Determinants of annoyance from humming sound as indicator of low frequency noise.

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ABSTRACT

The level of concern and health complaints related to low frequency noise (LFN) seems to be increasing, not only in the Netherlands, but also at international level. There is evidence suggesting an association between LFN and symptomatic effects such as annoyance and sleep disturbances. A systematic evaluation of the literature which we recently performed, focusing on epidemiological studies on residential sources of LFN in relation to various symptoms and well-being indicators confirms these findings. However, it is still hard to make a valid estimate of the burden of disease due to LFN. Therefore, based on several Dutch datasets we estimated the prevalence of health complaints due to low frequency noise or attributed to it. The available data only concerned perceived exposure rather than actual measurements of LFN, preventing to link the exposures to these effects. It was concluded that the number of complaints and the percentage highly annoyed has increased. Large differences were found between cities, regions and in particular neighbourhoods. This paper explored the relation between contextual, situational and personal features with the level of annoyance due to low frequency sounds, based on secondary analysis of existing data.

1 INTRODUCTION

The number of questions and complaints related to Low Frequency Noise (LFN) seems to be increasing. LFN is in the Netherlands defined as noise with a frequency below 125 Hz. Other definitions (Leventhall 2004; Leventhall, 2009) refer to 250Hz as upper limit and others (Slob et al, 2016) report an even higher cut off point of 250. The Ministry of Spatial Planning and the Environment (the Netherlands) has therefore asked the National Institute for Public Health and the Environment (RIVM) to build a knowledge base around the theme. Various efforts have been undertaken to shed more light on this topic. Despite these efforts there are still many uncertainties and in many cases it is not possible to give a clear cut answer to the many questions regarding LFN sources, and their potential effects on people. In general we can state that low frequency sound is an under-investigated noise component in relation to health effects. In view of this, a symposium around LFN was organized in 2014 (Van Poll, Van Kamp, 2015) to hear what we can learn from people who have been working in the field for a long time and with different backgrounds. In addition, a factsheet was prepared for the Ministry and a review (van Poll, van Kamp, 2013) mapping the current evidence for an association between exposure to LFN from different sources and acute and long-term health effects. For Municipal Health Services (MHS) provisional guidelines were published in 2016 (Slob et al, 2016), provisional since a new approach for the MHS is proposed to decide whether an external source could be present and how to deal with complaints regarding low frequency sounds. Experience with this new approach will be gained and evaluated systematically this year.

In our recent review (Baliatsas et al, 2016) we concluded that systematic evaluation of observational studies suggests an association between exposure to LFN components and self-reported annoyance and various symptoms in the population, based on a meta-analysis of recent studies. However, the number of studies is limited and only seven studies were eligible for further consideration. Estimates of the prevalence of high annoyance in four of these studies varied between 2% and 34% with a pooled prevalence of 10.5%. (see e.g. Persson Waye et al, 1997, 2001). An association with other health effects including sleep disturbance might exist, but evidence is still limited and inconclusive.

Also, we prepared an overview of the prevalence of complaints (van Kamp et al, 2017) about LFN and annoyance attributed to low frequency noise in the Netherlands based on existing registry and survey data. Results showed that in general some 2% of the general population of 18 years and older experienced problems from LFN (all sources) while at home. Estimates of a percentage self-reported highly annoyed with low frequency noise varied between 5 to 12% percent depending on the way it was calculated and what denominator was used (Balvers et al, 2012)(Van Kamp et al, 2011). The number of complaints as well as the percentage highly annoyed by low frequency noise (from all sources) seems to have increased and even doubled since 2012 (Dusseldorp et al, 2013, 2017). The difference between these estimates and estimates derived from the international literature, as documented in the review of Baliatsas at al (2016) might be related to differences in definition of the percentage of highly annoyed and the sources included.

In an earlier paper (van Kamp et al, 2017) it was concluded that further analysis of the role of contextual and personal variables in the responses to low frequency noise such as noise sensitivity, attitudes and hearing impairment was warranted. This paper therefor explores the determinants of annoyance with low frequency sound based on available data from the TASTE project. This study investigated people's perceptions of the sound quality of their immediate living environment in urban areas, including humming sounds from e.g. ventilators. TASTE also explored the interrelations between perceived soundscapes and level of noise exposure (measured and modelled), perceived physical and social aspects at neighbourhood level, personal and demographic characteristics.

This study was carried out in 31 neighbourhoods in the Netherlands from three cities in 2013. In particular the role of noise insulation was studied under the assumption that current measures (such as double glazing and cavity filling etc.) are indeed successful in reducing the noise levels indoors, but at the "cost of" the low frequency component.

2 METHOD

2.1 Towards Acoustic SusTainable Environments (TASTE)

The TASTE project (Van Kempen et al, 2014) was a strategic project at RIVM (2012-2015) looking into determinants of perceived acoustic quality at neighbourhood level. Participants were people of 18 years and older, recruited from 33 neighbourhoods in three Dutch cities (Arnhem, Amsterdam and Rotterdam) which we aggregated into 31 neighbourhoods in order to achieve approximately equal sample size. The selection and recruitment of these participants followed several steps. Neighbourhoods were selected according to level of urbanization, contrasting levels and variations in noise exposure and neighbourhood lay-out, and were subsequently matched on socio-economic status (SES) to ensure variation in categories of SES. Per neighbourhood, a random sample of 500 inhabitants (15,508 in total) was drawn from the municipal population registries of the three cities. By means of a letter, participants were invited to fill out an online questionnaire. If the participant preferred a postal questionnaire, this was provided on request. After two reminders, 3,972 respondents returned the questionnaire, which means a response percentage of 26%.

The questionnaire included a range of aspects relevant for the aim of the study and subdivided in the following themes: residential situation, noise situation, relaxation, health and well-being, the dwelling and demographics (see also van Kempen et al, 2014). Here we only describe the variables included in the analyses preformed in the framework of this paper.

Annoyance was measured by means of the standard ISO annoyance question scale ISO, 2003). This index enquires about the level of "bother, nuisance, annoyance over the past 12 months using answering categories between 0-10 ranging from not at all to very much. In the analysis, only the percentage (self-reported) highly annoyed was included following the Miedema standard (Miedema and Oudshoorn, 2001). Hereby the 0-10 scores were dichotomized using a cut-off score for severely annoyed at 7.2. This was used in further analysis. Annoyance was asked for road, rail and air traffic sources, low frequency noise, construction noise, neighbours and mopeds. The low frequency question was formulated as follows: *Thinking about the past 12 months how much were you annoyed, bothered or disturbed by the humming noise from for example ventilators, while at home on a scale of 0-10*).

Noise sensitivity was measured by means of an adapted version of the Weinstein noise sensitivity scale as was published and validated by Kishikawa, Matsui et al (2006). This index includes six items about attitudes toward noise under various circumstances encountered in everyday life e.g. "I am sensitive to Noise", "I find it hard to relax in a place that is noisy and "I am easily awakened by noise". Degrees of agreement on the statements were asked with six response options ranging from 0-5 (agree strongly to disagree strongly). The sum of all items (after recoding four items) was regarded as respondent's subjective noise sensitivity. The percentage highly sensitive was defined at a cut-off point of 25 on a scale ranging from 6-30).

Residential satisfaction was measured by several sets of questions, including a general question about satisfaction with the residential situation with answers ranging from very satisfied (1) to not satisfied at all (5). The information on both road traffic and cumulative noise levels(road traffic, aircraft, railway and industrial noise - Yearly averaged L_{den}, L_{night}, L95night , L95day) was gathered at the six digit postal code level (Six digits postal codes on average includes some 10-15 dwellings in the Netherlands) of the respondents, and the level of the neighbourhood.

Participants were also asked which insulation measures (against noise as well as in view of energy saving) were applied in their home (double glazing in living and sleeping room, cavity wall fillings and sound absorbing ventilation grilles or other. Answer categories for each were: *yes (1), do not know (2)*, no (3).

2.2 Analysis

After presenting key descriptive statistics (table 1 and 2), difference of means tests (ANOVA) were carried out per city to analyse the univariate association between the key predictors and annoyance. Next, multi-level regression analysis was applied to take into account the clustering of the data. Level 1 represented the individuals and Level 2 neighbourhood. The following potential confounders were used in all models: gender, age, level of education, L_{den} and L_{night} for road traffic, insulation measures, residential satisfaction and noise sensitivity.

3 RESULTS

In Table 1 the key demographic and individual characteristics of the participants are presented per city. From the table it can be seen that gender is equally distributed with a slight overrepresentation of women (Dutch Reference 50%). The mean age of the participants varies between 46 yrs. in Amsterdam and 50 yrs. in Arnhem and a mean age of 48 yrs. in Rotterdam. Compared to the age distribution in the Netherlands, the number of participants under 40 years is low. The percentage of participants with a non-Dutch nationality is 12% with the highest % in Amsterdam (18%) and lowest in Rotterdam (7%). In 2013 the number of people in the Netherlands with a non-Dutch nationality was 21%. The number of highly educated people is very high in all three cities. For comparison we may note that in 2012 28 % of the Dutch population had a completed educational level at College/University level. On average the participants have been living at their current address for 12 years. These indicators are comparable between cities. On a scale of 6-30 the percentage highly sensitive was defined with a score of 25 and higher. This resulted in a percentage highly sensitive ranging from 18% in Amsterdam to 15% in Arnhem.

Table 1: General characteristics of the participants

Characteristic	Amsterdam (N=1,532)	Rotterdam (N=1,182)	Arnhem (N=1,258)	Overall (N=3,972)
Women, %	53.3	52.7	49.4	51.9
Mean age (SD)	46.1 (17.2)	48.1 (17.1)	50.0 (15.4)	47.9 (16.7)
Dutch nationality, %	82.3	92.7	89.6	87.8
Education level, %††				
Low	5.5	8.1	4.0	5.8
Middle1	13.1	22.0	21.7	18.5
Middle2	21.9	27.7	32.1	26.9
High	59.5	42.2	42.3	48.9
Mean length of residence in yrs. (SD)	11 (11.4)	13 (11.8)	14 (11.6)	12.7 (11.7)
(very) satisfied with their living environment, %	82.8	76.5	84.0	81.3
Noise sensitivity % highly sensitive (SD)*	18	16	15	16.3

* noise sensitivity score above 25: sensi. vity is high) ††Educa onal level which originally contains 8 categories ranging from none to scientific education was reduced to four categories. Abbreviations: SD = Standard deviation, N = number of participants

Table 2 gives an overview of the modelled road traffic noise exposure levels (expressed in L_{den}, L_{night} and the background level L95day and night), the percentage highly annoyed for different noise sources and the percentage of people with specific noise insulation measures in their homes per city.

Table 2: Modelled road traffic noise, annoyance with different noise sources and insulation measures per city.

Characteristic	**Amsterdam (N=1,532)**	**Rotterdam (N=1,182)**	**Arnhem (N=1,258)**	**Overall (N=3,972)**
Mean modelled **road traffic** noise exposure levels, dB(A) in the street of the respondent				
L_{den} (SD)	58.8 (5.1)	57.8 (5.0)	55.9 (5.0)	57.6 (5.2)
$L_{95\ day}$ (SD)	48.9 (5.9)	47.0 (7.5)	43.9 (7.1)	46.7 (7.1)
$L_{95evening}$ (SD)	37.7 (7.4)	35.3 (8.5)	32.0 (6.2)	35.2 (7.7)
L_{night} (SD)	49.1 (4.9)	48.0 (4.8)	46.0 (4.9)	47.8 (5.0)
Severe annoyance % [3]				
Road traffic noise	21.7	23.9	19.8	21.7
Rail traffic noise	2.4	2.3	6.1	3.5
Industrial noise	5.3	4.1	3.7	4.4
Construction noise	17.3	8.9	10.3	12.6
Humming noise, e.g. from ventilators	**8.2**	**6.1**	**6.1**	**6.9**
Noise from neighbours	16.4	15.6	15.6	15.9
Noise from mopeds	19.1	18.1	19.4	18.9
Type of insulation %				
Double Glazing Living Room	85	85	91	87
Double Glazing Sleeping Room	76	78	81	78
Cavity wall fillings	31	32	47	37
Sound absorbing Ventilation grille	20	19	26	22

[3] Severe annoyance recoded into (0 = none and 1= high), Sound insulation measures recoded into 1=yes, 2= do not know and no)

Results show that in total some 7% of the respondents indicated to be highly annoyed by the humming sound of e.g. ventilators, with the highest score in Amsterdam of over 8%, and 6% in both Arnhem and Rotterdam. This difference is statistically significant, but not necessarily relevant. Also at neighbourhood level a statistically significant difference was found in the percentage of highly annoyed by humming sounds. Mean annoyance scores ranged from 1.5% to 15%. Table 3 presents the results of univariate analysis on the key predictors of annoyance due to low frequency noise

Table 3: Analysis of predictors of annoyance from humming sounds e.g. from ventilators while at home (ANOVA)

Model		**Sum of Squares**	**DF**	**Mean Square**	**F**	**Sig.**
	City	115.88	2	57.944	7.793	.000
	Neighbourhood	997.57	32	31.174	4.290	.000
	Sensitivity	597.21	1	597229.	81.769	.000
	Residential satisfaction	499.64	1	499.641	68.160	.000
	Double glazing living room	38.432	1	38.432	5.153	.023
	Double Glazing sleeping room	26.412	1	26.412	3.544	.060
	Cavity wall fillings	53.349	1	53.349	7.163	.007
	Sound absorbing Ventilation grille	13.633	1	13.633	1.829	.176

a. Variable: Annoyance

With the exception of double glazing in the sleeping room and sound absorption ventilation grilles, all predictors show a significant univariate association with mean annoyance due to low frequency sound. Next, the predictors were included in a multilevel model which was run in two step, with the first step including the L_{den} and L_{night} as well as the background levels (L95 day and night) for road traffic noise only (model 1). In the next step demographic, insulation measures, noise sensitivity and residential dissatisfaction were added to the model (Model 2).

Table 4: Multi-level regression analysis of annoyance from humming (LF) sounds. Amsterdam, Rotterdam, Arnhem) Mixed models: Estimates of Fixed Effects

Parameter	Estimate	Std. Error	df	t	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Intercept	-2.11	1.39	1115	-1.528	.127	-4.83	.60
City	-.15	.09	36	-1.559	.128	-.34	.04
L95_Day_ind	.04	.02	1708	2.168	.030	.00	.08
L95_Night	-.03	.02	548	-1.856	.064	-.07	.00
L_{den}_Road	.22	.13	1382	1.705	.088	-.03	.48
L_{night}_Road	-.22	.14	1458	-1.630	.103	-.49	.04
Gender	.11	.09	3865	1.240	.215	-.06	.27
Age	-.07	.09	3644	-.815	.415	-.26	.11
Education_cat	.00	.03	2875	.137	.891	-.05	.05
Living room insulated	.10	.16	3849	.611	.541	6.22	.42
Sleeping room insulated	.05	.14	3631	.395	.693	-.21	.32
Cavity wall fillings	.01	.10	3831	.118	.906	-.19	.21
Sound absorbing Ventilation grille	.06	.11	3876	.545	.586	-.16	.28
sensitivity_dich	.93	.12	3871	8.053	.000	.71	1.16
Residential dissatisfaction	1.52	.21	3876	7.070	.000	1.09	1.94
	Residual	6.99	.159	43.843	.000	6.688	7.314
Intercept [subject = Neigb]	Variance	.119	.045	2.649	.008	.056816	.249

a. Dependent Variable: annoyance with humming sounds

When the background levels are included in the model, L_{den} and L_{night} are no longer significant as predictors of annoyance. The daytime background levels are predicting levels of annoyance, while the influence of L95 night is reversed: the higher the night noise background levels the lower the level of annoyance due to humming sounds. Demographics and insulation measures did not add to the prediction of annoyance. Residential dissatisfaction and noise sensitivity are important determinants of annoyance: a high level of residential dissatisfaction and noise sensitivity is associated with a higher level of annoyance.

4 CONCLUSIONS

4.1 Summary of the main findings

This paper explored the determinants of annoyance due to humming (LF) sounds. We studied the association between exposure levels due to road traffic noise and annoyance while adjusting for demographic, physical and personal in an existing dataset. Results showed significant differences between the three cities included as well as at neighbourhood level. Background noise level, noise sensitivity and dissatisfaction with the residential situation were strongly associated with higher levels of annoyance. The association with night time background levels was reversed: the lower the levels the higher the annoyance due to humming sounds e.g. from ventilators. This is in line with the notion that low frequency noise is particularly an issue in location with low background noise levels (Insulation measures did not show an association with levels of annoyance, but noise sensitivity and residential dissatisfaction did). The reason for this could be that the humming sound as measured in this study is an internal noise source. We cannot not make any inference about the direction of the associations since we are dealing with cross sectional data.

4.2 Strengths and limitations

A strong point of the data included in this analysis is that it allows us to study annoyance from different sources while accounting for important physical, contextual and personal aspects. Moreover, the number of participants per neighbourhood was sufficient to make accurate statements at the level of neighbourhood. However the study also knows its weaknesses. The low response rate of 26% is disappointing, but in line with what one would expect currently with this type of survey. Although the statistical power needed has been reached with at least 100 participants per neighbourhood, selection bias cannot be ruled out. The mean age of the sample is higher than expected as is the level of education, in comparison with national averages, but in line with the percentage of highly educated in the larger cities in the Netherlands. Moreover, we deal with cross sectional study which excludes the possibility of statements about causality. Finally no modelled or measured levels of low frequency sound are available and the single question on annoyance due to humming sounds with reference to ventilation sound as example has not been tested to the fullest in terms of reliability and validity.

4.3 Implications for future research and practice

Results confirm the joint association between background noise levels and personal features and annoyance from humming sounds. The pattern seems complex and indicates that there is in particular a night time problem in those areas with low background noise levels from road traffic. Although differences between neighbourhoods and cities are remarkable both with respect to levels of annoyance and insulation measures, it is still not fully explained what causes these differences.

4.4 Conclusions

In an existing dataset we explored the association between physical, situational and personal aspects and annoyance due to low frequency noise. In particular the role of insulation measures was studied, under the assumption that insulation measures might lead to a shift in the noise spectrum towards the low frequency component. Recently it is hypothesized that there is a shift from high to low frequency transport noise due to noise reducing measured. However, this could not be confirmed in these analyses, because we are not sure that people responded to indoor as well as outdoor sources. Results showed strong differences between cities and neighbourhoods, a significant association between background noise levels from road traffic in the daytime and an interesting reversed effect at night. Also the role of noise sensitivity and residential dissatisfaction was confirmed. Further analysis is needed to get to grip with the complex issue of annoyance due to low frequency noise.

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