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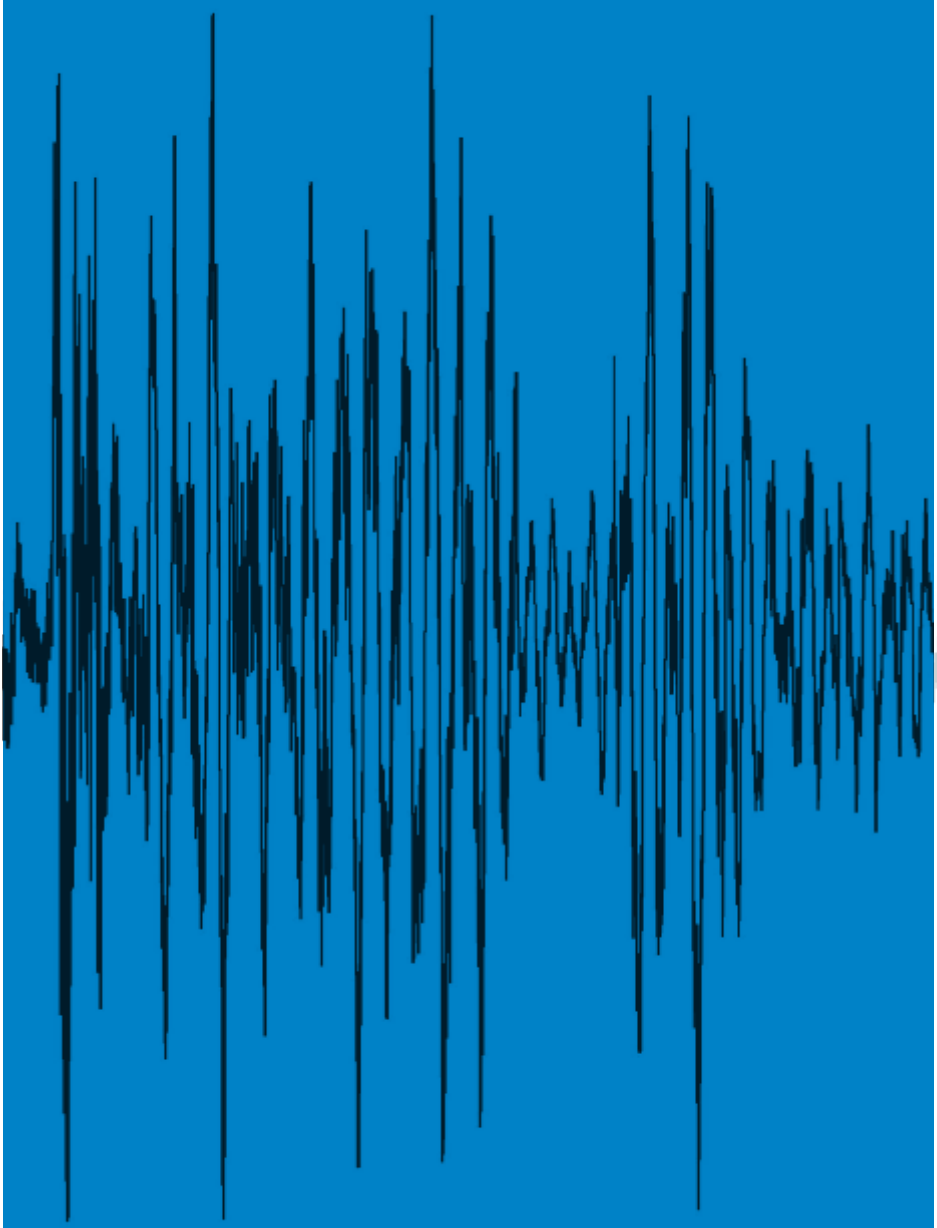

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Noise sensitivity and diminished health: Testing moderators and mediators of the relationship

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Abstract

The concept of noise sensitivity emerged in public health and psychoacoustic research to help explain individual differences in reactions to noise. Noise sensitivity has been associated with health problems, but the mechanisms underlying this relationship have yet to be fully examined. Participants (n = 1102) were residents of Auckland, New Zealand, who completed questionnaires and returned them through the post. Models of noise sensitivity and health were tested in the analyses using bootstrapping methods to examine indirect effects. Results indicated that gender and noise exposure were not significant moderators in the model. Perceived stress and sleep problems were significant mediators of the relationship between noise sensitivity and subjective health complaints, even after controlling for the influence of neuroticism. However, the relationship between noise sensitivity and mental health complaints (anxiety and depression) was accounted for by the variance explained by neuroticism. Overall, this study provides considerable understanding of the relationship between noise sensitivity and health problems and identifies areas for further research in the field.

Keywords: Health complaints, mental health, noise sensitivity, sleep problems, stress

Introduction

Researchers interested in the impact of environmental noise on health and well-being have long acknowledged the important role that noise sensitivity plays in the relationship.[1-5] Noise sensitivity is a strong predictor of noise annoyance[4,6-8] and has been found to moderate the association between noise exposure and self-reported health.[9] Although noise sensitivity is seldom the focus of public health research investigations, there is mounting evidence to suggest that noise sensitivity may be a health risk factor unto itself.[10-14]

Noise sensitivity has been described as a complex and multifaceted construct that encompasses physiological reactions to noise, psychological reactivity and coping mechanisms.[15] Although noise sensitivity is often included as a potential moderator or covariate in acoustics-based and public health research on the effects of environmental noise,[8,16,17] there is limited evidence to suggest that noise sensitivity involves a sensory component.[18,19] Noise sensitive individuals do not have superior hearing abilities, as assessed by a variety of psychoacoustic outcomes including absolute hearing thresholds, intensity discrimination and auditory reaction time.[18,20,21]

Instead of involving a sensory component, noise sensitivity appears instead to be related to attitudinal perceptions; negative correlations between noise sensitivity and the uncomfortable loudness level and discomfort thresholds have been reported.[3,22] As such, noise sensitivity has been labeled a personality trait that influences an individual's reaction to noise.[15,18,23]

A number of studies have revealed a positive relationship between noise sensitivity and another well-recognized personality trait, neuroticism,[3,11,24,25] defined as an individual's tendency to experience negative emotions including anxiety, anger and depression.[26] Notably, Smith *et al*.[27] suggested that the relationship between noise sensitivity and self-reported health could be accounted for by negative affectivity (included in their models as a covariate), which they measured using a neuroticism scale. Beyond their study, however, there has been limited research conducted to thoroughly examine the relationship among noise sensitivity, neuroticism and health and well-being. Nonetheless, due to the relationship between neuroticism and noise sensitivity,[11,24,25] neuroticism is an important trait to measure and control for in studies assessing the relationship between noise sensitivity and health.

Elevated stress levels may play a key role in better understanding the relationship between noise sensitivity and diminished health. There is evidence to suggest that noise

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sensitive individuals have a lower threshold for physiological stress reactivity[28-30] in addition to having a greater emotional response to stressors.[13,29] Chronic activation of the stress response has been implicated in the development of both physical[31,32] and mental illness[33] and therefore one possible explanation for the association between noise sensitivity and depreciated well-being is the bodily wear and tear associated with chronic stress.[34]

In addition, sleep disturbance, a well-established risk factor for a range of health problems,[35] may be involved in the relationship between noise sensitivity and health. Kishikawa *et al*.[9] reported that noise sensitive individuals, particularly those exposed to high levels of environmental noise, were more likely to report somatic complaints, anxiety and insomnia. The authors concluded that the association between noise sensitivity and health complaints is likely explained by sleep disturbance. However, to the best of our knowledge, no studies to date have addressed this research question.

Noise sensitivity has been linked to sleep disturbance in both laboratory-based[36-38] and community-based studies.[13,39-42] In a laboratory study by Marks and Griefahn (2007), noise sensitivity was found to be associated with decreased sleep quality as evidenced by increased body movements throughout the night and difficulty falling asleep after being awoken. Similarly, noise sensitivity has also been linked to sleep disturbance in various community-based studies on road traffic noise,[13,38,40,43] railway noise[39] and aircraft noise.[42] Further, noise sensitivity has also been linked to the use of sleep medication and other psychotropic mediations.[11]

There is some evidence that gender may influence the association between noise sensitivity and health.[12,13,44] Nivison and Endresen[13] reported a significant association between noise sensitivity and a variety of health complaints (muscle, intestinal, nervous, cold and flu, heart-related) among females, while, among males, noise sensitivity was only marginally associated with long-term (i.e., >3 years) allergy complaints. Similarly, Babisch[44] found that an association between self-reported doctor-diagnosed diseases was positively associated with noise sensitivity among women, but not men. It appears that the relationship between noise sensitivity and health problems is stronger among women than men. However, the mechanisms by which gender impacts the relationship – be it psychosocial or biological – have not yet been fully examined and gender remains an important consideration in assessing the relationship between noise sensitivity and health problems.

The Present Study

Noise sensitivity appears to be a health risk factor affecting the development of mental and physical health problems[9-11,14,45] and yet the mechanisms underlying the relationship have not yet been fully examined. Therefore, our study tested a model of noise sensitivity and diminished health to evaluate potential moderators and mediators of the relationship [Figure 1]. This model was developed through identification of potential mediators and moderators of the noise sensitivity-health relationship found in the literature.

In developing the model, stress and sleep problems have been identified as factors that can impact health and well-being[46,47] and thus were tested as potential mediators in the overall model. Specifically, the experience of perceived stress evokes physiological changes (i.e. release of stress hormones and catecholamines), which, if sustained, can contribute to the development of health problems and the development of disease.[48] Similarly, sleep problems and lack of sleep can impact an individual's health and potentially put an individual at risk for the development of chronic diseases.[49-51]

The psychological and health effects of noise sensitivity may differ between males and females; therefore, gender was tested as a moderator in the overall model. Finally, noise exposure is an important variable to consider in examining the relationship between noise sensitivity and well-being. An interaction between noise sensitivity and noise exposure is theoretically plausible; individuals who are noise sensitive and live in noisy areas should, theoretically, be more affected by the noise compared to noise sensitive individuals living in quiet areas. Indeed, an interaction between noise exposure and noise sensitivity interaction has been reported in the literature previously,[9] but there has been mixed evidence as well.[10,11,45] In order to test the interaction between noise exposure and noise sensitivity, noise exposure was included as a moderator in our model.

Subjective health complaints and mental health complaints (anxiety and depression) were tested in the models as outcome variables. Measures of subjective health complaints have been used previously in investigations on noise exposure, noise sensitivity and health.[13,17] In addition, mental health problems have been strongly associated with

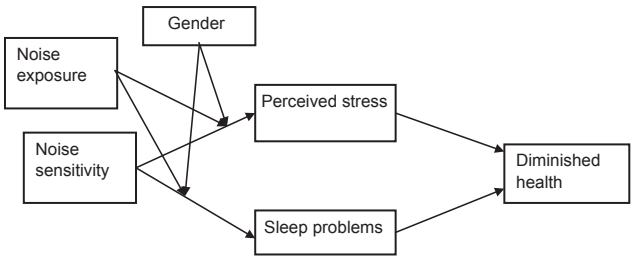

Figure 1: Noise sensitivity and diminished health model (Noise exposure and gender were included as moderators; perceived stress and sleep problems as mediators; diminished health is used as an umbrella term to describe the three outcomes variables – subjective health complaints, anxiety complaints and depression complaints. Covariates: neuroticism, age, education)

noise sensitivity.[9,19] Therefore, it was important to consider general subjective health complaints, but mental health problems as well.

Methods

Participants and procedure

Participants were residents of Auckland, New Zealand. Questionnaires were delivered from April to August 2011 (autumn and winter months) to both noise-exposed households (situated near high volume traffic roads) and households in control areas (not situated near high volume traffic roads). Traffic volumes, obtained from Auckland City Council records (collected during 2009), were used a proxy for traffic noise exposure in the present study.

Prior to distribution, questionnaires were coded according to road traffic volume (vehicles/24 h): (1) <10,000, (2) 10,000-20,000, (3) 20,000-30,000 and (4) >30,000. All houses included in the noise-exposed conditions (>10,000 vehicles/24 h) had at least one side of the house within 20m of the road, as determined with the use of Google maps. The delivery of questionnaires to noise-exposed households was exhaustive in that the majority of houses in residential areas on major arterial roadways identified from Auckland City Council data received a questionnaire. Control households were selected with the aid of the Auckland City Council records (traffic volumes < 10,000 vehicles/24 h). Individuals living at the residence, who were over the age of 18, were invited to participate. A total of 1102 residents participated in the study out of 7500 delivered questionnaires (response rate: 14.7%). The study was approved by the authors' university ethics committee.

Measures

Noise sensitivity

A three-item Noise-sensitivity scale (3-NS;[52]) was used in the present study. The 3-NS involves three statements to which participants respond on Likert scales ranging from (1) completely agree to (5) completely disagree. This format was modified from the original 4-point Likert scale used in the original study by Amann *et al*.[52] Scores are summed, with elevated scores indicating greater noise sensitivity. Good internal consistency and validity were reported in the research by Amann *et al*.[52] In this study, internal consistency was acceptable (Cronbach's α =0.68).

Subjective health complaints

The subjective health complaints inventory (SHCI) is a 29-item scale that measures the intensity and frequency of common health complaints in the last 30 days.[53,54] The questionnaire collects information regarding musculoskeletal pain, pseudo-neurological complaints (e.g., tiredness, dizziness, anxiety and sadness/depression), gastrointestinal problems, allergy complaints and flu complaints.

For each health complaint item, participants rate the extent to which they were suffering from the condition (severity rating) on a 4-point Likert scale ranging from (0) not at all to (3) seriously and they also indicate the number of days they were suffering from the health problem in the past month. A composite score for the scale was computed by adding the total severity ratings for 28 of the items. The sleep problems item was not included in the composite score as it was treated as a mediator variable in the analyses. The SHCI questionnaire has also been used in a large population studies and has been reported to have adequate validity and reliability.[53,55] In the present study, the overall scale had very good internal consistency (Cronbach's α =0.83).

Anxiety and depression

Information on anxiety and depression was collected through two items on the SHCI. Participants rated the extent to which they had been suffering from anxiety and depression in the past 30 days on a Likert scale ranging from (0) not at all to (3) seriously.

Perceived stress

The perceived stress scale (PSS) is a 10-item self-report measure that was designed for use among community samples with at least intermediate school (to 12 years of age) level education.[56] It measures the extent to which participants consider their lives to have been unpredictable, unmanageable and generally stressful within the past month. Participants respond to each question on a 5-point Likert scale ranging from (0) never to (4) very often. The scale is psychometrically sound, exhibiting adequate reliability and validity.[56] In the present study, the PSS had very good internal consistency (Cronbach's α =0.87).

Sleep problems

Sleep problems were measured in the present study also using the SHCI. Participants rated the extent to which they had been suffering from sleep problems in the past 30 days on a Likert scale ranging from (0) not at all to (3) seriously.

Neuroticism

The neuroticism subscale of the big five inventory (BFI;[57]) was used to collect information on this personality trait. For each of the eight items of the subscale, participants were asked to respond on a Likert scale ranging from (1) strongly disagree to (5) strongly agree. The neuroticism subscale had acceptable internal consistency in the present study (Cronbach's α =0.76).

Demographics and life-style questions

Participants were asked to report their age in years, gender, ethnic identification, level of education and current employment status.

Statistical approach

Bootstrapping estimates of indirect effects were used in the analyses of the present study.[58] The moderated mediation model [Figure 1] was tested using the process SPSS macro for 5000 samples provided by Preacher and Hayes.[59] The macro allows the estimation of conditional indirect effects. The output of the macro provides unstandardized regression coefficients and associated *P* values, as well as bias corrected and accelerated confidence intervals (BCa CI) for indirect effects. A significant effect occurs when the CI does not cross zero.

Subsequent models in the analyses were tested using the indirect SPSS macro.[58] In addition to calculating coefficients for the unique pathways among the variables, the macros calculate pairwise contrasts of the indirect effects and therefore the magnitudes of the indirect effect of the mediators can be compared. There is a significant difference in magnitude of the indirect effect of the mediators when the CI of the pairwise contrast does not cross zero.[59]

Controlling for confounding variables

Neuroticism was a particularly important covariate to include in the models as negative affectivity is closely related to noise sensitivity.[19,27] In addition, for any models testing the influence of personality and environmental variables on health, it is theoretically advantageous to control for the influence of age and socio-economic status.[60] In the present study, education was used as a proxy for socio-economic status, as the collection of such information is often preferred over asking participants to indicate income or value of their assets.[61] Age was also entered as a covariate in each of the models.

Results

Descriptive statistics

Descriptive socio-demographic statistics are presented in Table 1. A total of 1,102 participants, ranging in age from 18 to 94 years ($M = 51.39$, SD = 16.42), took part in the study. The majority of the sample was New Zealand European (64.9%) and had at least some university or post-secondary education (71.2%). Descriptive statistics for the health and psychological variables in the study are presented in Table 2.

Noise sensitivity and diminished health model

The overall model [Figure 1] was significant, F (6, 1008) =91.76, $P < 0.001$, $R^2 = 0.353$ indicating that the model predictors (including possible moderators and mediators) explained 35.3% of variance in health complaints. However, the moderated regression analyses (i.e., the influence of gender/noise exposure) revealed that the noise sensitivity × noise exposure and noise sensitivity × gender interactions were not significant in predicting the model mediators [Table 3; interaction $P > 0.05$]. Due to the non-significant interaction between noise sensitivity and the moderators, the conditional indirect effects were not examined. The indirect effect of noise sensitivity on health complaints through perceived stress and sleep problems did not depend on noise exposure or gender.

Table 1: Socio-demographics of the sample

Variable	Category	*n*	%	Valid %[a]
Gender	Male	367	33.3	34.0
	Female	713	64.7	66.0
	Total	1080	98.0	100.0
	Missing	22	2.0	
	Total	1102	100.0	
Ethnicity	NZ European	715	64.9	65.7
	Māori	3	4.8	4.9
	Pacific Islander	34	3.1	3.1
	Chinese	46	4.2	4.2
	Indian	58	5.3	5.3
	European	79	7.2	7.3
	North American	9	0.8	0.8
	Middle Eastern	11	1.0	1.0
	African	10	0.9	0.9
	Australian	13	1.2	1.2
	Central/South American	3	0.3	0.3
	Other Asian	48	4.4	4.4
	Other	10	0.9	0.9
	Total	1089	98.8	100.0
	Missing	13	1.2	
	Total	1102	100.0	
Education (completed)	Secondary school	289	26.2	26.9
	Polytechnic	223	20.2	20.8
	University	562	51.0	52.3
	Total	1074	97.4	100.0
	Missing	28	2.6	
	Total	1102	100.0	
Employment status	Full-time work	499	45.3	45.6
	Part-time work	207	18.8	18.9
	Retired	214	19.4	19.6
	Student	59	5.4	5.4
	Unemployed	31	2.8	2.8
	On leave or sick-leave	15	1.4	1.4
	Own household work	63	5.7	5.8
	Other	6	0.5	0.5
	Total	1094	99.3	100.0
	Missing	8	0.7	
	Total	1102	100.0	

Valid[a] percentages are presented to display frequencies for available data (excluding missing data)

Table 2: Descriptive statistics for health and psychological variables

Variable	*n*	Mean (SD)	Range	Possible range
Noise sensitivity	1088	8.95 (2.66)	3-15	3-15
Perceived stress	1087	15.38 (6.33)	0-36	0-40
Neuroticism	1074	2.55 (0.77)	1-5	1-5
Subjective health complaints	1088	11.17 (8.82)	0-75	0-84
Sleep problems	1088	0.84 (0.98)	0-3	0-3
Anxiety	1086	0.58 (0.84)	0-3	0-3
Depression	1088	0.58 (0.81)	0-3	0-3

SD = Standard deviation

Due to the lack of significant moderator effects in the overall moderated mediation model, a mediation model of noise sensitivity and health complaints was then tested to investigate the influence of the mediators in the model [Figure 2]. Results indicated a significant model, F (6, 1014) =93.32, $P < 0.001$, with predictors and mediators explaining 35.2% of the variance in health complaints. The total effect (c path) of noise sensitivity on health complaints was significant, $c = 0.326$, $P < 0.001$. The direct effect (c' path; controlling for the influence of mediators in the model) of noise sensitivity on health complaints was not significant, c' =0.171, P = 0.053 (after mediators were tested in the model), indicating significant influence of the indirect effects of perceived stress and sleep problems in the model. In terms of the influence of the covariates on health complaints, neuroticism was positively predictive of health complaints, B = 1.316, $P < 0.001$. However neither age, B = −0.008, P = 0.580, nor education, B = −0.177, P = 0.513, was significant in the model.

The total indirect effect was significant, ab_{total} = 0.155, 95% BCa CI: (0.074, 0.249). The indirect effects of noise sensitivity on health complaints via perceived stress, a_1b_1 = 0.088, 95% BCa CI: (0.024, 0.137) and sleep problems, a_2b_2 = 0.077, 95% BCa CI: (0.023, 0.143), were significant. Pairwise contrasts indicated there was no difference in strength between the indirect effect through perceived stress (a_1b_1) compared to that via sleep problems (a_2b_2), B = −0.0004, 95% BCa CI: (−0.075, 0.074).

Table 3: Moderated regression results for the effect of gender and noise exposure on the relationship between noise sensitivity and perceived stress and sleep problems

Model	B	SE	*t*	*P*
Moderated multiple regression of noise sensitivity on perceived stress				
Noise sensitivity	0.244	0.222	1.101	0.271
Noise exposure	−0.350	0.435	−0.805	0.421
Noise exposure×noise sensitivity	0.052	0.047	1.102	0.271
Gender	0.337	1.059	0.318	0.751
Gender×noise sensitivity	−0.108	0.116	−0.933	0.351
Neuroticism	5.183	0.199	25.993	<0.001
Age	−0.050	0.010	−5.225	<0.001
Education	−0.167	0.177	−0.945	0.345
F (8, 1006)=110.16, P<0.001, R^2=0.467				
Moderated multiple regression of noise sensitivity on sleep problems				
Noise sensitivity	−0.0003	0.044	−0.007	0.142
Noise exposure	0.031	0.087	0.359	0.720
Noise exposure×noise sensitivity	−0.0008	0.009	−0.084	0.933
Gender	−0.098	0.212	−0.462	0.645
Gender×noise sensitivity	0.021	0.023	0.905	0.366
Neuroticism	0.382	0.040	9.575	<0.001
Age	0.008	0.002	3.890	<0.001
Education	−0.024	0.035	−0.672	0.502
F (8, 1006)=17.66, P<0.001, R^2=0.123				

SE = Standard error, n = 1015

Noise sensitivity and anxiety complaints

The noise sensitivity and anxiety complaints model is presented in Figure 3. The results of the mediation model of noise sensitivity and anxiety complaints indicated a significant model, F (6, 1013) =110.30, $P < 0.001$, with the model variables explaining 39.0% of the variance in anxiety complaints. However, notably neither the total effect (c = 0.012, P = 0.173) nor the direct effect (c' = −0.001, P = 0.902) was significant, thereby suggesting that the significance of the model cannot be attributed to the mediators.

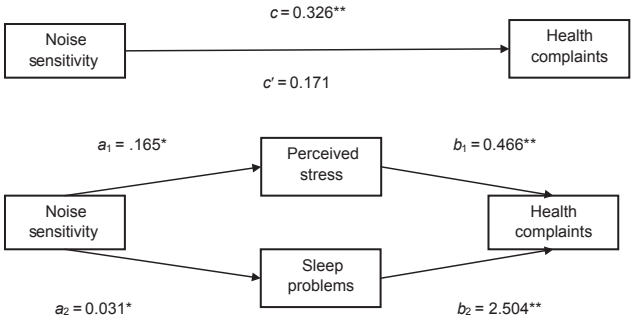

Figure 2: Noise sensitivity and health complaints mediation model. (Unstandardized coefficients are presented for the pathways between independent variable, mediators and dependent variable. a pathway = relationship between noise sensitivity and mediator [perceived stress/sleep problems]. b pathway = relationship between mediator [perceived stress/sleep problems] and health complaints. c pathway = relationship between noise sensitivity and health complaints [total effect]. c′ pathway = relationship between noise sensitivity and health complaints after controlling for model variables [direct effect]. Covariates: Neuroticism, age, education n = 1021 **P < 0.001 *P < 0.05)

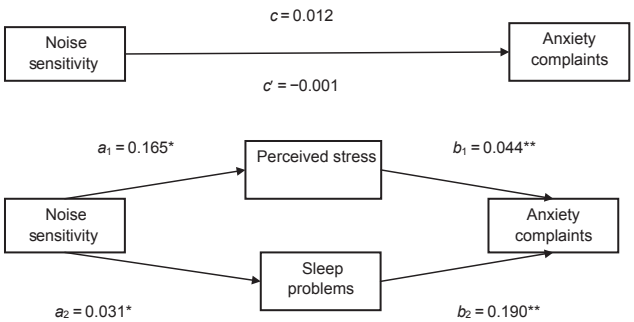

Figure 3: Noise sensitivity and anxiety complaints mediation model. (Unstandardized coefficients are presented for the pathways between independent variable, mediators and dependent variable. a pathway = relationship between noise sensitivity and mediator [perceived stress/sleep problems]. b pathway = relationship between mediator [perceived stress/sleep problems] and anxiety complaints. c pathway = relationship between noise sensitivity and anxiety complaints [total effect]. c′ pathway = relationship between noise sensitivity and anxiety complaints after controlling for model variables [direct effect]. Covariates: Neuroticism, age, education n = 1020 **P < 0.001 *P < 0.05)

Rather, the covariates accounted for the variance in anxiety complaints. Specifically, neuroticism was significant in predicting anxiety complaints, $B = 0.259$, $P < 0.001$, with elevated neuroticism being predictive of anxiety complaints. Age was also positively predictive of anxiety complaints, $B = 0.004$, $P = 0.009$, with increases in age being associated with increased anxiety. Education was not significant in the overall model, $B = 0.042$, $P = 0.093$.

The overall indirect effect was significant, $ab_{total} = 0.013$, 95% BCa CI: (0.006, 0.021), a result suggesting a significant difference between the total (c path) and direct effects (c'). This difference was accounted for by the indirect effect via both perceived stress, $a_1b_1 = 0.007$, 95% BCa CI: (0.003, 0.013) and the indirect effect via sleep problems, $a_2b_2 = 0.006$, 95% BCa CI: (0.001, 0.011). Pairwise contrasts revealed no significant difference in strength between the indirect effect via perceived stress compared with sleep problems, $B = 0.001$, 95% BCa CI: (−0.005, 0.008).

Noise sensitivity and depression complaints

The mediation model of noise sensitivity and depression complaints was significant, $F(6, 1014) = 112.53$, $P < 0.001$, with model variables explaining 39.6% of variance in depression complaints [Figure 4]. Neither the total effect of noise sensitivity on depression complaints ($c = 0.003$, $P = 0.683$) nor the direct effect ($c' = -0.008$, $P = 0.284$) was significant. However again, neuroticism, included in the model as a covariate, was significant in predicting depression complaints, $B = 0.270$, $P < 0.001$. The remaining covariates, age ($B = -0.001$, $P = 0.464$) and education ($B = 0.007$, $P = 0.781$), were not significant in predicting depression complaints.

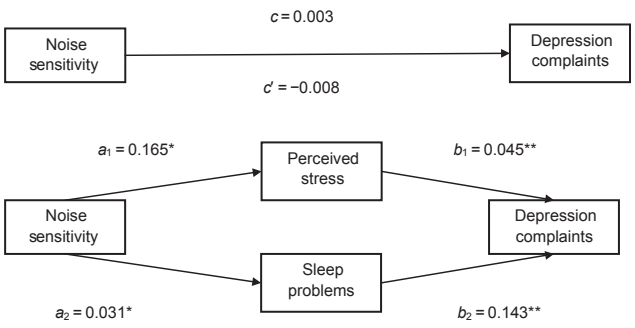

Figure 4: Noise sensitivity and depression complaints mediation model. (Unstandardized coefficients are presented for the pathways between independent variable, mediators and dependent variable. a pathway = relationship between noise sensitivity and mediator [perceived stress/sleep problems]. b pathway = relationship between mediator [perceived stress/sleep problems] and depression complaints. c pathway = relationship between noise sensitivity and depression complaints [total effect]. c′ pathway = relationship between noise sensitivity and depression complaints after controlling for model variables [direct effect]. Covariates: Neuroticism, age, education $n = 1021$ **$P < 0.001$ *$P < 0.05$)

The overall indirect effect of noise sensitivity on depression complaints through the mediators was significant, $ab_{total} = 0.012$, 95% BCa CI: (0.006, 0.019) indicating a significant difference between the c and c' paths. The indirect effects via perceived stress, $a_1b_1 = 0.007$, 95% BCa CI: (0.003, 0.013) and sleep problems were significant, $a_2b_2 = 0.004$, 95% BCa CI: (0.001, 0.009). Pairwise contrasts of the indirect effects revealed that the indirect effect through sleep problems was not stronger than that via perceived stress, $B = 0.003$, 95% BCa CI (−0.003, 0.009).

Discussion

The present study tested whether a number of variables act as mediators and moderators in the association between noise sensitivity and health problems. As expected, greater noise sensitivity was associated with more health complaints. Results of the study indicated that the proposed moderators, namely gender and noise exposure, did not impact the model significantly. Rather, perceived stress and sleep problems were significant mediators in the association between noise sensitivity and subjective health complaints. The results for the mental health complaints models indicated that neuroticism, included in the models as a covariate, largely accounted for the association between noise sensitivity and anxiety and depression complaints.

Notably, our results indicated that stress plays an important role in the relationship between noise sensitivity and health complaints. Although the relationships among noise sensitivity, physiological stress (i.e., activation of the stress response) and psychological stress (i.e., perceived stress levels) have been tested within laboratory settings,[29,62] the present study provides evidence for the role of perceived stress within a large community-based study and in relation to the association between noise sensitivity and health complaints.

While research indicates a close relationship between the experience of psychological stress and the physiological stress response,[63] it must be emphasized that, in our study, information was collected on perceptions of stress, not physiological stress parameters. Therefore, while we propose that the relationship between stress and health complaints is likely due to allostatic processes (i.e., bodily wear and tear from stress);[64,65] we cannot be certain due to the lack of biomarkers in the study. However, previous laboratory studies have demonstrated a relationship between noise sensitivity and stress reactivity, as evidenced by hyperactivation of the sympathetic-adrenal-medullary system and the hypothalamic-pituitary-adrenal axis in response to psychological or environmental stressors.[29,66,67] Further research on the physiological strain of chronic stress in relation to the association between noise sensitivity and health will help to elucidate the mechanisms underlying this relationship.

While it is rather than well-known that sufficient quality and quantity sleep help buffer risk for health problems,[68] the results of our study extend this finding to the relationship between noise sensitivity and health problems.[9,45,69] In other words, noise sensitivity is associated with sleep problems, which, in turn, can lead to poor health. Indeed, sleep disturbance has been associated with noise sensitivity in both field and laboratory studies.[36,39] Noise sensitive individuals may experience greater sleep disturbance because of greater stress reactivity,[28,30] which, in turn, may contribute to increased awakenings throughout the night. These awakenings could be due to nighttime noise either inside or outside the home. Additional research focused on the relationship between noise sensitivity and sleep in domestic settings, would be advantageous in further understanding the relationship.

Kishikawa *et al*.,[9] authors of a recent study on the association among noise exposure, noise sensitivity and minor psychiatric disorder (as assessed by the general health questionnaire [GHQ];[70]) proposed that the likely mechanism explaining the link between noise sensitivity and mental health problems was sleep disturbance. In their study, noise sensitive individuals who were exposed to considerable road traffic noise (>55 dB) were more likely to report psychiatric complaints (e.g., anxiety and insomnia, somatic symptoms) compared to non-noise sensitive participants. Due to the relationship between noise sensitivity and mental health problems, particularly among noise-exposed participants, it is reasonable that Kishikawa *et al*.[9] suggested sleep disturbance as a likely mediator. However, noise exposure was not a significant moderator in the present study and therefore we cannot conclude that the relationship between noise sensitivity and health complaints is attributable to sleep disturbance due to road traffic noise.

The relationship between noise sensitivity and mental health complaints in the present study was accounted for by neuroticism, included as a covariate in the models. This finding is consistent with the previous research by Smith *et al*.,[27] who reported that the relationship between noise sensitivity and self-reported health could be accounted by negative affectivity. Smith *et al*.[27] used self-reported physical illness and the GHQ (which measures anxiety, severe depression, social dysfunction and somatic complaints) as health outcomes. Specifically, the use of a largely mental health-orientated scale (GHQ) may account for the similar results between their study and the results from our mental health complaints models.

Indeed, the models tested in our study suggest that the relationship between noise sensitivity and mental health complaints is accounted for by neuroticism. These results might also be explained by the high degree of shared variance among neuroticism, mental health complaints and noise sensitivity, the common thread being anxiety. However, to contrast the research findings of Smith *et al*.,[27] in our study, neuroticism did not have the same influence over the relationship between noise sensitivity and subjective health complaints (i.e., sleep problems and perceived stress mediated the relationship even after controlling for neuroticism).

Limitations

Although the present study examined factors involved in the relationship between noise sensitivity and diminished heath relationship using a large (n > 1000) community-based study, there are some limitations with the use of this research design. First, as with all cross-sectional studies, the assumption of causality within the study models should be considered with caution. While the models were structured to suggest that noise sensitivity precedes the development of stress, sleep problems and health complaints, it is not possible to confidently confirm the direction of the associations in this study. Further research on the topic, longitudinal designs in particular, would be beneficial in discerning the nature of the relationship between noise sensitivity and health problems.

Second, we used road traffic volume as a proxy for noise exposure in the present study, which is not the ideal method for assessing environmental noise exposure. The methods for collecting information on environmental noise exposure range from relatively precise (e.g., personal dosimeters;[71,72] to the moderately accurate (e.g., Nordic prediction method;[73]) to the relatively crude (e.g., participant self-reports of the type of street on which they live;[74]).

In this study, we used road traffic volume as a proxy for noise exposure, which could be classified as a relatively crude measure of environmental noise exposure. It is possible that this could be a factor contributing to the lack of interaction between noise sensitivity and noise exposure in our model. We must emphasize, however, that noise exposure remains an important variable to consider in related models because of its theoretical relevance in the relationship between noise sensitivity and health. Further research on the relationship between noise sensitivity and health should consider using more precise methods of environmental noise exposure, such as personal dosimeters, in order to fully understand the strain of various forms of noise exposure on noise sensitive individuals.

Another limitation of our study is the use of a subjective health complaints scale as a health outcome. These types of scales require the researchers to rely on the participant's own perception of their health and well-being, which can be viewed as less accurate than more objective health outcomes such as physician-diagnosed illnesses and laboratory-tested conditions (e.g., hypertension, cancer, autoimmune disease). However, the use of health complaints scales is a common and reliable method to assess health

problems.[75-77] Further, they are strong predictors of visits to a medical physician and taking sick leave from work,[78] thus highlighting the relevance to public health research. Nonetheless, future research on noise sensitivity and health using more objective outcomes will help to appropriately expand this area of research.

Finally, the low response rate is a limitation of the study. Galea and Tracy[79] discussed the issue of declining participation rates in recent years. In particular, they suggested that people are now less likely to volunteer for studies due to the steep increase in survey-based research conducted by universities and government bodies. In other words, the oversampling of the general population has led to declining response rates. Auckland is the largest city in New Zealand and home to three universities, so it is possible that our low response rate could be reflective of oversampling and in turn, declining interest to participate in research among residents of Auckland, New Zealand.

There are some strategies that can be employed to help to increase participation in survey-based studies, such as offering financial incentives or extensive follow-up with participants.[79] Participants completed the questionnaire anonymously and therefore extensive follow-up was unfortunately not feasible. Despite a low response rate, our large sample had a good range of data, which allowed for the testing of our statistical models. Overall, these limitations should be considered in interpreting the results of the study.

Conclusion

While previous researchers have reported an association between noise sensitivity and diminished health,[10-13,45] there has been limited attention as to the mechanisms underlying the relationship. The present study fills an important gap in the literature through the assessment of mediators and moderators of the association between noise sensitivity and diminished health using a large community-based study. Perceived stress and sleep problems significantly mediated the association between noise sensitivity and subjective health complaints, even after controlling for the influence of neuroticism. Specifically, it is possible that noise sensitive individuals are more likely to experience psychological stress, which, in turn, places them at risk for developing health problems. Further research to elucidate physiological agents that may be involved will help to provide more understanding. In addition, research using more precise methods of noise exposure (e.g., personal dosimeters) will help to further understand the impact of noise on the relationship among noise sensitivity, stress and health problems. Overall, our study provides useful insight into the psychological factors involved in the relationship between noise sensitivity and diminished health and identifies areas for further study in the field.

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