Original Article

Sociodemographic Factors and Mental Distress as Determinants of Perceived Noise Pollution in Four European Regions

Triin Veber[1], Steven Nordin[2], John Andersson[2], Kati Orru[3], Hans Orru[1]

[1]Institute of Family Medicine and Public Health, University of Tartu, Tartu, Estonia, [2]Department of Psychology, Umeå University, Umeå, Sweden, [3]Institute of Social Studies, University of Tartu, Tartu, Estonia

Abstract

Background: Perceived environmental noise, in addition to objective sound levels, influences stress, sleep, and other health risks. This study examined sociodemographic and mental-distress factors associated with four aspects of noise perception: perceived noise pollution level, noise-related health risk perception, annoyance, and noise sensitivity. **Methods:** A population-based online survey of 4179 adults was conducted in Estonia, the Oresund area (Sweden/Denmark), Catalonia (Spain), and Kosovo. Participants rated aspects of noise perception on five-point scales. Predictors included region, age, gender, education, minority status, household income comfort, along with symptoms of anxiety, depression, burnout (6-item version of the Shirom–Melamed Burnout Measure), and sleep disturbance (Karolinska Sleep Questionnaire). One-way analyses of variance (Bonferroni-adjusted) tested group differences, and hierarchical regressions assessed unique contributions. **Results:** On average, participants rated the perceived pollution level, health risk, annoyance, and sensitivity at 2.89, 2.73, 3.09, and 2.66, respectively, on a 1-to-5-point scale. All ratings on each aspect differed by region and age, with the highest overall ratings in Kosovo and Catalonia. Younger adults rated all four aspects of noise perception higher than older adults. Women rated annoyance and sensitivity higher, minorities reported higher perceived noise pollution and health risk perception, and university education was associated with greater perceived noise pollution, annoyance, and sensitivity. Income difficulties were negatively associated with health risk perception and sensitivity. All mental distress indicators were positively associated with noise perception aspects, with burnout showing the strongest associations. Mental distress accounted for more unique variance (3.3%–9.9%) than sociodemographic factors (2.6%–4.8%). **Conclusions:** The perception of environmental noise varies by region and demographic profile but is strongly associated with mental distress, particularly burnout, underscoring the need for interventions that integrate noise mitigation and mental health support.

Keywords: noise, risk, perception, anxiety, depression, sleep quality

Key Messages

(1) Individuals' perceptions of environmental noise, including perceived pollution, health risk beliefs, annoyance, and sensitivity, vary significantly across Europe.
(2) Mental distress, especially burnout, predicts environmental noise perception more strongly than sociodemographic variables do.
(3) Interventions should address noise exposure and mental distress, especially burnout.

Introduction

The social cost of environmental noise—unwanted or harmful outdoor sounds created by human activities—in the EU has been estimated at €95.6 billion per year.[1] The most frequently reported health issues associated with noise pollution include annoyance, sleep disturbance, cognitive difficulties, cardiovascular disease, and metabolic disorders, such as type 2 diabetes and obesity.[2-5] Approximately 20% of the population in Europe (112 million people) are exposed to long-term noise that

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Address for correspondence: Hans Orru, Institute of Family Medicine and Public Health, University of Tartu, Ravila 19, Tartu 50409, Estonia. E-mail: Hans.Orru@ut.ee

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exceeds the thresholds set by the Environmental Noise Directive.[1] In particular, road traffic noise is a major source of annoyance that contributes to noise-related health problems,[6] with more than 50% of the urban inhabitants in European countries exposed to such noise.[7,8]

The health impacts of environmental noise depend not only on objective noise levels but also on individuals' perceptions of and reactions to noise. Individuals who perceive environmental noise as disturbing are more likely to report negative noise-related health effects, regardless of the actual decibel level.[9] Perceived noise pollution plays an important indirect role in various health conditions.[10] Noise perception is not only cognitive but also emotional, leading to substantial individual differences in responses to noise, including annoyance.[11,12] According to the noise/stress hypothesis, cognitive and emotional responses act as regulating mediators between noise exposure and stress reactions, which, in turn, impact biological parameters (e.g., blood pressure), potentially contributing to disease.[10] Accordingly, the WHO guidelines[5] indicate that noise annoyance predicts chronic stress, sleep disturbance, and related health conditions. These psychological factors can lead to inflammation and oxidative stress, which in turn contribute to cardiovascular and metabolic diseases, mental health disorders, and even premature death.[1]

Perceptions of environmental noise pollution (noise perception) influence health and well-being broadly, including self-perceived health, self-perceived happiness, and life satisfaction.[9] The present study considers four aspects of noise perception: perceived pollution level of noise (loudness, duration, and noise spectrum), noise-related health risk perception, annoyance, and noise sensitivity.[13-15]

The WHO[16] has highlighted the need to identify groups vulnerable to environmental noise pollution based on sociodemographic factors and health status, emphasizing health inequality. A nationwide US study found that non-white and low-socioeconomic-status residents encounter higher levels of environmental noise.[17] However, because individuals respond differently to the same level of exposure,[11] understanding differences in noise perception among vulnerable groups is of great importance.

Research on perceived noise pollution is limited. A Chinese study linked higher perceived noise pollution to increased anxiety, stress, and sleep disturbance.[18] Furthermore, limited evidence suggests that women, younger people, those with low socioeconomic status, and minorities may perceive their environmental noise-related health risks as higher.[19] Annoyance from environmental noise is more common among women, middle-aged individuals, immigrants, low-income individuals, and those with symptoms of depression or anxiety.[20-23] Systematic reviews suggest that noise annoyance is associated with depression, generalized anxiety disorder, and poor overall mental health[24] and that annoyance, along with sleep disturbance, mediates the relationship between noise exposure and poor mental health.[25] Sensitivity to environmental noise is more common in women and those suffering from anxiety, depression, sleep disturbance, or exhaustion syndrome,[14,21,26,27] but may be unrelated to age or education.[28]

Noise pollution varies across Europe, with estimated proportions of people exposed to harmful noise levels above the Environmental Noise Directive threshold (day–evening–night noise level) differing considerably between countries: 9% for Estonia, 16% for Denmark, 25% for Spain, and 29% for Sweden.[1] However, no study has investigated the various aspects of environmental noise perception across European regions.

The study aims to identify the factors that influence people's perceptions of noise pollution (perceived noise pollution, health risk perception, annoyance, and sensitivity) and to assess the unique strength of each factor across these aspects. Two research questions were addressed: First, which sociodemographic factors and aspects of mental distress are determinants of the four aspects of noise perception? Second, (i) to what extent do sociodemographic factors explain unique variance in each of the four aspects of noise perception that cannot be explained by either mental distress or other sociodemographic factors, and conversely, (ii) to what extent do aspects of mental distress explain such variance that cannot be explained by either sociodemographic factors or other aspects of mental distress?

Materials and Methods

Study Design

The research questions were addressed using the following study design [Figure 1].

Study Population

Population-based questionnaire data from Estonia, the Oresund area, Catalonia, and Kosovo were analyzed. These four regions from Northern, Southern, and Southeastern Europe were chosen to reflect variation in geographic location, cultural and historical context, economic development, environmental pollution levels, and health systems. We recruited at least 1000 persons aged 18 years and older from each region, ensuring that each regional sample had an age and gender distribution matching that of its adult population.

This study was approved by the Swedish Ethical Review Authority (Dnr 2024-01363-01), Research Ethics Committee of the University of Tartu (392/T-1), and Comité de Ética de la Investigación con medicamentos del Parc de Salut MAR (2024/11455). All participants ticked the box to agree to participate before beginning the questionnaire.

Questions and Questionnaire Instruments

The participants responded to a questionnaire in their local language that included single questions and validated

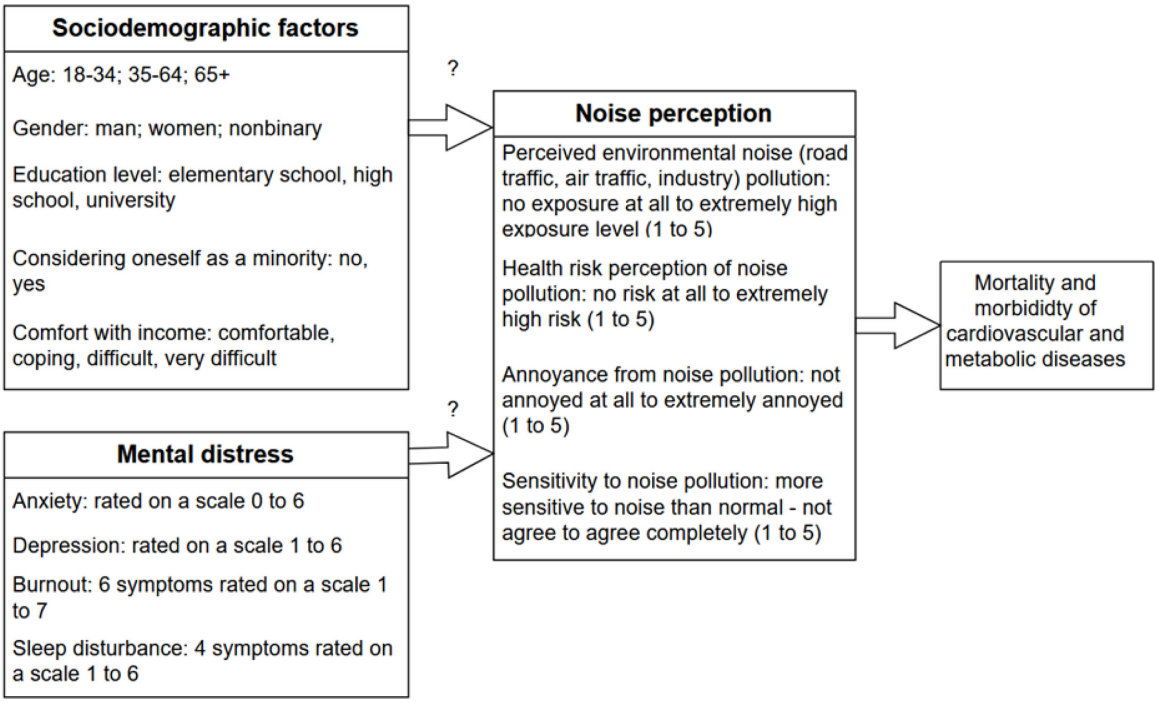

Figure 1: The study design.

questionnaire instruments on the four aspects of noise perception, sociodemographic factors, and mental distress. The sociodemographic factors included European region, age, gender, education level, self-identification as a minority, and comfort regarding one's household income. The aspects of mental distress included symptoms of anxiety, depression, burnout, and sleep disturbance and were chosen partly due to their association with noise perception and partly due to their high prevalence in the general adult population. For example, prevalence rates for symptoms in Sweden have been reported as 14% for anxiety, 6% for depression, 17% for burnout, and 29% for sleep disturbance.[29]

Regarding perceptions of noise, encompassing noise from road traffic, air traffic, and industry as examples, participants responded to four questions. Perceived pollution level of noise was assessed with the question "How would you rate the extent to which you are exposed to noise in your living environment?," responded to on a five-point scale ranging from "No exposure at all" (1) to "Extremely high level of exposure" (5). Health risk perception was assessed with the question "How would you rate the risk of noise affecting your health?," responded to on a five-point scale ranging from "No risk at all" (1) to "Extremely high risk" (5). Annoyance was assessed with the question "How would you rate the extent to which you are annoyed by noise?," responded to on a five-point scale ranging from "Not annoyed at all" (1) to "Extremely annoyed" (5). Sensitivity was assessed with the question "To what extent do you agree with the statement 'I am more sensitive to noise than what is normal'?," responded to on a five-point scale ranging from "Do not agree at all" (1) to "Agree completely" (5).

Age was classified as "18–24 years," "25–34 years," "35–44 years," "45–54 years," "55–64 years," and "65+ years." To achieve sufficient statistical power, these were categorized into the subgroups 18 to 34, 35 to 64, and 65+ years. Gender was assessed with the question "With which gender do you identify?" with the options "Man," "Woman," "Non-binary," and "I prefer not to answer." Because only 12 participants identifying as nonbinary, low statistical power motivated excluding these participants as a subgroup in analyses that included gender as a variable, resulting in the categories "Man" and "Woman." Education level was assessed with the question "What is your highest education?" with the options "Elementary school," "High school," and "University." Self-identification as a minority was assessed with the question "Do you consider yourself belonging to a minority (e.g., culturally, ethnically, health- or handicap-related, or sexual orientation)?" with the response options "No," "Yes," and "I prefer not to answer." Comfort with household income was assessed with the question "How do you presently perceive your household income?" with the options "I find it very difficult with the present income," "I find it difficult with the present income," "I can cope with the present income," "I live comfortably with the present income," and "I prefer not to answer."

Regarding mental distress, the symptom levels of anxiety and depression were assessed separately with the question "To what extent do you experience anxiety (strong worry)/ depression?," responded to from "Not at all" (0) to "A little" (1), "Partly" (2), "Pretty much" (3), "Rather much" (4), "To a large extent" (5), and "Extremely much" (6), which has ratio-scale properties and good reliability and validity.[30]

For categorization, responses of 0 to 2 were considered noncaseness, and responses of 3 to 6 were considered caseness of anxiety and depression symptoms.

Burnout was assessed with the 6-item version of the Shirom–Melamed Burnout Measure (SMBM-6).[31] Each item (e.g., "I feel physically exhausted") is rated on a 7-point scale ranging from "Almost never" (1) to "Almost always" (7). A mean score is calculated across items, with higher scores indicating greater burnout. The SMBM-6 has shown good internal consistency, construct validity, dimensionality, and model fit for clinical exhaustion disorder.[32] The internal consistency for the present sample was $\alpha = 0.92$. For categorization, a cutoff of 3.75+ was used to determine the caseness of burnout.[32]

Symptom level of sleep disturbance was assessed with the 4-item Sleep Quality subscale of the Karolinska Sleep Questionnaire.[33] Each item (e.g., "Difficulties falling asleep") is rated on a 6-point scale ranging from "Never" (0) to "Seldom (occasionally)" (1), "Sometimes (several times per month)" (2), "Often (1–2 times per week)" (3), "Most of the time (3–4 times per week)," and "Always (5 times or more per week)" (5). The Sleep Quality subscale has good internal consistency and criterion validity, and satisfactory construct validity.[34] The internal consistency for the present sample was $\alpha = 0.89$. For categorization, responding 4 or 5 (at least three times per week) to at least one item was considered caseness for sleep disturbance, in accordance with the Fifth Edition of the Diagnostic and Statistical Manual of Mental Disorders DSM-5 criteria for insomnia.

Procedure

This study was part of the research project "Methodologies for Assessing the Real Costs to Health of Environmental Stressors." Under the administration of the research company Kantar Emor, participants were invited from a pool of people who had expressed a willingness to participate in research studies. An invitation to participate was sent by email. They employed basic quality-control measures, including limiting access to the survey link to invited participants and excluding incomplete responses from analysis. In addition, response completion time and item completeness were reviewed to identify potentially low-quality responses. If the survey was not completed within 3 weeks, the person received a reminder by email.

Data Analysis

The four regional subsamples and the entire sample were described in terms of background variables. These variables were comparatively analyzed across subsamples using one-way analysis of variance (ANOVA) for continuous variables and chi-square tests for categorical variables. For the first research question about the identification of determinants of noise perception, the variance inflation factor (VIF) for multicollinearity between age, gender, education level, minority, and household income comfort was calculated by considering these five variables as independent variables and the perception of noise pollution as the dependent variable, with separate analyses for each of the four aspects of the perception of noise pollution. Following James *et al.*,[35] a VIF greater than 3 indicated that multicollinearity was not a problem. One-way ANOVAs were then conducted for level of perceived noise pollution, health risk perception, annoyance, and sensitivity as dependent variables. The cutoff-based categorical data for caseness were used regarding mental distress. Bonferroni correction was applied for analyses of sociodemographics ($P < 0.0021$) and mental distress ($P < 0.0031$). The effect size measure of eta squared was used and interpreted according to Cohen.[36] Post hoc Tukey's honestly significant difference test was conducted to compare sociodemographic subgroups when meeting the Bonferroni-corrected P value. Because the chosen cutoff scores can be questioned, supplementary analyses on this research question were conducted by instead using continuous data for the mental distress variables. For a more direct comparison, correlational analyses were conducted on the sociodemographic factors. However, because the variable was nominal, the region was excluded from these analyses. Pearson and Spearman correlation analyses were conducted because some variables were ordinal. Bonferroni correction was applied ($P < 0.0056$). The effect sizes of the correlation coefficients were interpreted according to Dancey and Reidy.[37] The results from these analyses are presented in the Supplementary material.

Regarding the second research question about the unique strength of determinants, the VIF for multicollinearity was calculated identically to that for the first research question, except that the sociodemographic variables were replaced with symptoms of anxiety, depression, burnout, and sleep disturbance. Thereafter, two sets of hierarchical regression analyses were conducted with each of the four aspects of noise perception as dependent variables. This approach enabled a direct comparison of the extent to which sociodemographic and mental distress variables explained the unique variance in noise perceptions. In the first analysis, sociodemographic factors were included in the first block, and aspects of mental distress in the second block. In the second analysis, the order was reversed, with mental distress aspects in the first block and sociodemographic factors in the second. The predictor variables were age, gender, education level, minority status, household income comfort (sociodemographic factors), and anxiety, depression, burnout, and sleep disturbance (mental distress). Bonferroni correction was applied ($P < 0.0125$). The effect sizes of the standardized β coefficients and the proportion of variance explained were interpreted according to Cohen.[36]

Results

Description of the Sample

In total, 4181 participants were recruited: predominantly middle-aged, with a university education, not a minority,

comfortable with or coping with household income, and with a nearly even proportion of men and women. Two respondents were excluded from the present analyses because they did not respond to any of the questions about noise perception. Consequently, a total sample of 4179 participants, comprising 1158 from Estonia, 1000 from Oresund, 1014 from Catalonia, and 1007 from Kosovo, was analyzed. The regional subsamples and the entire sample are described in Table 1.

One-way ANOVAs and chi-square tests showed significant differences between the regional subsamples for all five sociodemographic factors, except gender, and for all four aspects of mental distress. The Kosovo sample was the youngest, with only 9.53% of participants aged 65 or older. They reported the lowest proportion of self-identifying as a minority (9.04%), were the most comfortable with their income (40.62%), and had the lowest scores for anxiety (2.02), depression (1.84), burnout (2.68), and sleep disturbance (2.06). In contrast, the Estonian sample was the oldest, with 27.72% of participants aged 65 or older. Estonia also had the most highly educated respondents, with over 60% having a university education and only 1.38% having only an elementary school education. However, Estonian respondents were the least comfortable with their income (18.91%) and reported the highest depression score (2.29). Participants from Oresund reported the highest proportion of self-identifying as a minority (21.0%), had

Table 1: Description of the Regional Subsamples and Entire Sample, Including Results from One-Way Analyses of Variance and Chi-Square Tests Comparing the Regional Subsamples.

Characteristics	Estonia (n = 1158)	Oresund (n = 1000)	Catalonia (n = 1014)	Kosovo (n = 1007)	Entire Sample (n = 4179)
Age, *n* (%)					
18–34 years	252 (21.76)*	276 (27.60)	222 (21.89)	452 (44.89)	1202 (28.76)
35–64 years	585 (50.52)	476 (47.60)	585 (57.69)	459 (45.58)	2105 (50.37)
65+ years	321 (27.72)	248 (24.80)	207 (20.41)	96 (9.53)	872 (20.87)
Gender, *n* (%)					
Men	530 (45.77)†	500 (50.00)	502 (49.51)	498 (49.45)	2030 (48.58)
Women	621 (53.63)	500 (50.00)	507 (50.00)	504 (50.05)	2132 (51.02)
Non-binary	4 (0.35)	0 (0.00)	5 (0.49)	3 (0.30)	12 (0.29)
No answer	3 (0.26)	0 (0.00)	0 (0.00)	2 (0.20)	5 (0.12)
Education level, *n* (%)					
Elementary school	16 (1.38)*	165 (16.50)	45 (4.44)	113 (11.22)	339 (8.11)
High school	398 (34.37)	395 (39.50)	393 (38.76)	312 (30.98)	1498 (35.85)
University	733 (62.30)	428 (42.80)	568 (56.02)	575 (57.10)	2304 (55.13)
No answer	11 (0.95)	12 (1.20)	8 (0.79)	7 (0.70)	38 (0.91)
Minority, *n* (%)					
Yes	220 (19.00)*	210 (21.00)	149 (14.69)	91 (9.04)	670 (16.03)
No	918 (79.27)	762 (76.20)	851 (83.93)	855 (84.91)	3386 (81.02)
No answer	20 (1.73)	28 (2.80)	14 (1.38)	61 (6.06)	123 (2.94)
Household income comfort, *n* (%)					
Comfortable	219 (18.91)*	278 (27.80)	276 (27.22)	409 (40.62)	1182 (28.28)
Coping	580 (50.09)	405 (40.50)	391 (38.56)	410 (40.71)	1786 (42.74)
Difficult	256 (22.11)	210 (21.00)	244 (24.06)	115 (11.42)	825 (19.74)
Very difficult	93 (8.03)	84 (8.40)	87 (8.58)	54 (5.36)	318 (7.61)
No answer	10 (0.86)	23 (2.30)	16 (1.58)	19 (1.89)	68 (1.63)
Anxiety, mean (SD)	2.66 (1.49)*	2.44 (1.64)	2.71 (1.78)	2.02 (1.25)	2.46 (1.57)
No answer, *n* (%)	5 (0.43)	15 (1.50)	7 (0.69)	22 (2.18)	49 (1.17)
Depression, mean (SD)	2.29 (1.43)*	2.24 (1.48)	2.19 (1.59)	1.84 (1.15)	2.15 (1.43)
No answer, *n* (%)	5 (0.43)	18 (1.80)	12 (1.18)	18 (1.79)	53 (1.27)
Burnout, mean (SD)	2.74 (1.35)*	3.04 (1.51)	3.01 (1.58)	2.68 (1.33)	2.87 (1.45)
No answer, *n* (%)	28 (2.42)	31 (3.10)	17 (1.68)	30 (2.98)	106 (2.54)
Sleep disturbance, mean (SD)	2.59 (1.34)*	2.91 (1.36)	2.57 (1.42)	2.06 (0.93)	2.54 (1.31)
No answer, *n* (%)	11 (0.95)†	22 (2.20)	58 (5.72)	31 (3.08)	122 (2.92)
Perceived pollution level, mean (SD)	2.65 (1.17)*	2.68 (1.06)	3.10 (1.10)	3.18 (1.18)	2.89 (1.16)
Health risk perception, mean (SD)	2.25 (1.18)*	2.45 (1.14)	2.99 (1.17)	3.29 (1.16)	2.73 (1.24)
Annoyance, mean (SD)	2.72 (1.31)*	2.65 (1.16)	3.41 (1.14)	3.61 (1.21)	3.09 (1.28)
Sensitivity, mean (SD)	2.51 (1.32)*	2.43 (1.21)	2.99 (1.18)	2.74 (1.27)	2.66 (1.27)

SD = standard deviation; * $P < 0.001$; †Nonsignificant.

the lowest levels of university education (42.80%), and reported the highest scores for burnout (3.04) and sleep disturbance (2.91).

Overall Rating Levels and Multicollinearity

Mean (standard deviation) ratings for the subsamples and the entire sample for the four types of perceptions of noise pollution and the four aspects of mental distress are shown in Table 1. The means are rather close to the middle of the scales, suggesting limited risk of floor or ceiling effects. The four calculated VIFs for potential multicollinearity between the five sociodemographic variables ranged from 1.02 to 1.04, and those between the four aspects of mental distress ranged from 1.44 to 1.70, which were considered unproblematic for multicollinearity.[35]

Identification of Sociodemographic Determinants of Noise Perception

Mean ratings for the four aspects of noise perception for each sociodemographic factor are shown in Figure 2. Results from one-way ANOVAs and post-hoc analyses are presented in Table 2. All four noise perception aspects were associated with age and region, i.e., people in Kosovo and Catalonia perceived more noise than those in Estonia and Oresund. The noise ratings decreased with age, although some age groups were similar across noise perception aspects.

Women reported higher annoyance and sensitivity than men but not higher perceived pollution level or health risk. University education was associated with higher ratings of perceived noise pollution level, annoyance, and noise sensitivity, but not with health risk perception. Participants

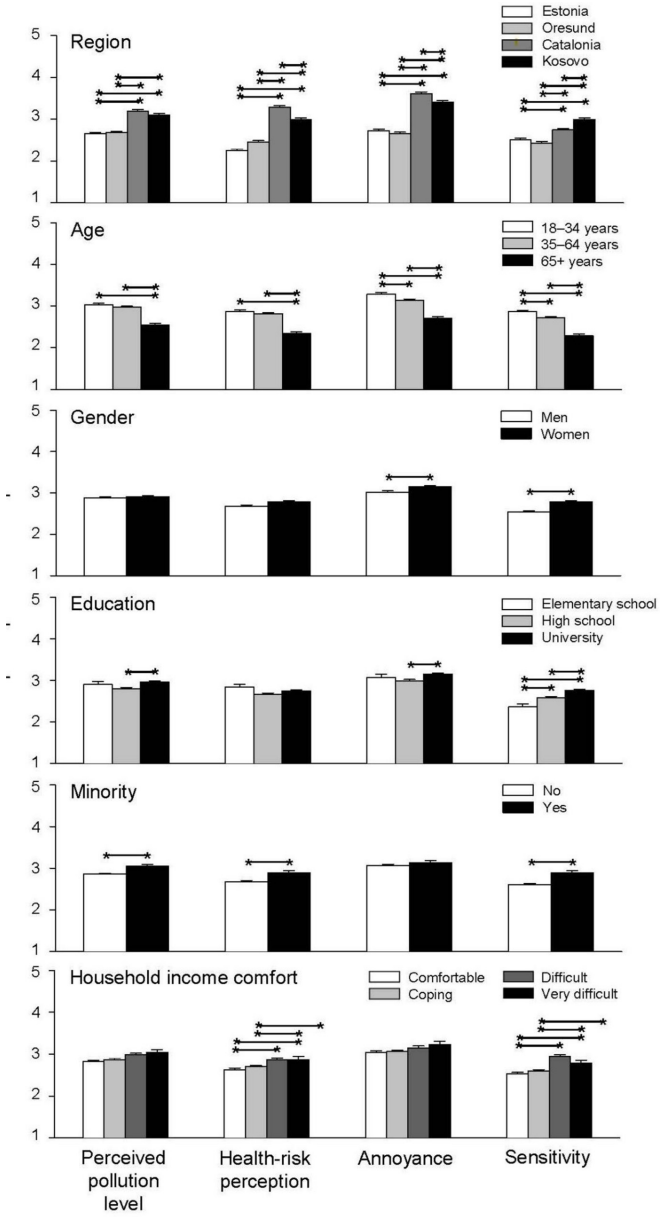

Figure 2: Mean (+ standard error) ratings of aspects of perception of environmental noise pollution in sociodemographic factors.

Table 2: Results from One-Way Analyses of Variance of Aspects of Perception of Environmental Noise Pollution in Sociodemographic Factors, and Post-hoc Tukey's Honestly Significant Difference Test When Meeting the Bonferroni Correction.

	F-Value	*P*-Value	η^2	Post-Hoc
Perceived pollution level				
Region	64.06	<**0.001**	0.044	K = C > O = E
Age	54.75	<**0.001**	0.026	18–34 = 35–64>65+ years
Gender	0.75	0.385		
Education level	8.84	<**0.001**	0.004	U > H; El = H; El = U
Minority	15.52	<**0.001**	0.004	Minority> not minority
Household income comfort	4.66	0.003	0.003	
Health risk perception				
Region	177.65	<**0.001**	0.114	K > C > O > E
Age	56.56	<**0.001**	0.027	18–34 = 35–64>65+ years
Gender	7.16	0.008	0.002	
Education level	3.76	0.023	0.002	
Minority	14.99	<**0.001**	0.004	Minority > not minority
Household income comfort	6.98	<**0.001**	0.005	VD = D > Cope = Comf
Annoyance				
Region	164.09	<**0.001**	0.106	K > C > E = O
Age	56.86	<**0.001**	0.027	18–34 >35–64 > 65+ years
Gender	9.51	**0.002**	0.002	Women > men
Education level	7.43	<**0.001**	0.004	U > H; El = H; El = U
Minority	1.28	0.257		
Household income comfort	2.87	0.035		
Sensitivity				
Region	40.86	<**0.001**	0.029	C > K > E = O
Age	56.93	<**0.001**	0.027	18–34 > 35–64 > 65+ years
Gender	36.97	<**0.001**	0.009	Women > men
Education level	19.05	<**0.001**	0.009	U > H > E
Minority	26.83	<**0.001**	0.007	Minority > not minority
Household income comfort	19.87	<**0.001**	0.014	VD = D > Cope = Comf

P-values meeting Bonferroni correction are given in bold; C = Catalonia, Comf = comfortable, Cope = coping, D = difficult, El = elementary school, E = Estonia, H = high school, K = Kosova, O = Oresund, U = university, VD = very difficult

who self-identified as minorities gave higher ratings for all types of noise perception, except annoyance. Finally, those reporting difficulty or very great difficulty with their household income reported higher health risk perception and sensitivity—but not higher perceived pollution level or annoyance.

Identification of Mental Distress Determinants of Noise Perception

Figure 3 presents the mean ratings for each aspect of noise perception and mental distress, with corresponding one-way ANOVAs results shown in Table 3. Significant associations meeting Bonferroni correction were found in almost all analyses, except for the association between annoyance and sleep disturbance. In general, people with mental distress symptoms reported higher noise perception ratings. Across aspects of mental distress, symptoms of burnout, followed by symptoms of depression, showed the strongest association, and across aspects of noise perception, sensitivity showed the strongest association. In eight of the associations, the effect size was below the cutoff for being considered small. In all associations with burnout and in all with sensitivity, the effect size was small, as was that for the association between depression and annoyance.

Unique Strength of Determinants of Noise Perception

The results from the hierarchical regression analyses, with demographics in the first block and mental distress in the second, are shown in Table 4. Both blocks (the latter controlling for demographic factors) significantly predicted all four aspects of noise perception. R^2 change ranged from 0.026 to 0.048 for the demographic blocks, and from 0.021 to 0.071 for the mental distress blocks. Based on the standardized beta coefficients, the variables burnout, age, and household income comfort contributed the most to the explained unique variance across aspects of noise perception.

Table 5 presents results from the hierarchical regression analyses in which mental distress in the first block and demographics in the second block predict aspects of perceived noise pollution. Again, both blocks (the latter controlling for mental distress) significantly predicted the four aspects of noise perception. R^2 change ranged from 0.033

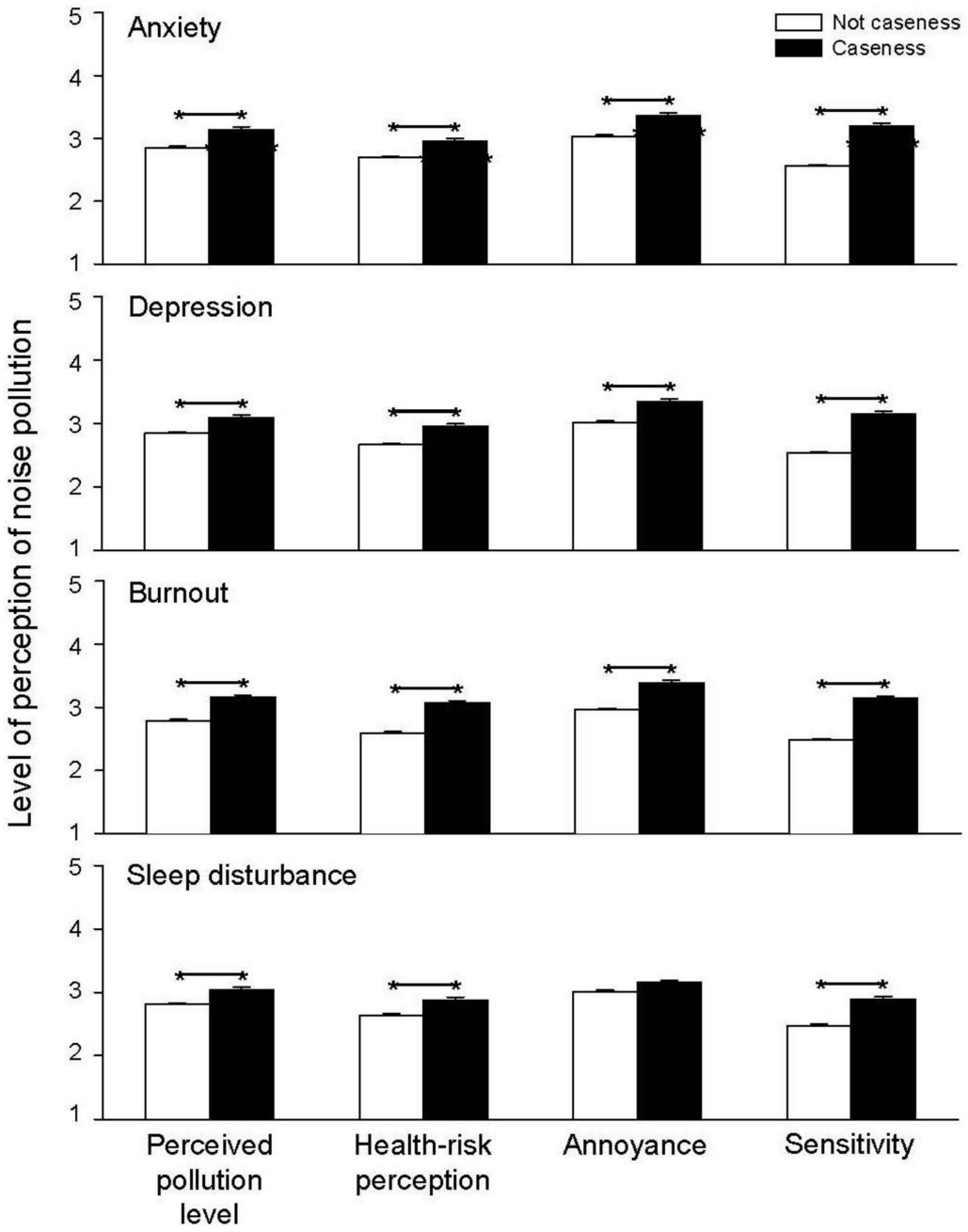

Figure 3: Mean (+ standard error) ratings of aspects of perception of environmental noise pollution in aspects of mental distress, meeting or not meeting criteria for caseness.

to 0.099 for the mental distress blocks, and from 0.009 to 0.020 for the demographic blocks. The largest standardized beta coefficients were found for burnout, age, and education level.

Discussion

The present study adopted a broad approach to identify determinants of key aspects of perception of environmental noise pollution in four European regions, as well as to assess their unique explanatory power.

Concerning the first research question on the determinants of noise perception, the results varied across these aspects depending on a sociodemographic factor. Regarding region, the highest ratings for the aspects of noise perception were found in Kosovo, followed by Catalonia, Oresund, and Estonia, respectively. Generally, higher ratings were found among young adults, women, minorities, those with a high level of education, and those who were uncomfortable with their household income. In contrast, consistent results across aspects of noise perception were found for mental distress. The association between mental

Table 3: Results from One-Way Analyses of Variance of Aspects of Perception of Environmental Noise Pollution in Mental Distress, Meeting or Not Meeting Criteria for Caseness.

	F-Value	*P*-Value	η^2
Perceived pollution level			
Anxiety	35.21	<**0.001**	0.009
Depression	35.15	<**0.001**	0.008
Burnout	86.27	<**0.001**	0.021
Sleep disturbance	18.26	<**0.001**	0.005
Health risk perception			
Anxiety	24.88	<**0.001**	0.006
Depression	37.46	<**0.001**	0.009
Burnout	129.35	<**0.001**	0.031
Sleep disturbance	12.92	<**0.001**	0.003
Annoyance			
Anxiety	35.20	<**0.001**	0.009
Depression	45.34	<**0.001**	0.011
Burnout	89.71	<**0.001**	0.022
Sleep disturbance	14.19	0.006	0.004
Sensitivity			
Anxiety	134.83	<**0.001**	0.032
Depression	172.81	<**0.001**	0.040
Burnout	236.21	<**0.001**	0.055
Sleep disturbance	114.72	<**0.001**	0.028

P-values meeting Bonferroni correction are given in bold.

distress and noise perception was stronger than that between sociodemographic factors and noise perception. Among aspects of noise perception, noise sensitivity showed the strongest associations with sociodemographic factors, followed by health risk perception. Noise sensitivity also had the strongest associations with the aspects of mental distress. The effect sizes of the associations were small or very small, except for those by region regarding health risk perception and annoyance, which were moderate.[36]

Taken together, our results broadly identify the determinants of aspects of noise perception and align with those of prior studies that have typically had a narrower focus. For example, perceived pollution level has been associated with stress, anxiety, and sleep disturbance[18]; health risk perception in terms of modern health worries with women, young age, low levels of education and income, and minority status[19,38]; noise annoyance with women, low income, migration background, and symptoms of anxiety, depression, and sleep disturbance[20-25]; and noise sensitivity with women, anxiety, depression, sleep disturbance, and clinical burnout.[16,21,27,28] We generally found a U-shaped relation for education, such that the aspects of noise perception were lower amongst those with middle-level education, compared to both those with the highest and those with the lowest levels of education.

Based on data from four European cities, Preisendörfer *et al.*[22] showed that those living in less privileged households (immigrants with a lower education level) reported greater annoyance from environmental noise pollution. More specifically, less privileged households (1) experienced higher noise levels, and (2) were less able to shield themselves from noise due to inadequate housing conditions. These pathways also apply to perceived noise pollution level, health risk perception, and sensitivity.

In our study, participants from Kosovo and Catalonia rated the various aspects of noise perception higher than those in Oresund and Estonia. When these perceptions are compared with objectively measured exposure, national-level prevalence estimates of modelled harmful noise—55 decibels (dB) for the day–evening–night period and 50 dB for the night period—are lower in Estonia than in Denmark and Sweden (Oresund area).[1] Although this may explain the differences in noise perception between Oresund and Estonia, it does not explain the difference between Catalonia (exposure estimate for Spain) and Oresund. This discrepancy is not surprising, given the distinction between objective and subjective noise pollution, and it highlights the need to assess subjective noise pollution, given that it mediates between environmental noise exposure and health.[39] Although this study did not aim to explain regional differences in noise perception, the observed regional differences in sociodemographic factors and mental distress [Table 1] may contribute to these differences. Regional differences in media reports of health risks associated with noise pollution may also be relevant, as media reports are the most frequently used method of environmental risk communication in general[40] and are likely to impact health risk perception, as well as sensitivity and annoyance related to noise exposure.[19] Future research may address these issues.

The current analysis revealed associations between all aspects of noise perception and all aspects of mental distress. Two interpretations can explain these broad sets of associations. First, repetitive environmental noise can act as a persistent stressor, amplifying loudness and annoyance[41] by activating the sympathetic nervous system and releasing cortisol and adrenaline.[24] Stress, in turn, can underlie anxiety, depression, burnout, and sleep disturbance.[42] In fact, noise annoyance can predict the development of symptoms of anxiety, depression, and sleep disturbance over 5 years.[43] Hahad *et al.*[39] proposed that noise may increase neuroinflammation and cerebral oxidative stress, thereby increasing susceptibility to mental distress. Bidirectionally, mental distress may amplify loudness and noise annoyance.[39] In addition, nighttime noise may cause micro-arousals that fragment deep sleep, which may increase anxiety, depression, and burnout the following day.[44]

Second, interrelations between the aspects of noise perception and between the aspects of mental distress may explain these associations. For example, health risk perception regarding air pollution has been associated with perceived pollution level and annoyance,[45,46] which may also apply to noise pollution. Noise sensitivity is positively associated with

Table 4: Results from Hierarchical Regression Analyses of Predictors of Aspects of Perception of Noise Pollution with Demographics in a First Block and Mental Distress in a Second Block.

	Standardized β	*t*-Value	*P*-Value	R^2 Change	*P*-Value
Perceived pollution level					
Block 1: Sociodemographics				0.027	<**0.001**
Age	–0.142	8.64	<**0.001**		
Gender	–0.009	0.53	0.595		
Education level	0.034	2.09	0.037		
Minority	0.037	2.27	0.024		
Household income comfort	–0.050	3.05	**0.002**		
Block 2: Mental distress				0.022	<**0.001**
Anxiety	–0.010	0.39	0.694		
Depression	0.021	0.82	0.412		
Burnout	0.146	6.36	<**0.001**		
Sleep disturbance	0.020	1.04	0.300		
Health risk perception					
Block 1: sociodemographics				0.026	<**0.001**
Age	–0.139	8.48	<**0.001**		
Gender	0.018	1.10	0.274		
Education level	–0.007	0.42	0.676		
Minority	0.035	2.13	0.033		
Household income comfort	–0.056	3.40	<**0.001**		
Block 2: mental distress				0.027	<**0.001**
Anxiety	–0.050	1.89	0.059		
Depression	–0.007	0.274	0.784		
Burnout	0.206	8.96	<**0.001**		
Sleep disturbance	0.008	0.39	0.694		
Annoyance					
Block 1: sociodemographics				0.029	<**0.001**
Age	–0.154	9.37	<**0.001**		
Gender	0.019	1.15	0.251		
Education level	0.040	2.43	0.015		
Minority	–0.003	0.20	0.839		
Household income comfort	0.037	2.23	0.025		
Block 2: mental distress				0.021	<**0.001**
Anxiety	0.000	0.004	0.997		
Depression	0.011	0.42	0.673		
Burnout	0.141	6.13	<**0.001**		
Sleep disturbance	0.022	1.13	0.256		
Sensitivity					
Block 1: sociodemographics				0.048	<**0.001**
Age	–0.132	8.12	<**0.001**		
Gender	0.071	4.41	<**0.001**		
Education level	0.091	5.67	<**0.001**		
Minority	0.048	2.98	**0.003**		
Household income comfort	0.085	5.24	<**0.001**		
Block 2: mental distress				0.071	<**0.001**
Anxiety	0.044	1.71	0.087		
Depression	0.035	1.44	0.149		
Burnout	0.178	8.05	<**0.001**		
Sleep disturbance	0.097	5.16	<**0.001**		

P-values meeting Bonferroni correction are given in bold. Man is coded as 1 and woman as 2; elementary school is coded as 1, high school as 2, and university as 3; not self-identifying as a minority is coded as 1, and self-identifying as a minority as 2; very difficult regarding household income is coded as 1, difficulty as 2, coping as 3, and comfortable as 4.

Table 5: Results from Hierarchical Regression Analyses of Predictors of Aspects of Perception of Noise Pollution with Mental Distress in the First Block and Demographics in the Second Block.

	Standardized β	*t*-Value	*P*-Value	R^2 Change	*P*-Value
Perceived pollution level					
Block 1: mental distress				0.036	<**0.001**
Anxiety	0.009	0.35	0.726		
Depression	0.020	0.79	0.430		
Burnout	0.171	7.67	<**0.001**		
Sleep disturbance	–0.001	0.05	0.959		
Block 2: sociodemographics				0.013	<**0.001**
Age	–0.103	6.02	<**0.001**		
Gender	–0.026	1.58	0.115		
Education level	0.042	2.63	**0.009**		
Minority	0.016	0.99	0.324		
Household income comfort	0.002	0.13	0.899		
Health risk perception					
Block 1: mental distress				0.044	<**0.001**
Anxiety	–0.029	1.11	0.267		
Depression	–0.011	0.42	0.673		
Burnout	0.236	10.60	<**0.001**		
Sleep disturbance	–0.008	0.41	0.681		
Block 2: sociodemographics				0.009	<**0.001**
Age	–0.099	5.80	<**0.001**		
Gender	–0.001	0.04	0.966		
Education level	0.003	0.20	0.841		
Minority	0.016	0.95	0.341		
Household income comfort	0.012	0.72	0.474		
Annoyance					
Block 1: mental distress				0.033	<**0.001**
Anxiety	0.019	0.71	0.476		
Depression	0.007	0.26	0.796		
Burnout	0.167	7.47	<**0.001**		
Sleep disturbance	–0.004	0.23	0.818		
Block 2: sociodemographics				0.016	<**0.001**
Age	–0.116	6.76	<**0.001**		
Gender	0.001	0.09	0.930		
Education level	0.048	2.95	**0.003**		
Minority	–0.024	1.49	0.137		
Household income comfort	–0.011	0.61	0.540		
Sensitivity					
Block 1: mental distress				0.099	<**0.001**
Anxiety	0.063	2.48	**0.013**		
Depression	0.030	1.23	0.218		
Burnout	0.198	9.15	<**0.001**		
Sleep disturbance	0.079	4.23	<**0.001**		
Block 2: sociodemographics				0.020	<**0.001**
Age	–0.070	4.24	<**0.001**		
Gender	0.039	2.48	0.013		
Education level	0.105	6.78	<**0.001**		
Minority	0.007	0.436	0.663		
Household income comfort	–0.009	0.55	0.582		

P-values meeting Bonferroni correction are given in bold; Man is coded as 1 and woman as 2; elementary school is coded as 1, high school as 2, and university as 3; not self-identifying as a minority is coded as 1, and self-identifying as a minority as 2; very difficult regarding household income is coded as 1, difficulty as 2, coping as 3, and comfortable as 4.

neuroticism,[47] and neuroticism may make individuals more likely to perceive environmental noise as more stressful and annoying.[34,48] Previous research has also found strong associations between symptoms of anxiety, depression, burnout, and sleep disturbance.[49,50]

To verify the results of the cutoff-based ANOVAs identifying determinants, supplementary analyses were conducted using Pearson and Spearman correlations (see Supplementary material). These analyses yielded results that largely aligned with those from the ANOVAs, thereby supporting those findings. The associations for the sociodemographic factors varied depending on the aspect of perception of environmental noise pollution, but, again, the strongest associations were found for age, followed by household income discomfort and noise sensitivity. Furthermore, all aspects of mental distress were associated with all aspects of perception of environmental noise pollution, with the strongest associations found between burnout and noise sensitivity, but with weak effect sizes.[37]

Relative Contribution of Mental Distress and Sociodemographics

The second research question concerned the unique strengths of determinants. Mental distress factors accounted for a greater amount of variance in how people perceive noise (range 3.3%–9.9%) than sociodemographic factors did (range 2.6%–4.8%). When controlling for sociodemographic factors, the contribution of mental distress to the explained variance in noise perception decreased to 2.1% to 7.1%. Furthermore, when controlling for mental distress, the contribution of demographic factors decreased to 0.9% to 2.0%, likely due to shared variance between the two sets of variables. According to Cohen's[36] guidelines, all observed contributions to explained variance were small in magnitude. Noise perception showed a stronger association with mental distress than with sociodemographic factors, which may be explained by stress being an important underlying factor in aspects of noise perception[18,34,39] and mental distress.[42] Nevertheless, despite a lower proportion of explained variance for sociodemographics than for mental distress, the sociodemographic results do indeed demonstrate inequality in health-related aspects of noise perception.

To examine the individual determinants within a set that contributed the most to explaining the unique variance in noise perception, each sociodemographic factor was analyzed while also controlling for the remaining sociodemographic factors, and each mental distress aspect was examined while controlling for the other aspects in that set. The results indicated that young age and discomfort with one's household income were the strongest contributors among sociodemographic factors, while burnout emerged as the most influential aspect of mental distress. Among the dimensions of environmental noise perception, the strongest associations were observed for noise sensitivity, followed by health risk perception, across sociodemographic and mental distress variables. Age may explain much of the variance because younger adults exhibit stronger physiological and psychological responses to stressors such as noise.[51] Environmental noise levels are positively associated with economically disadvantaged neighborhoods.[52] The finding that discomfort in household income is a stronger predictor than education and self-identification as a minority aligns with results from a previous study on traffic noise annoyance.[22] Regarding burnout, environmental noise is a systemic health stressor,[1] and a recent study revealed that both stress vulnerability and perceived noise significantly predict burnout.[53] However, in contrast to anxiety, depression, and sleep disturbance, burnout has so far rarely been studied in relation to perceived noise pollution. This, in combination with the present finding of burnout being a stronger determinant than these other aspects of mental distress, suggests that future research should pay considerably more attention to the role of noise pollution in burnout.

The associations for health risk perception and, in particular, noise sensitivity suggest that future research should pay more attention to these two aspects of environmental noise perception, which have received considerably less attention than annoyance in previous research.

With a few exceptions, the associations were generally weak according to guidelines.[36] While this may suggest that the associations are negligible and of limited significance for individuals, even small effect sizes can have meaningful implications at the societal level. The available guidelines for effect sizes[36] have been developed for studies with short-term, proximal outcomes and controlled laboratory settings, which differ fundamentally from population-based surveys[54] such as the present study.

The results of this study suggest that interventions to reduce adverse perceptual, cognitive, emotional, and behavioral reactions to environmental noise pollution should focus on improving overall health and well-being, including addressing common mental distress. To improve health equality, interventions should target vulnerable groups such as young adults, those with low and high education levels, minorities, and those experiencing discomfort with their household income, and preferably also women in general. Two aspects are particularly valid in this context: (1) sensitivity and (2) health risk perception. Interventions should be implemented across several regions to strengthen generalizability. Moreover, Herrera and Cabrera-Barona[9] have proposed incorporating citizens' perspectives to better understand environmental noise pollution and to enrich local planning for urban sustainability.

The present study takes a broad approach by addressing key aspects of perception of environmental noise pollution, sociodemographic factors, and aspects of mental distress across four regions of Europe, using a population-based approach. However, recruitment was conducted by inviting

participants from a pool of people who had previously expressed a willingness to participate in research studies. This nonrandom sample may have introduced selection bias. Therefore, the representativeness of the sample may be limited, and the findings should be interpreted with caution when generalizing to other populations or settings. However, the requirement that each regional subsample reflect the age and gender distribution of its respective population helps mitigate this limitation. Whereas validated questionnaire instruments were used to assess symptoms of burnout and sleep disturbance, nonvalidated questions were used to assess symptoms of anxiety and depression, calling for caution regarding those results.

Conclusion

The present findings suggest that perception of environmental noise pollution—including perceived noise pollution level, health risk perception, annoyance, and sensitivity—varies across European regions. Young age, low or high education, self-identified minority status, income discomfort, and mental distress (anxiety, depression, burnout, and sleep disturbance) are all significant determinants of the perception of noise pollution. Moreover, mental distress had a stronger effect on noise perception than sociodemographic factors. In terms of explained unique variance, young adult age and discomfort with household income, as well as burnout symptoms, appear to be the most important individual sociodemographic and mental distress determinants. Among aspects of noise perception, sensitivity followed by health risk perception are most strongly associated with sociodemographic factors and mental distress.

Availability of data and materials

The anonymous datasets generated and analyzed in this study are available from the corresponding author upon reasonable request.

Author contributions

Triin Veber: Contributed to the study design, supported data collection and analysis, and wrote the manuscript. Steven Nordin: Contributed to the study design, supported data collection, conducted data analysis, and led the manuscript writing. John Andersson: Supported the data analysis and contributed to manuscript revisions. Kati Orru: Led the study design and provided critical revisions to the manuscript. Hans Orru: Led the data collection, provided critical revisions to the manuscript, and acted as the corresponding author.

Ethics approval and consent to participate

This study was approved by the Swedish Ethical Review Authority (Dnr 2024-01363-01), Research Ethics Committee of the University of Tartu (392/T-1), and Comité de Ética de la Investigación con medicamentos del Parc de Salut MAR (2024/11455). All participants ticked the box to agree to participate before beginning the questionnaire.

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Conflicts of interest

The authors declare no conflicts of interest.

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