Factors influencing noise annoyance across various transportation modes: lessons from the citizen science project "*De Oorzaak*"

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ABSTRACT

The citizen science initiative "*De Oorzaak*" invited adult residents of Flanders (Belgium) to fill out the "Large Sound Survey" (LSS), gathering over 8,000 answers in a month. This comprehensive 51-question survey evaluated annoyance levels across various transportation modes, drawing on established questionnaires like the Epworth Sleepiness Scale, Weinstein Noise Sensitivity Scale and Written Environmental Survey (SLO), organized by the Flemish government. It also aided in selecting participants for subsequent project phases. Comparing the LSS results to the latest SLO report revealed a significant self-selection bias, with 33.3% highly annoyed by noise compared to 11.6% from the SLO. A profile could be drawn for the most annoyed participants: noise-sensitive individuals living in apartments or studios, adults (26-61 years old), and residing in densely populated areas. Regarding transportation noise, passenger cars and trucks lead as the most annoying sources, with %HA of 24.5% and 23.5%, respectively, followed by motorcycles and alike (%HA =21.5%). Conversely, rail and air traffic annoyance are considerably lower. Correlations were drawn between the several noise annoyance sources and individuals' characteristics. Overall, population density, age, fatigue level and quality of life are the personal aspects that correlate more consistently with road, rail, and air traffic noise annoyance.

1. INTRODUCTION

Long-term exposure to road traffic noise has been linked to non-auditory health outcomes such as cardiovascular diseases, cognitive dysfunction, and sleep disorders, among others [1]. These adverse effects arise from somewhat unconscious physiological responses to noise exposure that can be subjectively measured through "noise annoyance". This indicator is self-reported and assessed at the population level via social surveys. Noise annoyance is an early warning

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signal for health risks, playing a key role in setting noise exposure limits and creating action plans for noise exposure mitigation [2].

Noise annoyance is, however, only partially determined by physical noise exposure. The majority is attributed to other, often non-acoustic-related, aspects, such as expectations regarding the noise source, noise sensitivity, age, living conditions, among others [3].

Surveys at the population level have been conducted to measure annoyance in relation to noise exposure, besides aiming to identify additional relevant predictors of noise annoyance. See [4] for an elaborate review of this topic. These responses can vary considerably from region to region depending on multiple factors such as local noise policies, media coverage and overall coping strategies depending on cultural background [2].

Citizen Science (CS) is an approach to scientific work that integrates the public into the scientific process, from the design of the research question to data collection, interpretation, or analysis. The CS project called "*De Oorzaak*" has been launched in Flanders (Belgium), aiming to assess the impact of the environmental soundscape on the well-being of citizens on a large scale (see [5] for more details). *De Oorzaak* is realised through a collaboration between the University of Antwerp, the Antwerp University Hospital and the newspaper De Morgen.

One of this projects' first initiatives was to conduct a survey to collect data concerning primarily perceived noise annoyance among residents of Flanders. The cross-sectional "Large Sound Survey" (*Grote Geluidsbevraging*) is one of the pillars of *De Oorzaak*. The Large Sound Survey (LSS) serves different purposes, including being a starting point for longitudinal data collection. The current paper presents an initial analysis of 8784 answers to the LSS, focusing on transportation noise annoyance and non-acoustic factors related to it. Locally, it can be considered as additional, comparative data to the *Schriftelijk LeefOmgevingsonderzoek* (SLOs), written environmental surveys organized by the Flemish government [6].

2. METHODOLOGY

2.1. Survey design, content and data collection

Data were collected via convenience sampling between November 2023 and January 2024. The survey was promoted via a full-scale media campaign by the Flemish newspaper *De Morgen* (newspaper articles, radio and TV ads, billboards) and on social media. Anyone aged 18 and over and living in Flanders who agreed to the informed consent could complete the survey. N=8784 valid answers were recorded.

One important remark is that the participants voluntarily took part in this study, which likely means a relatively high proportion of self-selection bias: people exposed to higher environmental noise levels and associated annoyance may have been more inclined to participate. This contrasts with the Flemish governmental SLO data collection approach, which actively seeks participants to ensure a representative sample of the Flemish population. Thus, while the SLOs serve as our primary point of comparison, this should be approached cautiously.

The Ethics Committee for the Social Sciences and Humanities of the University of Antwerp granted ethical approval for the study on September 13th, 2023 (Ref No: SHW_2023_214_1).

The questionnaire was composed of 51 questions. The different constructs measured were primarily based on the SLO-5 questionnaire (data analysis currently pending). Other than those SLO measures, we also used Weinstein's noise sensitivity scale (WNS) [7], the Fatigue Assessment Scale (FAS) [8], the Perceived Stress Scale (PSS), and to assess participants' daytime sleepiness, the Epworth Sleepiness Scale (ESS) [9]. The remaining questions were mainly on other sociodemographics.

A key survey element was noise annoyance, assessed with a 5-point verbal scale with the verbal marks "not at all", "slightly", "moderately", "very", "extremely". We asked participants to what extent they are annoyed by environmental noise in general and by road, rail and aircraft traffic noise. The transportation noise sources were further divided into more specific types, as listed below:

- Road traffic: passenger cars, trucks, buses, mopeds/ scooters/ motorcycles/ quads, military vehicles, emergency vehicles, and tractors on public roads.
- Rail traffic: passenger trains, freight trains, and trams/metro.
- Air traffic: passenger/cargo aircraft, sports and business jets, military aircraft, helicopters, drones.

2.3. Data analysis

Existing recommendations [9] were followed to calculate ESS Scores and attribute accompanying categories (0-5 Lower Normal Daytime Sleepiness; 6-10 Higher Normal Daytime Sleepiness; 11-12 Mild Excessive Daytime Sleepiness; 13-15 Moderate Excessive Daytime Sleepiness; 16-24 Severe Excessive Daytime Sleepiness). Similarly, FAS scores were calculated and categorized (<22 nonfatigued; 22-34 fatigued; ≥35 extremely fatigued) based on existing work [8,10]. For noise sensitivity, three groups were made based on terciles of their WNS sum scores [7]: participants with sensitivity scores from 10-35 were relatively insensitive to noise, those with 35-41 relatively neutral, and those with 42-50 relatively sensitive.

For age, the sample was divided into three age groups: young adults (18-25 [11]), adults (26-61), and retired adults (62-92) based on the mean effective retirement age in Belgium [12].

GPS locations were retrieved for each participant through the Google Maps API using the provided address. Population density at the municipality level was retrieved from Flemish Government databases. We then classified their living zones into rural or urban using population density as a proxy: ≤600 inhabitants/km^2 and >600 inhabitants/km^2, respectively.

Noise annoyance from the different transportation sources was based on the ICBEN/ISO annoyance question [13], using the standardized 5-point verbal scale. However, to match the questionnaire used in the SLO-5, a sixth answer category, "not applicable", was added to represent those who do not hear a certain noise source and thus cannot attribute an annoyance level to it. This paper also explores the percentage highly annoyed (%HA), often reported in other surveys and used for policy purposes [4]. The two higher points of the scale (very and extremely annoyed) define the "highly annoyed" status.

We explored the differences in environmental noise annoyance among specific subgroups. For comparisons involving two groups, the results of the Wilcoxon signed-rank test are reported. For more than two groups, we reported Kruskal-Wallis results with Bonferroni corrections for multiple comparisons. Additionally, correlations between annoyance and personal characteristics were assessed pairwise. Pearson's correlation coefficient (ρ) was applied for two continuous variables, while Kendall's τ_b correlation coefficient was used when at least one variable was ordinal.

3. RESULTS

3.1. Sample characteristics

Table 1 details participants' characteristics. The sample comprised largely Belgian individuals (96.4%), mostly women (55.1%), with a mean age of 51.7 years old (SD=14.4). Most of them were salaried either part-time or full-time (55.4%) or retired (22.6%) and had a tertiary education degree (Bachelor's or Master's; 78.1%). Two-thirds of the participants live in urban zones (70.3%). In the SLO-4, which strives to sample each Flemish province equally, this value is 40.3%.

Compared to the SLO-4, more participants in our sample are relatively sensitive to noise. While 31% of the SLO-4's participants are relatively sensitive to noise, this value is 32.8% for the LSS sample. Additionally, while 36% are considered relatively insensitive in the SLO-4, this value is 33.7% group in our LSS dataset. These results reflect the differences in the sampling approach adopted by the two surveys and reiterate that the LSS probably attracted more people who had already experienced some noise annoyance, whether or not it was caused by excessive noise exposure.

Table 1: Sample characteristics.

Age - M (SD)	51.7 (14.4)	**Province - n (%)**	
Gender - n (%)		Flemish Brabant	1422 (16.2)
Men	3856 (43.9)	Antwerp	3381 (38.5)
Women	4842 (55.1)	Limburg	564 (6.4)
Non-binary	26 (.3)	West Flanders	907 (10.3)
Employment - *n* (%)		East Flanders	2462 (28)
Salaried			
Full-time	3610 (41.1)	**Dwelling - n (%)**	
Part-time	1253 (14.3)	Apartment or studio	1788 (20.4)
Self-employed	757 (8.6)	Row/terraced house	
Retired	1982 (22.6)	With garden	2410 (27.4)
Stay at home	99 (1.1)	Without garden	340 (3.9)
Seeking employment	109 (1.2)	Semi-detached	1648 (18.8)
Student	182 (2.1)	Detached	2411 (27.4)
Incapacitated for work	456 (5.2)	**Noise Sensitivity (WNS) - n (%)**	
Population density – n (%)		Relatively Insensitive	2960 (33.7)
Rural (≤ 600 hab/km²)	2592 (29.5)	Relatively Neutral	2941 (33.5)
Urban (> 600 hab/km²)	6174 (70.3)	Relatively Sensitive	288.3 (32.8)

3.2. Environmental noise annoyance

Regarding annoyance levels by environmental noise in general, a large portion of participants (79.4%) reported being moderately to extremely annoyed (Figure 1), with the percentage highly annoyed (%HA) equal to 33.3%. In the SLO-4, our reference survey, the %HA is 11.6%. These differences are expected due to differences in sampling, as explained previously.

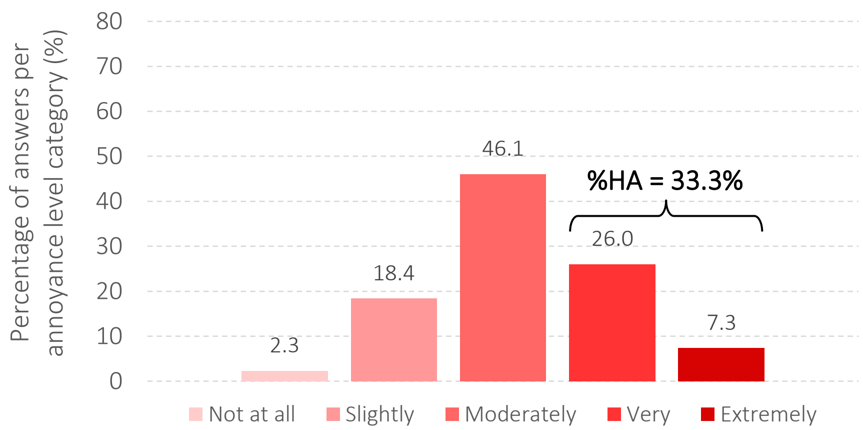

Figure 1: Annoyance by environmental noise.

Further investigation compared environmental noise annoyance levels across subgroups based on certain participants' characteristics. Firstly, relatively noise-sensitive participants reported more noise annoyance than relatively neutral or insensitive participants (MR=5037), X^2 (2)=472.534, p<.001.

Regarding dwelling type, residents of apartments or studios expressed higher noise annoyance levels (MR=4771.96) than those residing in row houses with gardens (MR=4484.93, p=.002), semi-detached (MR=4256.71, p<.001), or detached houses (MR=4061.52, p<.001). Individuals living in detached houses reported less noise annoyance than those living in a row house without a garden (MR=4061.52), with a garden MR=4484.93, p<.001), or a semi-detached house. Residents of semi-detached houses (MR=4256.71) reported less noise annoyance than those living in a row house with a garden and without a garden, (MR=4484.93, p=.04), c2(5)=106.429, p<.001. Taking gender, no significant differences were found between men and women, our two highest reported gender identities in terms of annoyance. We found significant differences between all age groups. Adults (MR=4466.83) reported more noise annoyance than both retired adults (MR=4309.28, p=.014) and young adults (MR=3423.65, p<.001). Similarly, retired adults reported more noise annoyance than young adults p<.001, c2(2)=47.573, p<.001. Lastly, we found that participants living in cities with higher population densities reported more noise annoyance compared to rural areas c2(2)=86.055, p<.001.

3.3. Transportation noise annoyance

Figure 2 illustrates the distribution of responses across different annoyance levels for the seven subtypes of road traffic noise sources. The percentage highly annoyed (%HA) is indicated below the category label.

Passenger cars and trucks lead as the most annoying road traffic noise sources, with %HA of 24.5% and 23.5%, respectively. This is expected as these categories are potentially the most common vehicle types in the urban/highway fleet and, therefore, are more readily associated with the overall perception of road traffic noise. Mopeds/scooters/motorcycles/quads entail a similar %HA than the first two most annoying categories (21.5%). Although in a considerably smaller number compared to passenger cars, these vehicles often produce a rather intermittent noise event that clearly stands out from background noise. These single events likely draw more attention to the noise source, inducing annoyance [2]. The same rationale could be applied to noise from emergency vehicles, however, the %HA is only 8.5% in this case. This rather low percentage could stem from the social perception that these vehicles are used for essential services of public safety and well-being, resulting in better acceptance of the loud event caused by sirens.

The literature reports a few noise exposure-%HA functions for the different transportation modes. Typically, the day-evening-night sound level (L_{den}) is calculated/measured and then used to predict the %HA in a certain region, employing these established exposure-response relationships (ERRs). Our LSS subjective data could not be associated with noise exposure levels at this stage of the data analysis; for this reason, the ERRs could be used conversely to estimate an approximate L_{den}, given the %HA of the entire sample. As an example, a %HA of 24.5% (passenger cars) would lead to a L_{den}=68.1 dBA, using the road traffic noise ERR from Guski et al. [4]. Additionally, according to the ERR developed by Brink et al. [2], derived from a random stratified sample of the entire Swiss population, a %HA=24.5% is associated with a L_{den} category of 65-70 dBA. Such noise exposure levels are notably high, especially considering that participants from the LSS are distributed across all regions of Flanders, with one-third residing in rural areas. This, again, underscores that the LSS dataset is a sample from the Flemish population skewed towards higher noise annoyance levels. For instance, recent noise maps from Antwerp, one of the most urbanized and densely populated cities in Flanders, indicate that 8% of its residents are exposed to noise levels around 70 dBA [14].

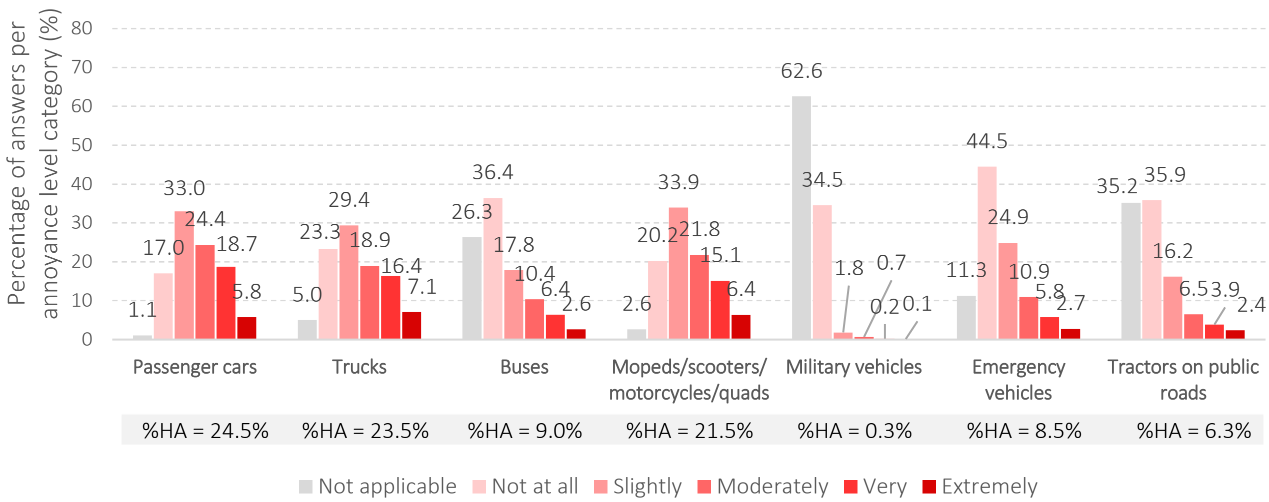

Figure 2: Annoyance by road traffic noise sources.

Figure 3, similar to Figure 2, shows the annoyance levels induced by the three categories of rail traffic noise. Over 50% chose "not applicable" to describe their annoyance across all three categories, which is expected as most participants likely live far from railway lines, and just a few cities in Flanders are equipped with a metro/tram system. The percentage highly annoyed is no more than 3.5% in either of the three categories. From the ERR by Brink et al. [2], these %HA would yield a railway L_{den} of 45-50 dBA. As calculated by Guski et al. [4]'s equations, L_{den} values of 42.8, 45.0, 41.0 are retrieved for passenger trains, freight trains and tram/metro noise, respectively.

Railway noise evokes less annoyance than road traffic (and aircraft) noise at equivalent noise levels [15]. Nevertheless, evidence suggests that railway noise is perceived as more annoying than road traffic noise at sound levels above 55 dB [15]. This prompts the consideration that participants from the LSS, treated as a single unit, may not be excessively annoyed by railway noise as they seem to be by road traffic noise. Further exploration of this observation could involve stratifying the LSS sample based on noise exposure levels, using existing railway noise maps.

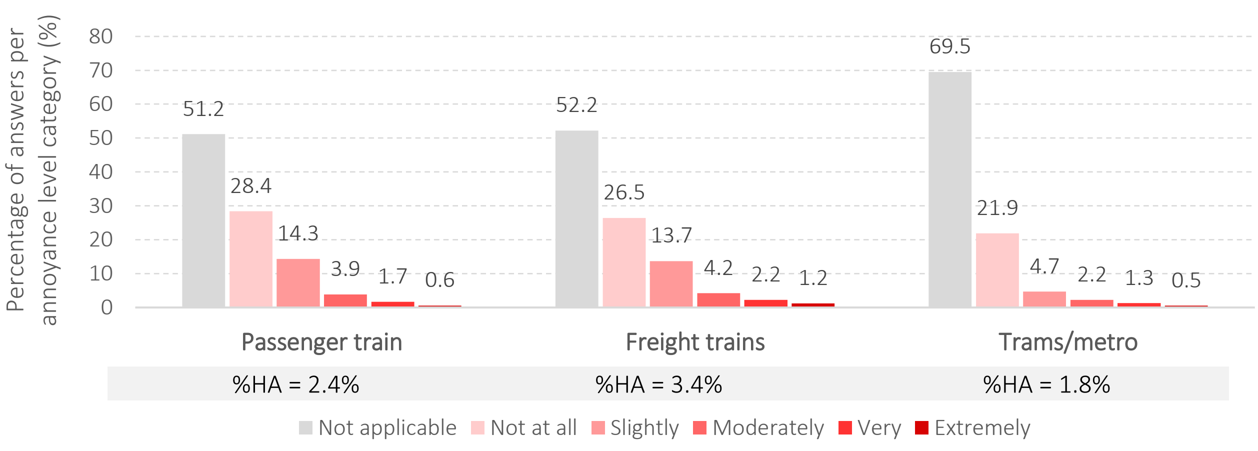

Figure 3: Annoyance by rail traffic noise.

Figure 4 illustrates the annoyance levels stemming from various sources of air traffic noise. While not as pronounced as with rail traffic, a significant portion of participants indicated that annoyance from air traffic does not apply to their experience. Although likely only a small fraction of the LSS participants live close to airports, the impact of overflying aircraft, particularly at lower altitudes, can extend across a wide area.

Passenger/cargo aircraft elicited a %HA about three times higher than passenger trains and two times higher than freight trains. This heightened annoyance level can be attributed to the perception of aircraft noise as more intrusive and unfamiliar, even within urban settings [2], especially given it is typically characterized as a loud event.

The %HA of passenger/cargo aircraft yields 45-50 dBA as per [2], and approximately 43.4 dBA as calculated by Guski et al. [4]. Similarly to railway noise, further analysis of these results should include splitting the participants over different air traffic noise exposure levels.

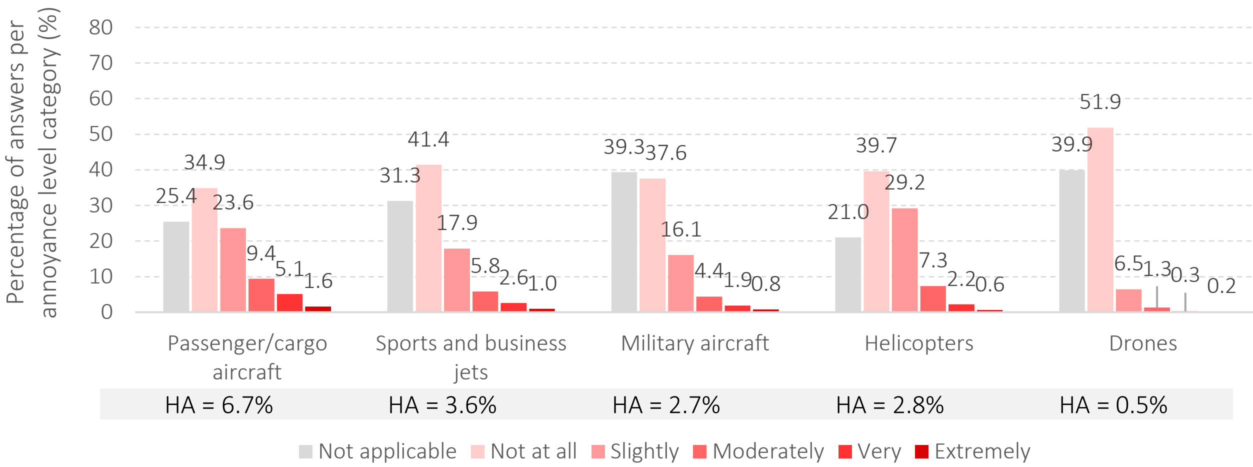

Figure 4: Annoyance by air traffic noise.

3.3. Sleepiness and Fatigue

Analysis of the ESS and FAS scores (Figure 5) showed that most participants had lower (43.1%, n=3782) or higher (38.3%, n=3363) normal daytime sleepiness. Some experienced mild excessive daytime sleepiness (9.3%, n=813), and moderate (6.7%, n=590) and severe (2.7%, n=236) daytime sleepiness were reported least. Additionally, nearly half of our sample (48.2%, n=4232) were not fatigued, according to FAS. Another 43.6% (n=3830) was fatigued, and 8.2% (n=722) was extremely fatigued. In sum, most of our participants did not seem to suffer from excessive sleepiness, although many reported being fatigued.

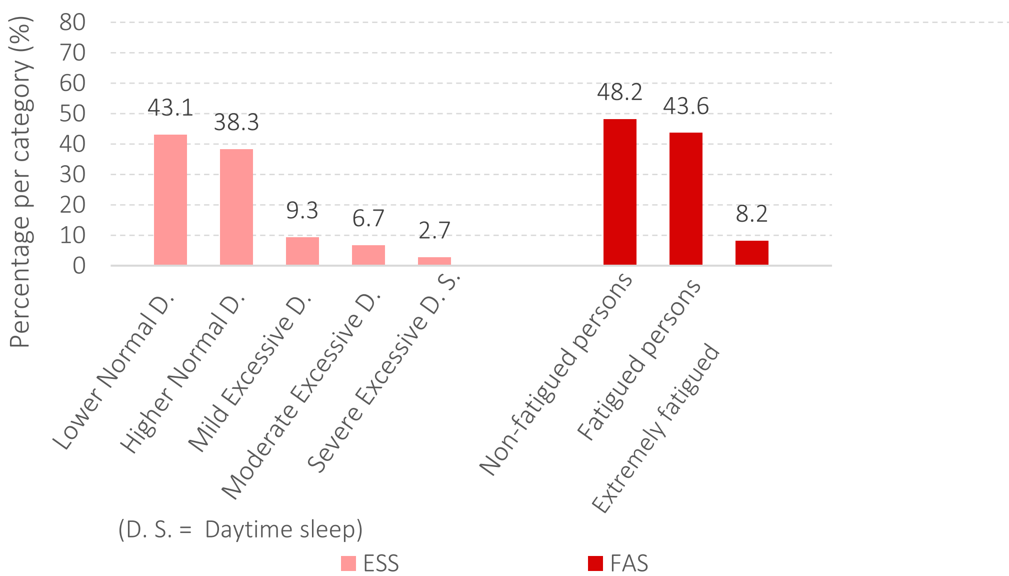

Figure 5: Sample sleepiness and fatigue data in percentages.

3.4. Correlations between transportation noise and individuals' characteristics

Figure 6 displays the correlation coefficients for pairwise correlations between some personal indicators – age, noise sensitivity, stress (via the PSS), fatigue (from the FAS) and sleepiness (via ESS) – with quality of life (QoL) and annoyance from environmental noise, alongside the multiple sources of road, rail, and air traffic noise. Only correlation coefficients from statistically significant correlations at a 5% significance level are presented. Pearson's correlation coefficient (ρ) is used for two continuous variables, while Kendall's τ_b correlation coefficient is applied when at least one variable is ordinal. This analysis excludes responses where "not applicable" was selected for annoyance from transportation noise.

As displayed in Figure 6, several correlations were statistically significant, although weak or moderate, with none exceeding ±0.5.

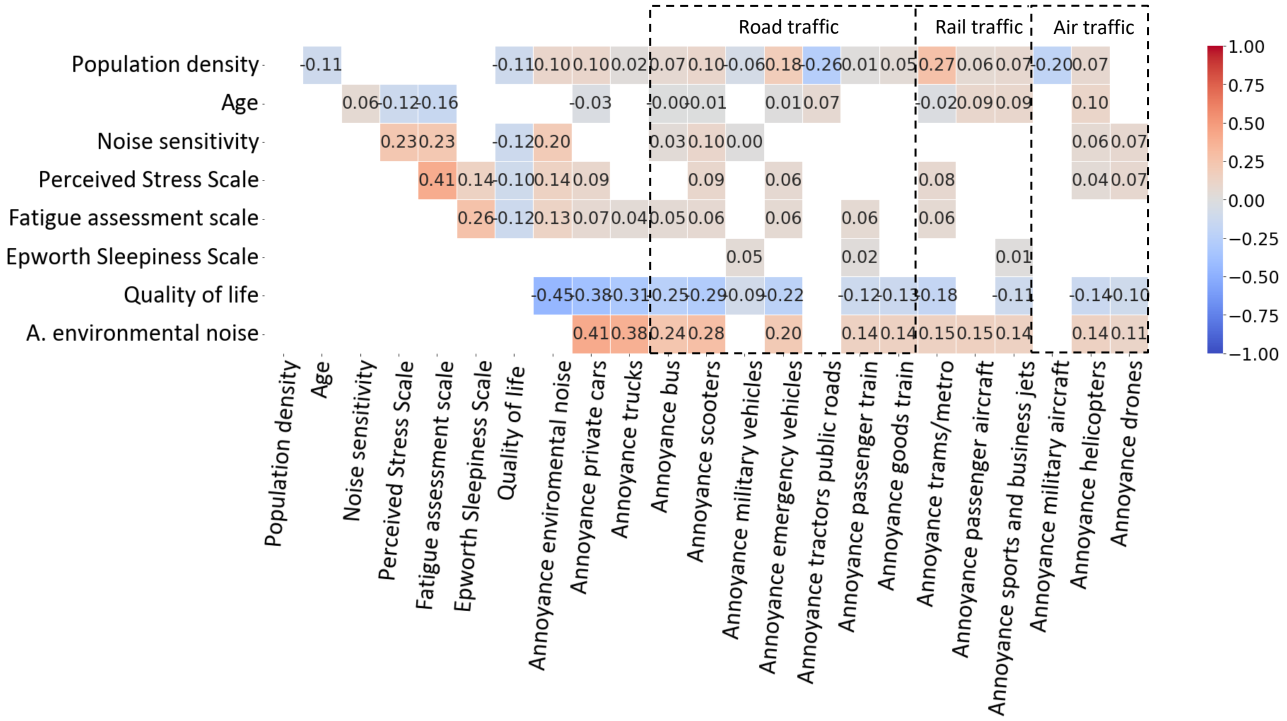

Figure 6: Correlation matrix between individual's characteristics and noise annoyance.

Population density correlated negatively with age and quality of life. For noise annoyance, virtually all sources present a significant correlation, mostly positive, with population density. The negative correlations include annoyance by military vehicles and aircraft, as well as tractors on public roads.

Age correlates positively to noise sensitivity, while older respondents are less stressed and fatigued. Annoyance from transportation noise does not present a regular trend in terms of age; for some sources, such as passenger cars, annoyance decreases with age, while for other sources, like passenger/cargo aircraft, older respondents were more annoyed.

Interestingly, noise sensitivity does not correlate or presents a very weak positive correlation with annoyance from most noise sources. It could be argued that the noise sources causing the highest noise annoyance levels, such as passenger cars and trucks, do so independently of an individual's sensitivity to noise. Still, a weak positive correlation (τ_b= 0.20) is observed with the overall environmental noise annoyance. On the other hand, noise sensitivity presents stronger positive correlations with PSS, and FAS, and negative with QoL.

Stress (PSS) correlates positively with fatigue (ρ = 0.41) and, to a lesser extent, with sleepiness and annoyance by environmental noise (ρ = 0.14 and τ_b=0.14). Quality of life decreases as stress levels increase (τ_b=-0.10). Regarding transportation noise annoyance, statistically significant positive correlations, although very weak, were found between a few sources and stress, especially for the two of the most annoying traffic noise sources: passenger cars and motorcycles & alike (τ_b=0.09 for both).

Sleepiness (ESS) shows minimal correlation with transportation noise annoyance. Correlations that do emerge as statistically significant are considerably weak, with a Kendall's τb no larger than 0.05.

Quality of life is a construct that appears to reflect noise annoyance levels the best. QoL and environmental noise annoyance present the strongest correlation in Figure 6 (τ_b=-0.45). Moreover, QoL also presents considerable negative correlations with most sources of road traffic noise annoyance. While rail and air traffic also exhibit correlations with QoL, these are less pronounced than for road traffic noise sources.

As expected, environmental noise annoyance showed statistically significant and positive correlations with all noise sources except military vehicles and aircraft, and tractors on public roads. The strongest correlations are obtained with annoyance by road traffic noise sources, meaning that road traffic is the main contributor to overall environmental noise, among the transportation noise sources discussed in this paper. Rail and air traffic show consistent but weaker correlations with overall environmental noise annoyance.

4. CONCLUSIONS AND FUTURE RESEARCH

Through a citizen science approach, a large pool of participants (n=8784) answered the 51-question "Large Sound Survey" (LSS) across Flanders, Belgium. The survey served primarily to gather participant information for the next steps of the CS project *De Oorzaak*. However, given the large sample size, these results can also be used to explore correlations between the multiple constructs covered in the questionnaire, with a focus on transportation noise annoyance. Locally, it can be considered as additional, comparative data written in an environmental survey organized by the Flemish government, especially the most recent SLO whose data is available.

Although interesting differences were observed between the LSS and the SLO-4, it is essential to highlight key disparities in data collection methods, including sample size, demographics, representativeness, and question formatting. Thus, any comparisons should be approached with the requisite level of nuance. For example, the percentage of highly annoyed (%HA) by environmental noise in our dataset is around three times higher than that of SLO-4, indicating a large self-selection bias from people who experience some degree of annoyance. Additionally, two-thirds of the LSS participants live in urban zones (70.3%), while in the SLO-4, which strives to sample each Flemish province equally, this value is 40.3%.

By analyzing the environmental noise annoyance levels among subgroups within the LSS, we concluded that those most affected are noise-sensitive individuals living in apartments or studios, adults, and those residing in densely populated areas.

The figures from road traffic noise annoyance indicate that passenger cars and trucks lead as the most annoying sources, with %HA of 24.5% and 23.5%, respectively. Motorcycles and alike entail a similar %HA than the first two (21.5%). Using established exposure-response relationships (ERRs) [2,4], the %HA of passenger cars would yield an L_{den} in the range of 65-70 dBA, which is notably high.

For rail traffic, most participants, likely residing far from railway lines, expressed minimal annoyance, with a %HA less than 3.5% across all three categories (passenger and freight trains, and trams/metro).

Although in a smaller number than for rail traffic, a significant portion of participants indicated that air traffic annoyance does not apply to their experience. Also, passenger/cargo aircraft evoked about three times higher annoyance levels than passenger trains, likely due to the perceived intrusiveness and unfamiliarity of aircraft noise even in urban settings.

Correlations were drawn between the several noise annoyance sources and indiviuals' characteristics. Overall, population density in the municipality tends to trigger more noise annoyance from all transportation modes. The correlations between annoyance and age do not present a regular trend; for some sources, such as passenger cars, annoyance decreases with age, while for other sources, like passenger/cargo aircraft, older respondents were more annoyed. Surprisingly, noise sensitivity does not correlate or presents a very weak positive correlation with annoyance from most noise sources, although it does correlate with overall noise annoyance. Stress (Perceived Stress Scale) and while fatigue (Fatigue Assessment Scale) correlates with environmental noise annoyance, while sleepiness (Epworth Sleepiness Scale) does not. One the other hand, these three indicators present few significant and weak correlations with most traffic noise sources. Quality of life is a construct that appears to reflect noise annoyance levels the best, given the strongest negative correlations with most sources of transportation noise annoyance.

The longitudinal studies on the agenda of *De Oorzaak* will enable causal analyses and conclusions, enriching the initial insights presented in this paper. Moreover, these studies will integrate objective noise and health measures. To achieve this, a comprehensive smart sound sensor network will be implemented across the metropolitan areas of Antwerp, Ghent, and Leuven for one year, consisting of over 2000 citizen sensor locations and 30 reference sensors [5].

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