Assessment of noise mitigation approaches along the construction site of a major highway in an urban environment

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ABSTRACT

Environmental noise can affect health. It might be associated with annoyance, sleep disorders, cardiovascular problems and communication problems. So far, few studies have been conducted regarding noise annoyance to large road infrastructure construction sites. In this study, 1,409 residents were interviewed to assess various noise mitigation approaches (temporary noise barriers, wideband backup alarms, online noise monitoring, construction site surveillance, citizens' committee, etc.) to reduce construction noise annoyance. A multivariate regression analysis showed that 10.8% of the variance of the construction noise annoyance is accounted for by the perception that road traffic management, construction site surveillance and temporary noise barriers effectively reduce noise levels and that watering within the construction site is reducing dust. The perceived efficacy of other aspects such as physical appearance of the temporary noise barriers, actions of the citizens' committees and use of wideband backup alarms did not significantly predict noise annoyance. Despite this, our results also demonstrate that the perception of efficacy about one specific mitigation measure strongly correlates to the perceived effectiveness of any other mitigation measures. Respondents seem to view mitigation measures as a whole.

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INTRODUCTION

Environmental noise can affect health. It might be associated with annoyance, sleep disorders, cardiovascular problems and communication problems [1]. In a 4-year longitudinal study, factors that may explain annoyance from noise generated by a large highway rehabilitation project were investigated [2]. Given the size (10 km) and duration (5 years) of the rehabilitation project, the Ministry of Transportation of Quebec put in place a series of mitigation measures in order to reduce noise annoyance [3]. Among those measures, providing information to the residents leaving nearby was one of the strategies used [4]. Websites were used to provide real-time access to construction noise levels [5], concentrations of pollutants in the ambient air [6] and access to construction schedule and road traffic modifications around the construction site [7]. Citizens' committees were organized on a regular basis throughout the project [4]. A specific complaint management system was put in place to respond upon complaints including noise [8]. The establishment of noise emission limits and independent site surveillance, the installation of temporary noise barriers, and compulsory use of white noise back-up alarms were put in place to limit noise propagation from the construction site [8]. Watering procedures were introduced to reduce dust generated by demolition and construction procedures [9]. The objective of this study is to describe satisfaction of residents living nearby with regard to the mitigation measures put in place to reduce the annoyance caused by construction noise of a large road infrastructure. The relationship between satisfaction for mitigation measures and noise annoyance is explored. This paper might be viewed as a companion to "*A 2-year longitudinal study on noise annoyance related to the construction of a major highway infrastructure*" by Pinsonnault-Skvarenina et al presented at the 13th ICBEN Congress on Noise as a Public Health Problem.

METHODS

Study area

The Turcot complex is a highway interchange located in the city of Montreal, in the province of Quebec, Canada, through which almost 300,000 vehicles pass daily. This complex constitutes a significant link between downtown Montreal, Montreal's international airport, the other provinces of Canada and northeastern states of the U.S.A. For several years, studies revealed that the infrastructures of the Turcot complex need major rehabilitation work. The demolition and reconstruction of this large highway began in 2016 and is expected to be completed by the end of 2021.

Participants and groups

The target group consisted of participants whose dwelling was located within 300 meters of the Turcot interchange structures. A control group was also set up with participants for whom the distance was between 300 and 1,000 m. These intervals were based on previous findings taken from an environmental impact assessment made in 2008 [10]. The inclusion criteria used to recruit participants were as follows: 1) be over 18 years of age and 2) reside for at least 6 months prior to the date of the interview (tenant or owner) at the sites selected for the survey. 1,409 residents participated in the study. Figure 1 shows the selection process for the study (for a full review of the selection process, see Pinsonnault-Skvarenina et al. (2021) [2]. Based on their home address, 483 participants were included in the target group and 926 in the control group.

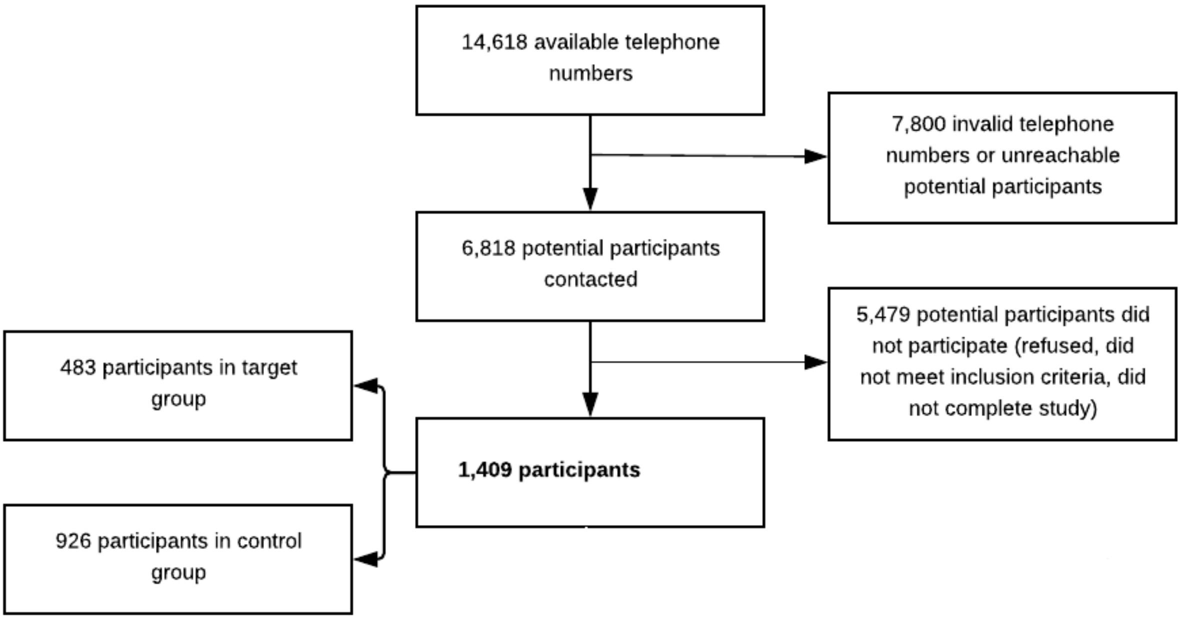

Figure 1: Flowchart detailing the selection process of participants in the study

Questionnaire

A perception survey questionnaire was developed in accordance with the international standard ISO / TS 15666 (2003) [11]. The questionnaire was administered by telephone. The questions relating to annoyance were the following: "*Thinking about the last year or so, when you are here at home, how much does noise from (NOISE SOURCE) bother, disturb or annoy you?*".

A specific section of the survey questionnaire was designed to collect respondent's satisfaction of mitigation measures put in place by the Ministry of Transportation of Quebec to reduce noise and other nuisances generated by the construction site. The question measured the satisfaction for:

1) Websites providing real-time information on the project itself, noise levels and air quality;
2) Citizen's committee;
3) Specific complaint management system and other available systems (e.g., police, cities);
4) Temporary noise barriers;
5) Procedures on the construction site: site surveillance for noise levels, watering procedures for dust control, white-noise back-up alarms;
6) Procedures around the construction site: traffic deviations, installation of safe corridors for pedestrians and cyclists, street and sidewalk cleaning, signalization of the deviations, etc.

A response scale, similar to the one prescribed for noise annoyance by ISO / TS 15666 (2003) [11], ranging from zero to ten was converted in satisfaction categories. A rating between 0 and 2 indicates that the respondent reported they are not at all or only negligibly satisfied, a rating of 3 or 4 indicates that they are slightly satisfied, between 5 and 7 that they are satisfied and between 8 and 10 that they were highly satisfied.

Analysis

A descriptive analysis of the data was performed by individually treating annoyance variables and the variables included in the satisfaction questionnaire as a dependent variable and using the group (target or control) as an independent variable. Chi-square tests (χ^2) were used to identify significant differences between groups for categorical variables and ANOVA for continuous variables. A factorial analysis was used to check if the satisfaction variables about the mitigation measures put in place by the Ministry of Transportation of Quebec were correlated and could be combined in one or more underlying factor. Exploratory univariate analysis were performed using Pearson correlations to measure the relation between satisfaction variables (or underlying factors) and the following construction noise annoyance variables as dependent variables: overall annoyance, annoyance by periods of the day, interference on various daily activities (e.g., concentration, relaxation, indoor conversations, outdoor activities and listening activities) and subjective sleep disturbance. A hierarchical multivariate regression was performed in order to identify the respective contribution of the satisfaction variables (stepwise selection) associated with overall construction noise annoyance. Analysis were performed using IBM SPSS Statistics version 25.0 with a significance level of 5%.

RESULTS

Sociodemographic variables

Most sociodemographic variables did not show difference between target and control groups, except for family income and owner residence status (see Table 1). Participants in the control group exhibited a higher family income and were more frequently owners of their residence. These differences between groups reflect the demography of the studied region for which the areas closer to the Turcot highway (target group) are generally poorer neighborhoods [12].

Table 1: Socio-demographic variables for target and control groups

Variables	Target group (n=483)	Control group (n=926)	P-value
Age in years (mean ± SD)	59.0 ± 15.2	60.3 ± 15.4	0.13
Male sex (%)	38	37	0.64
University educational level (%)	52	56	0.49
Family income > 100k Cdn$ (%)	**20**	**32**	**<0.001**
Owner residence status (%)	**45**	**53**	**0.003**
Between 11 and 15 hours spent at home daily (%)	46	45	0.78
20 years and more living at the residence (%)	32	34	0.23

Noise annoyance variables

As expected, proportion of highly annoyed (%HA) respondents was significantly larger in the target group for overall noise construction annoyance, annoyance per period, interference in daily activities and sleep (see Table 2). On average, the proportion of highly annoyed respondents is almost three times larger in the target group compared to the control group.

Table 2: Proportion of construction noise annoyance (%HA) for target and control groups

Annoyance variables	Target group (n=483)	Control group (n=926)	P-value
Overall annoyance	28	11	**0.001**
Period of the day (D;E;N)	13;15;18	4;4;7	**<0.001**
Daily activities (C;R;I;O;L)	7;10;4;14;7	2;5;1;6;2	**<0.001**
Sleep	22	6	**<0.001**

D=day E=evening N=night
C=concentration R=relaxation I=indoor communication O=outdoor activities L=listening radio-TV

Satisfaction about means of communication (websites, committee, complaint system)

Questions measuring satisfaction were asked only to participants who had consulted a specific informational website on at least one occasion in the year before the survey (overall rehabilitation project, noise levels, air quality). The same approach was taken for measuring satisfaction after participation to citizens' committee and use of the complaint management system at least on one occasion in the year before the survey. As shown in Table 3, combined proportion of satisfied and highly satisfied respondents was not significantly different between groups for each of the three informational websites. Similarly, there was no significant difference between groups for satisfaction about participation to citizens' committee and use of the complaint management system. However, in the last case, satisfaction levels were the lowest of all means of communication, as about half of the respondents were either satisfied or highly satisfied and conversely the other half dissatisfied or highly dissatisfied. The total number of respondents who actually lodged one or more complaints is small (25 individuals over 1,409 respondents).

Table 3: Combined proportion of satisfied/highly satisfied respondents about means of communication

Mean of communication	Target group (%) n=respondents	Control group (%) n=respondents	P-value
Rehabilitation project website	76 (n=115)	81 (n=155)	0.56
Real-time noise levels website	84 (n=32)	77 (n=22)	0.82
Real-time air quality website	65 (n=23)	90 (n=31)	0.10
Citizen's committee	60 (n=43)	78 (n=35)	0.48
Complaint management system	53 (n=15)	50 (n=10)	0.36

Satisfaction about temporary noise barriers

Respondents were first asked if a temporary noise barrier had been installed near their residence or, when there was no barrier, if a need for one to be installed was perceived. Satisfaction about temporary noise barriers was measured with questions asking about the desire to have a temporary noise barrier turned into a permanent mitigation measure. Respondents were asked about positive and negative effects perceived after a temporary noise barrier had been installed near their residence. As shown in Table 4, temporary noise barriers were more frequently installed near the residence of respondents of the target group. The respondents of the target group more frequently mentioned a need for a temporary noise barrier.

Both groups expressed in a 50% proportion the desire that a permanent one replace the temporary noise barrier. After the installation of a temporary noise barrier, about a third of respondents of both groups reported positive effects (subjective reduction of noise level was the more frequently reported positive effect for 70% of respondents). A similar but smaller proportion in both groups reported negative effects (deterioration of the visual landscape for 25% of respondents and increased levels of noise for around 10% of respondents).

Table 4: Dimensions of satisfaction about temporary noise barriers

Dimensions of satisfaction	**Target group (%) n=respondents**	**Control group (%) n=respondents**	**P-value**
Temporary noise barrier installed near the residence	**29** (n=133)	**5** (n=49)	**<0.001**
Perceived need for the installation of a temporary noise barrier (in absence of one)	**26** (n=83)	**9** (n=70)	**<0.001**
Desire to have a temporary installation to become permanent	51 (n=65)	49 (n=21)	0.83
Positive effects after installation of temporary noise barrier	37 (n=48)	33 (n=15)	0.64
Negative effects after installation of temporary noise barrier	18 (n=24)	11 (n=5)	0.25

Satisfaction about mitigation procedures within the construction site

Respondents had to indicate their level of agreement with a series of affirmations about the efficacy of various mitigation procedures used within the construction site. As shown in Table 5, a larger proportion of respondents of the target group disagree or strongly disagree that noise levels site surveillance, white-noise back-up alarms and watering procedures were effectively reducing nuisance generated by the construction site.

Table 5: Combined proportion of agreement/strong agreement – disagreement/strong disagreement about the efficacy of mitigation procedures within the construction site

Mitigation procedures on site n=respondents	**Target group (%)**	**Control group (%)**	**P-value**
	Agreement/Strong agreement	**Agreement/Strong agreement**	
	Disagreement/Strong disagreement	**Disagreement/Strong disagreement**	
Site surveillance to reduce noise levels T(n=436); C(n=824)	46	47	**<0.001**
	27*	**16***	
White-noise backup alarms T(n=460); C(n=840)	55	53	**0.040**
	23*	**18***	
Watering procedures to reduce dust levels T(n=470); C(n=876)	**65***	**73***	**0.001**
	23*	**12***	

*Significant difference at p<0.05 adjusted with a Bonferroni correction
T=target group; C=control group

Satisfaction about mitigation procedures around the construction site

Respondents had to indicate their level of agreement with a series of affirmations about the efficacy of various mitigation procedures used outside the construction site. As shown in Table 6, a larger proportion of respondents of the target group disagree or strongly disagree that traffic deviations effectively reduce noise levels around the construction site (39 vs 30%). The proportion of respondents from the target group agreeing and disagreeing about the efficacy of the traffic deviations to reduce noise levels is about the same (40 vs 39%). The proportion of respondents agreeing or strongly agreeing, in both groups, that traffic management effectively reduce risks associated with traffic movements is almost three time as large as compared to respondents who disagree or strongly disagree (≈ 61 vs 22%). Interestingly, a smaller proportion of respondents from the control group, located further away from the construction site, agree or strongly agree that signalization of traffic deviations effectively control the traffic flow around the construction site (44 vs 49%). The proportion of respondents agreeing (50%) and disagreeing (≈ 30%) about the efficacy of corridors to ensure safe movements of pedestrians and cyclists around the construction site is about the same in both groups. A larger proportion of respondents of the control group agree or strongly agree that street and sidewalk cleaning effectively reduce dust levels around the construction site (66 vs 59%). Conversely, a larger proportion of respondents of the target group disagree or strongly disagree that street and sidewalk cleaning effectively reduce dust levels around the construction site (30 vs 17%).

Table 6: Combined proportion of agreement/strong agreement – disagreement/strong disagreement about the efficacy of mitigation procedures outside the construction site

Mitigation procedures on site n=respondents	Target group (%)	Control group (%)	P-value
	Agreement/Strong agreement	Agreement/Strong agreement	
	Disagreement/Strong disagreement	Disagreement/Strong disagreement	
Traffic deviations to reduce noise levels T(n=513); C(n=802)	40	39	**0.001**
	39*	**30***	
Traffic management to reduce risks associated with traffic movements T(n=470); C(n=881)	62	60	0.592
	22	23	
Signalization of the traffic deviations T(n=469); C(n=895)	**49***	**44***	**0.024**
	44	45	
Installation of safe corridors for pedestrians and cyclists T(n=455); C(n=846)	50	50	0.693
	31	28	
Street and sidewalk cleaning T(n=475); C(n=880)	**59***	**66***	**<0.001**
	30*	**17***	

*Significant difference at p<0.05 adjusted with a Bonferroni correction
T=target group; C=control group

A factor analysis applied to the variables reported in Tables 5 and 6 (and three additional satisfaction variables regarding citizens' committee and temporary noise barriers) reveals that respondents opinion of agreement/disagreement about the efficacy of mitigation measures were closely related (Cronbach's alpha = 0.845). These eleven variables constitute a single principal component explaining 40.1% of the variance. This single component, called *agreement with efficacy of mitigation measures*, was then used as a combined score in the correlational analysis described in the next section.

Relation between satisfaction variables and construction noise annoyance

As shown in Table 7, significant inverse correlations are observed between satisfaction about the rehabilitation project website and overall noise annoyance, annoyance per period and interference to daily activities. Significant inverse correlations are observed between satisfaction about the real-time air quality website and every construction noise annoyance dimension, except for sleep where a positive correlation is observed (i.e., better subjective sleep quality is related to positive satisfaction). Perceived positive effects of noise barriers are inversely correlated to overall construction noise annoyance. Perceived negative effects are correlated to overall construction noise annoyance during the day and evening and for daily activities. Significant inverse correlations are observed between the combined score of agreement with efficacy of mitigation measures and every construction noise annoyance dimension, except for sleep where a positive correlation is observed (i.e., better subjective sleep quality is related to positive satisfaction). Increase in overall agreement of efficacy of mitigation measures reduces the magnitude of noise annoyance (overall, per period, daily activities and sleep).

Table 7: Correlation between satisfaction about mitigation measures and construction noise annoyance

Satisfaction about mitigations measures	**Overall**	**Per period**	**Daily activities**	**Sleep**
Rehabilitation project website (n=189-269)	**-0.207****	**-0.157****	**-0.179****	0.121
Realtime noise levels website (n=47-54)	-0.150	-0.087	-0.123	0.004
Realtime air quality website (n=46-54)	**-0.291***	**-0.340***	**-0.309***	**0.344***
Citizen's committee (n=64-78)	-0.088	-0.066	-0.123	0.110
Complaint management system (n=23-25)	-0.306	-0.305	-0.223	0.089
Positive effects of temporary noise barrier (n=63)	**-0.177***	D= -0.084 E= -0.088 N= -0.098	-0.104	0.096
Negative effects of temporary noise barrier (n=29)	0,099	**D= 0.152*** **E= 0.151*** N= 0.089	**0.245****	-0.109
Agreement with efficacy of mitigation measures (combined score) (n=824-1258)	**-0.333*****	**-0.326*****	**-0.301*****	**0.217****

*p<0,05; **p<0,01; ***p<0,001
D=day E=evening N=night

Regression for variables predicting noise annoyance

Of the eleven satisfaction variables introduced in the regression model, four variables significantly accounted for 10.8% of the variance of the overall construction noise annoyance: road traffic management, construction site surveillance, watering procedures to reduce dust within the construction site and perceived reduction of construction noise levels by temporary noise barriers. The other seven variables were not significant and were excluded from the model.

Table 8: Logistic regression to predict construction noise overall annoyance from level of agreement with perceived efficacy of mitigation measures

Mitigations measures	Coefficient	Standard Error	P-value
Traffic deviations to reduce noise levels	**0.456**	**0.101**	**<0.001**
Site surveillance to reduce noise levels	**0.350**	**0.117**	**0.003**
Watering procedures to reduce dust levels on site	**0.327**	**0,102**	**0.001**
Perceived reduction of construction noise levels by temporary noise barriers	**0.239**	**0.115**	**0.038**
Signalization of the traffic deviations	-0.014	-0.437	0.803
Street and sidewalk cleaning	0.060	1.605	0.616
Installation of safe corridors for pedestrians and cyclists	0,007	0.204	0.747
Citizen's committee	-0.013	-0.378	0.756
Contribution of temporary noise barriers to visual landscape	0.032	0.941	0.766
White-noise backup alarms	-0.012	-0,376	0.873
Traffic management to reduce risks associated with traffic movements	0.060	1.773	0.758

DISCUSSION

The informational means put in place by the Ministry of Transportation of Quebec (real-time websites on the project itself, noise levels and air quality, citizen's committee, complaints management system, etc.) were well received by residents who mostly reported to be satisfied or highly satisfied (in proportions varying between 50 to 90%). However, the number of website visits is quite small per respondent (a mean of six visits in the year before the study, not reported here). Considering the costs of setting up and managing these information tools or activities, it seems relevant to question the actual use made by members of a community targeted by a specific project. Similar questions also arise for other type of permanent environmental noise observatories set up for several years in France [13]. Nevertheless, our results show that satisfaction about informational tools is significantly correlated with construction noise annoyance. A high satisfaction rate about these information tools and communication activities contributes to the reduction of noise annoyance as suggested by other researchers [3,4,8].

The installation of temporary noise barriers is a question that needs more attention. Respondents who identified positive effects were in greater proportion than those who perceived negative effects. The most frequently mentioned positive effect is a subjective reduction of construction noise levels. This positive appreciation correlates with a decrease in overall construction noise annoyance. The unfavorable judgment given to the visual appearance of these barriers is correlated with an increase in noise annoyance during the day and the evening. One can suspect that these periods coincide with seeing the barrier during activities outside the residence unlike at night when people are more often indoors. This hypothesis is reinforced by the fact that interference with daily activities was also correlated with perceived negative effects of the noise barriers. Unfortunately, this hypothesis can't be tested since our study did not asked respondents about *seeing* a temporary noise barrier from their residence. Nevertheless, these results indicate that greater attention should be brought to the visual appearance of temporary noise barriers. Citizen participation in the design of the visual appearance of these barriers would be an avenue to explore. A better integration to the local visual landscape could possibly contribute to further reduction in construction noise annoyance.

Our results also demonstrate that the perception of efficacy about one specific mitigation measure strongly correlates to the perceived effectiveness of any other mitigation measures. Respondents seem to view these measures as a whole. In addition to temporary noise barriers, road traffic management to reduce noise levels around the construction site, construction site surveillance and watering procedures to reduce dust within the construction site accounted for a non-negligible proportion of the variance of the overall construction noise annoyance. According to these results, putting in place a comprehensive range of mitigation measures seems to be the most effective way of reducing construction noise annoyance [8].

CONCLUSION

Our results show that authorities should resort to comprehensive mitigation measures to reduce construction noise annoyance, especially in the case of a complex rehabilitation project of an urban highway infrastructure. Applying isolated measures, while useful, could be less effective in reducing noise annoyance. In the last phase of this 4-year longitudinal research project (2021-2022), we aim to verify if the anticipated reduction in construction noise levels generated by the highway rehabilitation project and the gradual withdrawal of certain mitigation measures will influence noise annoyance.

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