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소음 관련 변인이 아동청소년의 정서 및 행동 문제에 미치는 부정적 영향

Negative impact of noise and noise sensitivity on mental health in childhood

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이 논문을 의학석사 학위 논문으로 제출함

2018 년 08 월

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Abstract

Introduction

Noise and noise sensitivity have negative effects on mental health and are not well-studied in children and adolescents. In this study, we investigated these effects in the aforementioned population with respect to sociodemographic variables and environmental factors.

Methods and Material

In this population-based study conducted in two large cities in South Korea, 918 elementary and middle-school students were included. After direct measurements at the selected sites, a noise map was created using an interpolation method. The road traffic noise of the subjects' residential areas was calculated based on this noise map. Noise sensitivity was assessed on an 11-point Likert scale. Using multivariate logistic regression, we investigated the relationship between noise, noise sensitivity, and the Child Behavior Checklist. Further analyses were performed subdividing the data according to household income levels.

Results

Noise sensitivity was significantly associated with internalising, externalising, and total behavioural problems. Noise was positively associated with total behavioural problems. In the low-income group, the degree of association with problem behaviours was higher, while the relationship between noise sensitivity and externalization problems disappeared in the high-income group.

Conclusions

Noise and noise sensitivity negatively influence the mental health of children and adolescents, particularly in low-income groups. The findings of this study suggest that noise sensitivity and socioeconomic status should be considered in coping with negative effects of noise in children and adolescents.

Keywords: Adolescent, Children, Child Behavior Checklist, Income, Noise, Noise sensitivity

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Introduction

Noise negatively affects auditory and non-auditory health.[1, 2] With respect to the non-auditory health effects of noise, an association between noise exposure and hypertension, cardiovascular diseases, and stroke has been reported.[2-6] Although research on the effect of noise on mental health has yielded inconclusive results,[7, 8] studies have reported that noise exposure is associated with emotional distress,[2] sleep disturbances,[9-11] psychosomatic disorders,[12, 13] and psychiatric hospital admission rates.[14, 15] Because of these negative effects, noise can impair the quality of life.[16, 17] Among various noise sources, road traffic noise is of special interest, considering its generally wide and usually long exposure.[18] Traffic noise was cited as the second most influential environmental risk factor after particles in a recent European study.[19]

Noise sensitivity has firstly been defined as a 'general measure of attitudes towards noise' by Anderson.[20] Thereafter, different researchers have used different definitions of noise sensitivity; however, it is generally accepted that noise sensitivity refers to a stable trait or internal state of an individual.[21-23] While some researchers insist that noise sensitivity reflects subjective sensitivities towards the environment in general, rather than towards noise alone,[24] it is more likely that noise sensitivity reflects a specific discriminating sensitivity towards noise than towards the general environment.[25, 26]

It has been suggested that noise sensitivity rather than the actual noise level is the most important factor in noise-related health effects. In a previous study, noise sensitivity accounted for 10-26%of noise-induced annoyance.[27] Furthermore, it was reported that the non-auditory health effects of noise manifested only in a highly noise-sensitive group.[28] In individuals with high noise sensitivity, hypertension and emphysema are more frequent, while cardiovascular mortality levels are increased in noise-sensitive women. Studies have reported an association between noise sensitivity and various mental health-related factors, such as anxiety, depression, higher benzodiazepine usage, and future psychiatric disorder.[29-32]

Studies in children and adolescents have also report that environmental noise has a negative impact on children's health.[33, 34] In such studies, children living in noisy neighbourhoods

complained of more stress symptoms than did those living in silent environments.[33] Moreover, children who considered their classroom as noisier were found to have higher diastolic blood pressure in the Los Angeles Airport Study.[34] However, studies have also reported no association between noise and children's health. For example, Haines et al. found no association between airplane noise and self-reported health status, such as headache and tiredness,[35, 36] and Stansfeld et al. reported that neither airplane noise nor road-traffic noise are associated with children's self-reported health status.[37]

Studies investigating the effect of noise sensitivity in children are insufficient. Only one study reported on noise annoyance in children, not noise sensitivity, showing that a group, which was annoyed by airplane noise had more self-reported health symptoms and negative results on neurobehavioral assessments than a group that was not annoyed by noise.[38]

Children and adolescents are less able to cope with stress compared with adults.[37] It is therefore assumed that children are more vulnerable to environmental stresses, such as noise, than are adults. In addition, childhood mental health problems can have long-term negative implications by affecting individuals both academically and occupationally.[39, 40] It is thus important to examine how noise-related variables affect children's and adolescents' mental health and to screen for children and adolescents who are vulnerable. However, research on the relationship between noise and the mental health of children and adolescents, especially regarding noise sensitivity, is currently insufficient. In the present population-based study, we investigated the effects of noise and noise sensitivity in children and adolescents on their mental health as evaluated by the Child Behavior Checklist (CBCL). We hypothesised that high levels of both noise and noise sensitivity are negatively associated with the mental health of children and adolescents and that the effects of these noise-related variables depend on socioenvironmental factors.

Subjects and Methods

Study population

The present study was conducted between June and August 2016. We selected four elementary schools and four middle schools in Yangcheon-gu, Seoul, and in Nam-gu, Ulsan, and 120 students and their parents at each school (n = 960) were enrolled. In each city, we selected one elementary and one middle school with high noise levels, according to the noise map, and one elementary and one middle school with low noise levels.

A questionnaire was distributed to students and parents in each school and was sent back to the school after completion. All subjects agreed to participate and provided informed consent. A total of 918 of the 960 subjects, excluding 42 subjects with incomplete survey data, were finally included in this study. This study was approved by the Institutional Review Board of Ulsan University Hospital (2014–08-008).

Demographic characteristics

We investigated basic demographic characteristic, such as age, sex, height, weight, socioeconomic factors, that may affect the children's mental health and noise exposure and factors that may affect their development. As socioeconomic variables, parental educational level, monthly household income, residential environment, smartphone usage time, and computer gaming time were included. The average monthly income was categorised as <4 million Korean won (approximately 4000 US dollars) or ≥4 million won, based on the average income of households with two or more members in cities in South Korea, which amounted to 4.3 million won in 2015. As development-related variables, maternal illness during pregnancy (diabetes, hypertension, preeclampsia, and thyroid disease), parental age at birth, premature birth, low birth weight at birth, breastfeeding, parental smoking status, and passive smoking were included. The psychiatric history was obtained by asking parents to indicate the child 's illness on the questionnaire.

Noise sensitivity

Noise sensitivity was assessed using a visual analogue scale that had been translated

according to the International Organization for Standardization Technical Specification 15666 (2003). Noise sensitivity was assessed by the parents of each subject, using single-item questionnaires. On an 11-point Likert scale, scores of 0 and 10 points indicated the lowest and highest sensitivity, respectively. Judgments of parents and students were combined, while the parents provided the score in writing.

Noise level

The indicator of the noise level in the present study was the day-night average sound level (Ldn) of road-traffic noise. Ldn is an average of 24-hour noise that applies a 10-dB penalty to noise at night time (10 pm–7 am). It has been used by US government agencies since the 1970s as an indicator for the assessment of the impact of environmental noise.[41)] In this study, the level of road traffic noise at the exterior wall of a residential building was calculated using noise prediction software (Cadna A, DataKustik, Germany) based on a noise map. The noise map was created in 2014 by a research team that modelled the terrain, buildings, and roads of the study area, measured the traffic volume, the large-car ratio, and speed limits, and verified the difference between the predicted and measured values.

Child Behavior Checklist

The CBCL 6-18 has been developed to identify behavioural problems in children via their parents' observation. It has been translated and normalised in many Eastern and Western cultures, and its reliability and validity as an effective screening tool is well established.[42)] It consists of 120 items that are assessed on a 3-point scale, from 0 to 2, judging whether the child or adolescent showed the described behaviour in the past 6 months. The problem behaviour scale is the most critical part of the CBCL 6-18 and includes eight syndrome scales (Anxious/Depressed, Withdrawn/Depressed, Somatic Complaints, Social Problems, Thought Problems, Attention Problems, Rule-Breaking Behavior, Aggressive Behavior) as well as broadband scales consisting of the sum of these subscales (internalising, externalising, total problem score). The internalising problems scale refers to behaviours that are overly controlled, such as passive and restricted behaviours, and consist of the sum of the Anxious/Depressed, Withdrawn/Depressed, and Somatic Complaints subscales. The

externalising problem scale refers to under-controlled behaviour and consists of the sum of the Rule-Breaking Behavior and Aggressive Behavior subscales. The total problems score is the sum of the scores of all problem items and represents the extent of the overall behavioural problems. The raw score is converted into a T score using the mean, standard deviation, and percentile distribution of the raw score. A T score of 64 or higher is classified as the clinical range for internalising, externalising, and total behavioural problems.

Statistical analysis

The demographic characteristics, socioeconomic variables, and variables that may affect the development of the participants in the high- and low-noise sensitivity groups were compared according to the median value (noise sensitivity = 3) of the study population. A *t*-test was used for continuous variables, the chi-squared or Fisher's exact test was used for categorical variables, and the Mann–Whitney U test was used for ordinal variables.

Logistic regression analysis was performed on the internalising, externalising, and total behavioural problems scales, which are the broadband scales of the CBCL 6-18. Before multivariate analysis, a univariate analysis was used to examine the association of variables with behavioural problems and to select covariates for the multivariate analysis. Variables that not only showed moderate associations ($p < 0.200$) with behavioural problems in the univariate analysis but were also sufficiently frequent to qualify for multivariate logistic regression were selected as covariates for multivariate logistic regression. The adjusted models included the variables age, sex, monthly income, premature birth, maternal age at birth, passive smoking, disease during pregnancy (hypertension and preeclampsia), and mental disorders (attention deficit hyperactivity disorder, attention deficit hyperactivity disorder [ADHD], motor disorder, and conduct disorder). The results are presented as odds ratios (ORs) and 95% confidence intervals (CIs). In the regression analysis, an evaluation of the variance inflation factors of the independent variables (Ldn = 1.05, age = 1.03, sex = 1.03, income = 1.07, premature birth = 1.07, maternal age at birth = 1.07, passive smoking = 1.02, hypertension during pregnancy = 1.08, preeclampsia = 1.11, ADHD = 1.50, motor disorder = 1.48, and conduct disorder = 1.64) confirmed that multi-collinearity was not an issue.

To investigate the relationship between behavioural problems and noise exposure in schools, the schools in each city were classified as high- and low-noise level schools, and the proportion of behavioural problems in each group was compared using a chi-squared test.

To examine the effect of income on the association between noise sensitivity and behavioural problems, we performed additional analyses where we stratified the study population into low- and high-income groups. In addition, the differences in socioeconomic as well as birth- and developmental-related variables were compared between the low- and high- groups. A *t*-test was used for continuous variables, and the chi-squared or Fisher's exact test was used for categorical variables; the Mann–Whitney U test was used for ordinal variables.

For the sensitivity analysis, all main analyses were performed as described while excluding those subjects who had lived in their respective residential area for less than 1 year. For all tests, statistical significance was set at $p < 0.05$ (two-tailed). Data were analysed using IBM SPSS Statistics for Windows, Version 23.0 (IBM, SPSS Inc., Chicago, IL, USA).

Results

Demographic characteristics

The subjects had a mean age of 11.47 ± 1.54 years (age range, 9–14 years); 51.6% were in the elementary school, 48.4% were in the middle school, and 46.5% were boys. The proportion of students in the high-income group was 75.6%. The mean noise level (Ldn) of all schools was 56.84 ± 9.34 dB, and the mean noise sensitivity was 3.31 ± 2.03. There was no significant difference between the low- and high-noise groups with respect to demographic variables, birth-related variables, and medical and mental health status variables (Table 1). The subjects spent an average of 12.97 hours on weekdays and 16.48 hours on weekends at home. Supplement Table 1 presents the noise level at each school. There were no significant differences in behavioural problems according to the noise level at each school (Supplement Table 2).

Univariate analysis

A univariate logistic regression analysis was performed using each variable as an independent variable and CBCL internalising, externalising, and total behavioural problems as dependent variables (Table 2). The variables significantly associated with internalising problems were noise sensitivity (OR = 1.35; 95% CI: 1.15, 1.60), passive smoking (OR = 3.16; 95% CI: 1.55, 6.46), preeclampsia (OR = 3.77; 95% CI: 1.07, 13.30), and ADHD (OR = 6.29; 95% CI: 1.7, 23.32). The variables significantly associated with externalising problems were noise sensitivity (OR = 1.29; 95% CI: 1.09, 1.52), age (OR = 1.26; 95% CI: 1.00, 1.59), ADHD (OR = 10.41; 95% CI: 3.13, 34.60), autism spectrum disorder (OR = 13.15; 95% CI: 1.16, 148.72), and conduct disorder (OR = 27.13; 95% CI: 3.70, 198.73). The variables significantly associated with total behavioural problems were noise sensitivity (OR = 1.37; 95% CI: 1.13, 1.65), noise level (OR = 1.07; 95% CI: 1.01, 1.13), maternal age at birth (OR = 0.90; 95% CI: 0.81, 0.99), passive smoking (OR = 3.06; 95% CI: 1.35, 6.93), ADHD (OR = 8.64; 95% CI: 2.29, 32.54), and conduct disorder (OR = 10.78; 95% CI: 1.09, 1.07.00).

Table 1. Demographic and socioeconomic variables of all subjects according to noise sensitivity

Characteristic		**Total (n=918)**	**Low NS (n=334)**	**High NS (n=580)**	**t-test or χ^2 test**
Age (years)		11.47 ± 1.54	11.47 ± 1.54	11.47 ± 1.54	0.992
Sex					0.091
	Boy	427 (46.5)	144 (42.9)	283 (48.6)	
	Girl	491 (53.5)	192 (57.1)	299 (51.4)	
Education level					
	Elementary school	474 (51.6)	175 (52.1)	299 (51.4)	0.539
	Middle school	444 (48.4)	161 (47.9)	283 (48.6)	0.553
Monthly income (Won)					0.390
	< 4 million	221 (24.4)	75 (22.8)	146 (25.3)	
	≥ 4 million	684 (75.6)	254 (77.2)	430 (74.7)	
Low birth weight		36 (4.0)	15 (4.5)	21 (3.7)	0.528
Premature birth		41 (4.5)	20 (6)	21 (3.7)	0.099
Maternal age at birth (years)		30.28 ± 3.74	30.56 ± 3.34	30.12 ± 3.94	0.443
Passive smoking		127 (13.9)	45 (13.5)	82 (14.1)	0.780
Maternal illness during pregnancy					
	Diabetes	15 (1.6)	7 (2.1)	8 (1.4)	0.415
	Hypertension	8 (0.9)	2 (0.6)	6 (1)	0.494
	Preeclampsia	24 (2.6)	7 (2.1)	17 (2.9)	0.448
	Thyroid disease	12 (1.3)	3 (0.9)	9 (1.5)	0.401
Mental disorders					
	ADHD	15 (1.7)	3 (0.9)	12 (2.1)	0.172
	Specific learning disorder	8 (0.9)	3 (0.9)	5 (0.9)	0.973
	Communication disorder	14 (1.5)	4 (1.2)	10 (1.7)	0.515
	Intellectual disability	4 (0.4)	1 (0.3)	3 (0.5)	0.622
	Autism spectrum disorder	3 (0.3)	1 (0.3)	2 (0.3)	0.899
	Motor disorder	15 (1.7)	4 (1.2)	11 (1.9)	0.410
	Depression	4 (0.4)	1 (0.3)	3 (0.5)	0.612
	Conduct disorder	4 (0.4)	1 (0.3)	3 (0.5)	0.612
Noise level(dBA)	Ldn	56.84 ± 9.34	57.01 ± 9.05	56.74 ± 9.53	0.699
NS		**3.31 ± 2.03**	**2.18 ± 1.31**	**5.67 ± 0.95**	

Abbreviations: ADHD, attention deficit hyperactivity disorder; Ldn, day-night equivalent level; NS, noise sensitivity

Table S1. Noise level at each school

City	Grade	Name	noise level (dB)
Seoul	elementary school	A	49.4
		B	60.8
	middle school	C	54.1
		D	61.9
Ulsan	elementary school	E	50.7
		F	59.2
	middle school	G	49.5
		H	62.0

Table S2. Comparison of behavioural problem ratio according to the noise level in schools

City	Noise level	n	Internalizing problem	p-value	Externalizing problem	p-value	Total behaviour problem	p-value
Seoul	Low noise level (A.C)	222	3.6%	0.994	3.2%	0.484	1.8%	0.396
	High noise level (B,D)	195	3.6%		2.1%		3.1%	
Ulsan	Low noise level (E,G)	231	4.8%	0.957	4.8%	0.957	3.9%	0.853
	High noise level (F,H)	279	4.7%		4.7%		3.6%	

Table 2. Univariate logistic regression analysis of each behavioural problem and candidate variables

Variable		Internalizing problem	p-value	Externalizing problem	p-value	Total problem	p-value
Noise sensitivity		**1.35 (1.15-1.60)**	**<0.001**	**1.29 (1.09-1.52)**	**0.004**	**1.37 (1.13-1.65)**	**0.001**
Noise level (Ldn)		1.01 (0.97-1.05)	0.652	1.03 (0.99-1.08)	0.138	**1.07 (1.01-1.13)**	**0.024**
Age		0.92 (0.75-1.14)	0.461	**1.26 (1.00-1.59)**	**0.047**	1.20 (0.94-1.54)	0.146
Sex		0.81 (0.43-1.54)	0.526	1.31 (0.66-2.60)	0.446	0.80 (0.38-1.68)	0.554
Monthly income		0.59 (0.29-1.17)	0.131	0.77 (0.36-1.64)	0.503	0.58 (0.26-1.26)	0.168
Low birth weight		0.69 (0.09-5.22)	0.723	NA	NA	0.95 (0.13-7.25)	0.964
Premature birth		0.61 (0.08-4.54)	0.627	2.26 (0.66-7.75)	0.195	1.78 (0.41-7.82)	0.443
Maternal age at birth		0.99 (0.90-1.09)	0.835	0.95 (0.86-1.04)	0.256	**0.90 (0.81-0.99)**	**0.033**
Passive smoking		**3.16 (1.55 - 6.46)**	**0.002**	1.96 (0.87 - 4.42)	0.107	**3.06 (1.35-6.93)**	**0.007**
Martenal illness during pregnancy							
	Diabetes	1.71 (0.22-13.35)	0.610	NA	NA	2.30 (0.29-18.14)	0.429
	Hypertension	3.44 (0.41-28.74)	0.253	3.77 (0.45-31.54)	0.221	4.64 (0.55-39.05)	0.158
	Preeclampsia	**3.77 (1.07-13.30)**	**0.039**	1.18 (0.15-9.00)	0.875	1.45 (0.19-11.15)	0.721
Mental disorders							
	ADHD	**6.29 (1.70-23.32)**	**0.006**	**10.41 (3.13-34.60)**	**<0.001**	**8.64 (2.29-32.54)**	**0.001**
	Specific learning disorder	3.41 (0.41-28.41)	0.258	3.73 (0.45-31.18)	0.225	NA	NA
	Communication disorder	NA	NA	2 (0.25-15.71)	0.512	NA	NA
	Intellectual disability	NA	NA	8.76 (0.89-86.46)	0.063	NA	NA
	Autism spectrum disorder	NA	NA	**13.15 (1.16-148.72)**	**0.037**	NA	NA
	Motor disorder	3.75 (0.82-17.28)	0.089	4.12 (0.89-19.03)	0.07	2.28 (0.29-17.98)	0.434
	Depression	NA	NA	8.76 (0.89-86.46)	0.063	NA	NA
	Conduct disorder	8 (0.81-78.81)	0.075	**27.13 (3.70-198.73)**	**0.001**	**10.78 (1.09-107)**	**0.042**

Abbreviations: ADHD, attention deficit hyperactivity disorder; CBCL, child behaviour checklist; CI, confidence interval; Ldn, day-night equivalent level; OR, odds ratio; NS, noise sensitivity.

Behavioural problems

The results of the analysis of the association between noise level, noise sensitivity, related covariates, and behavioural problems are presented in Tables 3, 4, and 5. Noise sensitivity was significantly associated with internalising, externalising, and total behavioural problems, even after adjustment for age, sex, monthly income, premature birth, maternal age at birth, passive smoking, maternal illness during pregnancy, and mental disorders in the multivariate analysis. In contrast, the noise level was significantly associated with total behavioural problems after adjustment for all covariates; however, it did not show any significant association with internalising and externalising problems. Monthly household income was not significantly associated with internalising, externalising, and total behavioural problems.

Internalising problems

Noise sensitivity was significantly associated with the clinical range of internalising problems, and the adjusted OR for a 1-point increase in noise sensitivity was 1.42 (adjusted OR [aOR] = 1.42; 95% CI: 1.15, 1.75). Internalising problems were significantly associated with maternal hypertension during pregnancy (aOR = 5.75, CI: 1.22, 27.12) and preeclampsia (aOR = 3.83, CI: 1.64, 8.92) (Table 3).

Externalising problems

Noise sensitivity was significantly associated with the clinical range of externalising problems. The adjusted OR for a 1-point increase in noise sensitivity was 1.24 (aOR 1.24, CI: 1.02, 1.51). The association between age and externalising problems was not significant after adjustment for sex, monthly income, maternal age at birth, passive smoking, and maternal illness. However, after adjustment for mental disorders, the association became significant (aOR = 1.35, CI: 1.02, 1.78) (Table 4).

Total behaviour problems

Total behavioural problems were significantly associated with the noise level and noise sensitivity, with or without multistep adjustment. The adjusted OR for a 1-point increase in noise sensitivity was 1.33 (aOR = 1.33, CI: 1.04, 1.70) and that of a 1-dB increase in the

Table 3. Associations between internalising problems of the CBCL and noise-related variables

	Model 1		Model 2		Model 3		Model 4	
	OR (95% CI)	p-value	aOR (95% CI)	p-value	aOR (95% CI)	p-value	aOR (95% CI)	p-value
Noise sensitivity	**1.41 (1.17-1.71)**	**<0.001**	**1.43 (1.17-1.73)**	**<0.001**	**1.45 (1.18-1.79)**	**0.001**	**1.42 (1.15-1.75)**	**0.001**
Noise level (Ldn)	1.01 (0.97-1.05)	0.676	1.01 (0.97-1.06)	0.556	1.02 (0.98-1.06)	0.423	1.02 (0.97-1.06)	0.455
Age			0.86 (0.66-1.11)	0.242	0.86 (0.66-1.12)	0.268	0.87 (0.66-1.14)	0.307
Sex			1.11 (0.52-2.40)	0.786	1.10 (0.50-2.43)	0.816	1.02 (0.45-2.30)	0.971
Monthly income			0.74 (0.31-1.74)	0.49	0.95 (0.38-2.40)	0.918	1.07 (0.41-2.79)	0.890
Premature birth					NA	NA	NA	NA
Maternal age at birth					1.00 (0.90-1.12)	0.977	1.00 (0.90-1.12)	0.981
Passive smoking					2.01 (0.15-26.50)	0.597	2.26 (0.17-29.62)	0.535
Maternal illness during pregnancy								
Hypertension					**6.49 (1.45-29.05)**	**0.014**	**5.75 (1.22-27.12)**	**0.027**
Preeclampsia					**3.77 (1.62-8.77)**	**0.002**	**3.83 (1.64-8.92)**	**0.002**
Mental disorders								
ADHD							3.55 (0.49-25.96)	0.212
Motor disorder							1.14 (0.08-16.61)	0.922
Conduct disorder							NA	NA

Abbreviations: ADHD, attention deficit hyperactivity disorder; CBCL, child behaviour checklist; CI, confidence interval; Ldn, day-night equivalent level; OR, odds ratio; NS, noise sensitivity.

Table 4. Associations between externalising problems of the CBCL and noise-related variables

	Model 1		Model 2		Model 3		Model 4	
	OR (95% CI)	p-value	aOR (95% CI)	p-value	aOR (95% CI)	p-value	aOR (95% CI)	p-value
Noise sensitivity	**1.26 (1.04-1.53)**	**0.017**	**1.26 (1.04-1.53)**	**0.017**	**1.27 (1.05-1.55)**	**0.016**	**1.24 (1.02-1.51)**	**0.033**
Noise level (Ldn)	1.03 (0.99-1.08)	0.154	1.03 (0.98-1.08)	0.21	1.03 (0.98-1.08)	0.271	1.03 (0.98-1.08)	0.247
Age			1.28 (0.98-1.66)	0.066	1.27 (0.98-1.66)	0.076	**1.35 (1.02-1.78)**	**0.038**
Sex			0.58 (0.26-1.33)	0.199	0.57 (0.25-1.31)	0.185	0.55 (0.24-1.29)	0.170
Monthly income			1.19 (0.44-3.24)	0.728	1.44 (0.48-4.32)	0.512	1.53 (0.50-4.72)	0.456
Premature birth					3.95 (1.01-15.52)	0.049	3.08 (0.71-13.41)	0.135
Maternal age at birth					0.98 (0.87-1.09)	0.686	0.98 (0.88-1.10)	0.756
Passive smoking					3.67 (0.25-54.13)	0.343	4.09 (0.26-63.59)	0.315
Maternal illness during pregnancy								
Hypertension					0.82 (0.07-9.41)	0.874	0.93 (0.08-11.3)	0.954
Preeclampsia					2.32 (0.87-6.19)	0.094	2.31 (0.85-6.25)	0.099
Mental disorders								
ADHD							10.07 (0.85-119.69)	0.068
Motor disorder							NA	NA
Conduct disorder							NA	NA

Abbreviations: ADHD, attention deficit hyperactivity disorder; CBCL, Child Behaviour Checklist; CI, confidence interval; Ldn, day-night equivalent level; OR, odds ratio; NS, noise sensitivity.

noise level was 1.08 (aOR = 1.08, CI: 1.01, 1.15). In addition to the noise-related variables, the only variable that was significantly associated with behavioural problems was preeclampsia during pregnancy (aOR 4.47, CI: 1.61, 12.42) (Table 5).

Noise sensitivity and income

In Table 6, we present the results from the analyses of the association between behavioural problems and noise sensitivity, stratified by monthly income. The effect estimates were higher in the low-income group than the high-income group, in analyses on internalising, externalising, and total behavioural problems. In the high-income group, the association between externalising problems and noise sensitivity disappeared. The high-income group lived in environments with higher noise levels, lived closer to roads, and had a higher maternal age at birth. Students in the low-income group were shorter in height, had a lower body weight, had parents with a lower education level, had higher exposure to passive smoke, had a higher percentage of fathers who were smokers, and spent longer time on smartphone/computer game use (Supplement Table 3).

Sensitivity analysis

In the sensitivity analysis, the significance of the associations between noise sensitivity, noise levels, and behavioural problems was maintained after excluding those students who had lived in their respective residential area for less than 1 year (n = 20, Supplement Table 4).

Table 5. Multivariate logistic regression analysis of CBCL total problems and noise-related variables

	Model 1		Model 2		Model 3		Model 4	
	OR (95% CI)	p-value	aOR (95% CI)	p-value	aOR (95% CI)	p-value	aOR (95% CI)	p-value
Noise sensitivity	**1.36 (1.09-1.71)**	**0.008**	**1.36 (1.08-1.71)**	**0.008**	**1.35 (1.06-1.72)**	**0.014**	**1.33 (1.04-1.70)**	**0.022**
Noise level (Ldn)	**1.07 (1.01-1.14)**	**0.024**	**1.07 (1.01-1.14)**	**0.024**	**1.07 (1.01-1.14)**	**0.034**	**1.08 (1.01-1.15)**	**0.034**
Age			1.25 (0.93-1.69)	0.141	1.24 (0.91-1.68)	0.168	1.27 (0.93-1.75)	0.135
Sex			1.23 (0.50-3.04)	0.652	1.26 (0.50-3.18)	0.626	1.22 (0.47-3.13)	0.683
Monthly income			0.82 (0.29-2.34)	0.714	1.20 (0.38-3.82)	0.762	1.29 (0.40-4.19)	0.675
Premature birth					1.54 (0.18-13.24)	0.693	1.59 (0.18-13.89)	0.674
Maternal age at birth					0.92 (0.80-1.05)	0.22	0.93 (0.81-1.06)	0.275
Passive smoking					1.87 (0.08-44.98)	0.701	2.09 (0.09-51.35)	0.652
Maternal illness during pregnancy								
Hypertension					1.69 (0.13-21.71)	0.687	1.74 (0.12-24.27)	0.682
Preeclampsia					**4.49 (1.64-12.31)**	**0.004**	**4.47 (1.61-12.42)**	**0.004**
Mental disorders								
ADHD							6.20 (0.41-92.77)	0.186
Motor disorder							NA	NA
Conduct disorder							NA	NA

Abbreviations: ADHD, attention deficit hyperactivity disorder; CBCL, child behaviour checklist; CI, confidence interval; Ldn, day-night equivalent level; OR, odds ratio; NS, noise sensitivity.

Table 6. Associations between behavioural problems and noise sensitivity stratified by income

CBCL	Income	n	Crude OR (95% CI)	p-value	Model 1, OR* (95% CI)	p-value
Internalizing problem	low	185	**1.54 (1.08-2.18)**	**0.016**	**1.63 (1.11-2.39)**	**0.012**
	high	570	**1.33 (1.08-1.65)**	**0.008**	**1.37 (1.09-1.71)**	0.006
Externalizing problem	low	185	**1.54 (1.03-2.32)**	**0.037**	**1.62 (1.04-2.52)**	**0.032**
	high	570	1.18 (0.96-1.44)	0.111	1.19 (0.97-1.46)	0.091
Total problem	low	185	1.48 (0.99-2.21)	0.057	**1.55 (1.00-2.40)**	**0.050**
	high	570	1.26 (0.99-1.60)	0.059	**1.29 (1.01-1.66)**	**0.044**

Abbreviations: CBCL, child behaviour checklist; CI, confidence interval; OR, odds ratio.

*adjusted for age, sex, noise level (day-night equivalent level).

Table S3. Demographic, socioenvironmental, and developmental variables of all subjects according to income

	All		Low income		High income		p-value
Variables	**n**	**mean ± SD or %**	**n**	**mean ± SD or %**	**n**	**mean ± SD or %**	
Height	243	150.83 ± 11.39	52	147.98 ± 12.43	191	151.6 ± 11.00	**.042**
Weight	243	44.29 ± 12.06	52	41.13 ± 12.22	191	45.15 ± 11.90	**.033**
NS	900	3.32 ± 2.03	221	3.37 ± 1.98	684	3.30 ± 2.05	.566
Noise level (Ldn)	762	56.82 ± 9.38	187	55.47 ± 10.98	575	57.26 ± 8.77	**.024**
Educational level of father							**<0.001**
Less than high school	2	0.2%	2	0.9%	0	0.0%	
High school diploma	177	20.0%	82	38.3%	95	14.1%	
Associate's degree	159	17.9%	48	22.4%	111	16.5%	
Bachelor's degress	423	47.7%	72	33.6%	351	52.2%	
More than Master's degress	126	14.2%	10	4.7%	116	17.2%	
Educational level of mother							**<0.001**
Less than high school	2	0.2%	1	0.5%	1	0.1%	
High school diploma	197	22.0%	85	39.7%	112	16.4%	
Associate's degree	202	22.5%	63	29.4%	139	20.4%	
Bachelor's degress	427	47.6%	60	28.0%	367	53.7%	
More than Master's degress	69	7.7%	5	2.3%	64	9.4%	
Distance to nearest road							**0.015**
neighboring road	195	21.6%	36	16.2%	159	23.3%	
< 50m	215	23.8%	49	22.1%	166	24.3%	
>50m, ≤ 100m	292	32.3%	79	35.6%	213	31.2%	
>100m, ≤ 500m	187	20.7%	56	25.2%	131	19.2%	
≥ 500m	15	1.7%	2	0.9%	13	1.9%	
Father's age at	885	32.75	210	32.41 ±	675	32.86 ±	0.139

birth (years)		± 3.84		4.05		3.77	
Mother's age at birth (years)	896	30.26 ± 3.74	214	29.70 ± 4.05	682	30.44 ± 3.62	**0.012**
Breast feeding							0.488
No	330	36.5%	76	34.5%	254	37.1%	
Yes	574	63.5%	144	65.5%	430	62.9%	
Smoking status of father							**0.009**
Never smoker	337	37.3%	65	29.8%	272	39.7%	
Former smoker	244	27.0%	63	28.9%	181	26.4%	
Current smoker	322	35.7%	90	41.3%	232	33.9%	
Smoking status of mother							**0.06**
Never smoker	892	98.8%	215	97.7%	677	99.1%	
Former smoker	6	0.7%	2	0.9%	4	0.6%	
Current smoker	5	0.6%	3	1.4%	2	0.3%	
Passive smoking							**0.007**
No	779	86.3%	177	80.8%	602	88.0%	
Yes	124	13.7%	42	19.2%	82	12.0%	
Smartphone usage							**0.002**
Never	115	12.7%	27	12.2%	88	12.9%	
< 1 hour	374	41.4%	66	29.9%	308	45.1%	
1-3 hours	306	33.8%	96	43.4%	210	30.7%	
3-5 hours	90	10.0%	23	10.4%	67	9.8%	
≥ 5 hours	19	2.1%	9	4.1%	10	1.5%	
Computer/Video game usage							**<0.001**
Never	100	11.1%	17	7.7%	83	12.2%	
< 1 hour	462	51.3%	87	39.4%	375	55.1%	
1-3 hours	289	32.1%	96	43.4%	193	28.4%	
3-5 hours	42	4.7%	17	7.7%	25	3.7%	
≥ 5 hours	8	0.9%	4	1.8%	4	0.6%	

Abbreviations: CI, confidence interval; Ldn, day-night equivalent level; NS, noise sensitivity; OR, odds ratio.

Table S4. Association between behavioural problems, noise, and noise-sensitivity, excluding subjects living in their residential area for less than 1 year

	Crude		Adjusted I		Adjusted II		Adjusted III	
	OR (95% CI)	p-value	aOR (95% CI)	p-value	aOR (95% CI)	p-value	aOR (95% CI)	p-value
Internalizing problem								
Noise sensitivity	**1.41 (1.17-1.71)**	**<0.001**	**1.42 (1.17-1.73)**	**<0.001**	**1.45 (1.18-1.79)**	**0.001**	**1.42 (1.15-1.75)**	**0.001**
Noise level (Ldn)	1.01 (0.97-1.05)	0.701	1.01 (0.97-1.06)	0.564	1.02 (0.97-1.06)	0.432	1.02 (0.97-1.06)	0.457
Externalizing problem								
Noise sensitivity	**1.26 (1.04-1.53)**	**0.018**	**1.26 (1.04-1.53)**	**0.017**	**1.27 (1.05-1.55)**	**0.016**	**1.24 (1.02-1.51)**	**0.032**
Noise level (Ldn)	1.03 (0.99-1.08)	0.156	1.03 (0.98-1.08)	0.217	1.03 (0.98-1.08)	0.284	1.03 (0.98-1.08)	0.250
Total problem								
Noise sensitivity	**1.36 (1.08-1.71)**	**0.008**	**1.36 (1.08-1.7)**	**0.008**	**1.35 (1.06-1.72)**	**0.014**	**1.32 (1.04-1.68)**	**0.023**
Noise level (Ldn)	**1.07 (1.01-1.14)**	**0.024**	**1.08 (1.01-1.15)**	**0.026**	**1.07 (1-1.14)**	**0.037**	**1.07 (1-10.15)**	**0.037**

Abbreviations: CI, confidence interval; Ldn, day-night equivalent level; NS, noise sensitivity; OR, odds ratio

Sensitivity analysis: participants who had been living at their current house less than 1 year were excluded

Adjusted I: age, sex, income

Adjusted II: premature birth, maternal age at birth, maternal disease during pregnancy (hypertension, preeclampsia), passive smoking

Adjusted III: mental disorders (ADHD, motor disorder, conduct disorder)

Discussion

This population-based study investigated associations between noise-related variables and the mental health of children and adolescents, measured using the CBCL. Noise was significantly associated with total behavioural problems, and noise sensitivity was significantly associated with internalising, externalising, and total behavioural problems after adjustment for various variables that could affect the children and adolescents' behavioural problems. This is the first report on the impact of noise sensitivity in children and adolescents, and our findings suggest that the negative impact of noise and noise sensitivity on mental health occurs from childhood.

Road-traffic noise in residential areas was significantly associated with total behavioural problems but not with internalising and externalising problems. In a longitudinal study on German children, road traffic noise and noise caused by neighbours were found to be risk factors for high total difficulty scores as well as high scores on the emotional symptoms, conduct problems, and hyperactivity subscales of the Strengths and Difficulties Questionnaire.[43)] However, this study was limited by the fact that it was based on subjectively assessed noise, not actual noise levels. Previous studies on the effect of road traffic noise exposure at school have reported no link between road traffic noise at school and children and adolescents' mental health.[37, 44, 45)] Meanwhile, aircraft noise exposure at school was associated with more hyperactivity symptoms.[36, 44, 45)] Therefore, the effects of noise on children could vary depending on the type of noise (e.g. road traffic, air traffic, neighbourhood noise) and the exposure location (e.g. school, home). In an additional analysis of our study, the proportion of students with behavioural problems did not differ according to the noise level at their school. Altogether, noise exposure in the evening and at night in residential areas may be more important for mental health than that during school activities.

In the present study, a 1-point increase in the noise sensitivity of children and adolescents increased their internalising problem score by 1.42, their externalising problem score by 1.24, and their total behavioural problem score by 1.33. This result is in concordance with previous studies on adults that have reported a relationship between noise sensitivity and

depression, anxiety, and nonspecific somatic complaints.[29, 46, 47] It has been reported that children with internalising problems are more vulnerable to depression later on[48-50] and that those with externalising problems are more likely to be diagnosed with anxiety disorder in the future.[50, 51] Behavioural problems in children and adolescents could lead to impairments in social skills, self-confidence, and peer relationships.[52] As a result, these behavioural problems might have long-term implications for educational attainment and occupational opportunities.[39, 40] Therefore, it is important to screen such problems early and intervene to avoid negative outcomes; noise sensitivity may be an important indicator in this process.

In the present study, the association between children and adolescents' behavioural problems and noise sensitivity was more consistent than the association with noise levels. Unlike noise, which was associated only with total behavioural problems, noise sensitivity showed significant associations with more specific items such as internalising and externalising problems, and the significance level of these associations was lower for noise sensitivity than for noise. For total behavioural problems, the effect of a 1-point increase in noise sensitivity was comparable to a 5-dB increase in noise level (OR = 1.40). Meanwhile, noise levels were not significantly different between the groups with high and low noise sensitivity, suggesting that noise sensitivity affects behavioural problems by a mechanism that is different from noise. This result corroborates a previous study conducted in the same region by our research group that showed that noise sensitivity rather than noise was predictive of adults' mental health, as manifested in depression, anxiety, insomnia, and stress.[53] It is also consistent with the findings of previous studies showing that noise sensitivity, independent of the noise level, is a factor that negatively influences physical and mental health.[26, 29, 54, 55] As higher cortisol levels[56] and hyperactivation of the sympathetic–adrenal–medullary system and hypothalamic–pituitary–adrenal axis[57-59] are observed in individuals with high noise sensitivity, it is assumed that stress reactivity is increased in those individuals.

Because some studies have suggested that prolonged noise exposure increases noise sensitivity,[55, 60] when interpreting the results of the present study, it should be considered that the exposure duration was not included in the analysis. However, the significance of the association between noise sensitivity and behavioural problems in children and adolescents did not change after excluding people who had lived for less than 1 year in their respective

residential area.

In this study, gestational hypertension was significantly associated with internalising problems, and preeclampsia was significantly associated with internalising and total behavioural problems. Gestational hypertension and preeclampsia can lead to abnormalities in blood perfusion and foetal nutrition. It can thus be assumed that both would have a negative effect on brain development, which would increase behavioural problems as well.[61, 62] In a previous study that investigated the relationships between gestational hypertension or preeclampsia and behavioural problems, gestational hypertension had a positive association with behavioural problems, while preeclampsia had a negative association with behavioural problems in some age groups,[63] suggesting that the use of maternal antihypertensive agents during pregnancy may have affected the neurocognitive functions of the children.[64, 65] However, information on the use of antihypertensive agents was not obtained in this study.

In genetic studies in monozygotic and dizygotic twins, noise sensitivity showed a heritability of 40%.[66] Because noise sensitivity played a role as an indicator of mental health from childhood in the present study, it could be a trait that is inherited and expressed from childhood. Some studies have insisted that noise sensitivity is a kind of personality trait, and studies investigating relationships between personality traits and noise sensitivity show that neuroticism has a relatively consistent association with noise sensitivity.[21, 67-70] However, there have been controversies regarding the association between noise sensitivity and personality, and other factors besides personality seem to be involved in the variability of noise sensitivity.[71] In addition, considering that personality is being formed during childhood and the adolescent period, longitudinal studies are needed to investigate the time course of noise sensitivity and whether it is maintained during development.

We found that the magnitude of the association between noise sensitivity and behavioural problems decreased in the high-income group. A high income level seems to be a protective factor against the negative impact of noise and noise sensitivity, in that the influence of noise sensitivity on behavioural problems was found to be reduced even when the average noise level was higher in the high-income group. In particular, the significance of the association between noise sensitivity and externalising problems disappeared in the high-income group. This result is consistent with previous studies reporting that household income is more

closely related to externalising problems than to internalising problems.[4, 72-74] Furthermore, the present findings that the association between noise sensitivity and internalising problems are maintained in the high-income group further support the claim mentioned earlier that noise sensitivity is a kind of personality trait.

Children and adolescents from low-income families showed a higher magnitude of association between noise sensitivity and behavioural problems than those from high-income families. Children and adolescents from low-income households have high scores on both self-reported[75] and biologically assessed stress.[76] It can thus be assumed that children and adolescents with high noise sensitivity (individuals who are vulnerable to environmental stress factors, such as noise) become more vulnerable to stress because of their external environment (at a low socioeconomic level). As a result, noise sensitivity may be related to a lack of attention control, which manifests as an internalising problem rather than as a lack of behavioural control, manifesting as an externalising problem.[77]

The higher rate of passive smoking and higher smartphone and game use in the low-income group (Supplementary Table 3) could be due to an environmental effect of low socioeconomic status, such as low accessibility to health knowledge because of poor parental education; however, passive smoking or addictive behaviours could also be a biological effect on brain development. It has been assumed that the auditory cortex, brainstem, reticular formation, amygdala, and hippocampus are involved in noise-induced responses.[78] In a study using EEG and fMRI,[79] an attempt was made to find differences in physical sensitivity according to noise sensitivity, but no definite conclusion could be reached. Further studies are therefore needed to understand the biological mechanism of noise sensitivity.

Strengths and Limitations

As a large population-based study conducted in two large cities in Korea, the present study confirms the association between noise and noise sensitivity and behavioural problems in children and adolescents. The main strength of our study is that the noise level was measured accurately because we created a noise map using direct measurements, unlike previous studies that used subjective noise estimates or outdated existing noise maps. In addition, this

is the first study that examines the effects of noise sensitivity on the mental health of children and adolescents.

However, the current study has several limitations. First, the measurements of noise sensitivity reflect not only the evaluation of the subject but also the opinions of their parents. Thus, there may be a controversy as to whether findings related to noise sensitivity from previous studies in adults can be applied to the interpretation of our results in children and adolescents. However, parental reporting is an important source of information when studying children and adolescents because these subjects have limited self-reflection. In addition, since the scale for assessing behavioural problems used in this study is also based on parental reporting, the fact that noise sensitivity also reflects parental evaluations is consistent and seems appropriate.

Second, in this study, only the residents of two large cities, Seoul and Ulsan, were included. Generally, large cities have higher average noise levels than do rural areas, and the proportion of aircraft noise and road traffic noise is higher, resulting in different types of noise distribution compared with rural areas. Urban areas also reflect different socioeconomic factors. Therefore, the effects of noise and noise sensitivity found in this study might not apply to the general population but only to specific groups.

Third, because this is a cross-sectional study, we could not determine the causality of the association. To investigate temporal changes in noise sensitivity in children and adolescents as well as to infer causality, further studies are needed.

Fourth, the noise level was calculated based on the exterior wall of the building. Therefore, the association between noise and mental health in this study may not reflect the effect of indoor noise actually exposed by the participants in the building.

Conclusion

We observed the negative mental health effects of noise in childhood. In addition, noise sensitivity and noise itself play an important role in the mental health of children and adolescents. The associations between noise sensitivity and emotions or behaviours were stronger in the low-income group. Therefore, when developing strategies to cope with mental health problems caused by noise in children and adolescents, subgroups classified by noise sensitivity or the socioeconomic status may require different approaches. Noise is an inevitable problem in modern societies, and considering long-term implications on behavioural problems in children and adolescents in terms of their educational and professional prospects, additional studies, including longitudinal studies, are needed.

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국문요약

서론

성인에서 소음과 소음민감도와 정신건강과의 관련성에 대하여 보고된 바 있으나, 아동에서의 연구는 부족하다. 본 연구는 아동청소년에서 소음, 소음민감도가 정신건강에 끼치는 부정적인 영향을 살펴보고 사회환경적 변수들과의 관련성을 살펴보았다.

연구대상 및 방법

두 대도시에서 시행된 인구기반 단면 연구로서 918 명의 초등학생과 중학생이 모집되었다. 연구 지역의 소음 수준은 소음측정 후 보간법을 이용해 소음지도를 작성하고, 소음지도를 바탕으로 연구대상자의 거주지 도로교통 소음을 계산하였다. 소음 민감도는 11 점 리커트 척도를 통해 평가하였다. 다항 로지스틱 회귀를 이용하여 소음, 소음민감도와 문제행동과의 연관성을 살펴보았다. 소득수준에 따라 자료를 세분화하여 추가 분석을 시행하였다.

결과

소음민감도는 내재화문제, 외현화문제, 총문제행동과 유의한 연관이 있었다. 이에 비해, 소음 수준은 총문제행동 점수와만 유의한 연관이 있었다. 소득이 낮은 군에서 소음민감도와 문제행동과의 연관성의 정도가 더 컸으며 소득 수준이 높은 군에서 소음민감도와 외현화 문제와의 연관성이 사라졌다.

결론

아동청소년에서 소음 및 소음민감도가 정신건강에 대한 부정적인 영향을 확인하였다. 소득 수준이 낮은 집단에서 소음민감도와 정서행동 특성간의 관련성이 더 컸다. 향후 아동청소년의 정신건강에 대한 소음의 영향을 개선하는 계획 수립 시, 소음민감도와 사회경제적 요인에 따라 개별적 접근이 필요하다.