Special session n°56

Transport, Heath and Socio-territorial Disparities

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Effect of road-traffic related nuisances on the active travel modes. What is the issue?

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Abstract

Purpose: Exposure to road traffic nuisance, such as noise, air pollution and traffic accidents, can lead to feelings of annoyance or road insecurity. Annoyance is defined as a feeling of displeasure claimed by an individual or group to be adversely affecting them, diminishing long-term quality of life; road insecurity is recognized as affecting welfare. The aim of this study was to identify the determinants (sociodemographic, socioeconomic, and related to daily mobility) of annoyance by noise and air pollution and of road insecurity.

Methods: A sample of 720 subjects, aged 18 years and over, living in the Rhone Departement (France) in 2013 was interviewed by questionnaire. Annoyance and feeling of road insecurity were estimated on a 10-point scale from 1 (not annoyed) to 10 (highly annoyed) for each nuisance, with a threshold of 8.

Results: The main finding was that active travel mode users experienced greater annoyance, whatever the nuisance than motorized users.

Conclusions: The least polluting are the most annoyed. These results are very interesting. Active travel mode users help improve air quality, alleviate traffic congestion and minimize the risk of road-accidents, as well as improving their own health. In a context in which active travel modes and public transport are being promoted, active travellers might be protected against such annoyance, liable to hinder the development of such a practice.

Keywords: noise, air pollution, annoyance, road insecurity, active travel modes

1. Introduction

Road transport is a common source of traffic accidents [1], noise, air pollution and environmental exposures which have heavy consequences for public health. Depending on the discipline, we talk about the three main road- traffic "nuisances" or "negative externalities". Beaumais and Chiroleu-Assouline talk about negative externalities when the well-being of an agent or his or her freedom of choice of behavior is directly negatively affected by another agent [2]. In public health, these negative externalities are known as "nuisances". Annual statistics for Europe show that road transport is responsible for 25,500 accidental deaths [3], road traffic noise for the loss of about 1 million years of good health [4], and air pollution causes more than 400,000 premature deaths [5]. These well-known negative effects make road traffic one of the most environmentally harmful human activities [6].

In this context, promoting active travel modes (walking, cycling) and public transport is a strategy used in many countries as a contemporary transport policy goal to improve air quality [7] by reducing exhaust and greenhouse-gas emissions [8], and reduce noise, traffic congestion [9] and traffic accidents. Such policies have another crucial objective: to improve health in the general population [10, 11]. Active travel modes have many health benefits, including improved physical and mental health and general well-being [12-14]. In recent decades, these health benefits have been demonstrated by many scientific studies [15-20]. Since 2008, the World

Health Organization (WHO) has recommended that people aged 18 to 64 years should practice at least 150 minutes of moderate endurance activity per week [21].

The interaction between humankind and its environment plays an important role in quality of life, and can unfortunately be a source of stress [22, 23]. "Looking at the impact of environmental conditions requires analysis of the annoyance which stands for a perturbation of the relation to the life space and may have long term effects on health", write Moser and Robin [24]. On the one hand, noise and air pollution can lead to annoyance and, on the other hand, the perception of road insecurity - in terms of fear of having a road accident by lack of protection and confidence - in accessing the public transport system for instance, is a loss of well-being [25].

Annoyance, as illustrated by Guski [26], is a feeling of irritation, discomfort, distress, anxiety, anger or frustration: i.e., a range of negative emotions [27, 28] diminishing long-term quality of life. This is a complex concept, comprising a mixture of perception, emotions and attitudes potentially causing a chronic stress response [29, 30]. Annoyance is defined by Lindvall and Radford as "a feeling of displeasure […] believed by an individual or a group to be adversely affecting them" [31]. Most of the studies dealing with annoyance related to road traffic focused on noise, and very few on air pollution. Noise annoyance has a significant negative effect on both mental and physical health [32]. The two main determinants of annoyance with traffic-related noise are noise level and individual noise sensitivity. Excessive exposure to daytime noise pollution and high noise sensitivity are associated with high levels of annoyance [33-37]. People working in a noisy workplace are more annoyed than those who report working in a quiet environment [35]. In addition to noise sensitivity, other individual factors, such as age, gender, marital status, employment and socioeconomic status, affect annoyance. However, results vary between studies. The degree of annoyance is higher in men than in women, in people aged from 30 to 49 years compared to others [35], in married compared to single people [35], in working people compared to those who stay at home, and in the working population, individuals aged from 45 to 64 are more annoyed than others. Work experience is also a determinant of the degree of annoyance [38]. Concerning socioeconomic status, annoyance is reported to be greater in the most advantaged groups [37], while other studies reported that people with the lowest incomes were the most sensitive to noise, maybe because they live in less sound-proofed dwellings [39-41].

To these acoustic and individual factors, mobility-related factors can be added. Wahl et al. showed that people who walk more frequently in their neighborhood are more annoyed by road transport phenomena (traffic flow, speeding, parked cars, cyclists on the sidewalk) than those who walk less frequently [42]. It is one of the few studies which takes travel mode into account in the association between annoyance and traffic-related factors, but unfortunately traffic nuisances such as noise, air pollution and accidents (related to feeling insecure) were not considered: only walking was studied.

Today, in most modern societies, car use rates are high while walking and cycling are much less frequent. There are some variations in travel modes across Europe. In France, for instance, cycling amounts to less than 8% whereas it reaches 30% in some countries, such as Netherlands, Germany and Denmark [43]. Likewise, in France, pedestrians represent 25% of the users, depending on the city, compared to 55% in some Spanish cities. The latest nationwide Household Travel Survey, which is conducted every 10 years, showed that the more a city is compact, the less the cars are used, in favor of public transport, walking and cycling [44]. In light of these results, it would seem that some countries, such as Germany, Netherlands and Denmark (aka "the European cycling country"), are more proactive than others (France). If, however, according to Wahl et al, active travelers are the most annoyed, it can be supposed that this annoyance or the feeling of road insecurity hinder the promotion of active travel modes.

To the best of our knowledge, traffic-related noise annoyance has been well documented, while the literature on air pollution annoyance and the feeling of road insecurity is sparse. Moreover, travel mode was taken into account only in one study. Very few studies have attempted to assess the relationship between annoyance related to road-traffic nuisances such as noise or air pollution and the feeling of road insecurity on the one hand and travel mode on the other.

There is a need to consider the different kinds of travel modes (cars, motorized two-wheelers, public transport, cycling, walking) when assessing annoyance related to the main road-traffic nuisances (noise, air pollution) and the feeling of road insecurity. The present study seeks to identify determinants (sociodemographic, socioeconomic, and daily mobility-related) of each kind of annoyance and of feelings of road insecurity.

2. Materials and methods

2.1. Study population

Subjects were recruited randomly from the general population, from a data file based on landline and/or cell-phone numbers for the Rhone *Département* in France. This administrative area has a population of about 1.7 million, with an average population density of 542 inhabitants per km^2 (INSEE[1], 2012), 1.3 million of whom live in the Greater Lyon urban area, and the remainder in medium-sized towns or rural areas (outside Greater Lyon).

Subjects were selected by a survey institute between January and April 2013, according to the following inclusion criteria: aged ≥18 years, living in the Rhône administrative *Département*. After selection, subjects were included in the survey and interviewed by phone between May and June 2013, by the survey institute investigators. A total of 720 participants took part in the study. Data were collected by a validated questionnaire.

2.2. The study variables

2.2.1 Outcomes: road-traffic related annoyance

Degree of road-traffic related annoyance was measured by responses a 10-point scale from 1 to 10 to the following question: "Here are three road-traffic related nuisances: noise, pollution, and traffic accidents (in terms of feeling insecure). Personally, how do you rate your level of annoyance on a scale from 1 to 10 (not annoyed to highly annoyed)?"

The dependent variable y_i was dichotomized and constructed as follows: to study subjects with the highest levels of annoyance, a threshold of 8 was chosen for each nuisance, in line with the French air quality index [45] approved by the Ministry of the Environment, which ranges from 1 (very good) to 10 (very bad) with a threshold of 8: < 8, slight or moderate annoyance; ≥ 8, great annoyance. There were thus three study outcomes: noise annoyance, air pollution annoyance and feeling of road insecurity.

2.2.2 Explanatory variables

[1] National Institute of Statistics and Economic Surveys

Mobility data: main travel mode

Subjects reported their main weekday travel mode, in three categories: motorized (cars and two-wheelers), public transport, and active travel (pedestrians and cyclists). None of the survey subjects reported using roller-skates, skateboards or a child's scooter. Each subject was asked to estimate their typical weekday travel time (< 30min, 30min to 1h, 1 to 2h, > 2h), and travel distance (< 5 km, 5 to 15km, 15 to 30km, > 30 km).

Sociodemographic and socioeconomic data

These variables are: place of residence (inside or outside Greater Lyon), age (18-24, 25-44, 45-64, ≥65 years), gender (female, male), marital status (single, in couple, widowed/ divorced), health status (good/good enough, not very good), employment (working/studying, looking for or without a job/student, retired), household size (number of children, number of adults), and way of life (living alone, not alone) were all collected for each subject, as were socio-occupational category (6: independent, executive-professional, intermediate profession, white-collar, blue-collar, never worked/ not working currently), educational level (4: no certificate or lower than school-leaving certificate (*baccalauréat*), school- leaving certificate, bachelor's or master's degree, PhD or equivalent), number of cars/motorized two-wheelers/ bicycles (0, ≥ 1), vacationing 4 or more nights away from home during the previous 12 months (yes, no), type of accommodation (social housing, house, apartment, other), accommodation status (home owner, tenant, supported by another person), and income. Based on income and household size, income per consumption unit was calculated.

Road risk perception data

Subjects were asked to give their opinion on:

– which is the riskiest travel mode (car, motorized two-wheelers, bicycles, walking, public transport, roller-skates/skateboard/child's scooter);

– their level of concern about road accidents:

a) indifferent, because it is an unusual event, is little or nothing to worry about, or aware of risk but trust in their ability to personally avoid an accident;

b) accidents are a worry and cause for caution; c) very afraid, and it guides their choice of travel mode;

– the degree of anxiety concerning road accidents (1 = does not matter, 10 = very distressed), dichotomized as < 7 = no, ≥ 7 = yes;

– the risk of being injured in case of a road accident (from 0 to 100%), dichotomized as < 70% = slight, ≥ 70% = high;

– assessment of their own behavior on the road compared to others of similar age and gander (more dangerous, neither more nor less dangerous, more cautious).

2.3. Statistical analyses

Firstly, the study population was compared to the general population of the Rhône Département, by χ^2 test, to measure the degree of representativeness.

Secondly, descriptive statistics were performed to identify the type of distribution for each variable. Then, univariate analyses were performed to determine factors associated with each outcome at a 10% significance level, using the Pearson χ^2 test (or Fisher's exact test, where sample size was small). Explanatory factors significantly associated with outcomes (each kind of annoyance) on univariate analysis were included in a multivariate model by logistic regression with descending selection ($p \leq 0.05$). Nevertheless, in line with the objectives of the paper, the variable "main travel mode" was integrated in each model even when the association did not appear significant. A model was constructed for each outcome: noise annoyance, air pollution annoyance and feeling of road insecurity. Odds ratios and 95% confidence intervals (95% CI) were determined on multivariate analysis. Each model was adjusted on age, gender and geographic area. In each model, to check independence between pairs of explanatory variables, interaction effects were assessed and potential correlations between explanatory variables were measured on Spearman's Rho coefficient. When two variables were strongly correlated, only one of them was entered in the model. Potential confounds were studied. Factors associated with all three outcomes (noise annoyance, air pollution annoyance and the feeling of road insecurity) are highlighted in the Results section.

2.4. Ethics approval and consent

The study protocol was submitted to and approved by the French Ministry of Research (CCTIRS: Advisory Committee on Information Processing in Material Research in the Field of Health) and the national data protection authority (CNIL) in 2014. The survey institute ensured subjects' oral consent before administering the questionnaire.

3. Results

3.1. Population characteristics

The main characteristics of the study sample are shown in Table 1. Median age was 45 years (±17); 47% were women; 74% lived inside Greater Lyon. When compared to the general population of the Rhône *Département*, men were found to be slightly overrepresented and younger subjects (18-24 years old) to be slightly underrepresented in the study population; distribution, however, was similar in terms of place of residence.

Table 1: Descriptive statistics of the study population compared to the general population

	Study sample n = 720	General population n = 1,327,755	χ^2 test
	%	%	
Gender			*
Male	53.3	47.2	
Female	46.7	52.8	
Age (years)			*
18 - 24	10.6	14.5	
25 - 44	38.2	35.7	
45 - 64	32.2	30.1	
65 and +	19.0	19.7	
Area			NS
Greater Lyon	73.9	76.5	
Other than Greater	26.1	23.5	

NS: non-significant

60.4% of the study sample were living in a couple. 58.8% were active, white-collar workers being the largest socio-occupational category (23.3%). 45.6% had at least a Bachelor's degree. In terms of accommodation, 47.5% lived in apartments and 59.6% were home owners.

56.3% mainly used a motorized travel mode (car or two-wheeler), which did not significantly differ from the general population (44.5% [46]), and only 14% of households did not own a car at all. Although 63.5% owned a bicycle, only 3.3% actually used the bicycle as their main travel mode, which was more than in the general population (about 1.6% [46]). Less than 21% used walking as the main travel mode, compared to 34.1% in the general population [46]. Differences were found according to area of residence ($p<0.001$): inhabitants inside Greater Lyon used motorized modes in 47.7% of cases, active travel in 27.1% and public transport in 25.2%, whilst residents outside Greater Lyon used motorized modes in 80.3% of cases, active travel in 14.4% and public transport in 5.3%.

Concerning perception of road risk, motorcycles were by far considered the most risky travel mode (60.8%). 74.4% of respondents worried about road-traffic accidents and reported being cautious during travel, 75.3% were very distressed because of the risk of accidents, but 96.5% estimated they had only a slight risk of being injured in case of a road-traffic accident.

3.2. Description of annoyance

According to the threshold chosen (see Table 2): 36% (n=259) of the study population (i.e., than one third) were highly annoyed by road traffic noise, 20.6% (n=148) by air pollution and 18.3% (n=132) felt road-insecure. Road traffic noise was identified as the principal cause of high levels of annoyance (mean=6.2+/-2.8), followed by air pollution and lastly by the feeling of road insecurity.

Table 2: Descriptive statistics according to annoyance level (/10) per nuisance

	Road traffic noise		Air pollution		Feeling of road	
Level	N	%	N	%	N	%
1	40	5.6	34	4.7	84	11.7
2	34	4.7	45	6.3	81	11.3
3	42	5.8	73	10.1	79	10.9
4	54	7.5	73	10.1	64	8.9
5	105	14.6	159	22.1	136	18.9
6	79	10.9	100	13.9	65	9.1
7	107	14.9	88	12.2	79	10.9
8	134	18.6	85	11.8	79	10.9
9	44	6.1	27	3.8	15	2.1
10	81	11.3	36	5.0	38	5.3
m(SD)	6.2 (2.8)		5.5(2.3)		4.9(2.6)	

3.3. Impact of travel mode on road traffic annoyance

The multivariate logistic regression model (see Table 3) revealed that the main travel mode used was significantly associated with the annoyance related to road traffic noise ($p<0.1$) and to air pollution ($p=0.02$). Compared to motorized users, public transport users and active travel mode users were more likely to be highly annoyed by road-traffic noise and air pollution. Concerning traffic accidents, active mode users had a higher propensity to feel road-insecure (OR=1.3, 95% CI: 0.8; 2.1), although the association was not statistically significant.

3.4. Impact of other factors on road traffic annoyance

3.4.1 Road-risk perception

Respondents who considered they had a high risk of being injured in case of a road accident were very few, but were highly annoyed by noise and air pollution and had a higher feeling of road insecurity than those who considered they had only a slight risk (see Table 3).

Another factor was associated with the feeling of road insecurity: those who had a higher feeling of road insecurity were also very afraid of road-traffic accidents, and this influenced their choice of travel mode, compared to those who felt indifferent to this issue.

3.4.2 Sociodemographic and socioeconomic characteristics

Gender and living situation were both associated with air pollution and road-traffic noise annoyance. Men were more likely to be annoyed than women, and those who did not live alone were more likely to be highly annoyed by air pollution and by road-traffic noise than those living alone. Socioeconomic factors did not seem to play an important role.

Table 3: Summary of the explanatory factors for high annoyance according to type of nuisance (multivariate analyses)

		Noise annoyance				Air pollution annoyance				Feeling of road insecurity			
Variables	Total sample n=720 N	Highly annoyed n=259 N (%)	ORa	95% CI	P-value	Highly annoyed n=148 N (%)	ORa	95% CI	P-value	Highly annoyed n=132 N (%)	ORa	95% CI	P-value
Adjustment variables													
Area					ns*				ns				ns
Other than Greater Lyon	188	52 (27.7)	1			37 (19.7)	1			32 (17.0)	1		
Greater Lyon	532	207 (38.9)	0.7	0.5-1.1		111 (20.9)	1.1	0.7-1.7		100 (18.8)	1.1	0.7-1.7	
Gender					<0.01								
Female	336	100 (29.8)	1			45 (13.4)	1			57 (43.2)	1		
Male	384	159 (41.4)	1.6	1.2-2.2		103 (26.8)	2.5	1.7-3.7		75 (56.8)	1.0	0.7-1.5	
Age (years)					ns				<0.01				ns
18-24	76	21 (8.1)	1			10 (13.2)	1			11 (8.3)	1		
25-44	275	96 (37.1)	1.2	0.6-2.3		50 (18.2)	1.8	0.8-3.9		49 (37.1)	1.3	0.6-2.7	
45-64	232	85 (32.8)	1.5	0.7-3.0		64 (27.6)	2.9	1.3-6.4		43 (32.6)	1.4	0.6-2.9	
≥65	137	57 (22.0)	1.6	0.7-3.4		24 (17.5)	1.5	0.6-3.4		29 (21.9)	1.4	0.6-3.2	
Main travel mode					<0.01				0.02				0.11
Motorized	405	122 (30.1)	1			74 (18.3)	1			67 (16.5)	1		
Public transport	144	62 (43.1)	2.1	1.3-3.1		34 (23.6)	1.9	1.2-3.3		26 (18.1)	0.9	0.5-1.6	
Active	171	75 (43.9)	1.7	1.1-2.5		40 (23.4)	1.5	0.9-2.4		39 (22.8)	1.3	0.8-2.1	
Socioeconomic factors													
Educational level									0.02				
No school-leaving certificate or lower qualifications	252	-	-	-		68 (26.9)	1			-	-	-	
Full secondary education	140	-	-	-		28 (20.0)	0.7	0.4-1.1		-	-	-	
Bachelor's or Master's degree	207	-	-	-		30 (14.5)	0.4	0.2-0.7		-	-	-	
PhD or equivalent	121	-	-	-		22 (18.1)	0.5	0.3-0.9		-	-	-	
Number of cars													0.03
≥1	619	-	-	-		-	-	-		104 (16.8)	1		
None	101	-	-	-		-	-	-		28 (27.7)	1.7	0.9-2.9	
Living situation					0.01				0.02				
Living alone	170	51 (28.7)	1			25 (14.7)	1			-	-	-	
Not living alone	550	208 (37.8)	2.1	1.3-3.5		123 (22.4)	2.0	1.2-3.4		-	-	-	
Accommodation status					0.01								
Home owner	429	83 (31.2)	1			-	-	-		-	-	-	
Tenant	263	59 (43.0)	1.8	1.3-2.5		-	-	-		-	-	-	
Supported by another person	28	6 (42.9)	1.9	0.8-4.2		-	-	-		-	-	-	
Level of concern													0.03
Not worried	111	-	-	-		-	-	-		17 (15.3)	1		
Worried	536	-	-	-		-	-	-		92 (17.2)	1.2	0.7-2.1	
Very worried	73	-	-	-		-	-	-		23 (31.5)	2.4	1.2-4.9	
Subjective factors													
Road behavior compared to others					0.04								
Neither more nor less dangerous	293	90 (30.7)	1			-	-	-		-	-	-	
More cautious	407	158 (38.8)	1.4	1.0-1.9		-	-	-		-	-	-	
More dangerous	20	11 (55.0)	2.7	1.1-7.4		-	-	-		-	-	-	
Perceived risk of being injured in case of road accident					<0.01				<0.01				<0.01
Slight	695	242 (34.8)	1			136 (19.6)	1			121 (17.4)	1		
High	25	17 (68.0)	3.3	1.4-8.1		12 (48)	2.7	1.1-6.7		11 (44.0)	3.5	1.5-7.9	

*ns=non-significant

4. Discussion

This study set out to identify the determinants of each kind of noise or air pollution related annoyance and the feeling of road insecurity. Our findings revealed two main points: the use of active travel modes and self-assessed high risk of being injured in case of a road accident play an important role in these associations. The discussion revolves around these main results.

4.1. Interpretation of results

Active travelers and public transport users felt highly annoyed by air pollution. The simplest explanation could be that those users are objectively more exposed to air pollution, by spending time out of doors near roadways. Year-round average NO2 concentrations (mostly emitted by road transport) on roadways in the Rhône Département were measured at around 27µg/m3 on expressways and freeways [47]. Those concentrations are below the recommended safe threshold of 40 µg/m3 asdefined in the French Environment Act [48] and by the World Health Organization [49], which is not the case for fine particles (PM10, PM2.5): year-round average PM10 concentrations in the Rhône Département were measured at around 19 µg/m3 (near the upper recommended limit of ≤20 µg/m3) and year-round average PM2.5 concentrations at around 13 µg/m3 (above the upper recommended limit of <10 µg/m3) [49].

A study was conducted in Paris a few years ago, in various locations (city center, urban areas, suburbs, highway), according to exposure levels applicable to various modes of travel, measuring concentrations of six pollutants:

CO, FN, NO, NO2, benzene and toluene [50]. The study found that the highest levels of these pollutants occurred inside cars, compared to exposure for other modes of travel, perhaps due to the car's self-pollution by accumulation of pollutants inside the compartment [51]. The same was seen for every pollutant, in each location. Cyclists and bus users were exposed to intermediate levels of pollutants, whilst pedestrians and subway users were exposed to the lowest concentrations. Other international studies complete the picture with more explanations. A study conducted in South Texas found that the average total particle concentrations observed inside a school bus depended on engine age and window position [52]: with windows closed, the pollution inside was more likely to be caused by bus self-pollution while with the windows open most inside air pollutants came from the roadway environment outside. Kaur et al. found a tendency for lower levels of air pollution exposure for cyclists and pedestrians [53].

According to Hudda et al., these lower exposures could be explained by the distance between the main traffic flow and active mode users, so that cyclists and pedestrians were exposed to only a diluted form of the pollution to which car users were exposed [54]. Even though cyclists and pedestrians both had lower levels of exposure, this was especially true for pedestrians and less true for cyclists, reflecting the fact that cyclists were frequently much closer to heavy traffic than the pedestrians were [55]. Cyclists differ from other users by another factor: in their effort to travel quickly, cyclists have greater lung ventilation than any other road users. For instance, cyclists breathed at a volumetric rate 4.3 times greater than car drivers [56]. Panis et al., in Belgium, demonstrated that inhaled concentrations of PM2.5 and PM10 (fine particles) per kilometer were significantly higher when cycling than driving [56]. Then even if cyclists are exposed to lower concentrations of pollutants than car drivers, because of their higher ventilation rate they are finally more exposed [57, 58].

The difference between the real level of exposure and the annoyance felt could also be explained by the notion of perceived risk. Maestracci et al. [59] and other authors [60] described a difference between perceived risk and the objective risk to which the person is exposed. They showed,,for instance, that the situation which motorcyclists considered to be the most frightening and liable to lead to a road accident was changing lanes, whereas this accounted for only 6.9% of actual accidents. Likewise, a comparison between the perception of robberies and crashes showed that robberies were perceived as a greater risk than crashes, whereas crashes lead to higher number of victims and severe injuries than robberies [60]. "The feeling of safety is facilitated by familiarity with the environment, but feelings of danger and vulnerability may be explained by a perception of supposed risk and a feeling of losing control of the environment", as Moser points out in another publication [61]. Consequently, people who feel they have no control over the situation are likely to experience a greater level of annoyance.

It is possible that active travel mode users are aware of road-traffic nuisances more than motorized vehicle users. It can then be supposed that, if they chose their kind of travel mode in order not to contribute to pollution (noise, air pollution), they may have a feeling of suffering unjustly, which could exacerbate their level of annoyance.

The degree of annoyance triggered by traffic noise depends firstly on noise level: the higher the level, the more annoyed people are and the greater the severity of perceived annoyance [62]. It depends also on other noise characteristics, such as duration and intermittency [63]. Beyond objective acoustic factors, feeling of annoyance depends on how the noise interferes with everyday life [64] and on an individual's sensitivity to noise [65, 66]. People frequently exposed to traffic noise develop strategies of adapting and coping with the problem [63]. The problem still remains, however, and subconscious physical reactions such as raised blood pressure and levels of annoyance due to chronic noise will not diminish unless the noise itself stops. This is the adaptation level theory defined by Brown [67]. Two reasons can explain why cyclists, pedestrians and public transport users feel highly annoyed by noise: either they are exposed to high levels of noise because they are outside, whereas motor vehicle users are either inside a car or have the noise muffled by their helmet; or they develop higher sensitivity to noise over time. Our findings are not very surprising and may seem trivial to some extent, but they deserve scientific interpretation.

Furthermore, Kahneman and Tversky explain that the recollection of an event is influenced by its frequency or probability [68]. Since traffic accidents are rare events, the risk for any one individual to be involved in an accident is quite low. In the present study, travel mode was not associated with feeling of road insecurity, maybe because each user feels sufficiently safe whilst traveling, and consider the risk of having a road accident insignificant.

According to Slovic, risk perception can be influenced by how the person imagines and/or memorizes the risk (here, the nuisance) [69], which may bias their perception and hence their annoyance. Likewise, according to Moser[70], sensations, memories and feelings from our past, like from our present, are bound up with experiences, which in turn are bound up with the places around which our lives developed; the environment carries meanings that are an integral part of cognitive functioning. The subject's relationship with their environment is thus determined by their past. Having sustained injury in a road-accident can cause a heightened awareness of there being some risk of being injured again, perhaps resulting in increased sensitivity to other environmental exposures, such as air pollution or noise. Likewise, a study [71] showed that the higher air pollution levels people are exposed to, the more likely they are to be annoyed by road traffic noise, and vice versa. This could explain why, in the present study, people who estimated that there was a high probability of being injured in a road-accident were more likely to be highly annoyed by air pollution, road-traffic noise and the feeling of road insecurity.

Levels of annoyance expressed by different individuals are hard to compare due to differences in current and prior experiences and the individual's sensitivity and the representation of the risk (here, nuisance).

4.2. Study strengths and limitations

The major strength of this study was to investigate perceived annoyance for three different nuisances. We focused on these three nuisances, which are usually studied separately, since they all have road transport as a common source. Whichever the nuisance studied, annoyance was evaluated using the same 10-point scale and each kind of annoyance was correlated to the same explanatory factors (socioeconomic, sociodemographic and related to daily mobility), making results comparable between the three. Analog 11-point scale (from 0 to 10) has become common since the 1980s to evaluate subjective feelings such as pain or other psychological feelings. Numerous studies have confirmed the sensitivity and the validity of these scales [72-74]. They are self-report scales, which measure the intensity of the sensory component, with a good reproducibility from day to day. This tool is very simple to use for epidemiological purposes, and it can doubtless be used for other types of subjective feelings such as annoyance, as in the present study, so that subjects evaluate annoyance, whatever the nuisance, with the same reproducibility and the annoyance caused by each nuisance may appropriately be compared when measured by an analog scale.

Initially, at the beginning of the study, the objective was to build a cumulative indicator of annoyance if the same factors appeared to be associated with all three types of annoyance, which would be very useful for further research. However, the determinants turned out not to be the same, suggesting that the populations annoyed by each nuisance are different.

Moreover, the lack of interaction and confounding effects between the independent variables included in each model suggests that each one impacts annoyance independently.

However, further limitations must be noted. The questionnaire lacked items about the reason why each individual had chosen their main travel mode. Some of the possible factors (financial, distance, ecological reason, nuisances, etc.) may have causal effects on the individual's sensitivity to the nuisances considered, inducing a significant causal bias. It would have been interesting to have some information about personal sensitivity unrelated to road traffic, such as fear of disease, nuclear disaster, war, etc., to compare with sensitivity to road traffic nuisances. The same applies to sensitivity to baseline or peak levels of pollution.

Furthermore, pedestrians and cyclists were included in a single category: active travel modes. This is debatable, and it would be interesting to study pedestrians and cyclists separately. Additional data, such as the time of day, duration and frequency of maximal annoyance could have made an interesting contribution to our analyses. Another limitation was small sample size, resulting in a lack of power for the analysis of certain characteristics. While the sample was representative of households in terms of place of residence, the study subjects were slightly less often young and slightly more often male than in the Rhône population as a whole, which may have introduced a bias in the results; this was taken into account by adjusting the analyses on gender, age and area.

Concerning the geographic area, it might be interesting to distinguish the urban area from the rural and peri- urban area. Additionally, one of the issues when studying the road- traffic related environment is the choice of perspective from which the respondents are supposed to answer the questions. We do not know if the respondents answered the questions in terms of the one specific travel mode that they reported as being their main mode, or which traffic-related experiences they were thinking of in estimating the annoyance they felt. Likewise, we had no guarantee that the interviewees kept in mind the fact that questions about, for instance, noise were meant to specifically concern road traffic and no other sources, which again may have introduced bias.

4.3. Implications

In spite of these limitations, the results presented in this paper are useful to better understand road-traffic related annoyance, which is a complex notion. Moreover, the study points to some keys for future research in this domain: travel mode should be taken into account when studying the relation between road-traffic annoyance and its determinants or the feeling of road insecurity and its determinants. Analog scales are an easy tool to evaluate annoyance related to several nuisances, and should be used in epidemiological studies on this topic.

The magnitude of road traffic nuisances is greatly affected by motorized transport, which mainly comprises cars. On the one hand, policy makers need to increase user awareness, and especially for car users. On the other hand, as active travel mode and public transport users feel the most annoyed about road-traffic nuisances, perhaps the space allocated for these travel modes ought to be better protected in order to continue to encourage these practices, especially if these travel modes are chosen for environmental reasons. Pro-cycling and pro-walking policies already in place in the Netherlands, Denmark and Germany [12] are good examples to follow.

The solution is certainly to create a "bicycle and pedestrian friendly" environment. To start with, it must be ensured that users of each mode will be respected by and get along with the others. Coordinated multifaceted implementation is needed, as in the Netherlands, Denmark and Germany in their promotion of active modes. Bicycle parking, multi-mode integration (bicycle with public transport for example), cycling facilities on roads and intersections, traffic education for pedestrians, cyclists and motor-vehicle users and promotion of hybrid vehicles are all key ingredients in increasing the success of active travel modes. This in turn will diminish the nuisances due to transport.

The literature [12, 44] tends to agree that compact and mixed-use urban spaces contribute to decreasing dependency on car and increase rates of walking and cycling, which is a key to sustainable development.

Finally, public decision makers must continue the efforts being made, but need to better promote cohabitation between different modes of travel, and specifically promote and support active travel modes to help people accept this choice.

5. Conclusion

The present study sought to identify the determinants (sociodemographic, socioeconomic, and related to daily mobility) of annoyance withy noise and air pollution annoyance and the feeling of road insecurity. The main finding was that active travel and public transport users were more strongly annoyed by traffic air pollution and road-traffic noise than motor- vehicle users. These results are very interesting, because annoyance and feeling of insecurity can hinder the practice of active mobility in the general population, which is not really helpful for ecology. However, active travel mode users specifically contribute to improving air quality, alleviate traffic congestion and minimize the risk of road accidents, as well as improving their own health. Thus, in a context in which active travel modes and public transport are being promoted in most European countries, active travelers should be protected from this kind of annoyance by proper land-use planning, taking account of all these nuisances, and particularly the risk of accidents.

6. References

1. Ait-Mlouk A, Gharnati F and Agouti T (2017) An improved approach for association rule mining using a multi-criteria decision support system: a case study in road safety. European Transport Research Review 9(3):40
2. Beaumais O and Chiroleu-Assouline M (2001) Économie de l'environnement. Édition Bréal, 240 p
3. Commission Européenne (2017) Statistiques de la sécurité routière pour 2016: que révèlent les chiffres ? Fiche d'information
4. Jarosinska D, Héroux ME et al (2018) Development of the WHO Environmental Noise Guidelines for the European Region: An Introduction. Int J Environ Res Public Health 15(4):813
5. European Environment Agency (2017) Air quality in Europe - 2017. Report n°13/2017
6. Lauper E et al (2015) Explaining Car Drivers' Intention to Prevent Road-Traffic Noise. Environment and Behavior 48(6):826-853.
7. Karner A, Hondula DM, Vanos JK (2015) Heat exposure during non-motorized travel: Implications for transportation policy under climate change. Journal of Transport & Health 2(4):451-459
8. Woodcock J, et al (2009) Public health benefits of strategies to reduce greenhouse-gas emissions: urban land transport. The Lancet 374(9705): 1930-1943
9. Litman T (2013) Transportation and Public Health. Annual Review of Public Health 34(1):217-233
10. American Public Health Association (2012) Promoting Active Transportation: An Opportunity for Public Health
11. Shephard RJ (2008) Is Active Commuting the Answer to Population Health? Sports Medicine 38(9):751-758
12. Pucher J, Buehler R (2008) Making Cycling Irresistible: Lessons from the Netherlands, Denmark, and Germany. Transport Reviews 28(4)
13. Reynolds CCO, et al (2009) The impact of transportation infrastructure on bicycling injuries and crashes: a review of the literature. Environmental Health 8:47
14. Norwood P, et al (2014) Active travel intervention and physical activity behaviour: An evaluation. Social Science & Medicine 113(Supplement C):50-58
15. Mindell JS (2015) Active travel is (generally) good for health, the environment and the economy. Journal of Transport & Health 2(4):447-448
16. Sallis JF, et al (2004) Active transportation and physical activity: opportunities for collaboration on transportation and public health research. Transportation Research Part A: Policy and Practice 38(4):249-268
17. Maizlish N, et al (2012) Health Co-Benefits and Transportation-Related Reductions in Greenhouse Gas Emissions in the Bay Area. California Department of Public Health.
18. De Hartog JJ, et al (2010) Do the Health Benefits of Cycling Outweigh the Risks? Environmental Health Perspectives 118(8):1109-1116
19. Jacobsen PL (2003) Safety in numbers: more walkers and bicyclists, safer walking and bicycling. Injury Prevention 9(3):205-209
20. Morabia A, et al (2010) Potential Health Impact of Switching From Car to Public Transportation When Commuting to Work. American Journal of Public Health 100(12):2388-2391
21. World Health Organization (2016) Physical Activity and Adults. Recommended levels of physical activity for adults aged 18 - 64 years. Global Strategy on Diet, Physical Activity and Health
22. Moser G (2003) Environmental psychology for the new millennium: towards an integration of cultural and temporal dynamics. Encyclopaedia of Life Support Systems III

23. Moser G and Uzzell D (2003) Environmental psychology. Comprehensive Handbook of Psychology. Personality and Social psychology. Édition John Wiley & Sons
24. Moser G and Robin M (2006) Environmental annoyances: an urban-specific threat to quality of life? Revue Européenne de Psychologie Appliquée/European Review of Applied Psychology 56(1):35-41
25. Börjesson M (2012) Valuing perceived insecurity associated with use of and access to public transport. Transport Policy 22:1-10
26. Guski R, Felscher-Suhr U, and Schuemer R (1999) The concept of noise annoyance: how international experts see it. Journal of Sound and Vibration 223(4):513-527
27. Michaud D, Keith S, McMurchy D (2005) Noise annoyance in Canada. Noise & Health 7(27): 39-47
28. Murphy E, King EA, Rice HJ (2009) Estimating human exposure to transport noise in central Dublin, Ireland. Environment International 35(2):298-302
29. Stenlund T, et al (2009) Annoyance and health symptoms and their influencing factors: A population-based air pollution intervention study. Public Health 123(4): 339-345
30. Sucker K, Both R, Winneke G (2001) Adverse effects of environmental odours: reviewing studies on annoyance responses and symptom reporting. Water Science and Technology 44(9):43-51
31. Lindvall T, Radford EP (1973) Measurement of annoyance due to exposure to environmental factors: The fourth Karolinska institute symposium on environmental health. Environ Res, 6(1):1-36
32. Oiamo TH, Luginaah IN, Baxter J (2015) Cumulative effects of noise and odour annoyances on environmental and health related quality of life. Social Science & Medicine 146:191-203
33. Den Boer LC, Schroten A (2007) Traffic noise reduction in Europe. Health effects, social costs, and technical and policy options to reduce road and rail traffic noise. Committed to the Environement Delft, Holland. p 70
34. Babisch W, et al (2010) Noise Annoyance As Reported by 8- to 14-Year-Old Children. Environment and Behavior 44(1):68-86
35. Alimohammadi I, et al (2010) Factors affecting road traffic noise annoyance whilte-collar employees working in Teheran, Iran. J Environ Sci Engg 7:25-34
36. Meline J, et al (2013) Transportation noise and annoyance related to road traffic in the French RECORD study. Int J Health Geogr 12:44
37. Abo-Qudais S, and Abu-Qdais H (2005) Perceptions and attitudes of individuals exposed to traffic noise in working places. Building and Environment 40(6):778-787
38. Kharazi P (2001) The Impact of Noise Pollution on Job-Related Exhaustion of an Oil Refinery in Tehran and Managerial Solutions to Reduce This Impact, in Environmental Studies. Islamic Azad University: Iran
39. Havard S, et al (2011) Social inequalities in residential exposure to road traffic noise: an environmental justice analysis based on the RECORD Cohort Study. Occup Environ Med 68(5):366-74
40. Grange D, Chatignoux I, Grémy I (2010) Perceptions et comportements face au bruit dans les zones urbanisées: l’exemple de l’Île-de-France. Santé Publique 2010/5-22:505-516
41. Kohlhuber M, Weiland SK, Bolte G (2006) Social inequality in perceived environmental exposures in relation to housing conditions in Germany. Environ Res 101(2):246-55
42. Wahl C, Svensson Å, Hydén C (2012) The link between traffic-related occurrence and annoyance. IATSS Research 35(2):111-119
43. Intelligent Energy-Europe (2012) European Platform On Mobility Managment Europe (EPOMM) [cited 2018 May 30]; Available from: https://ec.europea.eu/energy/ intelligent/projects/en/projects/epomm-plus
44. Armoogum J, et al (2010) La mobilité des Français. Panorama issu de l’enquête nationale transports et déplacements 1:228
45. Journal Officiel de la République Française (2011) Arrêté du 21 décembre 2011 modifiant l’arrêté du 22 juillet 2004 relatif aux indices de la qualité de l’air
46. Agence d’Urbanisme aire métropolitaine lyonnaise (UrbaLyon) (2016) Enquête déplacements 2015 de l’aire métropolitaine lyonnaise. Résultats sur le Scot de l’agglomération lyonnaise
47. Les critères nationaux de la qualité de l’air 2016 [cited 2016 May 10]; Available from: http://www.airparif.asso.fr/ reglementation/normes-francaises
48. Code de l’environnement (2010): Surveillance de la qualité de l’air ambiant. Legifrance. Section 1
49. ATMO Région Auvergne - Rhône - Alpes (2016) Bilan de qualité de l’air en 2016
50. Coursimault A, et al (1998) Evaluation de l’exposition des citadins aux polluants d’origine automobile au cours de leurs déplacements dans l’agglomération parisienne. Laboratoire Central de la Préfecture de Police et Laboratoire d’Hygiène de la Ville de Paris. p. 7
51. Rank J, Folke J, Jespersen PH (2001) Differences in cyclists and car drivers exposure to air pollution from traffic in the city of Copenhagen. Science of The Total Environment 279(1): 131-136
52. Zhang Q, Zhu Y (2010) Measurements of ultrafine particles and other vehicular pollutants inside school buses in South Texas. Atmospheric Environment 44(2):253-261
53. Kaur S, Nieuwenhuijsen MJ, Colvile RN (2007) Fine particulate matter and carbon monoxide exposure concentrations in urban street transport microenvironments. Atmospheric Environment 41(23):4781-4810

54. Hudda N, et al (2011) Vehicle and Driving Characteristics That Influence In-Cabin Particle Number Concentrations. Environmental Science & Technology 45(20):8691-8697
55. Strauss J, et al (2012) Investigating the link between cyclist volumes and air pollution along bicycle facilities in a dense urban core. Transportation Research Part D: Transport and Environment 17(8):619-625
56. Panis IL, et al (2010) Exposure to particulate matter in traffic: A comparison of cyclists and car passengers. Atmospheric Environment 44(19):2263-2270
57. De Nazelle A, Bode O, Orjuela JP (2017) Comparison of air pollution exposures in active vs. passive travel modes in European cities: A quantitative review. Environ Int 2017, 99:151-160
58. Ramos CA, Wolterbeek HT, Almeida SM (2016) Air pollutant exposure and inhaled dose during urban commuting: a comparison between cycling and motorized modes. Air Quality, Atmosphere & Health 9(8): 867-879
59. Maestracci M, et al (2012) Powered two-wheelers road accidents and their risk perception in dense urban areas: Case of Paris. Accident Analysis & Prevention 49(0): 114-123
60. Vilela da Silva LO, Braga MDC (2017) Violent events on the road: Risk perception of traffic-related and non traffic- related situations. Accident Analysis & Prevention
61. Moser C (1998) The Asset Vulnerability Framework: Reassessing Urban Poverty Reduction Strategies. World Development 26(1):1-19
62. Van Kempen EEMM, Staatsen BAM, Van Kamp I (2005) Selection and evaluation of exposure-effect relationships for health impact assessment in the field of noise and health The Dutch National Institute for Public Health and the Environment (RIVM) Netherlands
63. London Health Commission (2003) Noise and Health: making the link
64. Stansfeld SA, Matheson MP (2003) Noise pollution: non-auditory effects on health. British Medical Bulletin. 68(1):243-257
65. Ouis D (2002) Annoyance caused by exposure to road traffic noise: An update. Noise & Health 4(15):69-79
66. 66. Kruize H, Bouwman AA (2004) Environmental (in)equity in the Netherlands. A Case Study on the Distribution of Environmental Quality in the Rijnmond region The Dutch National Institute for Public Health and the Environment (RIVM)
67. Brown AL, Hall A, and Kyle-Little J (1985) Response to a reduction in traffic noise exposure. Journal of Sound and Vibration 98(2):235-246
68. Kahneman D, Tversky A (1979) Prospect Theory: An Analysis of Decision under Risk. Econometrica 47(2): 263-291
69. Slovic P (1987) Perception of risk. Science. 236(4799): 280-5
70. Moser G (2009) Psychologie environnementale. Les relations homme-environnement, Bruxelles.Editor Boeck. Développement durable et territoires. p. 298
71. Klæboe R, et al (2000) Oslo traffic study – part 1: an integrated approach to assess the combined effects of noise and air pollution on annoyance. Atmospheric Environment 34(27): 4727-4736
72. Jensen MP, Karoly P, Braver S (1986) The measurement of clinical pain intensity: a comparison of six methods. Pain 27(1):117-126
73. Maxwell C (1978) Sensitivity and accuracy of the visual analogue scale: a psycho-physical classroom experiment. British Journal of Clinical Pharmacology 6(1):15-24
74. Philip B (1990) Parametric statistics for evaluation of the visual analog scale. Anesth Analg 71(6):710
75. Briggs D, Abellan J, Fecht D: Environmental inequity in England: Small area associations between socio-economic status and environmental pollution. Social Science & Medicine 2008, 67(10):1612-1629.
76. Chaix B, Gustafsson S, Jerrett M, Kristersson H, Lithman T, Boalt A, Merlo J: Children's exposure to nitrogen dioxide in Sweden: investigating environmental injustice in an egalitarian country. Journal of epidemiology and community health 2006, 60(3):234-241.
77. Mahdjoub S., Hours M., Baumstark L., Haddak M.M.. Active travel mode users: the least polluting, and the most annoyed by noise, air pollution and road insecurity?. RTS - Recherche Transports Sécurité, IFSTTAR, 2018, 2018, 13p. ⟨10.25578/RTS_ISSN1951-6614_2018-04⟩. ⟨hal-01899822⟩
78. Tonne C, Beevers S, Armstrong B, Kelly F, Wilkinson P: Air pollution and mortality benefits of the London Congestion Charge: spatial and socioeconomic inequalities. Occup Environ Med 2008, 65(9):620-627
79. Van Kamp I, Davies H: Noise and health in vulnerable groups: a review. Noise & health 2013, 15(64):153-159