in the upper part of Manhattan in New York City. The apartment buildings consist of four 32-story aluminum towers. Open highway vents and vertical surfaces of the buildings produce high noise levels and an "echo chamber" effect. The buildings were constructed with the aid of a mortgage loan from the New York State Housing Finance Agency. The law limits admission to this housing development to so-called middle-income families. The children in the sample all attended a public elementary school not far from the apartments. Testing of the children was conducted on an individual basis in a room in the school set aside for this purpose.

Noise Measurements

Three types of noise measurement were made. The first consisted of a series of decibel readings outside each of the four buildings at five locations around the base of the building: (a) one at the center of the building length; (b) two at the center of the building width; and (c) two at the corners of the building immediately adjacent to the expressway. All readings were taken with a General Radio sound-level meter (type 1561-A) and a General Radio microphone (type 1560-P7). A windscreen was not used since wind velocity never exceeded 7 mph on the days of measurement. The meter was checked against its internal calibrator on the morning of July 6, 1972, and the actual readings were taken between noon and 1 PM on July 6 and repeated at the same time on July 7. Readings were made on the A-scale with a slow time constant.

The procedure used in making noise measurements was as follows. The experimenter held the meter in one hand and the microphone in the other, the latter approximately 3 ft from the ground and vertical. The noise source was thus perpendicular to the microphone. The meter was observed for 5 min at each data-collection point and the modal reading recorded on a writing pad. Peak deflections due to passing trucks and buses were ignored. The recorded readings were, therefore, conservative estimates of the noise levels.

A second set of ambient measurements was made in the hallways of three of the four apartment buildings. The purpose of these measurements was to provide a check on the assumption that noise level decreased as one moved from lower to higher floors. Noise generally dissipates as it moves away from its source (Knudson & Harris, 1950). Empirical support for this assumption permitted use of the floor of each subject's apartment as our index of noisiness.

Hallway measurements were made on July 7 between 1 and 3 PM, and again on July 14 and 15 between 1 and 4 PM. Measurements were taken on floors 8, 14, 20, 26, and 32. The sound-level meter was located in front of closed hallway windows which overlooked the expressway. The procedure for observing and recording meter readings was identical to that used for outdoor measurements.

Noise level readings were also taken in about 45% of the apartments included in the sample. Measurements were made in the living room with the window closed—this being the more typical pattern during most months of the year. Very few apartments had air-conditioning which might mask traffic noise.

Measures of Performance and Learning

Auditory discrimination. This variable was measured by the Wepman (1958) Auditory Discrimination Test. It consists of 40 pairs of words, 30 of which differ from each other in either initial or final sound; for example, "gear-beer" or "cope-coke." Each word pair is matched for familiarity, and every possible match of phonemes used in English was made within phonetic categories. The pairs of words were recorded on tape and presented to each child through earphones. The child was required to report if the two words in each pair were the same or different. The score was the number of correct responses for word pairs that were different.

Reading. The Metropolitan Achievement Tests (Durost, Bixler, Wrightstone, Prescott, & Balow, 1971) are routinely administered in New York City elementary schools. Annual administration of these tests occurred soon after the initial testing session (see below). The tests yielded three percentile scores based on national norms: (a) word knowledge, or reading vocabulary (WK); (b) reading comprehension (RC); (c) reading total (RT)—a percentile score based on a weighted average of the first two raw scores.

Other measures. Two additional tests were administered for exploratory purposes. Previous research (Glass & Singer, 1972a) had shown that performance on the Stroop (1935) Color Word Test is affected by high-intensity noise and, accordingly, we administered an adaptation of the color-word test (Uleman & Reeves, 1971) to our subjects. A noise-making test developed by one of the authors (SC) was also given to the subjects. Distributions of scores on both tests failed to show systematic associations with other variables in the study. For this reason, we do not discuss these measures in the remainder of this paper.

Control Variables

Audiometric test. A major purpose of this study was to test for the relationship between noise level, auditory discrimination, and reading ability. Children with hearing loss would not constitute an appropriate sample for examining this relationship. Accordingly, an audiometric pure tone threshold test was administered to a majority of the subjects by a professional audiometrist. Thresholds were determined separately for each ear. As we indicated earlier, three cases were eliminated from the potential sample because their detection thresholds in at least one ear were above what is considered normal range.

Social background and experiental factors. Each subject was given a questionnaire in which he was asked how long he had lived in his current apartment, and how many brothers and sisters he had. The same questions were asked of the parents in a mailed questionnaire sent out several weeks after testing was completed.[3] Included in that questionnaire were additional items asking for the parents' educational levels, where response categories ranged from 1 = "Less than eighth grade" through 5 = "Some college" to 9 = "Ph.D., M.D., other advanced degree." Also in the parents' questionnaires were a pair of items asking for subjective ratings of the noisiness of the respondent's apartment. Average ratings on the two items for all respondents who returned the questionnaire ($N = 44$) were 3.5 and 3.0, respectively, where a rating of "3" means "about average noisiness." However, both sets of ratings failed to show consistent relations with floor level and other variables of interest in this study. We will not, therefore, discuss these data in subsequent sections of the paper.

Data Collection

The study was conducted in several phases. In an initial testing session in the school, children were given the auditory discrimination test, the Stroop test, the noise-masking test, and the two-item questionnaire. The reading achievement test was administered by school authorities several weeks after this initial session, and percentile scores were made available about 2 mo later. The audiometric threshold test was given about a month after the first session, and soon after that, the parent questionnaire was mailed to the mothers of the 54 children in the sample. Follow-up letters and telephone calls brought the questionnaire response rate up to 80%.

Methods of Analysis

The sample of 54 cases was first separated arbitrarily into two criterion groups: 34 children who lived in the Bridge Apartments for 4 yr or more, and 20 children who lived there 3 yr or less. Response to the length-of-residence item in the parents' questionnaire was the basis for this division, except for instances of nonresponse, in which case we used the children's responses. A subsequent analysis divided the sample into different length-of-residence groups.

Specific procedures of data analysis included simple correlations between variables of interest within each criterion group. Partial correlation and regression procedures were used to determine the amount of variance in auditory discrimination and

[3] As already noted, all of the parent questionnaires were not returned. In cases of nonresponse, we followed the procedure of using the child's answer to the length-of-residence and number-of-siblings questions in lieu of parental answers. Discrepancies between the two sets of responses were minimal.

reading-test percentile scores accounted for by apartment noise level. Such techniques also permitted control over potential artifactual variables such as social class.

RESULTS

Noise Levels Inside and Outside of the Apartment Buildings

The means of all outside decibel readings taken on 2 successive days were 79 dBA, 78 dBA, 75 dBA, and 76 dBA for the four buildings. These values are based on measurements made at the sides of the buildings overlooking the expressway, as well as at the sides facing cross streets where traffic noise was considerably lower. Confining ourselves only to readings taken at the building points overlooking Interstate 95, the means for the 2 days of recording were 84 dBA, 84 dBA, 83 dBA, and 84 dBA. Judging from either set of locations, the ambient noise level surrounding the Bridge Apartments is relatively high.

Noise measurements were also made at the hallway windows overlooking the expressway in three of the four buildings.[1] On 3 separate days, recordings were taken on approximately every sixth floor beginning with the eighth floor. The overall averages of the readings for the three buildings were: 55 dBA for the 32nd floor; 58 dBA for the 26th floor; 60 for the 20th floor; 63 for the 14 floor; and 66 for the 8th floor. Recall that these values are conservative estimates, since recorded readings excluded peak deflections due to impulsive sounds such as those made by trucks. The results provide necessary evidence for the assumption that ambient noise level dissipates as one moves away from the source of noise. A product-moment correlation between floor level and decibel values yielded a coefficient of $-.90$. On the basis of these results, floor level was used as the index of noisiness in subsequent analyses. Further support for this decision comes from the noise readings taken in the 45% subsample of apartment living rooms. For these data, noise level correlated $-.77$ with floor.

Floor, Auditory Discrimination, and Reading

The correlation between floor level and auditory discrimination test scores was $+.48$ ($32\ df$, $p < .01$) for the sample of children living in the Bridge Apartments for 4 yr or more (hereafter called the primary sample). The corresponding correlation for the secondary sample (that is, those children living in the Apartments for 3 yr or less) was a clearly nonsignificant $-.06$.

In the primary sample, the relationships between auditory discrimination and reading test percentile scores were $+.55$ (WK), $+.48$ (RC),

[1] One building did not have hallway windows that overlooked the expressway.

and +.53 (RT). All three correlations were significant at beyond the .01 level. The corresponding coefficients for the secondary sample were +.31 (WK), +.37 (RC), and +.34 (RT), each of which approached statistical reliability at the .10 or .15 levels. It should be remembered, however, that the secondary sample consists of only 20 cases.

The preceding pattern of positive correlations indicates that auditory discrimination is indeed related to reading, and floor level is inversely related to the ability to make auditory discriminations—at least among subjects in the primary sample. The fact that the floor-discrimination correlation did *not* appear at all in the secondary sample ($r = -.06$) suggests that duration of noise exposure may be critical in mediating this relationship. The next analysis was designed to examine this possibility by using length of residence in the apartments as an index of duration of noise exposure.

Variations in length of residence. The total sample was divided into four different length-of-residence groups as follows: (a) 6 yr or more; (b) 4–5.9 yr; (c) 2–3.9 yr; (d) 0–1.9 yr.[5] Correlations between floor and auditory discrimination were computed for each criterion group, and they appear to increase as the sample becomes increasingly limited to those who have resided in the apartments for longer periods of time. The correlations are lowest for the groups living in the apartments for less than 2 yr and for 2-3.9 yr (−.02 and −.08, respectively). For those who resided there for 4–5.9 yr and 6 or more yr, the respective correlation values are +.41 and +.64. Duration of noise exposure is thus related to impairment of discrimination ability, and the latter variable seems to be implicated in the occurrence of reading deficits.

Potential Artifacts in the Noise-Discrimination–Reading Relationship

The general consistency of results might suggest that some more basic factor or artifact is at work. For example, it could be argued that social class is responsible for the correlations reported in this paper. Apartments on higher floors typically command higher rentals and are therefore occupied by families of higher socioeconomic status. It has been suggested that such families devote considerable time to teaching their children verbal skills which are then reflected in higher test performance (cf., Sewell & Shah, 1968). Indeed, correlations within the primary sample between floor and reading test scores were +.43 (WK), +.43 (RC), and +.46 (RT). Perhaps social class is the more basic factor underlying our results.

[5] Length of residence in the Apartments did not correlate with floor level in either primary or secondary samples (r's were +.18 and −.19, respectively).

Two factors argue against this conclusion. First, the sample itself represents a restricted socioeconomic range since residency in the Bridge Apartments is limited by law to middle-income families. Second, the price range of rentals between lower and upper floors is relatively narrow. For example, three bedroom apartments rent for between $235 per month and $250 per month, and two bedroom apartments for $185–$219. Third, correlations between floor level and reading scores in the secondary sample (r's $< .20$) did not even approach the significant values obtained in the primary sample. If differences in social class are responsible for our results, they should be operative irrespective of length of residence in the apartments.

On the other hand, mother's educational level in the primary sample correlated significantly with reading scores [+.51 (WK), +.55 (RC), and +.54 (RT)], and floor level correlated +.41 with mother's education. These findings dictated the decision to control for social class effects by computing partial correlations within the primary sample. Correlations were calculated between floor level and auditory discrimination, partialling out the effects of mother's educational level and then father's educational level. The coefficients were +.43 (31 df, $p < .02$) and +.45 (29 df, $p < .01$), respectively. Both values are essentially the same as the +.48 correlation obtained without partialling out social class.

We next computed a series of correlations between auditory discrimination and reading scores, again successively partialling out mother's education and father's education. Controlling on mother's education, the partial coefficients were +.51 (WK), +.43 (RC), and +.48 (RT). All three are statistically significant at the .02 level or beyond. The corresponding correlations with father's education held constant were +.47 (WK), +.42 (RC), and +.46 (RT). These coefficients compare favorably with the values obtained without partialling procedures; i.e., +.55 (WK), +.48 (RC), and +.53 (RT).

Finally, we computed correlations between floor level and reading scores partialling out the effects of mother's and father's education. The partial coefficients, with a control on mother's education, were +.29 (WK), +.26 (RC), and +.31 (RT). With 31 df, all three are marginally significant at about the .10, .15, and .08 levels, respectively. This represents a decline from the unpartialled correlations between floor and reading scores, which were of the order of +.43 (see above). The partial coefficients with father's education held constant were: +.35 (WK), +.33 (RC), and +.37 (RT). While somewhat lower than the unpartialled correlations, these values (with 29 df) are significant at the .06, .08, and .05 levels, respectively.

In general, then, the relationship between floor (i.e., noise level) and auditory discrimination does not result from a social class artifact—at least as measured by the indices used in this study. The same conclusion applies to the relationship between auditory discrimination and reading achievement. However, it is also true that only part of the common variance between reading scores and auditory discrimination is directly attributable to floor level. The fact that partialling out social class reduced somewhat the correlation coefficients between floor and reading supports this additional conclusion. On the other hand, correlations between floor and reading scores were also reduced when auditory discrimination was partialled out: [+.23 (WK), +.25 (RC), +.28 (RT)]. We may thus conclude that deficits in reading are, in part, mediated by noise-related impairments in auditory discrimination.

Stepwise Regression Analysis

Most of the correlational values reported above suggest associations of respectable magnitude. It would be instructive, therefore, to examine the amounts of variance in dependent variables actually accounted for by various independent variables. A stepwise regression procedure equivalent to analysis of covariance (Cohen, 1968) was carried out on data from the primary sample.

Table 1 presents these results with auditory discrimination as the dependent variable. Along with floor and social class indices, the analysis included grade of the child and number of children in the family. Socioeconomic variables were entered into the regression equation before introducing floor level. However, it is immediately apparent that floor accounts for a major proportion of the total variance (19%). Father's education, number of children, and grade level also provide reliable contributions (12, 10, 6%, respectively). Mother's education does not enter

TABLE 1
AMOUNT OF THE TOTAL VARIANCE IN AUDITORY DISCRIMINATION ACCOUNTED FOR BY VARIOUS INDEPENDENT VARIABLES

Independent variables[a]	Variance accounted for (%)
Floor level	19
Father's education	12
Number of children in the family	10
Grade level	6
Mother's education	0

[a] These factors were not entered into the regression equation in the order presented here. Socioeconomic and background variables were introduced before floor level.

TABLE 2
AMOUNT OF THE TOTAL VARIANCE IN READING TEST PERCENTILE SCORES ACCOUNTED FOR BY VARIOUS INDEPENDENT VARIABLES

	Variance accounted for (%)		
Independent variables[a]	Word Knowledge (WK)	Reading Comprehension (RC)	Reading Total (RT)
Auditory discrimination	20	8	12
Mother's education	23	27	25
Number of children in the family	5	8	6
Father's education	0	4	3
Grade level	2	1	1

[a] These factors were not entered into the regression equation in the order presented here. Socioeconomic and background variables were introduced before auditory discrimination.

the picture, but this result probably reflects the high correlation between mother's and father's educational attainment (+.67).

Table 2 summarizes the regression analysis for the three reading test scores. Socioeconomic variables were again introduced before entering auditory discrimination into the regression equation. As expected, mother's education contributes the greatest amount to variability in these scores. Auditory discrimination, also as expected, provides the next largest contribution.

Table 3 shows the degree of relationship between floor and reading

TABLE 3
AMOUNT OF THE TOTAL VARIANCE IN READING TEST PERCENTILE SCORES ACCOUNTED FOR BY VARIOUS INDEPENDENT VARIABLES

	Variance accounted for (%)		
Independent variables[a]	Word Knowledge (WK)	Reading Comprehension (RC)	Reading Total (RT)
Floor level	3	2	4
Mother's education	23	27	25
Number of children in the family	5	8	6
Father's education	0	4	3
Grade level	2	1	1

[a] These factors were not entered into the regression equation in the order presented here. Socioeconomic and background variables were introduced before floor level.

TABLE 4
AMOUNT OF THE TOTAL VARIANCE IN READING TEST PERCENTILE SCORES ACCOUNTED FOR BY VARIOUS INDEPENDENT VARIABLES

	Variance accounted for (%)		
Independent variables[a]	Word Knowledge (WK)	Reading Comprehension (RC)	Reading Total (RT)
Auditory discrimination	20	8	12
Floor level	0	0	0
Mother's education	23	27	25
Number of children in the family	5	8	6
Father's education	0	4	3
Grade level	2	1	1

[a] These factors were not entered into the regression equation in the order presented here. Socioeconomic and background variables were introduced before auditory discrimination and floor level.

scores independent of such factors as social class. It is immediately apparent that the largest contribution to variability in reading is attributable to mother's education. The contribution of floor level is relatively small, which confirms the previously presented partial correlations between floor and reading. However, it is also important to note that the contribution of floor drops to zero when auditory discrimination is introduced into the multiple regression analysis (see Table 4). Clearly, the effects floor (i.e., noise) level upon reading achievement is mediated by the impairment of auditory discrimination. The regression procedure, then, confirms the previous correlational analyses.

DISCUSSION

The findings of this study are clear. Apartment noise level accounts for a substantial proportion of the variance in auditory discrimination, and the latter variable contributes significantly to variance in reading achievement. The results of the partial correlation and regression analyses also suggest an association between noisiness of the home environment and subsequent difficulties in learning to read.

But why is noise level related to deficits in acoustic discrimination? Why does auditory discrimination appear to mediate a relationship between noise and reading? Why does length of noise exposure affect the magnitude of these associations? The following discussion attempts to provide an integrated set of answers to these questions.

Our original thesis was that prolonged noise exposure is directly related to the inability to attend to acoustic cues. The basis for this assumption can be found in studies demonstrating habituation to high-intensity noise (Glass & Singer, 1972a). The results of such research suggest that repeated noise exposure activates a kind of central filtering mechanism in the individual (cf., Broadbent, 1958, 1971), in which disturbing sounds are deliberately excluded from immediate attention. It is not unreasonable to expect exaggeration of this filtering process in children who are exposed to prolonged noise stimulation. A child may become generally inattentive to acoustic cues as he attempts repeatedly to cope with unwanted sounds; that is, the longer he must endure noise, the more likely he is to ignore all sounds, whether relevant or not. A probable consequence of this process is failure to learn to discriminate speech relevant cues at a time which may be optimal (if not critical) for such learning. Deficits in auditory discrimination reflect this learning problem and they should become increasingly evident with longer periods of noise exposure. This is, of course, precisely what was found in the study reported in this paper.

The association between noise level and reading deficits is indirect, however. We assumed from the outset that auditory discrimination is an important component of reading. This assumption was predicated on the notion that ability to distinguish speech sounds is fundamental in learning to associate these sounds with their corresponding written signs. We further assumed that the relationship between auditory discrimination and reading would occur in children, irrespective of length of residence in a noisy environment. Auditory discrimination ability, by contrast, was expected to covary with duration of noise exposure. Such an association was in fact obtained. We then predicted that noise-related discriminatory impairments would be related to deficits in reading. This expectation was at least partly confirmed by partial-correlation and regression analyses carried out within the primary sample. It appears that reading ability is dependent upon auditory discrimination and whatever impact noise level has on this ability is mediated through impairment of auditory discrimination.

We did not expect the magnitude of the reading-discrimination relationship to be affected by duration of noise exposure. Yet, we found that the relationship was marginally significant in the secondary sample. It must be remembered, however, that this sample consisted of only 20 cases, and the magnitudes of the correlations were not at all small (r's $>$ .30). Moreover, other analyses were conducted in which there was a systematic variation of the length-of-residence criterion. These results revealed significant correlations between reading scores and auditory discrimination even for samples which included subjects living in the Bridge Apartments for only 2 yr (r's = .46). On balance, we conclude that auditory discrimination is reliably associated with reading, irrespective of duration of noise exposure.

There are undoubtedly a number of alternative explanations that could account for the significant results of this study. One of these alternatives is particularly interesting and warrants further comment. It can be argued that impaired auditory discrimination is a consequence of physiological damage produced by high noise levels and/or carbon monoxide poisoning. The first part of this explanation is easily dismissed, for it will be recalled, subjects with hearing loss were deliberately excluded from the sample.

The second part—monoxide poisoning—can also be discounted. In the summer of 1967, the National Center for Air Pollution of the US Public Health Service conducted a carbon monoxide survey at the Bridge Apartments at the request of then Senator Robert F. Kennedy. Carbon monoxide levels measured inside a third floor apartment averaged 14 parts per million, which was seven times greater than the outside atmosphere for the same hours at New York City's 121st Street air sampling laboratory. However, samples of air collected inside the apartments at floors 30, 24, 19, 12, 8, and 3 revealed that carbon monoxide levels at all floors were essentially the same—about 13–15 parts per million. Such data are not consistent with a physiological damage interpretation of the relationship between floor level and auditory discrimination. Indeed, the study found a slight tendency for carbon monoxide levels to increase with height above Interstate 95.

To sum up, we have shown that living in a noisy, in contrast to less noisy, environment is related to auditory-discrimination deficits in children. We have also found evidence for a relationship between such deficits and impaired reading skills. Prolonged noise exposure in a real-life setting is thus associated with aftereffects in much the same manner as brief noise exposures in the laboratory lead to task degradations. Children in our sample may learn to filter out noise and adapt to an aversive environment but a toll is exacted in the process. Deficits in both auditory and verbal skills constitute this behavioral toll. We cannot, of course, determine the extent to which the intermittent and uncontrollable quality of the traffic noise contributed to adverse aftereffects. Previous laboratory studies have documented the impact of such cognitive variables (Glass & Singer, 1972a), but in this research only the intensity of noise was systematically varied. Future replications will examine cognitive factors, as well as physical parameters of the noise source.

The principal significance of this research can be summarized as follows. It demonstrates that despite seeming adaptation, perhaps even because of it, prolonged exposure to high-intensity traffic noise is related to deleterious aftereffects. This result supplements the findings of earlier community surveys (McKennell & Hunt, 1966) which report traffic as the major source of noise annoyance. But, most important of all, the research documents the existence of noise aftereffects in a nonlaboratory setting. Taken together with the findings of laboratory research (Welch & Welch, 1970; Broadbent, 1971; Glass & Singer, 1972), a case is gradually emerging for the stressful impact of noise on behavior.

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