THE EFFECTS OF NOISE AND CROWDING ON THE DEVELOPMENT OF VERBAL SKILLS

Sheldon Cohen
Department of Psychology
University of Oregon
Eugene, Oregon

David C. Glass
Department of Psychology
University of Texas
Austin, Texas

Jerome E. Singer
Department of Sociology
State University of New York at Stony Brook
Stony Brook, New York

INTRODUCTION

Do urban stressors such as noise and residential density have serious implications for the psychological well-being of the urban dweller? The urgency for evidence pertaining to this question is increasing. With rising construction and land costs in urban centers, developers call for the revision of zoning laws. Among their demands are more units per site, smaller units, and cheaper construction materials that provide less attenuation of traffic and other street noises. Should such revisions be allowed? Environmental planners and decision makers are asking the behavioral scientist to provide the evidence necessary to answer this and other similar questions.

A growing literature on the effects of urban stress on behavior provides us with only limited evidence. Most studies on noise and density have concentrated on the effects of relatively short-term exposure. Thus, research has focused on the impact of noise on perceived annoyance, task performance, and temporary threshold shifts. In a like manner, studies on density have looked primarily at the effects of short-term crowding on performance and social behavior. Urban dwellers, of course, experience noise and crowding over months and years. Little effort, however, has been concentrated on studying the effects of long-term exposure. Even more distressing is the lack of information available on the effects of ubiquitous urban stress on children. Are developmental processes retarded by the stimulation levels in the urban environment? The purpose of this paper is to suggest some possible implications of long-term exposure to noise and residential density for human development, particularly the development of intelligence related skills, and to provide some evidence in support of these suggestions.

NOISE

Evidence concerning the effects of noise in the home on infant development is reported in a study by Wachs, Uzgiris and Hunt [2]. These investigators administered a psychological development scale based on Piaget's model of intellectual development to two matched groups of infants, one disadvantaged and one middle-class. A second scale measured home stimulation and consisted of items that were scored on the basis of the examiner's observations of the physical circumstances in the home environment as well as detailed questioning of the mother. Consistently high negative relationships were obtained between scores on the development scales and questions about the level of noise in the home. Infants exposed to continual high levels of noise performed more poorly on these developmental indices than those living in quieter environments.

One possible explanation of the reported deficits is that children reared in noisy environments suffer from hearing losses--damage to the receptive sensory apparatus. Since Wachs and his colleagues did not administer audiometric tests to the infants, this damage would not have been detected. Severe hearing impairment, especially if undetected, would of course impede the development of intelligence skills.

While hearing loss is a real possibility in such an environment, there is evidence that excessive noise in the home affects the development of intelligence related skills in a more subtle manner. Deutsch [3] suggests that a child reared in a noisy environment eventually becomes <u>inattentive to acoustic cues</u>. 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 generally show an inability to recognize relevant sounds and their referents. The inability to discriminate sound is presumed to account, in part, for subsequent problems in learning to read. A child that cannot readily discriminate basic speech sounds faces a difficult task in learning to associate these sounds with their appropriate signs. In support of her hypothesis, Deutsch reports positive correlations between reading ability and accurate auditory discrimination in a sample of children from a slum area. While her assumption that a slum area is particularly noisy seems intuitively reasonable, her failure to include a control group of children from a less noisy environment limits the theoretical significance of the reported relationship.

The study reported here will provide further support for Deutsch's theoretical notions. 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 traffic is a major source of noise disturbance [4]. It seemed reasonable to assume, therefore, that learning deficits might also covary with exposure to chronic traffic noise.

To give an overview of the research, elementary school children living in four 32-floor apartment buildings that span a heavily travelled 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 84dBA. 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 the 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 the 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 written permission to the school principal for their inclusion in the study.

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 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.

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. Empirical support for this assumption permitted use of the floor of each subject's apartment as our index of noisiness.

Noise level readings were also taken in about 45 percent 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.

Measures of performance and learning

Auditory discrimination--This variable was measured by the Wepman [5] 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 [6] are routinely administered in New York City elementary schools. The tests yield three percentile scores based on national norms: a) word knowledge, or reading vocabulary (WK); b) reading comprehension (RC); and c) reading total (RT), a percentile score based on a weighted average of the first two raw scores.

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. 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 experiential 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. Included in that questionnaire were additional items asking for the parents' educational levels.

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 four years or more, and 20 children who lived there three years 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.

RESULTS

Noise levels inside and outside of the apartment buildings

The means of all outside decibel readings taken on two 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 two 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 indeed high.

Noise measurements were also made at the hallway windows overlooking the expressway in three of the four buildings. On three 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 14th floor, and 66th for the 8th floor. 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. From these data, noise level correlated -.77 with floor level.

Floor, auditory discrimination, and reading ability

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 four years or more (hereafter called the primary sample). The corresponding correlation for the secondary sample (that is, those children living in the apartments for three years or less) was a clearly non-significant -.06.

In the primary sample, the relationships between auditory discrimination and reading test percentile scores were +.55 (WK), +.48 (RC), 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 years or more; b) 4 to 5.9 years; c) 2 to 3.9 years; and d) 0 to 1.9 years. 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 two years and for 2 to 3.9 years (-.02 and -.08, respectively). For those who resided there for 4 to 5.9 years and 6 or more years, 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 the 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 class. It has been suggested that such families devote considerable time to teaching their children verbal skills which are then reflected in higher test performance [7]. 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 result.

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 and $250 per month, and two bedroom apartments for $185 to $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), +.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 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.

Thus, 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 (i.e., noise) 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) and +.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 [8] was carried out on data from the primary sample.

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% and 6%, respectively). Mother's education does not enter the picture, but this result probably reflects the high correlation between mother's and father's educational attainment (+.67).

Table 1

Amount of the Total Variance in Reading Test Percentile Scores Accounted for by Various Independent Variables

Independent variables[a]	Variance accounted for (%) 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.

Table 1 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.

CONCLUSION AND SUGGESTIONS

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.

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 [9]. The results of such research suggest that repeated noise exposure activates a kind of central filtering mechanism in the individual [10,11], 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. 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. That is, of course, precisely what was found in the study reported in this paper.

The association between noise level and reading deficits, however, is indirect. 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 linguistic 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 analyses carried out within the primary sample. It appears that reading is dependent upon auditory discrimination, and whatever impact noise level has on this ability is mediated through impairment of auditory discrimination.

Crowding

Whie noise is clearly an important problem in urban neighborhoods, an even more pervasive source of stimulation is population density. Are there any effects of density on the development of verbal skills? Before considering the evidence for this question it is important to clarify exactly what we mean by density. A thorough review of the literature on the effects of population density on man and animals [12] concludes that density, defined as the number of individuals per unit space, does not produce substantial effects on behavior. However, "there is evidence ...that substantial effects may be due to the absolute number of individuals who must interact. That is, assuming that the space available is small enough or arranged in such a way that individuals in it must interact, the sheer number of individuals is crucial" [12].

Unfortunately, none of the existing studies deal with the effects of the presence of "too many people" on the development of verbal skills. Suggestive evidence, however, is provided by a large body of literature on the effect of family size on the development of language and intelligence. Reviews of the literature [13,14] indicate that studies of large populations have shown repeatedly that children from large families score significantly lower in intelligence tests. This relationship holds across social class [15]. In fact, figures from the British National Survey of Health and Development [16] suggest that while other ill effects of large numbers of siblings disappear in upper middle class families, the negative relationship between family size and intelligence remains.

Why would an increase in number of siblings result in a decrease in intelligence? One possible explanation is provided by a limited resources interpretation. The mere fact of belonging to a large family implies restricted contact with adults and fewer opportunities for acquiring adult habits of speech and thought [17]. This, in turn, could lead to deficits in reading and other verbal tasks. This interpretation is supported by differences in correlations between family size and intelligence test scores with non-berbal and verbal tests. Non-verbal tests show substantially smaller correlations with family size than do verbal tests [15,17]. More direct support derives from the apartment noise study described earlier, in which a significant negative relationship was found between number of children in the family and auditory discrimination ability.

A second, but less compelling interpretation of the family size-intelligence relationship views increases in the number of children as leading to substantial increases in environmental noise. This increase in auditory stimulation could result in the tuning out process described by Deutsch, and, in turn, to deficits in auditory discrimination and reading ability. Thus the effects of population density on school performance may be similar to those attributed to noise.

A theoretical analysis of the experience of crowding [18] suggests a final interpretation of these results. Desor argues that crowding effects occur when one receives excessive stimulation from social sources. Relevant to this argument is a study by Wachs and his colleagues [2]. They report that children raised in homes with high levels of activity, and therefore greater levels of stimulation, are slower to develop intelligence-related skills than those raised in homes with lower activity levels. As documented above, increases in the number of children, and thus in the level of stimulation, have a similar effect.

Implications for design

The data we have reported on the effects of noise and crowding on development is not conclusive. It does, however, suggest possible effects of these stressors. It also suggests that design features such as sound absorbing materials, partitions, and larger units with many rooms may be essential for normal development.

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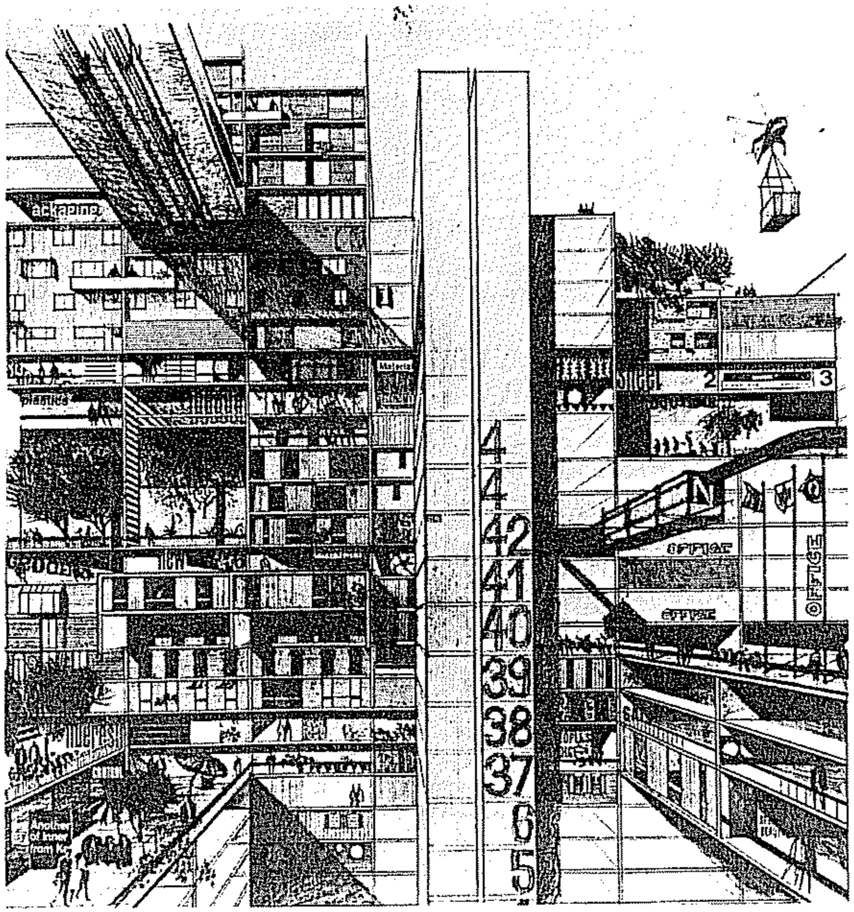

DESIGN OF URBAN HOUSING + TRANSPORTATION SYSTEMS 4

INFORMATION + SYSTEMS

SYSTEMS + DESIGN METHODOLOGIES

DESIGN RELATIONS IN HOUSING + TRANSPORTATION

CASE STUDIES + APPLICATIONS

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