Odor perception and air quality annoyance in noise sensitivity

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ABSTRACT

Noise sensitivity (NS) may be subsumed by the environmental intolerance approach, characterized by the attribution of several multisystem symptoms to specific environmental exposures. NS increases the reactivity to noise and predicts noise annoyance. In multiple chemical sensitivity, an impairment in smell cognitive abilities with increased smell hypersensitivity has been found. Analyses of laboratory (n = 74) and epidemiological (n = 1005) data were carried out, focusing on the relationship between NS and annoyance with a variety of olfactory-related stimuli. In the first study, we examined the relationships between NS, noise annoyance, and the perceptual ratings of 16 odors. A significant association between NS and noise annoyance was found, but no significant associations between NS and odor pleasantness, intensity or familiarity were found. In the second study, differences between mean noise and air pollution annoyance scores across NS categories were sought. Only for the sample consisting of people living within 50 m of a motorway was a mean difference found in air pollution annoyance across the three NS groups, with larger means associated with larger degrees of NS. Neither of the two data sets described offers definitive support for the environmental intolerance approach, with divergent findings between noise and olfactory data.

Keywords: Noise Sensitivity, Odor Perception, Air Quality Annoyance, Idiopathic Environmental Intolerance, Multiple Chemical Sensitivity I-INCE Classification of Subjects Number(s): 63.2

1. INTRODUCTION

Noise sensitivity (NS) refers to physiological and psychological internal states, which increase the degree of reactivity to noise in general (1), and predicts noise annoyance (2, 3). It is a stable trait (2), and also a common trait; in different studies the prevalence of NS has varied between 20 % and 40 % as reviewed by Heinonen-Guzejev (2008) (4) and the prevalence of high NS has varied between 12 % and 15 % (3). NS aggregates in families, meaning that there is a higher frequency of NS in first-degree relatives compared to the general population. Heritability is estimated to be 36 % (4, 5).

As an identifiable reaction modifier to noise, NS is currently well described but as yet not sufficiently explained. This lack of etiological progress is likely caused by the fact that NS mechanisms may be multifactorial in nature, with factors influencing the degree of NS acting either independently or interactively. Weinstein (1980) postulated that NS could be understood as a general tendency to express negative judgments of a person's immediate environment, and noise sensitive individuals should therefore be sensitive to other environmental stimuli such as odor, brightness or temperature (6).

Idiopathic Environmental Intolerance (IEI) is an acquired condition with multiple nonspecific symptoms attributed to low levels of chemical, biologic, or physical agents, tolerated by most persons and not explained by known medical or psychiatric disorders. Multiple chemical sensitivity (MCS), a

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significant part of IEI, is characterized by recurrent symptoms, referable to multiple organ systems, occurring in response to a demonstrable exposure to many chemically unrelated compounds at doses far below those established in the general population to cause harmful effects. Most patients complaining of MCS are women (from 70 to 90 percent) (7, 8). MCS is a highly stable trait (9). The prevalence of MCS found in different studies has varied from 0.2 % to 42 %, and the prevalence of severe MCS from 0.5 to 6.3 %. Various genes, especially genes of importance to the metabolism of xenobiotic compounds, have been associated with MCS, but findings have been inconsistent. It may be that variants in the genes examined are of less importance to MCS, or that gene-environment interactions or significant degrees of genetic heterogeneity in MCS underlie inconsistent findings in the literature (10, 11).

NS may be subsumed by the environmental intolerance approach, arguing that NS is part of a more global sensitivity to environmental stimuli, with a focus on neurophysiological rather than personality explanations (12). It has been suggested that sensitization is a major mechanism for MCS (13) and also that there is a psychobiological mechanism underlying a cluster of illnesses, referred to as "subjective health complaints", including annoyance to noise. Sustained stress responses or sustained arousal may be an important factor for the development of these conditions (14). Young adults with both chemical sensitivity and NS have been more similar in MCS patients than in their peers with chemical sensitivity or NS alone. The findings suggest that limbic system dysfunction associates more with chemical sensitivity than with NS (15).

Nordin et al. (2014) assessed differences in odor and noise intolerance between persons with electromagnetic hypersensitivity and healthy controls, reporting that the former scored significantly higher than the controls on all chemical sensitivity and NS scales (16). In the study of Palmquist et al. (2014), the overlaps between intolerance to odorous/pungent chemicals, certain buildings, EMFs and sounds for both self-reported and diagnosed intolerance (except for the overlap between diagnosed intolerance to sounds and EMFs), were found to be greater than predictions based on coincidence (17). However, according to a Finnish study by Heinonen-Guzejev et al. (2012), NS and MCS seem to be different entities rather than being a part of general sensitivity. In that study, the Noise Sensitivity Factor was not correlated with the Chemical Sensitivity Factor, despite a modest correlation between Weinstein's Noise Sensitivity Scale and QEESI's Chemical Intolerance Subscale. The association profiles of the Noise Sensitivity Factor and the Chemical Sensitivity Factor with medical, psychological and life-style factors were mainly different (18).

In MCS, an impairment in smell cognitive abilities with increased smell hypersensitivity has been found (19). It has been hypothesized that individual differences in limbic system reactivities and central nervous system sensitizabilities underlie vulnerabilities to environmental stimuli (12). Individuals who are sensitive to both chemicals and noise might be among the most vulnerable to limbic dysfunction and to the sensitization of the limbic and central nervous systems as a result of multiple environmental factors (15). The amygdala, one of several brain regions that modulates startle reactions to unexpected noise (20), is also the most dominant regions of the brain when responding to chemical stimuli (21).

In this study, we investigated the relationship between NS and annoyance with a variety of olfactory-related stimuli.

STUDY ONE

2. MATERIAL AND METHODS

2.1 Participants

Seventy-four participants aged 20–69 years (Mean = 33.51, SD = 12.28) were recruited, totaling 31 males and 43 females. Participants consisted of staff and students from the University of Auckland and the Auckland University of Technology, New Zealand, recruited via institutional email advertisements. The methods and procedures used in this study were reviewed and endorsed by the University of Auckland Human Participants Ethics Committee prior to commencement of the study.

2.2 Noise Sensitivity

NS was estimated using the Noise Sensitivity Questionnaire (NOISEQ) scale (22) which measures global noise sensitivity as well as NS for different domains of everyday life: Leisure, work, sleep, communication, and habitation. There are 35 NOISEQ items, each requiring the respondent to indicate their degree of agreement to statements about their responses to noise using a five-point Likert-type scale, modified from the original four-point NOISEQ scales (22). Global NS is computed as the average of the leisure, work, habitation, communication and sleep subscales, with data recoded so that higher means indicate greater levels of NS. For this dataset, the Cronbach's alpha was an acceptable 0.855.

2.3 Noise Annoyance

Six questions regarding annoyance to different noise sources were combined to create a total noise annoyance score. The six items measured general annoyance to neighborhood noise, and annoyance to noise while reading, watching television, relaxing, working, or sleeping. Each item was rated on a three-point category scale: 0 = "No"/1 = "Sometimes"/2 = "Yes". Ratings to the six items were summed to produce a Total Score, with higher scores indicating higher annoyance. The Cronbach's Alpha for the six items was an acceptable 0.724.

2.4 Odor Perception

Responses to odors involved the identification of the odor and ratings of odor pleasantness, intensity, and familiarity. A commercially-available product, the Sniffin' Sticks Olfactory Test, was utilized consisting of 16 distinct odors (orange, leather, cinnamon, peppermint, banana, lemon, liquorice, turpentine, garlic, coffee, apple, cloves, pineapple, rose, anise, fish) (23). The Sniffin' Sticks test employs pen-like odor-dispensing devices, each housing a tampon containing either a liquid odorant or odorant dissolved in propylene glycol to a total volume of 4 ml. The pens each have tight-fitting lids designed to eliminate odor contamination. When a lid is removed, the pen dispenses a constant concentration of odor (23). Following Distel et al. (1999), participants were required to verbally rate the odor's familiarity, pleasantness, and intensity, on a five-point scale (24). On these scales, "1" represented the most familiar, pleasant, and intense rating and "5" the least. This part of the assessment is not part of the 12 original Sniffin' Sticks battery, but was added to assess the properties of these odor characteristics and how they might be related to measures such as personality.

2.5 Procedure

The experimental session began with the administration of the Sniffin' Sticks odor identification test. During this task, participants were also asked to rate the familiarity, pleasantness, and intensity of each odor. Following removal of the cap, the pen was positioned approximately two centimeters under the participant's nostrils for three seconds. There was at least a 30-s delay prior to the presentation of the next odor to prevent carryover effects. No feedback was given to the participant during the task. Following the presentation and rating of odors, the participants were given a battery of surveys to complete, including NS and noise annoyance questionnaires.

2.6 Analysis

Preliminary analysis was conducting using zero-order and first-order correlation coefficients. All tests were two-tailed and participant age was controlled for as age is a known covariate of NS (25). Cohen's effect size categories are useful when assessing the strength of correlation coefficients: Small ($r < 0.3$), moderate ($r = 0.3$ to 0.5), and large ($r > 0.5$). Associations between NS and noise annoyance, and NS and odor perception were explored using hierarchical multiple linear regression, ensuring the effects of participant age were partialled out.

3. RESULTS AND DISCUSSION

Age was positively correlated with NS ($r = 0.331$, $p = 0.004$), necessitating its inclusion as a covariate. In relation to gender, independent samples t-tests uncovered no significant differences between males and females in terms of NS, percentage correct odor identification, and the Total Scores for pleasantness, intensity, or familiarity ratings ($p > 0.05$). Consequently, gender was not used as a between-group factor in subsequent analyses.

3.1 Associations between Noise Sensitivity and Odor Perception

Across the entire sample, peppermint and pineapple were judged the most pleasant, and fish the least. Garlic, peppermint and fish were deemed the most intense, as well as the most familiar. Nonparametric Mann Whitney tests uncovered no significant differences in NS between those able to identify specific odors and those who couldn't ($p > 0.05$). The correlation between NS and overall percentage correct identification was likewise non-significant ($r = -0.058$, $p = 0.311$). This null result is of interest, as certain psychopathologies (e.g., schizophrenia) are characterized by both odor identification deficits and NS (26). As such, it is possible that this finding would not be replicated in clinical populations. To further explore the associations between odor perception and NS, both zero-order and first-order (controlling for age) correlation coefficients were computed. Significant correlations between NS and the pleasantness of both turpentine (a negative coefficient) and coffee (a positive coefficient) were found, both increasing in magnitude when controlling for age. However, if Bonferonni post hoc corrections are applied, statistical significance ceases for these two relationships.

3.2 Associations between Noise Sensitivity, Noise Annoyance and Odor Perception

Multiple linear regression analyses were undertaken to test whether, after controlling for age, there would be a significant association between NS and noise annoyance. We found a significant association between NS and noise annoyance ($\beta = 0.081$, $p < 0.001$). There was no statistically significant relationship between NS and odor pleasantness ($\beta = -0.066$, $p > 0.05$). Non-significant findings were also found with odor intensity ($\beta = 0.006$, $p > 0.05$) and odor familiarity ($\beta = -0.044$, $p > 0.05$).

STUDY TWO

4. MATERIAL AND METHODS

Study Two involved three datasets and a selection of common variables. These variables included measures of NS, and both noise and air quality annoyance.

4.1. Participants

Data for Study Two were obtained in New Zealand's two largest cities: Auckland (2010; 2013) and Wellington (2012). The Auckland data consists of two datasets. The first set compromised the "Motorway" (n = 373) and the "Non-Motorway" (n = 253) samples. The Motorway sample consists of residents living within 50 meters of Auckland's motorway system, with noise levels estimated to be approximately 76 dB(A) LDN (28). The Non-Motorway reference sample contains residents from two areas within the Auckland region, located at least two kilometers away from any significant source of environmental noise (e.g., industry or roads), and with noise levels estimated to be around 55 dB(A) LDN. The second Auckland dataset consists of two samples from the central business district (CBD), denoted "CBD-Traffic" (n = 134) and "CBD-Pedestrian" (n = 65); the latter was from a road closed to traffic, while the former was the main thoroughfare through the central city (28). Mobile monitoring of noise levels was undertaken using a commercially-available dosimeter (CEL-350 dBadge, Casella) providing sound level measurements (dB LAeq) every minute. Each location was monitored for 10 h, with dB LAeq values of 70.98 (CBD-Traffic) and 69.55 (CBD-Pedestrian) being recorded. The Wellington data comprises the "Airport" sample (n = 87) and the "Non-Airport" sample (n = 93). The Airport sample resided within 250 meters of the Wellington International Airport's runway, with aviation noise levels estimated at 62 dB(A) LDN, with peak values legislated to stay below 75 dB(A) Lmax (29). The Non-Airport reference sample consisted of residents living on the city's urban/suburban border, and was far from the airport's main flight path. The Motorway and Non-Motorway samples were socioeconomically matched (middle to high deprivation) and were from suburban neighborhoods, whilst the Airport and Non-Airport samples were also matched (low to middle deprivation), but were neighborhoods on the suburban/urban boundary.

4.2. Survey

Data for the Motorway, Non-Motorway, Airport, and Non-Airport samples were taken from a larger questionnaire entitled "Wellbeing and Neighborhood Survey" (27, 30). Items pertinent to the current analysis were the seven items probing annoyance from environmental factors, including air pollution ("air pollution from traffic", "air pollution from household chimneys", "other, please specify") and noise ("noise from traffic", "noise from other neighbors", "other noise, please specify"), where "traffic" was unspecified and the source non-specific. These items were presented by way of a five-point scale ranging from "not annoyed at all" to "extremely annoyed".

NS was measured using a single item made up of three response categories representing low, moderate, and high noise sensitivities. The final section of the survey sought personal information including gender and age. Each house received two copies of the questionnaire, delivered in their post-box, a participant information sheet, and stamped-addressed envelopes. Though not identical, the survey used to gather data from the CBD-Pedestrian and CBD-Traffic samples contained a number of items found in the aforementioned Wellbeing and Neighborhood Survey, including the NS and annoyance questions. In this study, surveys were distributed to pedestrians in transit and were returned immediately upon completion. No information regarding residency was recorded. These studies were approved by the Auckland University of Technology Ethics Committee (08/256).

4.3. Statistical Analysis

Data analyses were carried out using SPSS Version 18. Differences in mean annoyance scores across NS categories were tested using analyses of variance and Bonferonni post hoc tests, while differences across areas, but within a NS band, were tested using independent samples t-tests. Covariates (i.e., age) were included if significant associations were uncovered between factors during preliminary analyses.

5. RESULTS AND DISCUSSION

5.1. Noise Annoyance Ratings

The mean noise annoyance ratings are displayed in Figure 1 (left column). The expected positive relationship between NS and noise annoyance is evident for all but two samples: The Non-Motorway and Non-Airport samples. Two tests compared groups of highly noise sensitive individuals exposed to different levels (and sources) of noise (Motorway vs. Non-Motorway and Airport vs. Non-Airport) in which non-significant differences would support the negative affect hypothesis. Secondly, a test was carried out comparing groups of highly sensitive individuals exposed to similar noise levels (CBD-Traffic versus CBD-Pedestrian) in which a significant difference in annoyance ratings would suggest responses reflecting processes unrelated to noise exposure.

The left column in Figure 1 shows the mean noise annoyance ratings for the three datasets, with asterisks indicating significant differences between groups (e.g., Motorway versus Non-Motorway) within each of the three levels of NS. For the high NS groups, significant results are obtained when comparing Motorway versus Non-Motorway and Airport versus Non-Airport samples, and a non-significant result when comparing the CBD-Traffic versus CBD-Pedestrian samples. The interaction between noise exposure and NS was significant for both motorway ($F(2,501) = 4.278$, $p = 0.014$), and airport ($F(2,178) = 4.499$, $p = 0.035$) data. The interaction between noise exposure and NS found in this study supports the notion that the effect of NS upon the noise exposure—noise annoyance relationship is not only additive in nature (25), as demonstrated by the flat functions associated with low NS and step functions with high sensitivity. Furthermore, if NS is uncoupled from acoustic factors such as level and thus reflects other processes (e.g., negative affect), an invariant relationship between noise annoyance and NS should be observed, irrespective of the noise exposure context.

Figure 1 shows that the noise context does shape the association between noise annoyance and NS. For samples exposed to greater noise levels (i.e., the Motorway and Airport groups), a proportional relationship between noise annoyance and sensitivity is demonstrated, with significant differences in mean noise annoyance scores between levels of NS for both the Motorway ($F(2,505) = 5.888$, $p = 0.003$) and Airport ($F(2,85) = 4.908$, $p = 0.010$) groups. Subsequent post hoc tests revealed significant differences in mean noise annoyance ratings between the least and moderate sensitivity groups ($p = 0.004$), and the least and highly sensitive group ($p < 0.001$) in the motorway locale, and the low and high NS groups ($p = 0.007$) in the Airport sample. However, for samples exposed to relatively lower noise levels (i.e., Non-Motorway and Non-Airport), significance across the three NS groups was not obtained ($p > 0.05$). For samples exposed to equivalent noise levels (i.e., CBD-Traffic and CBD-Pedestrian), a main effect of NS was noted for the CBD-Traffic data ($F(2,129) = 9.083$, $p < 0.001$: all post hoc tests $p < 0.05$), though the CBD-Pedestrian data were marginal ($F(2,62) = 2.847$, $p = 0.050$), with post hoc tests revealing a difference between the least and highly sensitivity groups ($p = 0.044$).

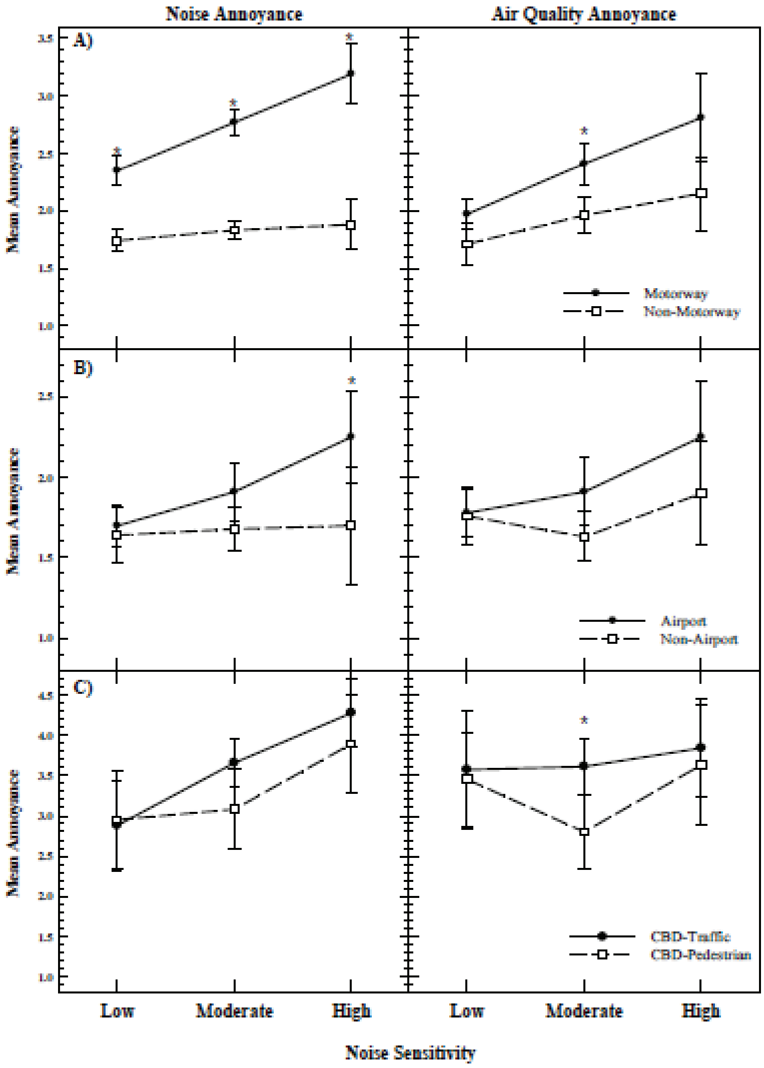

Figure 1 – This Mean annoyance to noise and air pollution as a function of self-reported NS for samples collected in two New Zealand cities: Auckland (top and bottom panels) and Wellington (middle panel). Whiskers are 95% confidence intervals, with asterisks indicating significant differences between means ($p < 0.05$). Note the different scales on the y-axes (Shepherd et al. 2015).

5.2. Air quality Annoyance Ratings

Only one of six of the air quality annoyance functions displayed in Figure 1 (second column) differed significantly across NS groups: The Motorway sample ($F(2,505) = 6.403$, $p = 0.002$). Significant differences in mean air pollution annoyance ratings between the least and moderate NS groups ($p = 0.024$), and the least and the highly sensitive group ($p = 0.003$), were noted. Further scrutiny of the plotted air quality data invites comparisons between areas within a single level of NS, though interpretation of the trends become more complex.

It is noted across the three datasets that, for the low NS groups, there are no significant differences between areas. Furthermore, with the exception of the motorway/non-motorway data, there are no statistical differences between the low and high noise sensitive groups in terms of mean air quality annoyance ($p > 0.05$).

Interestingly, for both the motorway/non-motorway and CBD-Traffic/CBD-Pedestrian data sets, there is statistical significance for the moderate NS samples, though in the current context it is difficult to derive meaning from these significant results other than perhaps representing a Type I error.

Persson et al.2007 report significant correlations between NS and self-reported annoyance to traffic exhaust fumes, as well as between noise annoyance and physical measures of nitrogen oxide exposure (31). Of further note is that while a significant difference in noise annoyance means was found between the motorway and non-motorway areas at the high NS level, no such finding emerged from the air quality data. This finding is in opposition to that expected if individuals have a general sensitivity to environmental quality (22).

In all three noise annoyance plots (Figure 1, left column), the mean annoyance scores in the moderately noise sensitive group lie almost halfway between the mean scores for the least noise sensitive group and the highly sensitive group. This suggests that the NS scale is appropriate and robust, despite being only a single item scale and the validity of such scales being doubted in previous research (32).

6. GENERAL DISCUSSION

In the first study, no significant associations between NS and odor pleasantness, odor intensity or odor familiarity were found; only a significant association between NS and noise annoyance was found. The second study sought differences between mean noise and air pollution annoyance scores across NS categories. Only for the Motorway sample, was there a mean difference in air pollution annoyance across the three NS groups, with larger means associated with larger degrees of NS. Neither of the two datasets offered definitive support for the environmental intolerance approach, with divergent findings between noise and olfactory data.

Of relevance is a well-designed study by Lercher & Kofler (1996) which demonstrated that those who reported higher levels of noise annoyance more likely embraced coping strategies and complained about other traffic-related irritants (i.e., global sensitivities). On the other hand, those reporting greater NS engaged less coping strategies and complained less about traffic-related irritants, but reported increased sleep disturbance and health issues (33).

The small variance-accounted-for statistics that typically accompany significant coefficients marking the relationship between NS and sensitivity to other sensory dimensions (e.g., olfaction) suggest that the environmental intolerance approach cannot be considered a general principle, and indeed it may be that NS can be explained by a multitude of mechanisms working independently or interactively.

The divergence between our findings and those of Nordin et al. (2014) may be explained by the separation of their sample into EMF-sensitive and EMF-non-sensitive groups, with the former group possibly exhibiting traits consistent with negative affectivity. If it is accepted that NS itself is multifactorial, as the current authors would argue, then it would be perilous to interpret the finding of Nordin et al. (2014) as proof that NS by its nature manifests general environmental sensitivities, or that NS is sufficiently explained by negative affectivity (16).

It is more difficult to reconcile our results with Stansfeld et al. (1985) as they recruited only females, and utilized a composite scale of ‘general sensitivity’ questions that included a single smell item (“I am very aware of smells and scents”) which does not necessarily reflect negative evaluations, and was, unfortunately, not analyzed in isolation (34). Alternatively, information processing approaches, originating from cognitive psychology, would predict that while a significant positive association between NS and noise annoyance should be observed, no association between NS and olfactory-based judgments would be expected. Specifically, this approach would predict that annoyance may differ between the sensory modalities due to different neural infrastructures and sensory processing characteristics. For example, while the visual, auditory, gustatory and tactile modalities all utilize parts of the thalamus as a relay station, the olfactory modality takes a very different pathway through the olfactory bulb and olfactory (Pyriform) cortex (35). Hence, an uncoupling between NS and olfactory evaluations might be expected on the basis of differing underlying neurological processes.

More studies are needed on NS as a part of more global sensitivity to environmental stimuli. In addition the neural mechanisms of NS and IEI should be studied further to find out if there are similarities.

7. CONCLUSIONS

A significant association between NS and noise annoyance was found, but no significant associations between NS and odor pleasantness, odor intensity or odor familiarity were found. Only for the Motorway sample, there was a mean difference in air pollution annoyance across the three NS groups, with larger means associated with larger degrees of NS. Neither of the two data sets we described offers definitive support for the environmental intolerance approach, with divergent findings between noise and olfactory data.

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