Research Article

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Montreal soundscapes during the COVID-19 pandemic: A spatial analysis of noise complaints and residents' surveys

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Abstract: Public health measures during the COVID-19 pandemic provided researchers with a quasi-experimental situation to examine what happens when anthropogenic noise sources (*e.g.*, traffic) are greatly reduced. This article combines noise-related calls to Montreal's 311 service (29,891 calls from 2014 to 2022) with original survey data from 240 residents collected in 2020 after the lockdown and the summer reopening. The spatial analysis of the calls revealed that, across all pandemic phases, noise complaints increased with population density, the proportion of low-income residents, and the proportion of greenspace. However, the change in the spatial distribution of noise-related calls due to the pandemic measures is positively associated with the proportions of residential and greenspace land use. That is, areas with higher proportions of residential land use and greenspace experienced the greatest increase in noise-related calls. The analysis of the survey revealed that the sounds of traffic and construction decreased during both the lockdown and the subsequent reopening, while the sounds of the neighborhood and nature increased. However, the decreased traffic noise in the downtown core also allowed for the emergence of noise from the heating, ventilation and air conditioning systems in the area. We discuss these results considering the interest in reducing noise levels in cities.

Keywords: noise, sound, spatial analysis, lockdown, urban area

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1 Introduction

Measures to curb the effect of the COVID-19 pandemic affected every aspect of daily life and society. While the disruptions were at times severe, they provided a quasi-experimental situation for researchers in the fields of sound and noise. The pandemic period was an opportunity to examine what happens when anthropogenic noise in general, and transportation noise in particular, is greatly diminished.

Sound and noise researchers around the world responded by leveraging existing sources of data to compare pre- and during-pandemic sound environments. In this article, we add to the literature with two studies, the first using noise-related calls to Montreal's 311 service and the second using online surveys we conducted with Montreal residents in the Fall of 2020 about their experience with the lockdown and subsequent progressive reopening. However, the value of this research extends beyond the COVID-19 pandemic to consider the sound-related outcomes in urban spaces of any situation (including possible future pandemics) where anthropogenic noises are greatly reduced. As such, we gain insights relevant to the future of urban planning and policies. We present the methods and results of these studies separately and then bring these two studies together for a general discussion and conclusion.

2 Literature review

As a response to the COVID-19 pandemic, governments around the world applied various measures to minimize illness and loss of life for their residents. The exact measures taken differed from one region to the next, but they tended to reduce the amount of human activity in major cities. This includes partial or complete lockdowns, where residents were required to stay home unless they were fulfilling an essential service, and travel bans on air and rail services.

Several studies have documented changes in noise levels in major cities due to the response measures to the pandemic. Studies found decreases of 2–6 dB(A) in Stockholm [1], Lyon [2], London [3], Athens [4] and Chelsea, Massachusetts [5]; 6–10 dB(A) in Milan [6], Paris [7], Delhi [8], Lorient, France [9] and Montreal [10]; and more than 10 dB(A) in Muscat, Oman [11] and Granada, Spain [12].

2.1 Changes in perception of sound environments

While noise levels fairly consistently decreased due to the pandemic, changing perceptions of sonic environments during the lockdown were more mixed [13]. Between March and May 2020, Acoucité collected 3,242 completed questionnaires online from all over France (62% from urban areas) between March 18 and May 11 [7]. They found that during the lockdown, road, rail, and air traffic were all perceived as having highly decreased, natural sources as slightly or highly increased, and neighborhood sources as unchanged or slightly increased. They also found that road and air traffic were the dominant sources before the lockdown (followed by neighborhood sources), while natural sources became predominant (followed by neighborhood sources) during the lockdown. Additionally, their respondents judged the soundscape during the lockdown as pleasant, peaceful, and calm. Finally, of 250 comments, 30% mentioned liking the silence brought by the lockdown, and 13% commented on the emergence of unpleasant sounds usually masked by the bustle of the city.

These positive perceptual changes are similar to the findings from an urban square in Getxo, Spain, that has low levels of technological noise (*i.e.*, heating, ventilation and air conditioning (HVAC) and transportation), where survey respondents rated the sound environment using the Swedish Soundscape Quality Protocol (SSQP) [14]. The SSQP uses ratings to project the perception of a sound environment onto a circumplex model along Eventfulness and Pleasantness dimensions [15]. Here, evaluations of pleasantness were associated with natural sounds, while eventfulness was associated with human sounds.

Finally, a survey from Italy also shows that natural and neighborhood sounds increased in prominence [16]. The study also identified reduced levels of noise annoyance and improved soundscape perceptions as a result of the decrease in traffic noise. The type of home also affected noise annoyance outcomes: respondents living in a detached home had less noise annoyance from neighborhood noise sources than those living in an apartment.

In contrast, negative perceptual changes to the sound environment during lockdown were generally associated with the need to work from home [13]. In particular, some home sound environments presented challenges for concentration and led to vocal fatigue from online work activities.

2.2 Noise complaints

There is a smaller body of literature investigating the effect of the COVID-19 pandemic on noise complaints. Using open data from New York City's 311 service, Ramphal *et al.* [17] found that complaints increased during the pandemic in comparison with the previous 10 years. London also saw an increase in the number of complaints from 2.97 per 1,000 people before the pandemic measures to 4.29 per 1,000 people during the pandemic [18]. In a review of five US cities, Yildirim *et al.* found that noise complaints increased only in San Francisco [19]. In comparison, they found that New York City, Dallas, Phoenix, and Chicago all saw decreases in noise complaints. The results of New York City conflict between Ramphal *et al.* [17] and Yildirim *et al.* [19], though the reason for this divergence is unclear.

In addition, these studies indicated spatial patterns in noise complaints. In general, noise complaints increased with the density of the neighborhood, though this was not defined uniformly in the literature. Noise complaints in New York City were found to be clustered around high-density areas [20]: Ramphal *et al.* [17] estimated this to be an increase of 1.7 noise complaints for every 1 person per 100 m^2. Similarly, Yildirim *et al.* [19] found that noise complaints in New York City, Chicago, Dallas, and San Francisco increased with compactness, a score provided by the National Institutes of Health that combines variables on density, land use, and accessibility and availability of services.

The sound sources mentioned in the noise complaints also reflected spatial patterns that changed during the COVID-19 pandemic. Yildirim and Arefi [21] analyzed the text descriptions of the Dallas 311 noise complaints based on the distance from the central core of the city. Prior to the pandemic, common terms for each buffer zone were *construction*, *work* and *night* (1-mile); *noise*, *night*, *loud* and *Saturday* (3-mile); *construction*, *working*, *loud* and *music* (5-mile); and *dumpster*, *weekends*, *sleep-time* and *management* (8-mile). However, after the pandemic, the common terms are more consistent between buffer zones and reflect the sounds of neighborhood activities: *apartment*, *neighbor*, *street,* and *music*.

Noise complaints are associated with other features of urban morphology as well. Wider roads can accommodate more traffic at higher speeds, and Tong and Kang [20] found that noise complaints increased in areas with a higher number of 20–40 m wide roads. (At a width of 20 m, roads comfortably have 2 lanes in each direction.) Conversely, the number of noise complaints was negatively associated with the distance to the nearest road crossing. Finally, the number of noise complaints was positively associated with every type of land use except greenspace. Blocks that are more enclosed and denser are associated with a higher rate of noise complaints, though building morphology was less important in high-density areas.

Beyond urban morphology, there is a social context to noise complaints. The number of noise complaints in New York City is positively associated with the percentage of low-income residents [17]. During the pandemic, this inequality expanded such that the monthly year-over-year rate of complaints increased more for the quintile with the highest percentage of low-income residents than the others. A similar relationship was found in London where noise complaints increased faster in neighborhoods that are poorer, have higher levels of unemployment, and have higher proportions of residents without qualifications [18].

2.3 Montreal COVID-19 timeline

Montreal is a sonically vibrant city that hosts a large number of festivals, cultural events, and pedestrianization projects. In addition to several important cultural streets (*e.g.*, St-Denis, St-Laurent, St-Henri, Ste-Catherine E., and Wellington), the downtown core has an entertainment district that has nearly year-long festivals. These activities were quieted as pandemic-related measures were rolled out in phases in Montreal beginning in the month of March 2020. The period between March 20 and May 22 is the Lockdown period. Indoor gatherings of any size were banned as part of the lockdown measures during this period. Subject to a 2-m "bubble," people from different households could gather outside, making access to greenspace all the more valuable. Residents were required to work from home unless the nature of their work required them to be on site. Between mid-May and early July, there was a gradual reopening of activities and services in the city, such that by late-June many activities were available (if still limited), though working from home was still required. This period corresponds to the Summer period. Figure 1 provides a detailed timeline for the key pandemic-related measures that were put in place in Montreal in 2020 when we were collecting survey data. In Montreal, some measures continued longer than in many other cities, with some still in place at the end of Summer 2021.

To our knowledge, no study has looked at the effect of pandemic-related measures on noise complaints in Montreal. As well, no study combines data on noise complaints with survey data to better understand the context in which these complaints are made. We therefore ask the following research questions.

(RQ1) How are noise complaints spatially distributed in Montreal?

(RQ2) How did the COVID-19 pandemic affect noise complaints? Were residential zones affected differently than other zones (mixed-uses, industrial, commercial)?

(RQ3) How did Montreal residents describe soundscapes in their neighborhood during the pandemic? What were

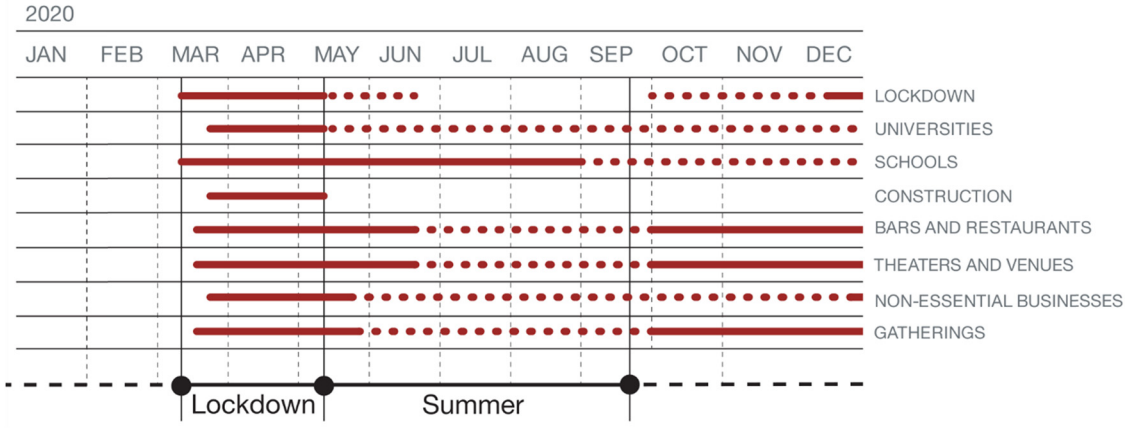

Figure 1: Timeline of COVID-19 restrictions in 2020 when we carried out data collection for the COVID-related changes to Montreal's sound environment. Solid red line: closure; dotted red line: partial opening; no red line: no restrictions. Timeline adapted from Di Croce *et al.* [22].

their main concerns about noise? What sounds did they enjoy hearing? Are there differences between the central districts and the rest of the island?

To address these research questions, we report on (1) the analysis of noise complaints in Montreal before and during the COVID-19 pandemic (RQ1 and RQ2) and (2) surveys with residents about Montreal soundscapes before and during the pandemic, specifically one survey about their experience during the first lockdown (20 March–22 May 2020) and one about their experience during the first COVID-19 Summer (22 May–mid-September) (RQ3).

3 Noise complaints analysis

3.1 Methods

3.1.1 Noise-related calls

We downloaded reports to 311 submitted through any applicable method using Montreal's Open Data portal for all available years (2014 through 2022). For simplicity, these will be referred to as calls, given that the telephone is the most frequently used method of reaching 311 (phone: 87.6%; in-person: 6.5%; email: 5.6%; and other: 0.2%). The full data set contains 5.2 million calls, only some of which are noise related.

Noise-related calls were selected based on the term used to categorize the topic of the call as determined by the 311 agents. There were a total of 1,815 categories. We retained only those categories that contained the word "Bruit" (Noise) as no other noise- or sound-related words were used in the names of the categories (*e.g.*, sound, music, *etc.*). After filtering, the set of noise-related calls contained 29,891 observations. Montreal's 311 service categorizes calls into four types: Information, Comment, Request, and Complaint. Information calls ask for information or a document and do not require follow-up by an agent of the city or borough, in which case there is no reference to the location (postal code is not collected). In comparison, request calls include authorizations for permits, services or support, and residents' complaints that require the intervention of an agent, in which case the postal code is included. Comments and complaints are both categories used when a resident wants to express an opinion or address a grievance directed toward the city. Calls categorized as comments or complaints are not directed toward a noise event, but toward the city and are thus excluded from this analysis.

For the spatial analysis, only noise-related calls categorized as Request with a valid postal code were retained, yielding a dataset of 14,150 calls or just over 47% of all noise-related calls. These calls were grouped into three phases, based on the year they were placed: pre-pandemic (2014–2019), during-pandemic (2020–2021), and post-pandemic (2022).

3.1.2 Spatial data

We downloaded shapefiles for the Forward Sortation Area (FSA). An FSA is a well-defined section of a major geographic region or province within Canada, represented by the first three characters of the postal code (all FSAs in the city of Montreal begin with the letter H). The FSA provides the primary basis for sorting the destination of mail.

We obtained residential and greenspace land use data for Montreal from Open Street Maps. All data were downloaded using R v4.2.1 [23] and the *osmdata* package [24]. We downloaded residential land use data using the tag landuse (residential). We used these data to calculate a continuous variable for the proportion of FSA land used for residential purposes (residential) in km^2 (min.: 4.3%; mean: 49.4%; max.: 87.0%). As well, we downloaded land use data related to greenspace, and as there were several relevant categories for greenspace, we downloaded all locations tagged as leisure (park, nature_reserve, playground, or garden); land use (forest or recreation_ground); or natural (wood or wetland). All overlapping greenspace areas were combined so that a given area was only counted once, and the resulting land use data were used to calculate the proportion of FSA land filled with parks or greenspace in km^2 (min.: <0.01%; mean: 11.3%; max.: 49.5%).

3.1.3 Demographic data

We obtained the demographic data from the 2016 Canadian census, organized according to the FSA. We used two demographic variables for our analysis. First, we obtained the total population (all ages and sexes). Using this number and the population growth rate given by the city of Montreal, we extrapolated the population of each FSA from 2014 through 2022. We calculated the area of each FSA and used that to determine its population density for each year. Second, we obtained the proportion of low-income residents in the FSA, which is defined by Statistics Canada as an after-tax household income that is below the median after adjusting for the number of residents in the household.

3.1.4 Analysis

In order to properly structure our data for spatial analysis, we first investigated the temporal aspects of the full set of

noise-related 311 calls and any effects caused by our response to the COVID-19 pandemic. In particular, we investigate the distribution of calls according to the year, the season, and the hour using Chi-square tests. We distinguish two seasons in our analysis (Cold and Warm), rather than the traditional four, as they better reflect temperature and weather conditions in Montreal. The Warm season reflects a period of the year (May through September) when people in Montreal are most likely to have their windows open due to the warmer temperatures. In comparison, the Cold season is from October to April, when windows are more likely closed and heating on.

Following that, the spatial analysis examined the call volume and the ways the response to the COVID-19 pandemic might shift the major geographic locations of the calls. We first used a mixed effect Poisson regression model to investigate the relationship between the rate of calls per 1,000 residents for each FSA (as the dependent variable) and its population density, proportion of low-income residents and proportion of greenspace (as the independent variables). A Poisson regression is appropriate to use when the dependent variable consists of count data that follow a Poisson distribution [25]. We then fit linear regression models to further understand how the COVID-19 pandemic affected spatial changes in call volume in Montreal. In the first model, we regressed the spatial changes (the dependent variable) on the population density, the proportion of low-income residents, and the proportion of greenspace (the independent variables). In the second model, we regressed the spatial changes (the dependent variable) on the proportion of the FSA that is residential, the proportion of low-income residents, and the proportion of greenspace (the independent variables).

3.2 Results

Every year from 2014 to 2022, over 3,000 noise-related calls were placed to 311. On average, this represents just under 1.7 calls per 1,000 Montreal residents. Figure 2 provides the number of calls per 1,000 residents for each year. The number of noise calls trends downward from 2014 through to 2019 and then increases for 2020 and 2021.

3.2.1 Temporal analysis

Comparing the total number of calls across years, a Chi-square test suggested differences across years in terms of month-to-month distributions (X^2 = 331.57, df = 96, p < 0.0001). The distribution of calls per hour was also significantly different when collapsing the years into periods corresponding to pre-, during-, and post-pandemic (X^2 = 36.988, df = 24, p = 0.044). Pairwise Chi-square tests indicate that the difference is between the during- and post-pandemic phases (Table 1 for results). Regardless of the pandemic period, most calls were placed in the morning (Figure 3).

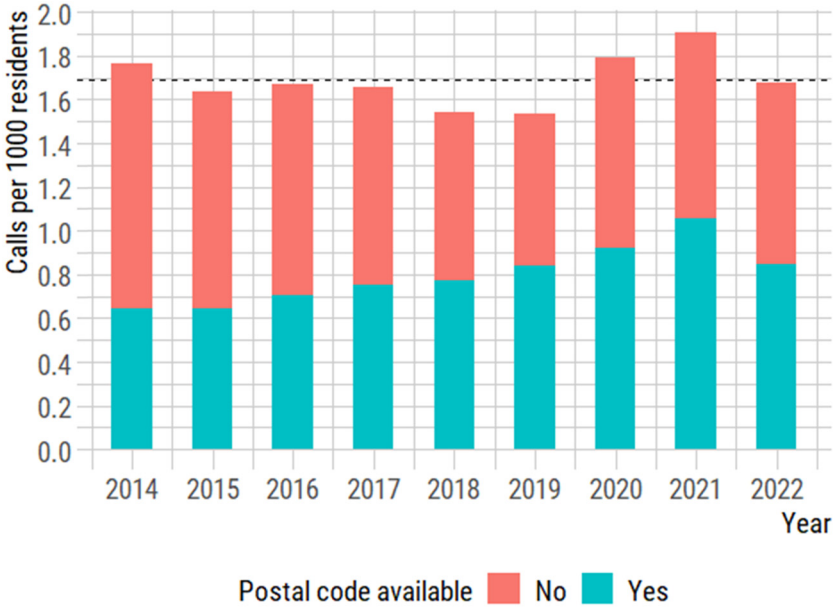

Figure 2: Number of noise-related calls to 311 per 1,000 residents. The dashed line indicates the average (mean) number of calls across all years. The postal codes were not available for every noise-related call.

Table 1: Pairwise Chi-square tests of the distribution of calls per hour between the pre-, during-, and post-pandemic phases indicating that there is a significant difference between the during- and post-pandemic phases

Phases	X^2	Df	*p*-Value
Overall	36.988	24	0.044
Pre *vs* During	16.268	12	0.179
Pre *vs* Post	18.081	12	0.113
During *vs* Post	21.959	12	0.038

Table 2: Results of the pairwise chi-square tests comparing distribution of seasonal call volume between phases

Comparison (seasons)	X^2	Df	*p*-Value
All phases	26.74	2	$P < 0.0000$
Pre *vs* During	23.848	1	$P < 0.0000$
Pre *vs* Post	6.913	1	$P = 0.0086$
During *vs* Post	0.68824	1	$P = 0.41$

3.2.2 Trends in noise complaints due to COVID

Across all years, call volume was consistently higher from the months of May to September. This trend continued through the pandemic period, though a Chi-square test indicates that the overall seasonal distribution of call volume differed significantly between Warm and Cold seasons. In particular, the pre-pandemic phase is different from both the during- and post-pandemic phases, but the during- and post-pandemic phases are not significantly different from each other. (Table 2 shows the results of the pairwise chi-square tests.)

Given the low volume of calls during the winter months, our analysis compares phases using January to December consistently rather than beginning the pandemic in March 2020 (Figure 4).

3.3 Spatial analysis

The raw number of calls in each FSA appears relatively consistent from one year to the next. Across all years, the FSAs with the highest call volume are in Montreal's Downtown or adjacent to it (Figure 5).

We expect that the number of noise-related calls would increase with both the number of residents in the FSA and its population density. We correlated the number of noise-related calls, regardless of category, with the total population and population density (per km^2) of the FSA. The number of calls was negatively correlated with the total population ($r = -0.42$, df = 754, and $p < 0.001$). However, the number of calls was only very slightly positively correlated with the population density of the FSA ($r = 0.09$, df = 754, and $p = 0.011$). Given the significant negative correlation between the number of residents and the number of noise-related calls, the rest of the analysis uses the rate of calls per 1,000 residents so as not to bias the analysis toward FSAs with high populations (Figure 6).

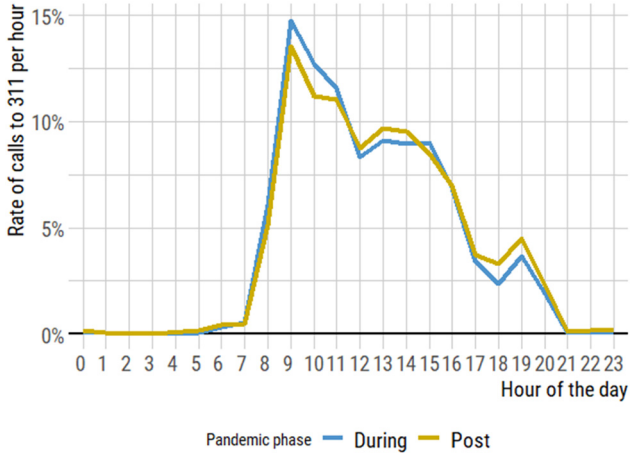

Figure 3: Comparison of the rate of noise-related calls to 311 per hour between the during-pandemic phase (2020–2021) and post-pandemic phase (2022). The distribution of calls differed significantly between these two periods: during the pandemic, there was a greater call volume in the morning and a decreased call volume at the end of the day.

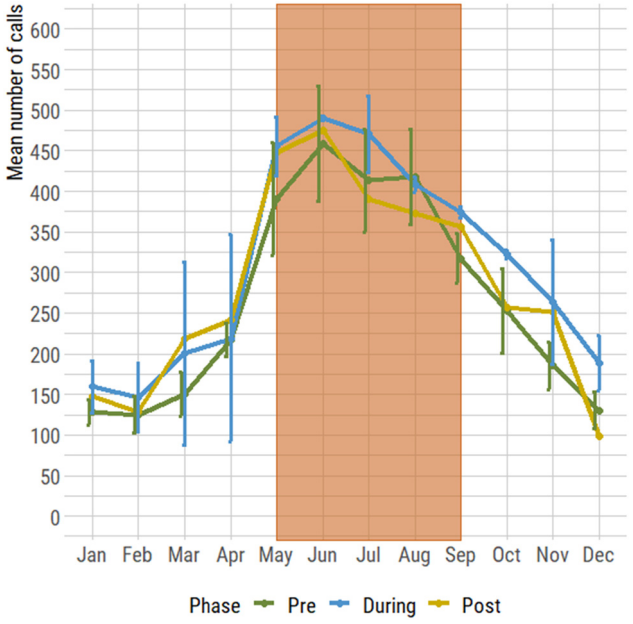

Figure 4: Average (mean) call volume to 311 per month for noise-related issues, with each line indicating a different phase of the pandemic (pre, during, or post). The shaded region represents the warmer months when windows are mostly likely to be open in Montreal. As well, they are the months with the highest consistent call volume.

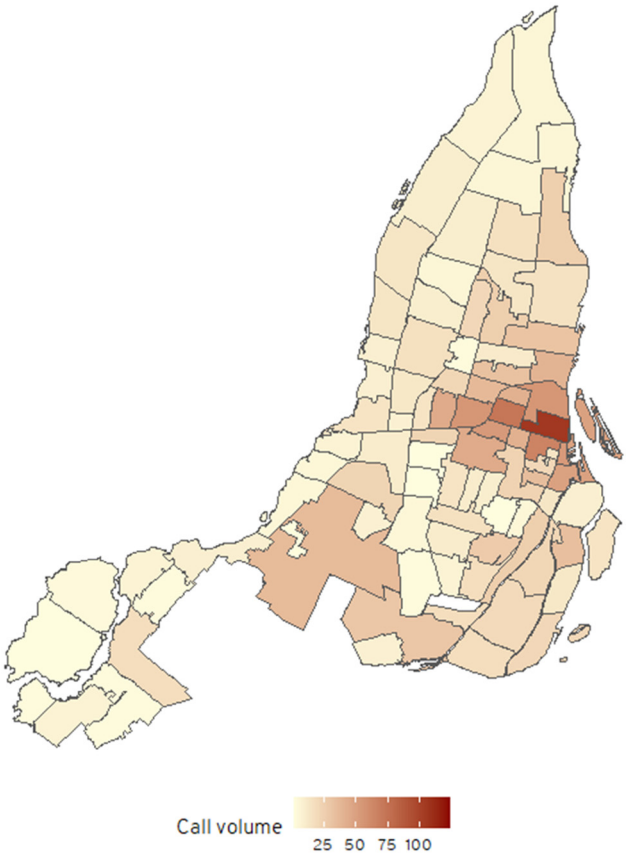

Figure 5: The total call volume for each FSA across all years (2014–2022). The top 5 FSAs for calls are H2L (898 calls), H2K (603 calls), H2J (559 calls), H3C (519 calls), and H2S (507 calls). These are all located in or near Montreal's downtown core.

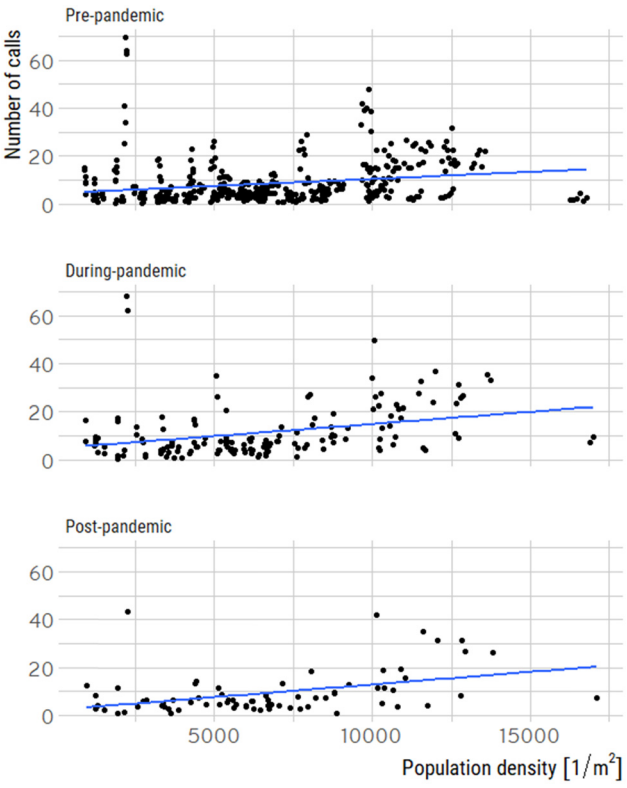

Figure 6: Density positively correlated with the rate of calls during each phase of the pandemic (pre, during, and post). The level of correlation is always low.

We used a mixed effects model to relate the total call volume per phase of the pandemic with the population density, socioeconomic factors, and available greenspace. Table 3 provides the complete results of the model. The mixed effects model suggests that call volume increases by 1 for every 1,000 people per square kilometer of the FSA; by 0.01 calls for every 1% increase in the proportion of low-income residents; and by 1.48 for every 1% increase in the proportion of greenspace.

Between the pre- and during-phases, there was a shift in the spatial distribution of calls. Figure 7 shows the change in call volume between the pre- and during-pandemic phase (left panel) and the pre- and post-pandemic phase (right panel) for each FSAs in Montreal. FSAs in red experienced an increase, while FSAs in green experienced a decrease. The shift in the spatial distribution of calls continued after the end of the lockdown period and into the post-pandemic phase.

We further investigated the change between the pre- and during-pandemic phases as a function of density and proportion of residential areas (RQ2). To so do, we used two separate linear models given the potential co-linearity between the two: one using the population density of the FSA and the second using the proportion of the FSA land use that is residential. In both models, the proportion of low-income residents and the proportion of greenspace were also included as explanatory variables. Table 4 provides the complete results from both models. Only Model 2 had any significant results. FSAs with a higher proportion of residential land use are associated with a higher change in call volume from the pre- to during-pandemic phases. In particular, a 1% increase in the proportion of the FSA that was used for residential land is associated with an increase of 5.69 more calls per year. As well, the change in call

Table 3: Results of the mixed effect Poisson model associating total call volume with population density, proportion of low-income residents, and proportion of greenspace. All three variables are significant

	Estimate	Standard error	*z*-Value	*p*-Value
Intercept	2.61	0.38	6.844	$P < 0.0001$
Pop. density	0.0001	0.000003	39.778	$P < 0.0001$
Low income	0.01	0.000977	10.071	$P < 0.0001$
Greenspace	1.48	0.08535	17.280	$P < 0.0001$

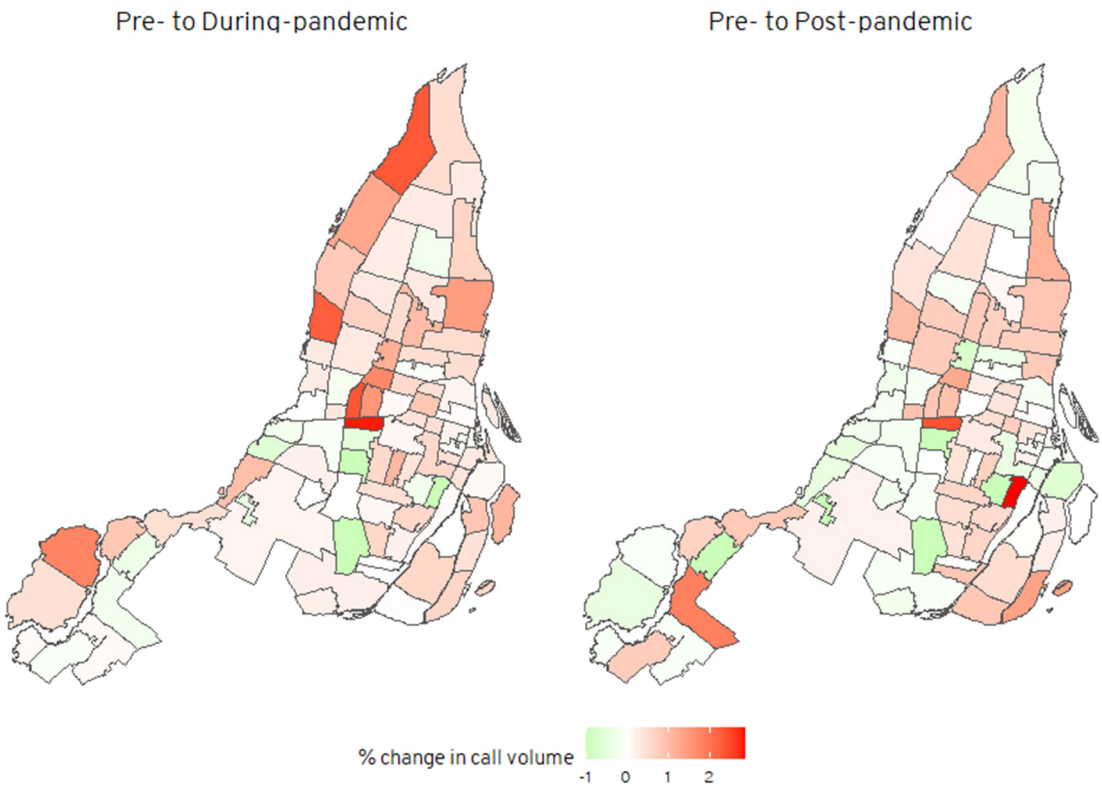

Figure 7: Graph of the change in the rate of call volume (as a percentage) from the pre- (2014–2019) to during-pandemic (2020–2021) and the pre- to post-pandemic (2022) phases. Red indicates an increase in call volume while green indicates a decrease.

volume increased with the proportion of greenspace, such that an additional 1% of greenspace increased the change in call volume by 18.54 calls per year.

As well, changes in the spatial distribution of call volume were not related to distance from the downtown core. The FSAs with the largest increases in call volume as a percentage were heavily residential neighborhoods.

Noise complaints from an open data service are easily accessible and can be a source of information about noise issues. There are some limitations to the richness of the data. First, many of the important details about the complaint that could be used for context may not be made available, which in our case includes consistent postal codes and call descriptions. Some calls are redirected to the police, for example, if they are after hours, in which case they are not registered in the 311 database. As well, 311 only accepts calls about certain sources of noise (*e.g.*, HVAC, heat pumps, construction, and neighborhood noise), and complaints about other sources (such as transportation noise) are directed to other services (*e.g.*, transportation ministries at the provincial or federal level depending on the transportation infrastructure). Finally, residents only call 311 when there is a

Table 4: Results of the linear regression models associating the changes in call volume with (1) FSA population density and (2) proportion of FSA land use that is residential. Significant results shown in bold

		Estimate	Standard Error	*t*-value	*p*-value
Model 1	Intercept	−5.47	2.96	−1.849	$p = 0.07$
	Pop. density	0.0005	0.0003	1.665	$p = 0.10$
	Low income	0.15	0.11	1.426	$p = 0.16$
	Greenspace	15.54	9.32	1.668	$p = 0.1$
Model 2	Intercept	−4.46	2.40	−1.858	$p = 0.07$
	Residential land	**5.69**	**2.60**	**2.189**	$\mathbf{p = 0.03}$
	Low income	0.098	0.06	1.535	$p = 0.13$
	Greenspace	**18.54**	**5.61**	**3.307**	$\mathbf{p = 0.001}$

problem; therefore, 311 open data offers no insight into positive sonic experiences. For all of these reasons, we complement the noise complaints data with survey data from residents taken after the COVID-19 lockdown and Summer 2020 period.

4 Surveys with residents

4.1 Methods

Two online surveys were conducted retrospectively in Fall 2020 concerning the full lockdown period (March to May 2020 in Montreal) and the subsequent summer (approximately May to September 2020). The former was distributed to all Montreal boroughs, and the latter to only the central boroughs of Outremont, Plateau-Mont-Royal, and Ville-Marie (Figure 8). The surveys were posted to the website of the research lab and promoted using email and the research lab mailing list.

4.1.1 Questionnaires

The questionnaires distributed during the two surveys consisted of different sections and included questions from pandemic surveys conducted in France by Acoucité [2] adapted to the Montreal context.

The first section pertained to open descriptions of the sound environment either during the lockdown (March–May 2020) or during the summer following the lockdown (May–September 2020), and a comparison with the previous year. Both questionnaires included the following three questions (with a different phrasing for each survey shown in italics):

- How would you describe the sound environment during the COVID lockdown (March–May)/this summer?
- How did your neighborhood sound different during that period compared to last year around the same period/this summer from last summer?
- What did you appreciate the least about the sound environment in your neighborhood during the lockdown/this summer?

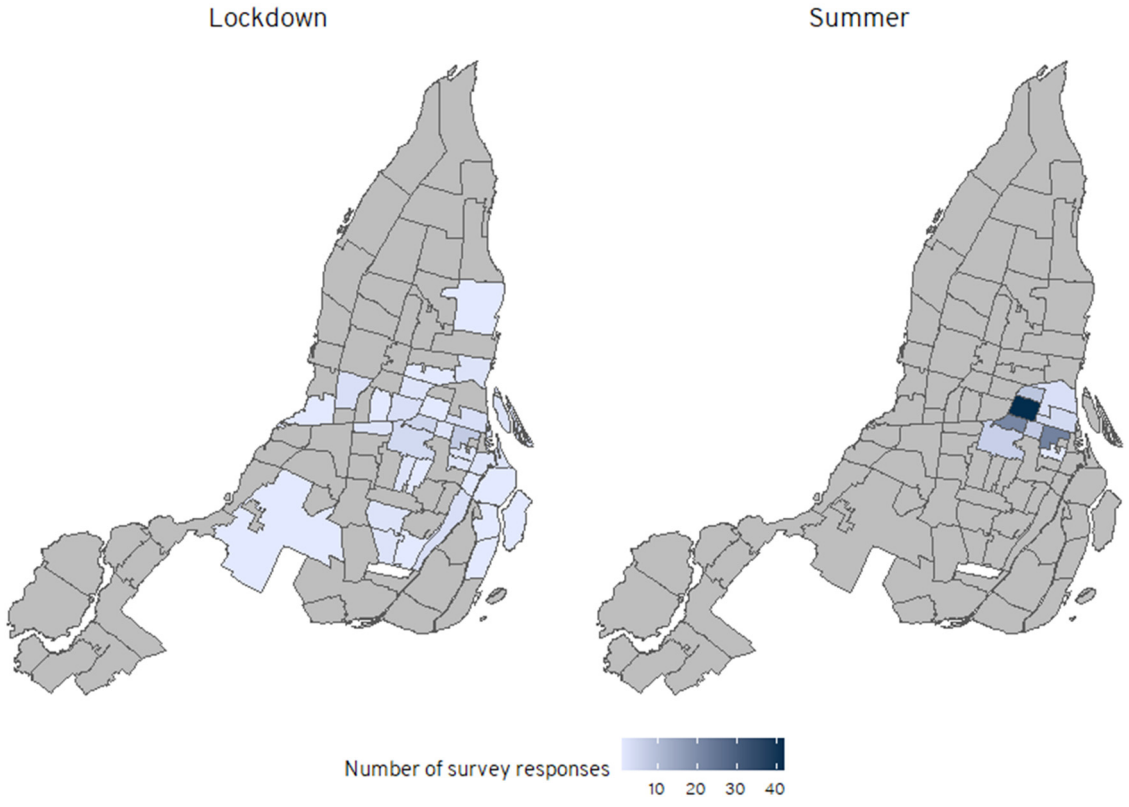

Figure 8: Number of survey responses per FSA for the lockdown and summer surveys. The lockdown survey has less representation from each FSA but gathers responses from a larger section of Montreal. In contrast, the summer survey is concentrated in the Plateau-Mont-Royal borough and Quartier des Spectacle neighborhood.

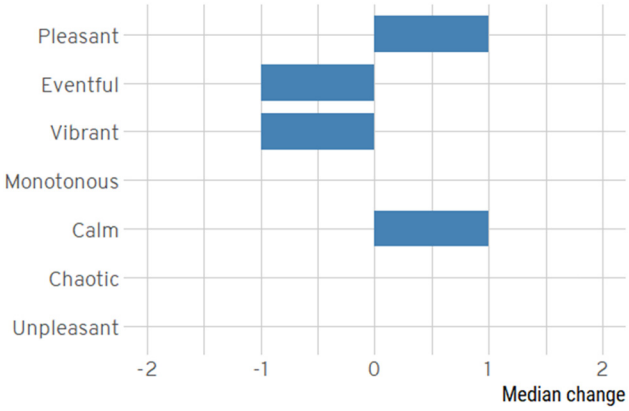

Figure 9: Median change in soundscape ratings from before to during the lockdown.

Additionally, in the lockdown questionnaire, respondents were asked to evaluate their sound environment before and during the pandemic using 5-point Likert scales for the following attributes from the SSQP: *pleasant, eventful, vibrant, monotonous, calm, chaotic*, and *unpleasant* [15].

The second section pertained to specific types of sound sources. Both questionnaires asked the respondents to evaluate the change in presence between before and during the lockdown or summer on a scale from highly decreased to highly increased for the following sound sources: road traffic, railway traffic, air traffic, construction, commercial activities, recreational activities, industrial activities, mechanical sources, neighborhood sources, educational activities, and natural sources (adapted from Acoucité, 2020). Additionally, in the lockdown questionnaire, respondents were asked to select the dominant sound source before and during the lockdown, from a list of the same sources (adapted from Acoucité, 2020 as well). From these dominant source selections, we calculated the difference in the number of mentions before and after the lockdown (Figure 11).

4.1.2 Recruitment

Both questionnaires were hosted online, and a link was distributed *via* the newsletter of the pertinent boroughs in Montreal and further advertised on the social media accounts (Facebook and Twitter) for Sounds in the City and Partenariat du Quartier des Spectacles. Any time the questionnaire was opened, the host system saved a new entry in the database. Additionally, no question was mandatory so that numbers of respondents differ per question.

For the lockdown survey, 120 questionnaires were started past the instruction page (of 148 times, it was opened). Of those, between 68 and 75 respondents filled out all the questions analyzed in this article. These respondents were 32 women, 32 men, and two of other gender identities (two preferred not to say), for a total N = 68 responses), and were 35 years old on average (SD = 12, N = 67).

For the summer survey, 174 questionnaires were started (out of 233 opened), of which 118 to 121 were filled out for the questions analyzed here. These respondents were 74 women, 33 men, and 1 of another gender identity (seven preferred not to say, N = 115), and were 48 years old on average (SD = 14, N = 113).

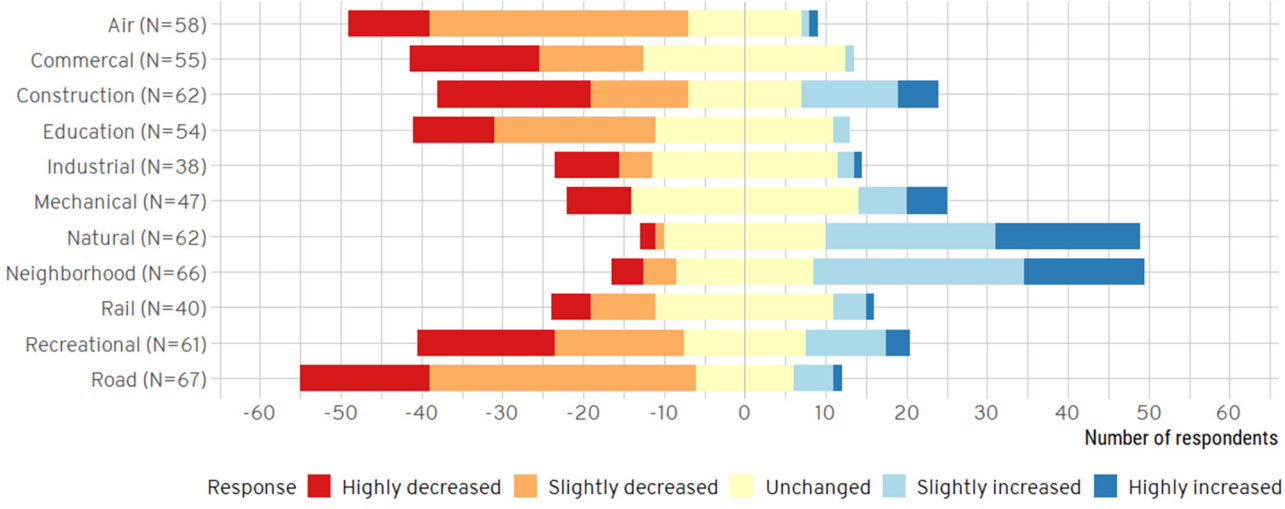

Figure 10: Judgments of change in the presence of sources in the soundscape between before and during the lockdown.

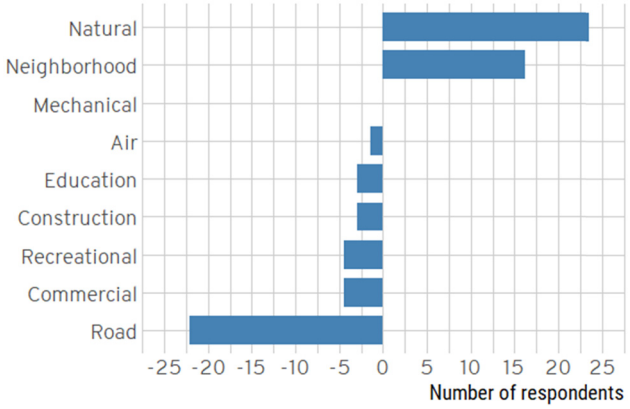

Figure 11: Proportion of change in selected dominant source before and during the lockdown.

4.2 Results of the first lockdown survey

4.2.1 Section 1

This section refers to the main findings related to the analysis of Section 1 of the questionnaire about the first lockdown (75 respondents).

4.2.1.1 Open description of the sound environment

Overall, respondents described the soundscape during lockdown as calm (52 respondents) and less loud (13 respondents). Twenty did not report any negative aspects, five explicitly reported appreciating the change (described as "welcome" or "refreshing"), but about 12 described it negatively as "too quiet," "eerie" ("*Sometimes it was as if part of the city life was gone, everything seemed sometimes frozen*"), or "disquieting" ("*The disquieting silence of empty streets in the middle of the day*"[i]).

Through a bottom-up classification by the authors, free-format descriptions of sound sources were categorized into the following:

- **Road traffic**: cars, trucks, emergency vehicles, buses;
- **Air and rail traffic** (collapsed due to low count);
- **Construction**: direct mentions as a whole or mentions of specific sources like compressor, tractor backing noise, *etc.*;
- **Other mechanical and industrial sources**: HVAC, leaf blowers, garbage trucks, and small factories;
- **Human activities**, including recreational and commercial sources, *e.g.*, sounds of other people – excluding neighbors, bars/restaurants, kids playing, and festivals/music;
- **Sounds of neighbors**, including direct mentions of "neighbors";
- **Natural** sounds, *e.g.*, birds, dogs, and trees.

In terms of sound sources, road traffic (38 respondents), air and rail traffic (10 respondents), and construction (16 respondents) were mostly perceived as having decreased (34/38 for road traffic, 8/10 for air and rail traffic, and 9/16 for construction); the direction of change for sounds of human activities (25 respondents) was more mixed (14/25 decrease, 10/25 increase); and natural sounds (nine mentions) and neighbors (seven respondents) were mentioned as more audible (6/9 for natural sounds and 5/7 for neighbors). This increase in perceived neighborhood noise can be attributed to the work-from-home situation ("*More noise coming from inside homes around me as people stayed home more*"), as well as to the poor sound insulation ("*Sounds from neighbouring buildings and units were more perceptible and made me realize how thin my walls and ceiling are*").

Figure 13 shows a detailed breakdown of mentions by descriptor and by source. Additionally, when asked about the least liked sound aspect of the lockdown, respondents mentioned road traffic (15 responses), construction (13 responses), and sounds of neighbors (13 responses) and human activities (nine responses).

4.2.1.2 Change in SSQP ratings between pre-pandemic and lockdown

By calculating the difference between before and during the lockdown and based on 68 responses, we see a median increase in soundscape pleasantness and calmness, and a median decrease in soundscape eventfulness and vibrancy as a consequence of the lockdown (Figure 9).

4.2.2 Section 2 – Change in sound sources between pre-pandemic and lockdown

This section refers to the main findings related to the analysis of Section 2 of the questionnaire about the first lockdown (68 respondents). We see that neighborhood noise and natural sources have increased, while road traffic, air traffic, construction, commercial activities, recreational activities, and sources related to education have decreased (Figure 10).

This is in line with the changes in sources selected as dominant before and during the lockdown (Figure 11): we see an increase in neighborhood noise and natural sounds, and a decrease in road traffic, air traffic, construction,

i *Le silence anxiogène des rues vides en pleine journée.*

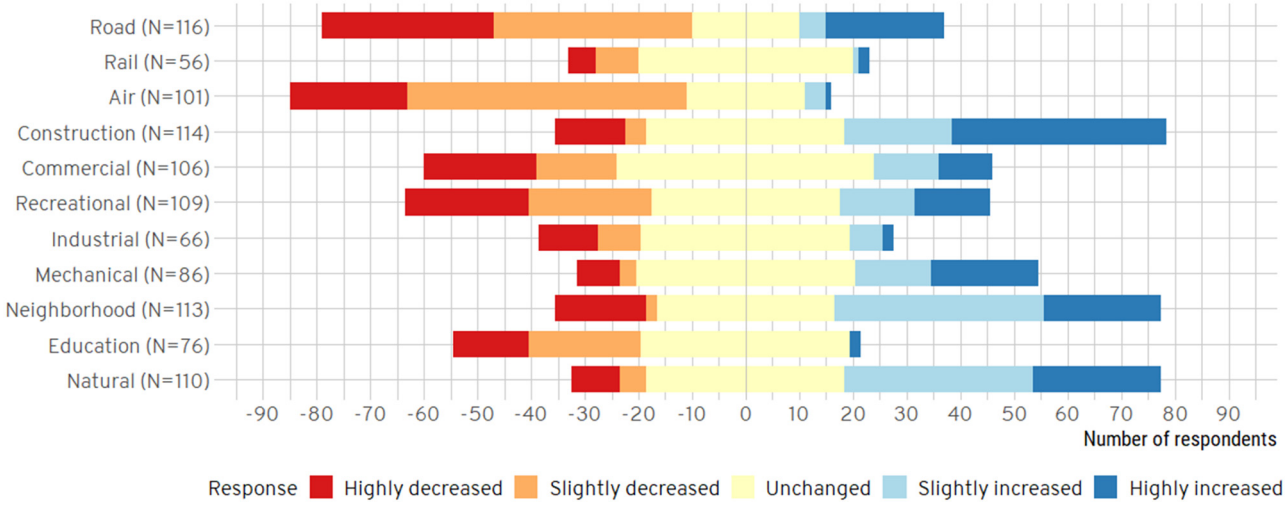

Figure 12: Judgments of change in the presence of sources in the soundscape between Pre-pandemic and Summer 2020.

commercial activities, recreational activities, and sources related to education.

4.3 Results of the Summer 2020 survey in Plateau and QdS neighborhoods

4.3.1 Section 1 – Open description of the sound environment

This section refers to the main findings related to the analysis of Section 1 of the questionnaire about Summer 2020 in the Outremont, Plateau, and Ville-Marie neighborhoods (121 respondents). Overall, respondents described the soundscape during the lockdown as calm (45 respondents) and some described it as loud (30 respondents). Seventeen did not report any negative aspects, 14 explicitly reported appreciating the change (described as "joyful" or "blissful"), but about three described it negatively as "less alive" ("*Sometimes the quiet made the neighborhood feel like a ghost town*") or "lonely" ("*How quiet it was, no students and the people who were here did no go out left me feeling alone*"). Others mentioned becoming more aware of annoying sounds ("*I realized the infernal noise that the Montreal city trucks make when they come by my street (cleaning, trash*"[ii]) and generally being more sensitive to noise ("*The silence of the pandemic made me realize the noisiness of daily life*"[iii]).

In terms of sound sources (categorized in the same way as for the lockdown responses), road traffic (62 respondents) and air and rail traffic (6 respondents) were mostly perceived as having decreased (34/62 for road traffic and 5/6 for air and rail traffic); the direction of change for sounds of human activities (59 respondents) was more mixed (25/59 decrease, 14/59 increase, and 20 additional mentions); and natural sounds (13 mentions) and neighbors (12 respondents) were mentioned as more audible (5/13 and 7 additional mentions for natural sounds, and 6/12 and 5 additional mentions for neighbors). Because construction work was reauthorized shortly after the first lockdown, construction work was mentioned more in the summer (41 respondents) with only 3/41 mentions of a decrease, 8/41 increase, and 30 additional mentions.

Figure 13 shows a detailed breakdown of mentions by descriptor and by source. Additionally, when asked about the least liked sound aspect of the lockdown, respondents mentioned construction (41 responses), mechanical sources (28 responses, 16 of which were HVAC systems), road traffic (23 responses), as well as sounds of human activities (31 responses) and of neighbors (10 responses).

4.3.2 Section 2 – Change in sound sources between Pre-pandemic and Summer 2020

This section refers to the main findings related to the analysis of Section 2 of the questionnaire about Summer 2020 (118 respondents). We see that construction, neighborhood noise, and natural sources have increased, while road traffic and air traffic decreased (Figure 12). Results were mixed for recreational and commercial activities. In the entertainment

ii *J'ai pris conscience du bruit infernal que font les camions de la Ville de Montréal quand ils passent sur ma rue (entretien, vidange)*
iii *Le silence de la pandémie m'a fait réaliser le vacarme de la vie quotidienne*

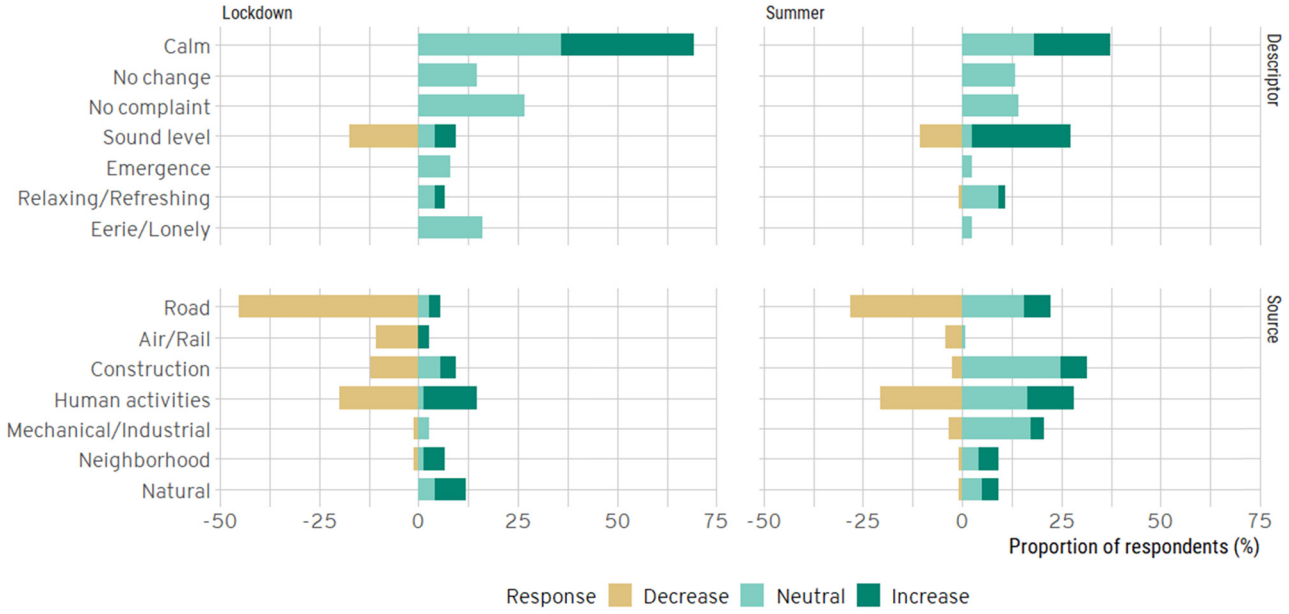

Figure 13: Proportion of respondents (%) for free format mentions by descriptor (top) and by source (bottom) for the lockdown (darker bars) and summer (lighter bars) surveys (only showing categories with more than five mentions over both surveys).

district, participants commented on the lack of cultural activities that are the raison-d'être of their neighborhood, particularly during the summer festivals (*"No shows at the Quartier des Spectacles"*[iv]) and the absence of tourists and students (*"this summer no deluge of noisy tourists"*). In the Plateau borough, the major artery was pedestrianized all summer attracting many visitors and small street performances, which was appreciated by most respondents *("Because of Mont Royal ave being closed this summer, there was far less traffic noise and more street musicians (official and unofficial) – it was wonderful.")* but generated sound (*"With Mont-Royal Street closed there was even more noise, more pseudo-musicians, stores use loudspeakers outside or maybe there was some participatory installation that was extremely noisy, opera singer."*[v])

4.4 Comparison of the two surveys

In this section, we compare the results of the two surveys: the lockdown survey was distributed over all of Montreal (spatial distribution in Figure 8), while the Summer 2020 Survey was distributed only in the central neighborhoods of Quartier des Spectacles and Plateau.

4.4.1 Summary of descriptions (Section 1)

In comparing the proportions of mentions of free-format descriptors between the lockdown and summer surveys, we see that the lockdown over all of Montreal was considered calmer and less loud, but more eerie than the summer in central neighborhoods (Figure 13, top). As for sources, road traffic, construction, and mechanical sources can be seen to increase from the lockdown phase to the summer (partial) reopening (timeline in Figure 1), while human activities remain mixed with a similar proportion of respondents finding them to have decreased but more mentions of their presence in summer (Figure 13, bottom).

4.4.2 Summary of changes in sound sources (Section 2)

To compare the amount of change in sound sources between lockdown (March–May) and summer, we also (i) converted the Likert scale data (from Highly decreased to Highly increased) into numerical data (from −2 to +2, respectively), (ii) calculated the median for each source for each survey, and (iii) subtracted the lockdown median from the summer median, thus obtaining a median change value for each source (Figure 14), interpreted below.

Based on this difference in median change of each source between the two surveys, we see that air traffic decreased between the lockdown and the summer. This could be explained by the different neighborhoods that

iv *Pas de spectacles au Quartier des Spectacles.*

v *Avec la rue Mont-Royal fermée, il y a eu encore plus de bruit, plus de pseudo-musiciens, les commerces mettent des hauts-parleurs dehors ou bien il y avait une installation participative extrêmement bruyante, chanteur d'opéra.*

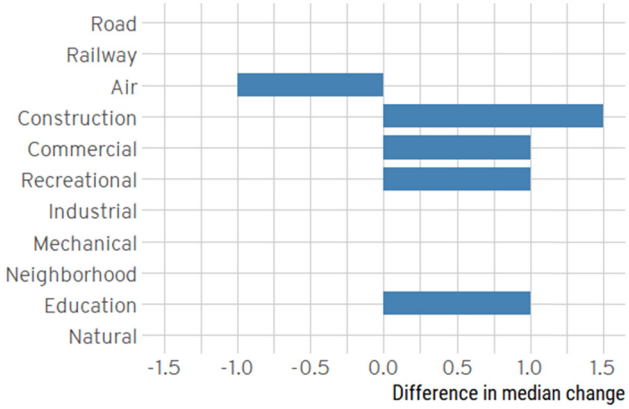

Figure 14: Difference in median change in sound sources between the lockdown (N = 68) and the summer surveys (N = 118).

were surveyed, as the neighborhoods of QdS and Plateau (surveyed in the summer) are more central and less subject to air traffic. We also see an increase in construction, commercial, recreational, and educational sounds as activities started up again in the summer (especially construction). Sounds from outdoors were also more audible in the summer when residents leave their windows open, as mentioned by several respondents, both in reference to annoying sounds (*e.g.*, *"over the summer the construction noise was a big impediment to daily life as I had to have my windows open with the heat"*) and to appreciated sounds (*"I liked to leave my windows open and listen to the bird sounds"*[vi]).

5 General discussion

We investigated the temporal and spatial distribution of noise complaints in Montreal and the effect of measures related to the COVID-19 pandemic on these distributions. Of particular interest was the outcome on residential neighborhoods, given the requirement to work and study from home. In addition, we investigated the soundscape outcomes during the pandemic. Specifically, we formulated the following three research questions.

(RQ1) How are noise complaints spatially distributed in Montreal?

(RQ2) How did the COVID-19 pandemic affect noise complaints? Were residential zones affected differently than other zones (mixed-uses, industrial, and commercial)?

(RQ3) How did Montreal residents describe soundscapes in their neighborhood during the pandemic? What were their main concerns about noise? What sounds did they enjoy hearing? Are there differences between the central districts and the rest of the island?

The pandemic affected the temporality of the calls. Overall, our noise complaints were placed more often during the morning hours, between 9 am and 12 pm, and decreased during the course of the afternoon. This is in contrast to the pattern for New York City found by Tong and Kang [20] where the calls are mostly placed during the night. This is likely because Montreal's 311 service is not available during the night and noise-related calls will be directed to 911 (the emergency line) if they require immediate intervention (*e.g.*, if they involve loud neighbors), while non-urgent calls are placed in the morning when the 311 service reopens. The initial pandemic measures did not affect the temporality of the calls, though the transition from the pandemic to the post-pandemic period was found to be significantly different. It is unclear what pandemic-related element would cause a shift in call volume toward the afternoon. Given that we have only one year of data for the post-pandemic period (2022), this could represent the variance. Thus, more data are warranted to see if this trend continues.

Additionally, the during- and post-pandemic periods experience a higher volume of calls during the colder months of the year. This could be due to residents leaving their windows open more frequently as a way to minimize the risk of COVID-19, despite the colder temperatures. However, our analysis does not account for the effect of temperature, and we therefore cannot rule out the potential that this is due to warmer winters in Montreal from 2020 to 2022. Despite this shift, the Winter was consistently the season with the lowest call volume in the year, comparable with findings from New York City [20].

In terms of the spatial distribution of the calls, we found that, within each phase of the pandemic, total call volume for the FSA increased with (i) the population density, (ii) the proportion of low-income residents, and (iii) the proportion of greenspace. Our finding of increasing complaints with population density is consistent with studies from New York City [17,20], though the rate of increase is much lower in Montreal. There are several possible factors that could explain the difference. One possibility is that there are local factors in each city, including a higher density in New York City, that makes density a bigger problem. The more likely explanation is that Montreal's 311 service closes for the night, the time during which calls about disruptive neighbours are most often placed. In this case, our analysis underestimates the importance of population density to noise complaints.

vi *j'aimais laisser mes fenêtres ouvertes et entendre le son des oiseaux.*

That said, the population density was not related to the change in the call volume from the pre- to during-pandemic phases. Instead, we found that FSAs with higher proportions of residential land use (regardless of density) and greenspace saw increases in call volumes, while FSAs with lower amounts of residential land use and greenspace were more likely to have decreases in call volume. In comparison, Tong and Kang [20] found no consistent relationship between the volume of noise complaints and proportion of greenspace.

Our survey data suggest the association we found with greenspace could be related to bans on gathering which encourage raising voices to interact with others while respecting social distancing (*"neighbors shouting to communicate with others because of social distance (i.e., third floor neighbor will shout to converse with a friend of theirs on the street)"*, *"Sometimes invasively loud conversations between people on the street or in the alley who were physically distancing and felt the need to shout."*) or meeting outside in greenspaces when indoor gatherings were banned (*"Crowds gathering in the park much more than usual."*, *"People talking in the park across from my house, often late in the night"*), as well as the consciously heightened perception of neighborhood sounds (*"Neighbouring yards, backyard (small) get togethers – heard more prominently this summer but less of them."*).

Specifically, survey respondents were aware that more people had to stay home *("More noise coming from inside homes around me as people stayed home more."),* including families (*"When indoors, I heard my downstairs neighbours a lot more. They have two young children and I heard more tantrums (crying, yelling)."*), and trying to be understanding (*"Kids yelled every morning, but I understand that they need to play in the yard"*[vii]) depending on the type of noise (*"The neighbours played a lot more loud music. It was irritating"*). Sounds of children were often mentioned as one of the big changes due to the lockdown ("More children loudly playing in the back alleys."[viii], *"A lot of children and parents yelling non-stop in the park"*[ix]). It was also noted by many respondents that the sound insulation of their home was poor (*"Sounds from neighbouring buildings and units were more perceptible and made me realize how thin my walls and ceiling are.","The building is not well insulated"*[x]), which may be especially likely in less advantaged neighborhoods.

Further research is needed to better understand the effect of greenspace on noise-related complaints given that greenspaces are usually associated with positive effects on noise-related health outcomes. For example, access to greenspace is associated with reduced levels of noise annoyance [26], and hearing the sounds of nature is associated with greater stress reduction in comparison with less pleasant sounds [27,28].

As with previous studies from New York City [17,18], we found that neighborhoods with high proportions of low-income residents were associated with a higher number of noise-related calls. However, unlike those studies, none of our results indicate that the COVID-19 pandemic increased the rate of calls from low-income neighborhoods specifically.

In general, the Lockdown and Summer survey data reveal a similar trend as was found in France [7] and Spain [14]. Traffic of all types (road, rail, and air) was perceived as having decreased during the lockdown and stayed lower during the summer (partially and gradually reopening). Additionally, construction work highly decreased during the lockdown, but increased again during the summer as construction had fully restarted by then (Figure 1). In contrast, neighborhood and natural sources were perceived as having increased, whether because the city noise usually masking them was absent or because the city uses (such as work) were relocated. As well, the sound environment was described as more pleasant and calmer for the most part, although some respondents found the silence eerie. Finally, similarly to the Montreal specificity pointed out by Steele *et al.* [10], the surveys collected in central neighborhoods about the Summer 2020 highlight a perceived increase in HVAC sounds, which could be more audible due to the reduction of other sounds (*e.g.*, traffic) usually masking them.

Taken together, the surveys illustrate the importance of considering the totality of the sound environments rather than focusing on noise levels alone. Specifically, the reduction of anthropogenic sounds (mostly from transportation) allowed other sounds to emerge, and while some of these were well received (*i.e.*, the sounds of nature), the outcome was not always positive. This suggests that practitioners working in city spaces need to consider how they can improve sound environments rather than just reducing noise levels.

5.1 Limitations

There were a number of limitations imposed by the use of noise-related calls from Montreal's 311 service. First, the 311 service is only available between the hours of 8:30 am and

vii *Des enfants criaient chaque matin mais je comprends qu'ils doivent jouer dans la cour.*
viii *Plus d'enfants qui jouaient bruyamment dans les ruelles.*
ix *Beaucoup de cris d'enfants et de parents en continu au parc.*
x *Le bâtiment n'est pas bien insonorisé.*

8:30 pm from Monday to Friday and 9 am to 5 pm on weekends and holidays. Noise complaints that are outside of those hours are directed to the 911 emergency services and calls that are not within the 311 mandate (*e.g.*, transportation noise) are directed to other services, making all of that data inaccessible. Additionally, none of the Information calls to Montreal's 311 service are geolocated, making half of the existing data set unusable for spatial analysis. Finally, the details of the call (*e.g.*, the source of the noise) are not made available to the public. The data set used does represent all available noise complaints, however.

We used Open Street Maps for residential and land use data. The data from Open Street Maps are community contributed. Land use data is tagged based on guidelines but can depend on the interpretations and methods of the individual contributors. As such, there may be residential or greenspace areas that are improperly tagged. To compensate, we included all of the tags related to residential or greenspace that seemed appropriate without over collecting data.

We divided the noise-related calls to 311 into three phases corresponding to the pandemic measures that were in place. The post-pandemic phase only contains data from 2022 and is therefore subject to an amount of uncertainty as to the extent of the trends identified in this paper. More data are required to confirm that these trends continue beyond 2022.

Finally, we were not able to account for city-wide noise levels in our analysis given that there is no permanent noise monitoring network that covers this territory. However, we were able to use the survey data to understand how the various sources of noise increased or decreased during the pandemic.

Despite these limitations, we contributed a study combining open data sources (311 noise calls and Open Street Maps) with context from survey data. This use of multiple sources of data helps to mitigate the limitations of either study alone.

6 Conclusion

We combined noise-related calls to 311 with survey data to understand the effect of the COVID-19 pandemic on the spatial distribution of noise-related issues in Montreal. In so doing, we found that noise complaints increased with the population density, the proportion of low-income residents, and the proportion of greenspace. We also determined that the pandemic-related measures shifted noise complaints toward areas that had higher amounts of residential land use and greenspace. The proportion of low-income residents is not associated with any changes in the spatial distribution of calls during the pandemic. Based on the survey data, we determined that the decrease in transportation and mechanical noise made Montreal's sound environments generally more pleasant, but that the lack of the usual human activity could be eerie. Moreover, the lockdown measures could also have the opposite effect and make sounds from neighbors more disruptive, even though they represent human activity, or reveal mechanical sounds (*e.g.*, HVAC) usually masked by transportation noise.

Furthermore, in a context where cities actively work to reduce noise levels, this study demonstrates the importance of understanding the sound environment beyond just the noise level. Indeed, as cities work to reduce noise exposure, it is important to consider how we can encourage dynamic sound environments that enable a variety of human activities.

This article used only 2022 as a post-pandemic comparison. However, there is a continued interest in working from home where this is possible. This change in work patterns could have an effect on noise complaints, and as such, future research should analyze data beyond 2022 to identify trends post-COVID.

Due to the use of multiple sources, we were able to provide context and meaning to the publicly available data. The calls to 311 provide a large data set with few qualitative details about the context of the call. In comparison, the surveys had fewer respondents but included questions about the lived experience that provide the kind of context missing from the 311 data set. Therefore, this article demonstrates the value to researchers of multiple perspectives. Future studies should do as much as possible to incorporate data sets from different collection methods. This includes sound level measurements, which we unfortunately did not have for Montreal at the time of the pandemic, but more importantly qualitative data to fully explore the experience of residents and their reasons for making complaints.

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Conflict of interest: The authors report no conflict of interest.

Data availability statement: Survey data generated for this study will not be made publicly available. Requests to access this data should be directed to the corresponding author.

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