Community noise exposure and stress in children

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Although accumulating evidence over the past two decades points towards noise as an ambient stressor for children, all of the data emanate from studies in high-intensity, noise impact zones around airports or major roads. Extremely little is known about the nonauditory consequences of typical, day-to-day noise exposure among young children. The present study examined multimethodological indices of stress among children living under 50 dB or above 60 dB (*A*-weighted, day-night average sound levels) in small towns and villages in Austria. The major noise sources were local road and rail traffic. The two samples were comparable in parental education, housing characteristics, family size, marital status, and body mass index, and index of body fat. All of the children were prescreened for normal hearing acuity. Children in the noisier areas had elevated resting systolic blood pressure and 8-h, overnight urinary cortisol. The children from noisier neighborhoods also evidenced elevated heart rate reactivity to a discrete stressor (reading test) in the laboratory and rated themselves higher in perceived stress symptoms on a standardized index. Furthermore girls, but not boys, evidenced diminished motivation in a standardized behavioral protocol. All data except for the overnight urinary neuroendocrine indices were collected in the laboratory. The results are discussed in the context of prior airport noise and nonauditory health studies. More behavioral and health research is needed on children with typical, day-to-day noise exposure. [DOI: 10.1121/1.1340642]

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I. INTRODUCTION

Although the predominant health concern of chronic noise exposure is auditory damage, increasing attention is being paid to the nonauditory health effects of noise. The nonauditory effects of noise have been conceptualized in terms of stress, suggesting that chronic noise exposure leads to an overload of stimulation that is experienced as an irritating, annoying stimulus that interferes with relaxation as well as the ability to concentrate (Broadbent, 1971; Evans and Cohen, 1987; Lercher, 1998). The uncontrollability of chronic noise exposure also appears to be a salient aspect of its stressful properties (Cohen *et al.*, 1986; Glass and Singer, 1972). Evidence that noise can function as a stressor includes elevated psychophysiological activation, greater psychosomatic symptoms of anxiety and nervousness, and deficits in motivation indicative of helplessness (Cohen *et al.*, 1986; Evans, 2001; Ising, Babisch, and Kruppa, 1999; Ising and Braun, 2000; Kryter, 1994; Lercher, 1996; Medical Research Council, 1997). It is important to recognize that most of the evidence for these findings comes from individuals with no discernible hearing deficits. Nonauditory effects of noise appear to occur at levels far below those required to damage hearing.

The present study fills a gap in the noise and health effects literature by examining stress outcomes of typical, everyday community noise exposure among children. Prior work on the stress effects of noise has focused on high-intensity noise, predominantly occupational and airport noise sources, which typically exceed day-night sound levels (L_{dn}) of 70 dBA (Kryter, 1994; World Health Organization, 1995). We currently know very little about the nonauditory health effects of chronic, lower intensity, everyday noise exposure. A typical urban neighborhood residential area in the United States ranges from 55 to 70 dBA L_{dn} (Kryter, 1994). In the European Union about 20% of the population lives in areas with daytime Leq$>$65 dBA (Gottlob, 1995).

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Psychophysiological activation, particularly blood pressure, has been inconsistently related to occupational noise (Babisch, 1998; Medical Research Council, 1997; Thompson, 1993) but is correlated with airport noise exposure among children (Cohen *et al.*, 1986; Evans, Hygge, and Bullinger, 1995; Evans, Bullinger, and Hygge, 1998a; Ising *et al.*, 1990; Regecova and Kellerova, 1995). Herein, we examine both cardiovascular and neuroendocrine sequelae of low-intensity noise exposure among young children. Furthermore, only one prior developmental study has examined psychosomatic symptoms of high-intensity noise, revealing a positive correlation between aircraft noise and high stress symptoms among 11-year-olds (Evans *et al.*, 1995). Thus, we need to determine whether more typical community noise exposure has analogous impacts.

Beginning with the pioneering work of Glass and Singer (1972), many studies have demonstrated, both in the laboratory and in the field, that exposure to high-intensity, uncontrollable noise can cause motivational deficits (Cohen, 1980). Work with children has shown that chronic aircraft noise exposure is associated with similar deficits (Bullinger *et al.*, 1999; Cohen *et al.*, 1986; Evans *et al.*, 1995).

All prior nonauditory noise research with children with one exception (Evans *et al.*, 1998a) is cross sectional, and thus subject to concerns about the comparability of noise and quiet community samples. Although most of these studies have employed statistical controls for social class, none has examined a wide range of other potentially important variables including biological (e.g., gender), social (e.g., family size), or other environmental conditions (e.g., housing). Thus in addition to examining the potential nonauditory health concomitants of regular, everyday community noise exposure, we investigate other biological, social, and environmental variables that might covary with community noise exposure and nonauditory health.

II. METHOD

A. Sample

The sample consists of 115 children in grade 4 who were selected from a large, representative sample of children living in the lower Inn Valley of Tyrol Austria. This area consists of small towns and villages with a mix of industrial and agricultural activities in rural areas outside of Innsbruck. The purpose of the larger study is to investigate alpine environmental conditions in Austria and monitor over time how changes in environmental quality are related to children's physical and mental health. The selected subsample was chosen for the purpose of more in-depth investigation of children exposed to either relatively low or relatively high, typical community noise levels. The primary noise sources are road and rail traffic. One half of the sample reside in neighborhoods below 50 dBA (day-night average sound level) ($M=46\,L_{dn}$) and one half live in areas above 60 dBA ($M=62\,L_{dn}$). The interquartile range of sound levels in the low exposure sample was 34–50 dBA, L_{dn} with 1% peak levels 57 dBA. For the high exposure group the interquartile range was 52–71 dBA, L_{dn}, with an $L_1=74$). Overall median night rail sound levels were 3 dBA higher than daytime levels and road traffic levels during the day exceeded night-time levels by 7 dBA. Noise measurement was based on sound exposure modeling data (Soundplan) according to Austrian guidelines (OAL Nr. 28+30, ONORM 8 5011). Afterwards, calibration was conducted and corrections were applied to the modeled data based on day and night recordings from 31 measuring points. Based on both data sources, approximate day–night levels (L_{dn} in dBA) were calculated and linked via GIS to each home address.

TABLE I. Sample background information.

	Low noise sample	High noise sample	Statistic
Age	9.90	10.25	$t(113)<1.0$[a]
Gender			
(% male)	54	60	$X^2(1)<1.0$
Mother's education	2.50	2.44	$t(112)<1.0$
(1=<high school−5=graduate school)			
% Single parent	7	5	$X^2(1)<1.0$
Family size	4.33	4.41	$t(113)<1.0$
Density (people/room)	0.80	0.84	$t(112)<1.0$
Housing type			
% multiple dwelling	22	27	$X^2(2)=2.47$, ns
% row house	26	14	
% single family detached	52	59	
Body mass index (kg/m^2)	17.31	17.77	$t(107)<1.0$

[a]Degrees of freedom vary because of missing data.

Table I depicts basic background information for the two samples. Note that the samples do not differ on any of these variables. The sociodemographic homogeneity of the selected subsamples also closely matches the overall representative sample and is consistent with Austrian national census data for rural, alpine regions.

B. Procedure

The children were tested individually in a mobile laboratory that was climate controlled and sound attenuated (Leq<35 dBA). The experimenter was blind to the child's ambient noise condition. Data collection from the children took approximately 1 h and consisted of three general topics: noise annoyance, cognitive processing, and stress. All children were given the same protocol in the exact same order. Given the focus of the present article on stress, only these measures are detailed.

School children were tested in the trailer for normal hearing with a calibrated screening audiometer (EFEU type A 120). The audiometer and training of the testers were provided by the Environmental Protection Agency in Berlin and its exclusion criteria applied (30 dB at 250 or 500 Hz or 4 kHz).

1. Psychophysiological stress

Overnight (8-h) urine was collected with the assistance of the child's mother. The total volume was measured and four small subsamples were randomly extracted. For two of these the *p*H was adjusted with HCl to reduce catecholamine oxidation. The four subsamples were immediately frozen and stored at −70 °C until assayed. The catecholamines, epinephrine and norepinephrine, were assayed with high-performance liquid chromatography (HPLC) with electrochemical detection (Riggin and Kissinger, 1977) and free cortisol (Schoneshofer *et al.*, 1985) and 20a-dihydrocortisol, a cortisol metabolite (Eisenschmid *et al.*, 1987; Schoneshorfer *et al.*, 1986) with HPLC. Recent biochemical research indicates that 20a-dihydocortisol may be a more sensitive index of chronically elevated corticosteroids. Urinary cortisol, epinephrine, and norepinephrine are valid indices of chronic stress (Baum and Grunberg, 1995). Resting blood pressure was evaluated while the child was seated quietly. After acclimating the child to the apparatus and an initial practice reading, two blood-pressure readings were taken with a calibrated sphygmomanometer (Bosch, Sysditon model) over a 6-min period. These two readings were then averaged. Resting heart rate was monitored continuously (Polar Accurex Plus) over the 6-min rest period and during the experimental protocol. Heart rate reactivity was calculated by subtracting the mean resting heart rate from the average heart rate during the most stressful part of the protocol (a difficult reading test that lasted approximately 5 min).

2. Motivation

An adaptation for children of the Glass and Singer (1972) stress-aftereffects test was given to measure motivational deficits (Evans *et al.*, 1995). Children were given geometric puzzles consisting of common objects (e.g., animals) interconnected by lines. The child's task was to trace over the lines between all of the objects without going over any line twice or lifting their pencil. Multiple copies of the same puzzle were stacked in a pile, and the children instructed to work on each puzzle until solved or to take another copy when they wished to try it again. The children were informed that they could work on the first pile of puzzles until solved or they felt unable to complete the puzzle. At that point they could move on to a second set of puzzles. The children were also informed that once they moved on to the second pile of puzzles, they could not return to the first pile. Unbeknownst to the child, the first pile of puzzles was unsolvable. The number of puzzles attempted on the first pile of puzzles is the index of motivation. The second set of puzzles was solvable to insure that all children completed the procedure with a success experience. All children were assured that they did very well and that most children find the initial puzzle very difficult. Many studies of both acute and chronic stressors have shown the sensitivity of performance on this task to exposure to uncontrollable stressors including noise, crowding, and electric shock (Cohen, 1980; Evans, 2001; Glass and Singer, 1972). The child-adapted version of this procedure has also proven reliable in measuring exposure to both crowding and noise (Evans, 2001). The measure is believed to reflect motivational deficits indicative of learned helplessness because of its sensitivity to experimental or naturalistic variability in controllability of adverse stimuli. This measure is also sensitive to individual differences in control-related beliefs (e.g., locus of control) (Cohen, 1980; Evans, 2001; Glass and Singer, 1972).

TABLE II. Psychophysiological results.

	Low noise sample	High noise sample
Diastolic blood pressure	73.00 mmHg	72.75 mmHg
Systolic blood pressure	115.32 mmHg	117.29 mmHg[c]
Heart rate	89.99 bpm[a]	90.43 bpm
Heart rate reactivity	3.87 bpm	5.81 bpm[c]
Epinephrine	697.96 ng/8 h[b]	690.48 ng/8 h
Norepinephrine	8920.38 ng/8 h	9900.86 ng/8 h
20A-dihydrocortisol	7.75 ug/8 h	9.80 ug/8 h[c]
Cortisol	3.86 ug/8 h	4.87 ug/8 h[c]

[a]bpm=beats per minute.
[b]h=hours.
[c]Statistically significant difference (see the text for details).

3. Stress symptoms

A symptoms subscale of a standardized German instrument for the assessment of stress in children, Streßerleben und Streßbewältigung im Kindesalter (SSK) (Lohaus *et al.*, 1996) was administered to each child. The SSK subscale for stress symptoms consists of eight, 3-point ratings (never, sometimes, often) of symptoms for the previous week. Sample items include ''felt tired,'' ''didn't have a good appetite.'' The eight items formed a coherent scale ($\alpha = 0.62$). As a partial check on ambient noise exposure, each child was also asked to indicate how noisy he/she felt their neighborhood was on a three-item, 4-point rating scale ($\alpha = 0.72$).

III. RESULTS

As a partial check on the ambient noise comparisons, children from noisier areas rated their neighborhoods as significantly more noisy ($M=2.57$, s.d.$=0.86$) than those from relatively quiet areas ($M=2.21$, s.d.$=0.75$), $t(113)=2.35$, $p<0.01$ (all significance levels are one tailed, unless otherwise noted). Except where noted there were no interactions between gender and noise exposure, and thus the results are collapsed across gender. As expected, given the homogeneity of the two samples (Table I), statistical controls for background factors had no impact on the results.

As shown in Table II, children exposed to higher levels of ambient noise had marginally elevated resting systolic blood pressure in comparison to their low-noise counterparts, $t(107)=1.34$, $p<0.09$. Degrees of freedom vary throughout because of missing data. Both resting diastolic blood pressure and heart rate were equivalent between the two groups (see Table II). However, the noise group had higher reactivity to the acute stressor (difficult reading test) than the quiet group, $t(106)=1.74$, $p<0.04$. Addition of a statistical control for body fat (body mass index) had no effect on the results and thus was omitted from the analyses of cardiovascular functioning. Overnight resting epinephrine levels were equivalent for the quiet and noisy groups, $U=1388$, $p<0.23$. Similar results were found for urinary norepinephrine, $U=1617$, $p<0.97$. Total free cortisol was elevated in the noise group relative to the quiet group, $U=1273$, $p<0.05$, as was the 20a-hydroisomers, $U=1184$, $p<0.02$. Because the neuroendocrine data were highly skewed, nonparametric tests (Mann-Whitney U) were employed.

TABLE III. Motivation results (number of puzzle attempts).

Sex	Noise	
	Low	High
Male	4.91	5.54
Female	5.50	4.26

Children from the noisier neighborhoods reported greater stress symptoms over the previous week ($M=1.55$, s.d.$=0.38$) in comparison to those from quiet areas ($M=1.39$, s.d.$=0.34$), $t(113)=2.41$, $p<0.005$.

Table III depicts the motivation results. For the number of attempts on the unsolvable puzzle, there was a significant gender by noise interaction $F(1,111)=4.61$, $p<0.03$ (two tailed). Inspection of the simple slopes revealed that noise had no effect on motivation for the boys [$b=0.93$, $t(111)=1.41$ ns]; whereas for girls, increases in noise were related to decreased task performance [$b=-1.24$, $t(111)=1.62$, $p<0.05$]. There were no main effects for noise or gender on motivation.[1] Given prior research showing similar patterns of motivational deficits and residential density, the above analysis was repeated with an additional control for density (people per room). The statistical interaction remained significant with this additional control.

IV. DISCUSSION

To our knowledge the present results represent the only published data on the nonauditory health effects of typical, ambient community noise levels. Utilizing a cross-sectional sample of fourth-grade children from towns and villages in alpine areas in Austria, we provide evidence that differences among low-intensity, common everyday noise exposures may have health consequences for children. Children residing in noisier areas of communities have marginally higher resting systolic blood pressure, greater heart rate reactivity to an acute stressor (a test), and higher overnight cortisol levels indicative of modestly elevated physiological stress. Recall also that these physiological measures were taken at rest, and in the case of the cardiovascular measures, under well-controlled, quiet conditions. Since the overnight neuroendocrine measures were taken at home overnight, noise exposure during the assessments were different for the two samples. However, the overnight data represent the long-term, habitual noise environment, which typically remains stable over time. The combination of elevated cardiovascular and neuroendocrine measures provides support for the stress model of chronic noise exposure (Baum and Grunberg, 1995; Evans and Cohen, 1987). These elevations are similar but smaller than those found in prior studies of high-intensity aircraft noise exposure among children (Evans, 2001; Medical Research Council, 1997). Although the degree of physiological activation is modest and well below levels indicative of pathology, it does suggest that children living in noisier areas of residential communities are subject to stress. This interpretation is bolstered by the findings that these same children also report higher levels of stress symptoms on a standardized scale. The latter data also replicate and extend the one prior finding on chronic, high-intensity airport noise exposure and psychological distress in children (Evans *et al.*, 1995).

When people are continuously confronted with aversive stimuli that they cannot control, negative motivational consequences ensue (Peterson, Maier, and Seligman, 1993). Learned helplessness describes a syndrome in which the organism learns that the outcomes of its efforts to control or escape from an uncontrollable stimulus are futile (Seligman, 1975). Several studies have shown that both acute and chronic high-intensity noise are capable of inducing helplessness (Cohen, 1980; Evans, 1998; Glass and Singer, 1972). The present motivational results replicate three prior airport noise studies (Bullinger *et al.*, 1999; Cohen *et al.*, 1986; Evans *et al.*, 1995), but demonstrate the noise–helplessness relation only among girls. There is evidence in the general learned-helplessness literature of greater vulnerability to helplessness among females (Dweck and Elliot, 1983). Furthermore, a recent residential crowding study found the same gender interaction pattern (Evans *et al.*, 1998b).

Although the two groups of children in the present study reside in sociodemographically homogeneous communities and are very similar on a host of background variables (see Table I), the results are based on a cross-sectional design. We have demonstrated that typical, relatively low-intensity community noise is associated with modest, nonauditory health effects. The data need replication, preferably in a prospective, longitudinal study. Our intention is to monitor these same children over time with expected changes in noise levels coincident with Austrian compliance with European Union-mandated improvements in transportation infrastructure.

Since the geographic location of the present study is in small towns and villages in an alpine region, it would also be good to extend the findings to urban residential areas. It would also be valuable to evaluate children's nonauditory health responses to acute noise under laboratory conditions. We currently have a much more developed knowledge base on the nonauditory health effects of atypical, high-intensity noise exposure among children. We need to learn more about the potential consequences of typical ambient noise conditions for children's nonauditory health and well being.

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[1]Use of the more conventional t tests to compare individual group means yielded the same pattern of results; for boys there was no noise effect, $t(64)=1.31$, whereas for girls there was an effect, $t(47)=1.83$, $p<0.04$. Tests for the simple slope are preferable, however, because they enable use of the overall error term in the analysis (see Aiken and West, 1991).

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