

CHRONIC NOISE EXPOSURE AND READING DEFICITS

The Mediating Effects of Language Acquisition

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ABSTRACT: First- and second-grade schoolchildren chronically exposed to aircraft noise have significant deficits in reading as indexed by a standardized reading test administered under quiet conditions. These findings indicate that the harmful effects of noise are related to chronic exposure rather than interference effects during the testing session itself. We also provide evidence that the adverse correlation of chronic noise with reading is partially attributable to deficits in language acquisition. Children chronically exposed to noise also suffer from impaired speech perception, which, in turn, partially mediates the noise-exposure-reading deficit link. All of these findings statistically controlled for mother's education. Furthermore, the children in this study were prescreened for normal hearing by a standard audiometric examination.

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Numerous studies have uncovered associations between ambient noise exposure and reading deficits among elementary-aged schoolchildren. The primary objective of the present study is to determine whether this relation between noise exposure and reading is caused by deficits in language acquisition. To address this question, two language acquisition processes, speech perception and phoneme comprehension, are examined among elementary schoolchildren exposed to aircraft noise. We examine the hypothesis (see Figure 1) that the reason why chronic noise exposure interferes with the development of reading skills is because it disrupts language acquisition. There is abundant psycholinguistic evidence that reading acquisition is strongly language based. Problem readers have delayed language acquisition, and prospective studies have shown that language acquisition is a critical precursor to the development of reading skills (Mann & Brady, 1988; Wagner & Torgesen, 1987).

A secondary objective of this study is to ascertain whether the link between noise exposure and reading deficits is the result of chronic or acute noise exposure. Prior studies of chronic noise exposure and reading have relied on archival indices of reading achievement. Standardized reading test scores emanate from testing sessions that have occurred under ambient acoustic conditions. Therefore, children from elementary schools located in noisy areas completed these standardized testing batteries under noisy conditions (e.g., while airplanes were flying overhead). Thus, we cannot determine whether the positive associations uncovered between ambient noise exposure and reading in prior studies were the result of acute interference during the actual testing sessions, or whether the noise-related deficits in reading resulted from altered cognitive processing strategies due to chronic exposure to noise.

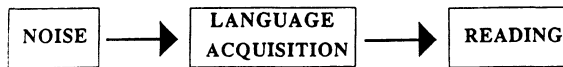


Figure 1: Schematic Representation of the Language Acquisition Mediation Hypothesis

Numerous studies have uncovered associations between noise exposure and reading deficits (see Evans & Lepore, 1993, for a review). These findings include a dose response function between noise exposure and reading deficiencies (Green, Pasternack, & Shore, 1982) and a noise-reduction intervention in a school that eliminated previously found deficits in reading ability (Bronzaft, 1981; Bronzaft & McCarthy, 1975). Household noise also has been correlated with basic cognitive abilities among 1-year-olds (Wachs & Gruen, 1982). Furthermore, the negative impacts of school noise levels on reading acquisition were exacerbated by home noise exposure (Cohen, Evans, Stokols, & Krantz, 1986; Lukas, DuPree, & Swing, 1981) and appeared more severe among children with poorer reading aptitudes (Maser, Sorensen, Kryter, & Lukas, 1978).

In the most thorough study of noise and reading to date, Cohen, Glass, and Singer (1973) measured reading and auditory processing among children living on different floors of an apartment building located over a busy highway. The higher the floor level children resided on (i.e., lower noise levels), the better their reading scores. Furthermore, the longer the duration of noise exposure, the wider the gap in reading scores. Children residing in quieter apartments also more accurately discriminated between similar sounding words (e.g., goat—boat) than their noise-exposed neighbors. Of particular interest to the present study, Cohen et al. investigated whether the noise-related reading deficits could be explained by auditory discrimination ability. After statistically controlling for parental education and income levels, they found that the noise-reading linkage was largely explainable by auditory discrimination. To our knowledge this is the only study to directly test an underlying mechanism for noise-related deficits in reading abilities. Cohen et al.

reasoned that children chronically exposed to loud noise would cope with the interfering and annoying impacts of noise by learning to tune out auditory stimuli. Although this coping strategy is adaptive on one hand, it could become maladaptive if overlearned. What if children learned to not only tune or filter out unwanted sounds such as transportation noise but also developed a more generalized strategy of ignoring auditory stimuli, including important information such as speech? Consistent with the Cohen et al. (1973) test of the tuning-out hypothesis, Cohen et al. (1986) found that noise-exposed children, relative to their quiet area counterparts, had more difficulty determining the optimum signal to noise ratio in a listening task in which a story was embedded in white noise. Evans, Hygge, and Bullinger (1995) also found that noise-exposed children were less accurate in adjusting background, broad-band noise to maximize clarity when listening to a story. Although these findings all point toward the potential role of auditory discrimination in accounting for the noise-reading linkage, only Cohen et al. (1973) directly tested this relation. However, the two studies by Cohen and colleagues confounded chronic and acute noise exposure in assessing reading performance, since archival indices of standardized reading test batteries were employed as the reading ability index.

The psycholinguistic literature indicates that auditory discrimination is a relatively minor component of learning to read. Much more important is speech perception (Brady, Shankweiler, & Mann, 1983) generally, and phoneme recognition specifically (Mann & Brady, 1988; Wagner & Torgesen, 1987). Brady et al. (1983), for example, showed that the recognition of speech significantly discriminated between good and poor third-grade readers. Children listened to words that had been masked with digitally matched signals. Good readers were significantly better at this task than were poor readers. Words presented without a mask did not discriminate between good and poor readers. Of particular interest to the present study, sound perception did not discriminate between good and poor readers. In the sound perception task, the same sample of children listened to sounds that had been masked. Instead of

words, however, the auditory stimuli were common environmental sounds (e.g., door closing, dog barking). Performance on this task was unrelated to the child's reading status. These results are important because they specifically point toward the processing of speech as opposed to more general, auditory information processing as the key element in the reading acquisition process. Additional psycholinguistic work has focused on specific elements of speech, critical to the acquisition of early reading skills. A particularly promising area of inquiry has been phoneme processing. Phonemes are the basic unit of spoken language, represented by consonant and vowel-sized segments. Words are composed of sequences of phonemes that must be recognized to understand language. The word *cat* consists of three phonemes that must be processed to recognize this word. Phonological recognition performance predicts subsequent reading ability; phonological training enhances reading acquisition; and reading performance is partially mediated by phoneme recognition (Mann & Brady, 1988; Wagner & Torgesen, 1987).

In the present study, we incorporated two language acquisition-processing paradigms from the psycholinguistic literature that have been shown to be robust in accounting for reading acquisition. Children from noisy and quiet schools were assessed on a phoneme recognition task and on a speech-processing task, along with a sound-processing control condition. We also incorporated the methodological strategy of assessing children's reading skills with a standardized test under carefully controlled, quiet conditions. Given the importance of knowing whether chronic or acute noise exposure is responsible for the well-established positive association between ambient noise exposure and reading ability, this methodological issue is important.

We hypothesized that chronic noise exposure would be positively correlated with reading deficits and that this association would, in turn, largely be accounted for by underlying deficiencies in language acquisition (see Figure 1). We also predicted, consistent with the psycholinguistic literature, that the expected adverse impacts of chronic noise exposure on reading skills would be specific to speech and not accounted

for by general auditory processing. Speech and phoneme perception, respectively, and not sound perception, would be significantly correlated with chronic noise exposure.

METHOD

SUBJECTS

One hundred and sixteen first and second graders (53% female) from two elementary schools participated in the study. The median household income of the sample was \$30,000. Mother's educational level ranged from grade school to some graduate work, with the average being high school completion. Father's education level was not included in the analyses because of insufficient data. Preliminary analyses substituting father education mean levels for missing values did not alter any of the conclusions herein. Department of Labor standard occupational codes (single digit) were utilized to classify mother's and father's occupations. Chi-square analyses revealed no differences in the proportion of mothers who were professional, clerical/sales, service workers, transportation workers, or unemployed $\chi^2(4, n = 74) = 6.99$. Father's occupation was not included because of insufficient data. Both schools are predominantly Black (82% noise school; 97% control school). Only children whose first language was English were included in the sample. The average years in residence did not differ between the noise ($\bar{x} = 6.28$ years) and control schools ($\bar{x} = 7.47$), $t(112) < 1.0$.

PROCEDURES

An elementary school within the 65 Leq flight contour of a major New York metropolitan airport was selected as the target school. Leq represents the average sound pressure level measured in 1-second intervals over a specified time period (24 hours in this case).¹ A Leq of 65 means that the average level

of sound intensity for this geographic area over a typical 24-hour period was 65 decibels (A scale). Leq is a widely used metric for assessing chronic noise exposure in the ambient environment. Peak dBA during frequent overhead flights exceeded 90 decibels.

The number of overflights during school hours averaged one flight per 6.6 minutes. A control school located in a quiet neighborhood was selected with the assistance of the New York City Board of Education. All of the children attending the noisy school in our sample also resided in the 65 Leq or louder contours. None of the children attending the quiet school lived within a 65 Leq or louder noise contour.

The control school was closely matched to the noise-exposed school on percentage of children receiving subsidized school lunches, ethnicity, and the percentage of pupils with English as a second language.

All participants were initially screened by a certified audiologist to ensure normal auditory thresholds. All testing occurred under quiet conditions. Each child was tested individually while wearing Telephonic TDH-39P headphones fitted with Audiocups. This configuration achieves substantial sound attenuation exceeding 20 decibels. A normal speaking voice at typical conversation distance is barely discernible when the headphones and audiocups are worn.

All children were tested in one 20-minute testing session. They were tested individually in their school by a female college student. Children wore the headphones and Audiocups throughout the testing procedure. Following participation, each child was given a small gift and praised for her/his performance.

Dependent measures. Reading skills were assessed with two subscales of the Woodcock Reading Mastery Test (Woodcock, 1987). Word identification requires the child to identify isolated words. As the child moves through the test, the words become less and less common. Examples of early words include *cat*, *stop*, *come*; with the next group including *play*, *sun*, *blue*, and the most difficult set including words like: *heterogeneous*, *cygnet*, *expostulate*. For an answer to be scored correct, the child must produce a natural reading of the word

within 5 seconds. The level acquired is determined until six consecutive items are failed. Word Attack requires children to read nonsense words. This test measures ability to apply phonetic strategies to realistic yet unknown letter combinations. Letter combinations advance from simple consonant-vowel combinations (e.g., *dee ift poe*) to eventual, multisyllabic nonsense words (e.g., *cigbet, bafmotbem, quiles*). The test continues until the child misses six nonsense words in a row. The test administrator was trained on an audiotape supplied with the Woodcock test.

Each of the Woodcock reading subscales has undergone extensive psychometric development and has American normative data available. Children's raw scores were transformed to standardized scores based on Woodcock grade norms. Reading ability was operationalized as the sum of the two standardized scores. These two particular subscales were chosen because they are valid indicators of reading ability (Woodcock, 1987) and because of their use in psycholinguistic research to distinguish between good and poor readers (Brady et al., 1983).

Language acquisition processes were assessed by two paradigms. Speech perception was measured by exposing children to 12 high-frequency words (Carroll, Davies, & Richman, 1971); half of the words began with stop consonants (e.g., /b/) and half with fricatives or affricates (e.g., /s/). The words were recorded by a phonetically trained male speaker. The words were then noise-masked by multiplying the digitized waveform of the stimulus by the digitized waveform of another, randomly chosen word. This technique preserves the time-varying amplitude of the speech signal. Each digitized word and its amplitude-matched mask were added linearly to yield a 0 dB signal to noise ratio (Schroeder, 1968). The masked words were presented at a comfortable, listening volume. Each word was experienced as the correct sound embedded in thick static. Each response was scored as correct or incorrect. These masked speech stimuli were part of a larger testing battery used by Brady et al. (1983) in their study of language processing and reading. Brady et al. found the most discrimination between good and poor

readers utilizing the high frequency, noise-masked speech perception stimuli.

Each participant was instructed to repeat the word he or she heard. Children were instructed to guess if unsure. The test sequence was preceded by two practice trials in which feedback was given. During the test, no feedback was given. The 12 test words were *child*, *sleep*, *breath*, *knife*, *speech*, *road*, *crowd*, *scale*, *front*, *chance*, *plant*, and *clouds*.

To determine whether ambient noise exposure produces problems specific to speech or more general auditory processes, a control condition consisting of noise-masked sounds also was included (Brady et al., 1983). Twelve familiar environmental sounds were recorded, digitized, and then masked.

Because the sound characteristics of nonspeech differed in significant ways from speech, a broad band mask (0-10kHz) was used. The 0 dB signal to noise mask employed for speech did not sufficiently mask the stimulus, whereas a -2 dB signal to noise ratio did (see Brady et al., 1983, for more details). The sounds presented were a piano, clock chime, door shutting, artillery guns, cat meowing, orchestra, train whistle, dog barking, whistle, drums, baby crying, and wedding music.

Sound perception was scored as in Brady et al. (1983) with 0 assigned if the response bore no relation to the stimulus; 1 if the response reflected the nature of the sound, although wrong in detail (e.g., coughing for talking); 2 if the response was accurate but nonspecific (e.g., *music* for an organ playing the wedding march); and 3 was assigned when the correct response was given.

Finally, an embedded phoneme test (Fowler, 1990) was given to each participant. The child was presented with an initial target word (e.g., *fan*) and asked to choose one of three words following that had the same initial sound located some place in the word (e.g., *camera*, *dinosaur*, *butterfly*). Pictures accompanied the target and comparison words to ensure that phoneme perception and not short-term memory was involved in the task. The 10 target words were *wig*, *chair*, *van*, *up*, *run*, *game*, *ice*, *tie*, *leg*, and *juice*. Feedback was given on a practice

trial, and then the test items were presented without feedback. Each response was scored as correct or incorrect.

RESULTS

ANALYTIC STRATEGY

Our analytic strategy was designed to address two principal questions: (a) Is there a relationship between chronic noise exposure and reading skills among young children? and (b) Assuming an affirmative answer, can we explain why/how noise affects reading? Specifically, we hypothesized that noise interferes with language acquisition, which, in turn, will account for the expected negative association between noise exposure and reading ability (see Figure 1). To examine the relations among ambient noise exposure and reading, and language acquisition, respectively, several steps are necessary. First, the zero-order correlations are depicted among the relevant variables along with potential statistical controls (e.g., parental education). To evaluate the main and intervening effects of noise on reading and language acquisition, respectively, a series of regression equations are calculated (Baron & Kenny, 1986; Evans & Lepore, in press). The initial analysis regresses reading scores onto the control variable(s). This test is the same as a correlation coefficient or a *t* test, because noise/quiet is dummy coded as 0 or 1. In the second equation, reading scores are regressed onto noise, controlling for potentially confounding background factors such as mother's education. In the third equation, we investigate the potential mediational status of language acquisition. Equation 2 is replicated, except a hypothetical mediator is forced into the equation prior to noise. The mediating role of language acquisition would be shown by the previously significant association between noise and reading (Equation 2) becoming either nonsignificant (full mediation) or significantly smaller (partial mediation) in Equation 3.

SIMPLE CORRELATIONS AND DESCRIPTIVES

Inspection of Table 1 reveals several important facts. First, the principal hypothesis of this study is supported. Chronic noise exposure is significantly correlated with reading scores ($r = -.58$, $p < .001$). Second, speech perception meets two necessary prerequisites to function as a mediator of the chronic noise—reading linkage. Chronic noise exposure is correlated to speech perception ($r = -.33$, $p < .001$), and speech perception and reading ability are correlated also ($r = .27$, $p < .01$). Table 1 also indicates that sound perception, which was a control measure to show that the noise effects are specific to speech and not to general auditory functioning, operated as expected. Sound perception is not correlated to noise levels ($r = .11$, *ns*) or to reading ability ($r = .15$, *ns*). Unexpectedly, the embedded phoneme task is unrelated to either noise levels or to reading scores. Therefore, the embedded phoneme test cannot be operating as a mediator of the noise-reading linkage.

Data shown in Table 1 also indicate the need to statistically control for mother's education in the inferential analyses below. Note that the mother's educational levels are correlated both with noise exposure and with reading ability. It should be noted also that income is not correlated to noise exposure or to reading. The former was expected since the quiet community was selected to match the noise-exposed community on income levels. Our matching procedure was apparently successful. The means and standard deviations for reading, speech perception, sound perception, and embedded phonemes are shown in Table 2. Consistent with the zero-order correlations, higher noise levels are associated with poorer reading and speech perception but are unrelated to sound perception or embedded phoneme performance.

MEDIATIONAL ANALYSES

Table 3 depicts the results of three regression equations. Line 2 in Table 3 shows that the linear association between noise exposure and reading found in Table 1 is not attributable to the

TABLE 1
Zero-Order Correlation Results

	Noise	Reading	Speech Perception	Sound Perception	Embedded Phoneme	Mother's Education	Income
Noise		-.58***	-.33**	.11	-.05	-.37**	-.12
Reading			.27*	.15	.15	.41**	.23
Speech perception				.14	.07	.12	.18
Sound perception					-.17	.05	-.14
Embedded phoneme						.10	.03
Mother education							.52***

* $p < .05$. ** $p < .01$. *** $p < .001$.

TABLE 2
Means (standard deviations) of Dependent Measures

	Noise (n = 58)	Quiet (n = 58)
Reading	191.2 (31.4)	235.1 (30.5)
Speech perception	1.5 (1.6)	2.7 (1.9)
Sound perception	21.1 (3.4)	20.0 (5.3)
Embedded phonemes	5.8 (1.9)	5.9 (1.7)

TABLE 3
Mediational Analyses of Noise and Speech Perception on Reading Scores.

Variable	ΔR^2	F for ΔR^2	Raw Beta	Standard Error Raw Beta
Mother's education	.07	9.11** (1,115)	6.29	3.58
Noise	.27	46.46*** (2,114)	-39.44	5.79
Noise with additional control for speech perception	.22	37.41*** (3,113)	-24.44	6.11

** $p < .01$. *** $p < .001$.

confounding factor of mother's education. Noise remains as a significant predictor of reading scores after statistically controlling for mother's education. This is shown in Line 2 of Table 3 by the F test for delta R^2 for noise. Noise significantly increases the amount of variance explained in reading ability over and above that explained by mother's education. Noise levels

are a significant predictor of reading ability in elementary schoolchildren, independently of mother's educational levels.

Line 3 in Table 3 indicates that speech perception functions as a partial mediator of the noise-reading effects. Some of the covariance between noise exposure and reading, after controlling for mother's education, can be accounted for by speech perception. To put it differently, noise exposure affects speech perception, which, in turn, affects reading ability (see Figure 1).

Evidence for partial mediation is based on a comparison of the raw beta weight for noise in line 2 of Table 3 to the raw beta weight for noise in line 3. The reduction in the magnitude of the raw beta weight (39.44-24.44) is greater than one standard deviation of the original, raw beta weight. Partial mediation is calculated by taking 1.65 times the standard error of the zero-order beta weight (1.65×5.79). This total is exceeded by the shrinkage in the beta weight for noise when speech perception is forced into the regression equation prior to the noise term. Noise, when residualized for speech perception, predicts significantly less variance in reading in comparison to when noise alone is used as the predictor. As expected, speech perception is significantly related to reading scores, $b = 4.86$, $p < .01$, after controlling for mother's education. (For further reading about partial mediation, see Evans & Lepore, in press; Waldron & Lye, 1990.)

Noise remains, however, as a significant contributor to reading even after partialing out speech perception. Total mediation would have been indicated by noise no longer having any significant, independent effect on reading. Clearly, this is not the case as the delta R^2 for noise in line 3 of Table 3 remains significant, even after partialing out speech perception. Language processing in the form of speech perception significantly contributes to the impairment of reading skills among children chronically exposed to noise. Nonetheless, other factors in the link between chronic noise exposure and reading impairments remain unspecified.

DISCUSSION

Children chronically exposed to aircraft noise have poorer reading skills than children attending elementary school in a quiet neighborhood. This finding replicates several previous studies showing an association between chronic noise exposure and reading acquisition (Evans & Lepore, 1993). The present study makes two additional contributions to the literature on noise and reading. First, because children were given a standardized reading test under carefully controlled quiet conditions, we have shown that the association between noise exposure levels and reading is due to chronic exposure and not acute interference by noise during the actual testing session. Only one prior study of noise and reading also has included this important methodological control (Evans et al., 1995). Chronic noise exposure is linked to reading deficits among children. This association has been demonstrated in two different studies, utilizing two different reading test batteries. The Evans et al. (1995) study was conducted in Germany and used a different reading evaluation instrument.

The second important contribution of the present study is our investigation of language acquisition as an underlying, intervening mechanism to account for the noise-reading deficit link (see Figure 1). We find partial support for our hypothesis. Ambient noise exposure is associated with impairments in speech perception, which, in turn, are correlated with reading development. As shown in Tables 1 and 3, speech perception functions as a mediator of the relation between noise exposure and reading development. Results from the control protocol of sound perception also indicate that this intervening effect of speech perception is language based. Speech, and not sound perception, mediates the relation between ambient noise exposure and reading acquisition among young children.

This intervening process, however, only reflects partial mediation. Speech perception does explain a significant amount

of the covariation between noise exposure and reading deficits, but a significant amount of that covariation remains unaccounted for (see Table 3). In other words, speech perception explains some but not all of the relation between noise exposure and reading development in early readers.

We chose to examine speech perception as a mediator of the relation between noise and reading for two reasons. First, prior research and theorizing had suggested that perhaps the reason why noise exposure is harmful to reading acquisition is because noise-exposed children, in their efforts to cope with ambient noise, learn to indiscriminantly tune out auditory signals, including speech (Cohen et al., 1973). Second, psycholinguistic research had indicated the critical importance of speech perception in reading acquisition (Brady et al., 1983). Our findings that speech but not sound perception help account for the noise-reading link are consistent with the psycholinguistic research. Our results also raise questions about the overgeneralization or tuning-out hypothesis (Cohen et al., 1973). Children chronically exposed to noise do appear to have altered auditory processing, but the effects seem specific to language-based stimuli, not auditory stimuli in general. As shown in Tables 1 and 2, there is no association between noise exposure and sound perception. Recall also that good and poor readers do not differ in general auditory-processing skills—speech but not sound processing discriminates between good and poor readers (Brady et al., 1983; Mann & Brady, 1988).

The finding of partial mediation also raises the question of what other underlying factors might intervene between ambient noise exposure and reading. In addition to showing that auditory perception in general is not a major intervening factor, our data suggest that phoneme recognition is unaffected by chronic noise exposure and therefore does not function as an underlying mechanism that could account for the association of chronic noise exposure with reading deficits. We are not confident about this latter conclusion, however, since phoneme recognition also was unrelated to reading (see Table 2). This finding contradicts several previous studies linking phoneme recognition with reading (Mann & Brady, 1988; Wagner & Torgesen, 1987). We used

a subset of an embedded phoneme test developed by Fowler (1990) that significantly discriminated between good and poor readers. Conceivably, our shorter test was less sensitive than the original, although our scale had good internal consistency ($\alpha = .78$), indicating adequate reliability of measurement. In any case, we think it prudent to keep the question open whether phoneme recognition is a significant intervening process that also might explain the noise-reading deficit relation.

Another important limitation in this field study is the lack of random assignment of children to schools that precludes complete confidence in attributing the differences uncovered to noise alone. The possibility always remains with a static, correlational design that some other variable(s) is behind the apparent noise-reading relationship shown. Although the most plausible self-selection alternatives (income, education) have been eliminated, our results need to be replicated in a prospective, longitudinal design.

Although our focus and other theoretical explanations of noise and reading have emphasized cognitive processes, we believe interpersonal, social processes also should be considered. For example, several studies have documented that in noisy schools, actual teaching time is disrupted (Bronzaft & McCarthy, 1975; Crook & Langdon, 1974). Moreover, teachers in noise-exposed classrooms report considerable annoyance and cumulative fatigue from their efforts to instruct under the difficult, interfering conditions created by ambient noise. One also could imagine that parents residing in noisy neighborhoods might be less apt to read aloud to their children, and perhaps the frequency and/or duration of oral communications are curtailed. Thus, the behaviors of primary caregivers might shift in reaction to chronic noise exposure. Noise is also a documented irritant, straining interpersonal relationships and, on occasion, elevating overt hostility and aggressive behaviors (Cohen & Spacapan, 1984). Any one of these social psychological adjustments to ambient noise conditions, let alone in combination, could have unintended but adverse consequences on children's development. Thus, in considering how suboptimal, physical environmental conditions adversely affect development, we also

need to consider more complex pathways that might include alterations in the microenvironmental systems of children (Bronfenbrenner, 1979).

Although the primary health concern with chronic noise exposure is hearing damage, a growing body of literature highlights an array of nonauditory effects of chronic noise exposure, especially among children. Psychophysiological changes indicative of chronic stress, elevated annoyance and irritation, motivational deficits related to learned helplessness, and alterations in cognitive development and reading achievement, have now all been well documented (Cohen et al., 1986; Evans & Lepore, 1993; Evans et al., 1995). It is important to recognize that these advances in knowledge of the probable effects of chronic noise exposure on children have been accompanied by exponential increases in worldwide, ambient noise levels that are an unfortunate by-product of economic development particularly prevalent among economically underdeveloped countries (Suter, 1991). This research area is now at a stage where more rigorous, prospective longitudinal studies are necessary, along with more analyses of underlying cognitive and social processes than can account for the adverse effects of chronic noise exposure on human health and development.

NOTE

$$1. Leq = 10 \log 1/n = \left(\sum_{i=1}^n 10^{L_i/10} \right). \text{ Log is base 10. } i = 1 \text{ is the first second, } i = n \text{ is}$$

the last second. L is the sound pressure level of each one second interval during the 24-hour time period.

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