Bibliographical reference

Noise Annoyance Due To Urban Road Traffic with Powered-Two-Wheelers: Quiet Periods, Order and Number of Vehicles, Laure-Anne Gille, Catherine Marquis-Favre and Achim Klein, Acta Acustica **vol. 102** (Number 3), 2016, pp. 474-487

DOI

https://doi.org/10.3813/AAA.918966

Acta Acustica united with Acustica
Vol. 102 (2016) 474 – 487

DOI 10.3813/AAA.918966

Noise Annoyance Due To Urban Road Traffic with Powered-Two-Wheelers: Quiet Periods, Order and Number of Vehicles

Laure-Anne Gille[1,2], Catherine Marquis-Favre[2], Achim Klein[2]
[1] CEREMA, Direction Territoriale Île-de-France, 21-23 rue Miollis, 75732 Paris Cedex 15, France.
[2] Univ Lyon, ENTPE, Laboratoire Génie Civil et Bâtiment, 3 rue Maurice Audin, 69518 Vaulx-en-Velin, France.
catherine.marquisfavre@entpe.fr

Summary
This paper aims to assess the influence of different acoustical characteristics of urban road traffic including powered-two-wheelers on noise annoyance. The factors studied under laboratory conditions are the number and order of the different urban road traffic noise events, and the position and duration of quiet periods between noise events as well as their cumulative duration. Several listening experiments were carried out. The urban road traffic noise sequences were presented to a panel of participants for short-term noise annoyance assessment.

First, the presence of quiet periods was found to reduce noise annoyance but there is no effect of the duration and the position of quiet periods on noise annoyance due to urban road traffic noise. The order of the noise events within the sequence was not found to impact noise annoyance. It seems that annoyance due to urban road traffic noise is determined by the presence of a particularly annoying noise event. The findings of this study will contribute to the understanding of the influence of the studied acoustical factors on noise annoyance due to urban road traffic. Furthermore, the gained knowledge may be used to develop models for the assessment of noise annoyance due to urban road traffic.

PACS no. 43.50.Qp, 43.50.Rq, 54.50.Lj

1. Introduction

The European directive 2002/49/EC [1] requires that cities over 100,000 inhabitants produce strategic noise maps for environmental noise sources, such as industrial sites and road, rail and air traffic. The index L_{den} – the day-evening-night level [1] – is used for the construction of noise maps. As several annoyance models are based on this index [2], noise maps may be interpreted as annoyance maps. For road traffic noise maps, two main drawbacks can be mentioned. First, powered-two-wheelers (PTWs), such as motorcycles or scooters, are considered as light vehicles in the construction of the current noise maps. Whereas they are often cited among the most annoying noise source in survey (*e.g.* [3, 4]), they are little studied in literature dealing with annoyance due to urban road traffic. Furthermore, their use over the past 10 years has increased considerably (*e.g.* [5]). Concerning the second drawback of road traffic noise maps, it is well known that acoustical energy-based indices, such as the L_{den}, explain only a small part of variance in noise annoyance (*e.g.* [6]). This index takes into account the effect of only one acoustical factor – the noise level – whereas different acoustical factors are known to influence noise annoyance responses [7, 8]. Several studies (*e.g.* [9]) showed the influence of spectral and temporal features of road traffic noise on annoyance. Few studies investigated the influence of these features on annoyance due to urban road traffic noise including PTWs. For example, Vos [10] found a better correlation between noise annoyance and several psychoacoustical indices, such as fluctuation strength, roughness and loudness, than between noise annoyance and A-weighted sound pressure level. Paviotti and Vogiatzis [11] identified maximum sound pressure level and roughness indices as characteristics of the noise signature of the PTWs.

Concerning road traffic noise with heavy vehicles, Björkman [12] demonstrated that an increase in the number of heavy vehicles leads to an increase in the extent of *in situ* noise annoyance. The author identified a breakpoint, after which a further increase in the number of heavy vehicles does not induce a further increase in annoyance. It will be interesting to investigate if a breakpoint can be found when the number of urban road vehicle pass-by noises with PTWs is increased. For identical numbers of vehicles, Kaczmarek and Preis [9] studied different time structures of the traffic flow. They showed that noise annoyance is well correlated with mean loudness.

Loudness is actually well known to be a basis of noise annoyance [13]. This was highlighted in studies dealing

---

Received 25 September 2015,
accepted 24 March 2016.

with annoyance due to road traffic noise [9, 14, 10]. Studies on loudness assessment [15, 16] have demonstrated that sounds with different time-intensity profiles lead to different loudness ratings and that the time-intensity profile has an effect on temporal weights for loudness [17]. These differences in the temporal structure might contribute to urban road traffic noise annoyance. As the different noise events of urban road traffic noise have different slopes of loudness versus time, the order of the different noise events within the urban road traffic noise sequence may have an influence on annoyance. If such effect exists, it would be of great importance to take it into account for the construction of road traffic noise sequences for laboratory studies.

To enhance noise annoyance models in future studies, it is necessary to gain understanding of the influence of the different acoustical factors on annoyance due to urban road traffic noise, when PTWs are considered in presence of other urban road vehicles such as buses, heavy and light vehicles.

The potential influence of different acoustical factors will be investigated by considering urban road traffic noise in cities comprising PTWs, buses, heavy and light vehicles, under laboratory conditions. First, noise annoyance due to single urban road vehicle pass-by noises is assessed in laboratory conditions. Two pilot experiments are conducted in order to gather noise annoyance ratings for each single urban road vehicle pass-by noise. In experiment A, single urban pass-by noises are equalized to the same A-weighted equivalent sound pressure level (L_{Aeq}), whereas in experiment B, they exhibit different L_{Aeq}. The results from both experiments will be useful to select single urban pass-by noises, considering their annoyance ratings, for the construction of urban road traffic sequences in the main experiments I and II of this work. These main experiments aim to investigate the influence of acoustical factors on annoyance due to urban road traffic noise. In experiment I, the studied factors are: the position and duration of quiet periods, their cumulative durations and the number and order of urban road traffic pass-by noises (also called noise events). All types of urban road traffic vehicles at constant speed (PTWs, buses, heavy and light vehicles) will be used and equalized in L_{Aeq}, in order to assess a potential source effect without influence of the noise level. Experiment II will focus on fewer factors. First, the effect of the number of noise events within the sequence will be studied. Therefore, all types of urban road traffic vehicles (PTWs, buses, heavy and light vehicles) in different driving conditions (acceleration, deceleration and constant speed) will be included. Then, the order of noise events will be studied by considering sequences with different urban vehicles at constant speed. All the pass-by noises used in experiment II will exhibit differences in equivalent sound pressure levels, according to *in situ* measurements.

This paper is organized as follows: the pilot experiments A and B considering single urban road vehicle pass-by noises are presented in section 2. Section 3 presents the results of the pilot experiments. Sections 4 and 5 present the main experiments I and II, respectively, and their results. A discussion is given in section 6.

2. Pilot experiments: Noise annoyance due to single urban road traffic events

Two pilot experiments A and B were carried out, considering the single urban road traffic noise events, in order to obtain the annoyance rating of each noise event. These ratings will be used in this work to select the single events for the construction of the urban road traffic sequences in the main experiments. This will contribute to the understanding of the potential influence of each noise event on the judgment of the annoyance due to a road traffic.[1]

2.1. Stimuli of experiments A and B

The stimuli are single urban road vehicle noise events stemming from the perceptual typology of Morel *et al.* [14]. They were recorded in Lyon (France) and its suburbs using the ORTF technique (two cardioïd microphones spread to a 110° angle and spaced 17 cm apart) in accordance with French standards (*cf.* [14] for further details). This recording technique used for stereophonic sound reproduction in laboratory is known for its good representation, readability, plausibility and overall reproduction quality for fixed and moving noise sources [19].

The typology of Morel *et al.* [14] was composed of 57 pass-by noises and structured according to the type of urban road vehicles (PTWs, buses, heavy and light vehicles) and their driving conditions (acceleration, deceleration, constant speed), resulting in 7 perceptual and cognitive categories, (category 1: PTWs at constant speed; category 2: PTWs in acceleration; category 3: buses, heavy and light vehicles at constant speed; category 4: PTWs in deceleration ; category 5: buses, heavy and light vehicles in deceleration; category 6: light vehicles in acceleration; category 7: buses and heavy vehicles in acceleration). To limit the number of stimuli for experiments A and B, 33 pass-by noises were selected from the perceptual categories based on the following criteria: (i) for categories consisting of 4 pass-by noises, all the pass-by noises were chosen; (ii) regarding pass-by noises from categories comprising a larger number of stimuli, a maximum of five pass-by noises per category was selected according to their note of category representation measured by Morel *et al.* [14]. The pass-by noises are denoted xyz_N as follows: x for "vehicle type" (b = bus; d = PTW; p = heavy vehicle; v = light vehicle), y for "driving condition" (a = acceleration; d = deceleration; f = constant speed), z for "road morphology" (o = open street; u = U-shaped street) and N an arbitrary number to differentiate stimuli.

---

[1] Furthermore, the ratings obtained from these 2 pilot experiments were used in another work (*cf.* [18]) to physically and perceptually characterize the different noise events, in order to get an annoyance model for single road events.

Table I. Experiment B – Level differences (ΔL) between the average sound pressure levels measured *in situ* for the light vehicles at constant speed (vfo) and the average sound pressure levels measured *in situ* for other vehicles in different driving conditions (*cf.* [29]).

Vehicle type	Driving condition	Acronym	ΔL [dB(A)]
Bus	acceleration	bao	+9.1
Bus	deceleration	bdo	+4.2
Bus	constant speed	bfo	+7.5
PTW	acceleration	dao	+7.2
PTW	deceleration	ddo	+4.0
PTW	constant speed	dfo	+5.3
Heavy vehicle	acceleration	pdo	+9.1
Heavy vehicle	deceleration	pao	+4.2
Heavy vehicle	constant speed	pfo	+7.3
Light vehicle	acceleration	vao	-2.4
Light vehicle	deceleration	vdo	-4.5

The stimulus duration ranged from approximately 3 to 9 s. Previous studies demonstrated that the stimulus duration has a limited or no influence on short-term noise annoyance. Paulsen [20] showed that stimulus duration of highway road traffic noises ranging from 1 to 80 s had a very limited influence on annoyance judgments. For single urban road traffic pass-by noises, Morel *et al.* [21] found that stimulus duration between 3 and 9 s was not a criterion to formulate annoyance judgments. The same conclusion was drawn by Trollé *et al.* [22] for single tramway pass-by noises with durations ranging from 8 to 25.5 s.

In experiment A, the 33 single pass-by noises were equalized to the same A-weighted equivalent sound pressure level (L_{Aeq}) of 60 dB(A). In experiment B, the same 33 single pass-by noises were employed, with sound pressure level differences (ΔL) according to *in situ* observations. The level differences (ΔL) correspond to differences between the average A-weighted equivalent sound pressure levels measured for the light vehicles at constant speed (vfo) and the average A-weighted equivalent sound pressure levels measured for other vehicles in different driving conditions (*cf.* Table I). Spectral and temporal features of the single pass-by noises were not modified by applying this ΔL.

The reference level for light vehicles at constant speed was set to 54 dB(A) in order to obtain a sound pressure level range acceptable for listeners. From this level, the level differences ΔL were applied to the left and right channels of each pass-by noise depending on the vehicle type and the driving condition. The resulting sound reproduction levels for the different pass-by noises of experiment B ranged from 49 dB(A) to 62.5 dB(A), at the position of the participants in the room.

For all experiments in this paper, no filter simulating facade transmission was applied to the stimuli as wall material and window types have an effect on auditory judgments [23] and the choice of one kind of facade might have been too limiting. Thus, the worst noise exposure is considered (*e.g.* [7]) such as being in private outdoor spaces.

2.2. Apparatus

The experiments took place in a quiet room with a background noise measured at 19 dB(A). The stimuli were reproduced employing a 2.1 audio reproduction system consisting of two active loudspeakers (Dynaudio Acoustics BM5A) and one active subwoofer (Dynaudio Acoustics BM9S). This kind of sound reproduction system enables good plausibility and overall reproduction of the stimuli recorded with the ORTF technique [19].

Concerning the positioning of listener and loudspeakers, the center of the interaural axis of the listener and the loudspeakers formed an equilateral triangle. This was in accordance with the recommendations given by Bech and Zacharov [24]. The loudspeakers were placed at a height of 1.20 m from the floor, and the subwoofer was placed on the floor between the loudspeakers. The user interface was programmed using MATLAB©.

2.3. Procedure

Experiments A and B were carried out in a same test. Participants were asked to imagine themselves at home while relaxing (*e.g.* reading, watching television, discussing, gardening or doing other common relaxing activities). This procedure has been used in previous works (*cf.* [22, 21]). Prior to each experiment, the participants were trained. The stimuli were presented one by one in random order.

After each stimulus, the participants were asked: "*During your relaxing activity, you hear this noise. Does this noise annoy you?*". The participants gave the ratings on a continuous scale ranging from "0" to "10", with 11 evenly spaced numerical labels and two verbal labels at both ends ("*not at all annoying*" and "*extremely annoying*").

2.4. Participants

The test was performed by 34 participants (17 male, 17 female) aged between 20 and 54 years (mean age = 32.5; standard deviation = 11.8). All participants declared normal hearing abilities and were paid for their participation. In order to evaluate a potential effect of the experiment order (experiment A followed by experiment B or the reverse), the panel of participants was divided into two equal groups. One group performed experiment A and then participated in experiment B. The second group carried out the two experiments in reverse order. Two-factor mixed-design ANOVAs (with one within-subject factor "Stimulus" and one between-subject factor "Order") were carried out on the annoyance responses obtained in experiment A and experiment B, respectively. A non-significant effect of the experiment order was observed for experiment A and experiment B (respectively [F(1,32) = 0.57; p = 0.45] and [F(1,32) = 2.15; p = 0.15]). Hence, the annoyance responses from the 34 participants were grouped together in order to analyze the responses respectively gathered in experiment A and experiment B.

3. Results

3.1. Experiment A: Analysis of inter-stimulus differences

A repeated measures ANOVA was carried out on the data with the factor "Stimulus". The results showed that the stimuli had a significant effect on the annoyance responses [F(32, 1056) = 15.47; $p < 0.001$; ϵ[2] = 0.468]. The proportion of variance explained by the factor "Stimulus" (measured using eta-squared, denoted as η^2) was equal to 31.9 %.

Figure 1 illustrates the mean annoyance rating obtained for each stimulus and the corresponding standard error indicated as vertical bars.

It can be seen that there are clear differences in mean annoyance ratings between the different urban road traffic pass-by noises equalized in L_{Aeq}. According to Tuckey's HSD post-hoc test, the least annoying urban pass-by noises are a light vehicle at constant speed (vfo_5), a light vehicle in acceleration (vao_3), a bus and a heavy vehicle at constant speed (bfu_3 and pfu_2). According to the post-hoc test, the most annoying urban pass-by noises are PTWs in acceleration (dao_2, dao_3), PTWs in deceleration (ddo_1, ddu_2) and heavy vehicles in deceleration (pdo_3, pdo_6).

To study the influence of the type of vehicle, the driving condition and the road morphology, the annoyance ratings given by participants were averaged over pass-by noises with characteristics corresponding to the 3 studied factors (type of vehicle, driving condition and road morphology). An ANOVA was conducted considering three within-subjects factors: "Source" (denoted S, with 3 levels: d, bp or v), "Driving Condition" (denoted DC, with 3 levels: f, a or d) and "Road Morphology"(denoted RM, with 2 levels: o or u). Table II sums up the results.

This analysis showed that the 2 main factors – S and DC – and all the interactions had a significant effect on the annoyance ratings. While the S and DC factors explained respectively 12 % and 16 % of the observed variance, each interaction explained a lesser extent of the variance (between 1 % up to 6 %). On the other hand, the main factor RM did not influence annoyance ratings. This result is in agreement with the observations of Morel *et al.* [14] in a categorization task: participants noticed if the vehicle was moving in an open street or in U-shaped street, but they did not base their judgments on this factor.

As can be seen on Figures 3 and 4, the three types of vehicles are significantly different, such as the three driving conditions. This was confirmed by Tuckey's HSD post-hoc tests. PTWs were judged significantly more annoying than the heavy vehicles, which were judged significantly more annoying than the light vehicles. Respectively, vehicles passing by at constant speed were judged significantly less annoying than accelerating vehicles, which were judged significantly less annoying than decelerating vehicles.

Table II. Experiment A – Results of the ANOVA considering S (Source), DC (Driving Condition) and RM (Road Morphology). SS: Sum of squares, dof: degrees of freedom, F: test statistics, p: p-value, ϵ: value of the dof Huynh-Feldt correction factor, η^2: measure of the magnitude of the experimental effect. *: $p < 0.05$.

	SS	dof	F	ϵ	η^2
S	129.35*	(2; 66)	43.45	0.94	0.12
DC	182.57*	(2; 66)	33.88	0.72	0.16
RM	0.29	(1; 33)	0.25	1.00	0.00
S x DC	15.1*	(4; 132)	4.19	1.00	0.01
S x RM	70.31*	(2; 66)	33.45	0.98	0.06
DC x RM	21.66*	(2; 66)	14.75	0.93	0.02
S x DC x RM	16.56*	(4; 132)	4.26	0.80	0.01

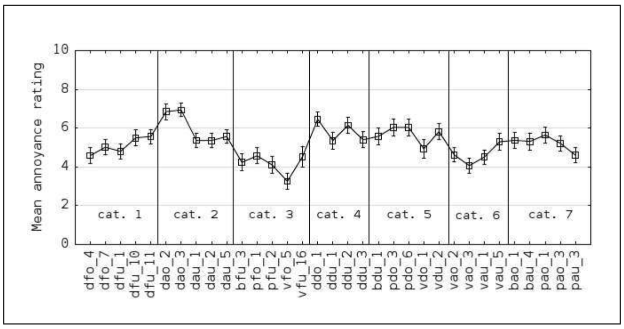

Figure 1. Experiment A – Mean annoyance rating for each pass-by noise equalized in A-weighted equivalent sound pressure level and the corresponding standard error (vertical bars). The perceptual categories from which the pass-by noises stem are reported (*cf.* Morel *et al.* [14]).

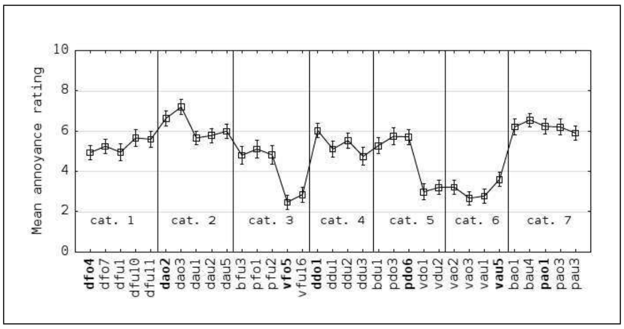

Figure 2. Experiment B – Mean annoyance ratings for the 33 pass-by noises and their corresponding standard error (vertical bars). Pass-by noises rated as the most representative of their category in the experiment of Morel *et al.* [14] are reported in bold characters.

3.2. Experiment B: Analysis of inter-stimulus differences

A repeated measures ANOVA was conducted on the annoyance ratings gathered for the non-equalized 33 stimuli. Differences between annoyance ratings for the stimuli are significantly different [F(32, 1056) = 43.056; $p < 0.001$; $\epsilon = 0.484$]. The proportion of variance explained by the factor "Stimulus" is equal to 56 %.

In Figure 2, there are clearer differences between mean annoyance ratings due to the different pass-by noises com-

---

[2] The Huynh-Feldt correction for the degrees of freedom (dof) [25].

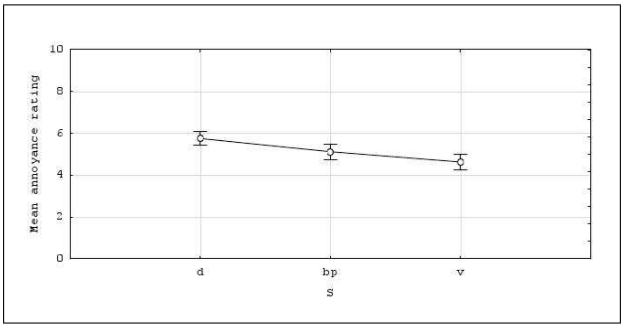

Figure 3. Experiment A – Mean annoyance rating as a function of the factor "Source" of the ANOVA and corresponding standard errors (vertical error-bars). d: "PTWs"; bp: "buses and heavy vehicles"; v: "light vehicles".

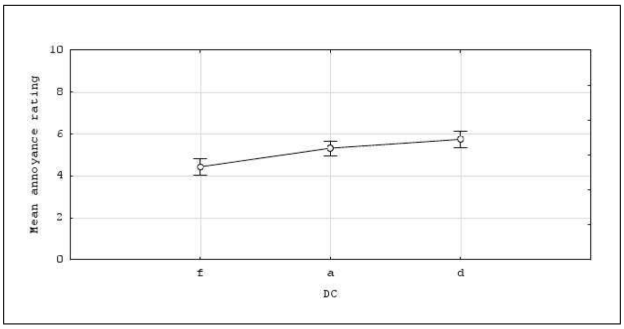

Figure 4. Experiment A – Mean annoyance rating as a function of the factor "Driving Condition" of the ANOVA and corresponding standard errors (vertical error-bars). f: "constant speed"; a: "acceleration"; d "deceleration".

pared to the mean annoyance responses obtained in experiment A. This can be explained by the sound pressure level differences applied to the different stimuli (*cf.* Table I). The light vehicles in different driving conditions are the least annoying pass-by noises and statistically differ in annoyance responses from the rest of the stimuli.

4. Experiment I: urban road traffic with single pass-by noises equalized in L_{Aeq}

For urban road traffic with different single vehicle pass-by noises (PTWs, buses, heavy and light vehicles), the influence of the following acoustical factors on noise annoyance will be investigated: the position and duration of quiet periods, their cumulative duration, the number and order of vehicle pass-by noises equalized in L_{Aeq} within the urban road traffic sequence.

For this first experiment, the different single pass-by noises (PTWs, buses, heavy and light vehicles) were equalized in L_{Aeq} in order to study the factors by limiting the effect of global loudness of each single noise event. Actually, sound stimuli equalized in sound pressure level (SPL) but with different time-intensity slopes get different global loudness evaluation [16, 26]. Furthermore, loudness appears to be an underlying basis of judged annoyance [13], confirmed by high correlation between loudness and annoyance [7, 27, 28, 29]. Thus, different slopes of loudness versus time related to different orders of the noise events within a sequence may impact annoyance. This effect will be studied.

Since urban road traffic with different types of vehicles is considered, the potential influence of the interaction between the investigated acoustical factors and the type of vehicle, later referred to as the "Source" factor is studied in detail.

4.1. Method

4.1.1. Stimuli

The noise sequences were composed of 2, 3 or 4 vehicle pass-by noises, separated by 0, 1 or 2 quiet period(s). During a quiet period, only the urban background noise (played for the whole duration of the noise sequence) can be heard. The urban background noise was recorded by Trollé *et al.* [22], early in the morning without distinguishable noise events in the street. The single urban road vehicle pass-by noises stemmed from experiment A. All the noises were recorded in Lyon (France) and its neighborhood using the same procedure and apparatus (*cf.* section 2.1). The sequences were constructed by combining different compositions of pass-by noises with different quiet period distributions.

The single urban road vehicle pass-by noises corresponded to vehicles at constant speed. Within a sequence, all the pass-by noises stemmed from the same perceptual category of Morel's typology [14] (category 1 for PTWs and category 3 for buses, heavy and light vehicles). No other driving condition (neither acceleration, nor deceleration) was considered since the short duration of the sequences does not allow to consider deceleration followed by acceleration of vehicles.

The compositions of pass-by noises studied within the different sequences were denoted as follows:

- Xd, X for "number of events" and d for "PTWs".
  - 2d: dfo_4+dfo_4;
  - 3d: dfo_4+dfo_7+dfu_1;
  - 4d: dfo_4+dfo_7+dfu_1+dfu_10.

  The selected PTWs were rated equally annoying in experiment A (*cf.* Figure 1; confirmed by a Tuckey's HSD test and Morel's results [21] showing no source effect within category 1 on annoyance ratings.)
- Xbp, X for "number of events" and bp for "buses and heavy vehicles".
  - 2bp: pfo_1+pfo_1;
  - 3bp: bfu_3+pfo_1+pfu_2;
  - 4bp: bfu_3+pfo_1+pfu_2+bfu_3.

  The selected pass-by noises were rated equally annoying in experiment A from a statistical point of view (*cf.* Figure 1).
- Xbpv, X for "number of events" and bpv for "buses, heavy and light vehicles".
  - 2bpv: vfo_5+vfo_5;
  - 3bpv: bfu_3+vfo_5+vfo_5;
  - 3bpv_bis: vfo_5+vfo_5+bfu_3;
  - 4bpv: bfu_3+pfo_1+vfo_5+vfo_5;

Table III. Experiment I – The sequences with their quiet period distribution (QPD). The letter "E" represents the pass-by noise and the letter "Q" represents a 3-second long quiet period. The quiet period distribution of each sequence is denoted Db, D for "Distribution" and b an arbitrary number to differentiate the sequences with different quiet period distributions.

Period number between events	QPD	2 events	3 events	4 events
2 periods	D1	E Q Q E	E Q Q E Q Q E	E Q Q E Q Q E Q Q E
1 period	D2	E Q E	E Q E Q E	E Q E Q E Q E
	D3	E Q E Q	E Q E Q E Q Q	E Q E Q E Q E Q Q Q
	D4	Q E Q E	Q Q E Q E Q E	Q Q Q E Q E Q E Q E
0 period	D5	E E	E E E	E E E E
	D6	E E Q Q	E E E Q Q Q Q	E E E E Q Q Q Q Q Q
	D7	Q Q E E	Q Q Q Q E E E	Q Q Q Q Q Q E E E E
	D8	Q E E		
	D9	Q E E Q		

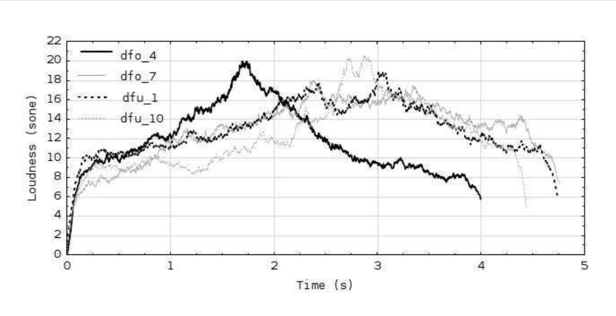

Figure 5. Experiment I – Loudness as a function of time for pass-by noises of category 1.

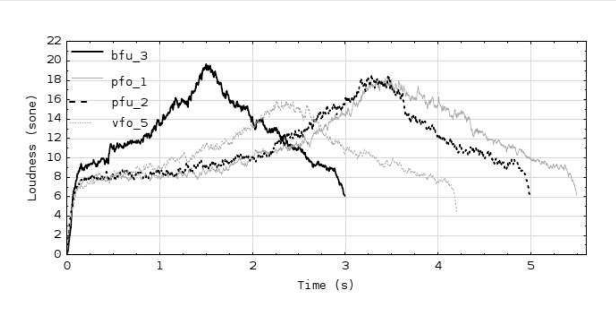

Figure 6. Experiment I – Loudness as a function of time for pass-by noises of category 3.

- 4bpv_bis: vfo_5+vfo_5+bfu_3+pfo_1.
  The pass-by noises composing the traffic of 3 or 4 events were rated differently in experiment A from a statistical point of view (*cf.* Figure 1). Thus, the corresponding sequences (3bpv versus 3bpv_bis and 4bpv versus 4bpv_bis) were studied in two conditions: in the first condition, the more annoying noise passes by before the less annoying one (3bpv and 4bpv) and in the second condition, in reverse order (3bpv_bis and 4bpv_bis).

The 2-event sequences were constructed in the aim of studying potential effects of quiet periods (position, duration, cumulative duration) and the dependency of this effect from vehicle types (PTWs, light vehicles, buses and heavy vehicles) without considering potential order effects. For 2-event sequences, the same pass-by noise was repeated twice.

Figures 5 and 6 illustrate the loudness of the pass-by noises as a function of time, measured at the position of the participant. The loudness values were determined using dBSonic software (01dB-Metravib). Zwicker's loudness calculation is based on DIN 45631 [30].

The pass-by noises were equalized to 64 dB(A) and the urban background noise to 50 dB(A). Consequently, the urban background noise was masked by the pass-by noises.

These different compositions of pass-by noises were then combined with different quiet period distributions to construct the noise sequences. A quiet period duration of 3 seconds was chosen as it corresponds to the recommendations provided by the French traffic code [31] regarding the minimal distance between vehicles to avoid collisions (at least 2 seconds). This duration is equal to the shortest pass-by noise used in this work. In addition, it corresponds to a quiet period duration of a high road traffic density. Furthermore, it is comprised in the interval of 0.5 to 5 seconds used by Kaczmarek and Preis [9] when studying road traffic noise. Table III presents the quiet period distribution (denoted as QPD in the following) used within the sequences. For each considered number of pass-by noises, the longest sequences, denoted as D1, contained 2 quiet periods between the pass-by noises. Shorter sequences (0 or 1 quiet period between the pass-by noises) were reproduced twice by extending their duration with quiet periods at the beginning or at the end, so that these sequences were of the same cumulative duration than the longest sequences. For example, the sequences D2 contained one quiet period between the noise events. These sequences were extended to be as long as the sequences D1, either with quiet periods at the end (sequences D3), or with quiet periods at the begining (sequences D4). These long sequences differed in terms of their QPDs.

Combining the different QPDs with the different compositions of pass-by noises (hereafter called "Source" and denoted S) leads to 83 sequences composed of the urban background noise and the pass-by noises (27 2-event sequences: 3 S × 9 QPDs; 28 3-event sequences: 4 S × 7 QPDs; 28 4-event sequences: 4 S × 7 QPDs). One sequence with the urban background noise alone was added to the experiment in order to test whether this background noise, which corresponds to the quiet period content of the other sequences, gets the lowest annoyance rating. Experiment I confirms this hypothesis.

Tables IV, V and VI present the duration and L_{Aeq} for each sequence.

4.1.2. Apparatus, procedure and participants

The sound reproduction system consisted of the same set-up as the one used for experiments A and B (*cf.* section 2.2). The procedure of experiment I is the same as the one used for experiments A and B (*cf.* section 2.3). Experiment I lasted approximately one hour.

Thirty participants took part in experiment I, 16 women and 14 men (mean age = 28; standard deviation = 11). All the participants declared normal hearing abilities. They were paid for their participation.

4.2. Results of the experiment I

In the following, the annoyance ratings obtained in experiment A for single vehicle pass-by noises will be called specific annoyance ratings, whereas the annoyance ratings obtained in experiment I for the road traffic noise sequences will be called total annoyance ratings. First, an ANOVA was conducted considering three within-subjects factors: "Number of Events" (denoted NE, with 3 levels: 2, 3 or 4 events), "Quiet Period Distribution" (denoted QPD, with 7 levels: D1 to D7) and "Source" (denoted S, with 3 levels: d, bp or bpv). The latter factor was introduced in the ANOVA in order to investigate the interaction between the type of noise source and the other factors. Table VII sums up the results.

This analysis showed that the 3 main factors – S, NE and QPD – and the S x NE and S x NE x QPD interactions had a significant effect on the annoyance ratings due to the road traffic sequences. While the S and NE factors explained respectively 20 % and 9 % of the observed variance, the QPD factor and the S x NE and S x NE x QPD interactions explained together 4 % of the variance.

4.2.1. Influence of the source

The post-hoc test performed on the S factor showed small but significant differences between the vehicle types. Figure 7 shows that the sequences with PTWs were judged more annoying than the ones with buses and heavy vehicles. The latter were judged more annoying than the sequences with buses, heavy and light vehicles. This result was in agreement with the trend observed in experiment A (*cf.* section 3.1): PTWs were among the most annoying pass-by noises whereas light vehicles were among the least annoying ones. It seems that the specific annoyance due to each single urban road vehicle influenced the total annoyance due to the sequences comprising this vehicle.

Table IV. Experiment I – Sequences with 2 events: duration and A-weighted equivalent sound pressure level. QPD: Quiet Period Distribution; 2d: 2 PTW; 2bp: 2 heavy vehicles; 2bpv: 2 light vehicles.

QPD	2d Time s	2d L_{Aeq} dB(A)	2bp Time s	2bp L_{Aeq} dB(A)	2bpv Time s	2bpv L_{Aeq} dB(A)
D1	14.0	62.3	17.0	63.0	14.4	61.8
D2	11.0	63.6	14.0	63.8	11.4	62.5
D3	14.0	62.2	17.0	63.0	14.4	61.8
D4	14.0	62.2	17.0	63.0	14.4	61.8
D5	8.0	64.6	11.0	64.8	8.4	64.0
D6	14.0	62.3	17.0	63.0	14.4	61.8
D7	14.0	62.2	17.0	63.0	14.4	61.7
D8	11.0	63.3	14.0	63.8	11.4	62.7
D9	14.0	62.2	17.0	63.0	14.4	61.8

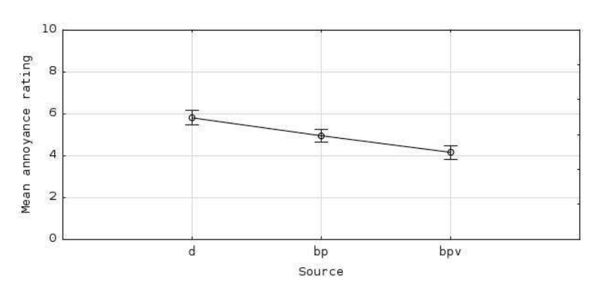

Figure 7. Experiment I – Mean annoyance rating as a function of the factor "Source" of the ANOVA and corresponding standard errors (vertical error-bars). d: "PTWs"; bp: "buses and heavy vehicles"; bpv: "buses, heavy and light vehicles".

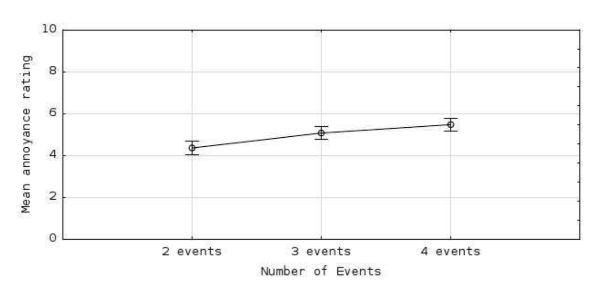

Figure 8. Experiment I – Mean annoyance rating as a function of the factor "Number of Events" of the ANOVA and corresponding standard errors (vertical error-bars).

4.2.2. Influence of the number of events

The post-hoc test performed on the NE factor showed that annoyance increased with this factor, with significant differences between each number of events (*cf.* Figure 8).

Table V. Experiment I – Sequences with 3 events: duration and A-weighted equivalent sound pressure level. QPD: Quiet Period Distribution; 3d: 3 PTW; 3bp: 3 buses and heavy vehicles; 3bpv and 3bpv_bis: buses, heavy and light vehicles in different orders.

	Noise sequences							
	3d		3bp		3bpv		3bpv_bis	
QPD	Time s	L_{Aeq} dB(A)	Time s	L_{Aeq} dB(A)	Time s	L_{Aeq} dB(A)	Time s	L_{Aeq} dB(A)
D1	25.5	62.6	25.5	62.3	23.4	61.6	23.4	61.6
D2	19.5	63.7	19.5	63.4	17.4	62.8	17.4	62.8
D3	25.5	62.6	25.5	62.3	23.4	61.6	23.4	61.6
D4	25.5	62.6	25.5	62.3	23.4	61.6	23.4	61.6
D5	13.5	65.3	13.5	65.0	11.4	65.0	11.4	64.5
D6	25.5	62.6	25.5	62.4	23.4	61.6	23.4	61.6
D7	25.5	62.6	25.5	62.3	23.4	61.6	23.4	61.5

Table VI. Experiment I – Sequences with 4 events: duration and A-weighted equivalent sound pressure level. QPD: Quiet Period Distribution; 4d: 4 PTW; 4bp: 4 buses and heavy vehicles; 4bpv and 4bpv_bis: buses, heavy and light vehicles in different orders.

	Noise sequences							
	4d		4bp		4bpv		4bpv_bis	
QPD	Time s	L_{Aeq} dB(A)	Time s	L_{Aeq} dB(A)	Time s	L_{Aeq} dB(A)	Time s	L_{Aeq} dB(A)
D1	36.0	62.4	34.5	62.1	34.9	61.7	34.9	61.6
D2	27.0	63.6	25.5	63.3	25.9	62.9	25.9	62.9
D3	36.0	62.4	34.5	62.1	34.9	61.7	34.9	61.6
D4	36.0	62.3	34.5	62.1	34.9	61.7	34.9	61.7
D5	18.0	65.3	16.5	65.1	16.5	64.6	16.9	64.6
D6	36.0	62.4	34.5	62.1	34.9	61.7	34.9	61.7
D7	36.0	62.4	34.5	62.1	34.9	61.7	34.9	61.7

Table VII. Experiment I – Results of the ANOVA considering NE (Number of Events), QPD (Quiet Period Distribution) and S (Source). SS: Sum of squares, dof: degrees of freedom, F: test statistics, p: p-value, ϵ: value of the dof Huynh-Feldt correction factor, η^2: measure of the magnitude of the experimental effect. *: $p < 0.05$.

	SS	dof	F	ϵ	η^2
S	851.43*	(2; 58)	31.85	0.61	0.20
NE	400.59*	(2; 58)	94.03	0.77	0.09
QPD	95.58*	(6; 174)	10.11	0.81	0.02
S x NE	19.33*	(4; 116)	3.39	0.97	<0.01
S x QPD	17.18	(12; 348)	1.29	0.75	<0.01
NE x QPD	13.55	(12; 348)	1.10	0.84	<0.01
S x NE x QPD	60.80*	(24; 696)	2.28	0.55	0.01

4.2.3. Influence of the distribution of the quiet periods

The post-hoc test performed on the QPD factor showed that the sequences without quiet periods, *i.e.* D5, were significantly more annoying than the other sequences (*cf.* Figure 9). The other QPDs were not significantly different. Considering the non-significant NE x QPD interaction and the results of the post-hoc test performed on the QPD factor, the sequences having the same cumulative quiet period duration (D1, D3, D4, D6 and D7 for a given NE) were not significantly different. Therefore, the position of the quiet periods within the sequence did not have any effect on annoyance ratings. Among these studied sequences, the sequences D1 and D2 for a given NE only differed in terms of the duration of quiet periods between events (6 s compared to 3 s, respectively). Thus, the results of this experiment also demonstrated that the duration of quiet periods between the noise events did not have any effect on annoyance ratings.

4.2.4. Influence of the order of the noise events

To study the influence of the order of the noise events, an ANOVA was performed on the sequences bpv and bpv_bis (sequences with the same pass-bys from category 3 but presented in different orders). Three within-subjects factors are considered: NE (2 levels: 3 or 4 events), QPD (7 levels: D1 to D7) and “Position of the Most Annoying noise event” (denoted PMA, with 2 levels: beginning – for

Table VIII. Experiment I – Results of the ANOVA considering NE (Number of Events), QPD (Quiet Period Distribution) and PMA (Position of the Most Annoying noise event). SS: Sum of squares, dof: degrees of freedom, F: test statistics, p: p-value, ϵ: value of the dof Huynh-Feldt correction factor, η^2: measure of the magnitude of the experimental effect. *: $p < 0.05$.

	SS	dof	F	ϵ	η^2
PMA	12.52*	(1; 29)	7.79	1.00	0.01
NE	19.68*	(1; 29)	17.55	1.00	0.02
QPD	120.42*	(6; 174)	10.11	0.73	0.10
PMA x NE	0.01	(1; 29)	0.01	1.00	<0.01
PMA x QPD	10.40	(6; 174)	1.66	0.72	<0.01
NE x QPD	6.15	(6; 174)	0.87	0.89	<0.01
PMA x NE x QPD	4.98	(6; 174)	0.87	0.73	<0.01

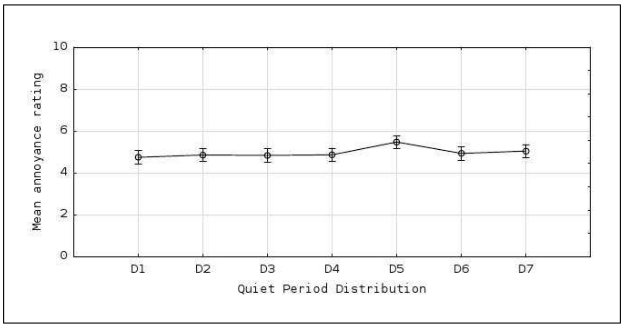

Figure 9. Experiment I – Mean annoyance rating as a function of the factor “Quiet Period Distribution” of the ANOVA and corresponding standard errors (vertical error-bars). The sequences are denoted DX, with X = 1,...,7 as defined in Table II.

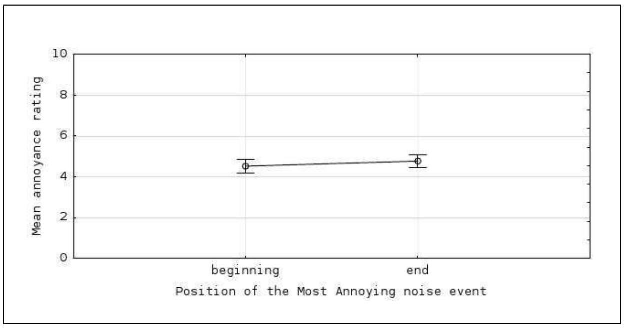

Figure 10. Experiment I – Mean annoyance rating as a function of the factor “Position of the Most Annoying noise event” of the ANOVA and corresponding standard errors (vertical error-bars).

the sequences bpv – or end – for the sequences bpv_bis). Table VIII sums up the results.

This analysis showed that the 3 main factors – PMA, NE and QPD – had a significant effect on the annoyance ratings due to the road traffic sequences. While the QPD factors explained 10 % of the observed variance, the PMA (*cf.* Figure 10) and NE factors explained respectively 1 % and 2 % of the observed variance. Using Tuckey’s HSD post-hoc tests to compare the sequences with the same NE and QPDs but different PMA, it appears that the sequences with the most annoying noise event at the beginning were not significantly different from the sequences with this most annoying noise event at the end. The results of the post-hoc tests are the ones to consider (*cf.* [25]). Overall tests and multiple-comparison tests are different in hypotheses and in levels of power.

Table IX. Experiment II – A-weighted equivalent sound pressure level of the 3-minute long sequences.

Sequence	L_{Aeq} [dB(A)]
10 vehicles	55.4
20 vehicles	58.6
30 vehicles	60.3
40 vehicles	61.3
50 vehicles	62.5

5. Experiment II: urban road traffic with single pass-by noises at different L_{Aeq}

Experiment II was designed to test whether the results of experiment I regarding the number and order of the pass-by noises were identical when considering vehicle pass-by noises with different L_{Aeq} and stemming from different perceptual categories of the typology [14].

5.1. Method

5.1.1. Stimuli

The urban background noise was the same as in experiment I (*cf.* section 4.1.1). The single vehicle pass-by noises studied in experiment B were used in this experiment (*cf.* section 2.1). In experiment II, the reference noise, a light vehicle at constant speed, was equalized to 58 dB(A). The urban background noise was equalized to 40 dB(A), in order to be masked by the pass-by noises with the lowest L_{Aeq}. The level differences observed *in situ* between the different types of vehicles at different driving conditions were applied to the pass-by noises as described in Table I (*cf.* section 2.1).

Experiment II was composed of 17 sequences. The urban background noise was played for the whole duration of the different noise sequences. Five of these sequences were 3 minutes in duration with an increasing number of pass-by noises, from 10 to 50 with a step of 10 (*cf.* Table IX). Such durations of sequences allow to study different vehicles at different driving conditions (acceleration, deceleration, constant speed). For these sequences, the vehicles were chosen from the different perceptual categories of the typology [14] (*cf.* Figure 2). They were selected randomly within each category. The sequences reproduced typical road traffic compositions observed in Paris on the Boulevard Montparnasse, with 70 % light vehicles, 20 % PTWs and 10 % heavy vehicles [32]. Four sequences were constructed without overlap between pass-by noises and one sequence (50 vehicles) was created with overlaps between pass-by noises. The overlaps' duration was comprised between 204 ms and 4.496 s, due to the fact that certain pass-by noises ended after the next one started. With these overlaps, the identification of each pass-by noise is still possible. Table IX gives the L_{Aeq} for these 5 sequences.

Twelve sequences were composed of 3 pass-by noises at constant speed: (i) one PTW, one heavy vehicle and one light vehicle, or (ii) two light vehicles and one PTW, or (iii) two light vehicles and one heavy vehicle, or (iv) two PTWs and one heavy vehicle. According to Morel *et al.* [14], the pass-by noise at constant speed chosen from the 1st or the 3rd perceptual category was rated as the most representative of its category. This is reported in bold characters in Figure 2: dfo_4 for category 1 and vfo_5 for category 3. In order to consider a heavy vehicle at constant speed, the pass-by noise pfo_1 was used as all heavy vehicles within the 3rd category were rated equally annoying (*cf.* Figure 2, and also confirmed by a post-hoc test). These sequences were also constructed in a reverse order, to study the influence of the order of pass-by noises within the urban road traffic noise on annoyance. Table X presents the 12 different sequences, their duration and their L_{Aeq}.

5.1.2. Apparatus, procedure and participants

The sound reproduction system and the procedure are the same as the ones used for the previous experiments and described in sections 2.2 and 2.3. At the end of experiment II, the participants carried out a verbalization task, to identify the main acoustical features the participants noticed. They were asked to describe the road traffic sequences they heard. Experiment II lasted approximately thirty minutes.

Thirty three participants took part in experiment II, 14 women and 19 men (mean age = 32 years; standard deviation = 12.5). All the participants declared normal hearing abilities. They were paid for their participation.

5.2. Results of the experiment II

5.2.1. Influence of the number of events

Regarding the 3-minute sequences, the results of a repeated measures ANOVA showed a significant effect of the factor “Number of Events” on annoyance [$F(4,128) = 49.19$; $p < 0.001$]. This factor explained 60 % of the observed variance. This result was expected since increasing the number of events implies an increase of the equivalent noise level of the sequences. This is also in accordance with the description of the participants: *“The road circulation is for me hardly supportable. There is the traffic density, but also the vehicle diversity.”* (*“La circulation routière m'est plus difficilement supportable. Il y a la densité de trafic, mais aussi la diversité des véhicules.”*). Figure 11 shows that the increase in annoyance with the number of pass-by noises was greater between 10 and 30 vehicles than between 30 and 50 vehicles. This change in annoyance variation constituted a breakpoint. It can be noticed that the breakpoint observed for 30 vehicles did not correspond to the number of events with overlaps between vehicles.

Table X. Experiment II – Durations and A-weighted equivalent sound pressure levels L_{Aeq} of the sequences with different orders of pass-by noises. In the first block, all of the 6 possible orders of the 3 different noise events are presented. In the remaining blocks, the sequences with different orders of their 2 different noise events are presented.

Sequence	Time [s]	L_{Aeq} [dB(A)]
dfo_4+pfo_1+vfo_5 dfo_4+vfo_5+pfo_1 pfo_1+dfo_4+vfo_5 pfo_1+vfo_5+dfo_4 vfo_5+dfo_4+pfo_1 vfo_5+pfo_1+dfo_4	13.7	64.1
dfo_4+vfo_5+vfo_5 vfo_5+vfo_5+dfo_4	12.4	60.9
pfo_1+vfo_5+vfo_5 vfo_5+vfo_5+pfo_1	13.9	63.0
dfo_4+dfo_4+pfo_1 pfo_1+dfo_4+dfo_4	13.5	64.9

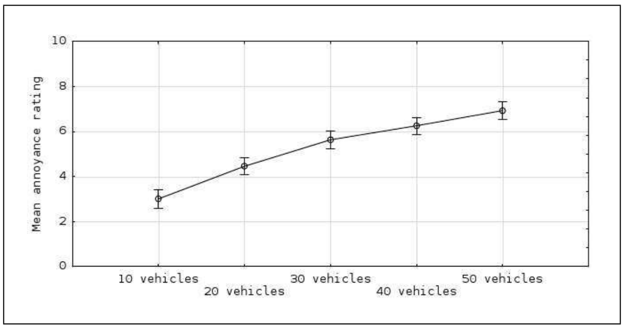

Figure 11. Experiment II – Mean annoyance rating as a function of the number of vehicles during 3-minute sequences and their standard errors (vertical error-bars).

5.2.2. Influence of the order of the noise events

Four repeated measure ANOVAs were performed on the sequences with 3 pass-by noises presented in different orders, one per block of the Table X, to avoid the potential influence of the composition of the sequence (different types of vehicle within the sequences and, for example, different numbers of light vehicles (0, 1 or 2) within the sequences). First, an ANOVA was performed on the first block of Table X with one within-subject factor: “Order of the noise events” (6 levels). No effect of the order of the noise events was observed [F(5,160) = 0.05; p = 0.99; ϵ = 0.85].

Then, three ANOVAs were performed, one per remaining block, with one within-subject factor: "Order of the noise events" (2 levels: loudest event at the beginning or at the end). For the three ANOVAs, no effect of the order of the noise events was observed (for dfo_4 +vfo_5 +vfo_5 and vfo_5 +vfo_5 +dfo_4: F(1,32) = 2.14; p = 0.15; for pfo_1 +vfo_5 +vfo_5 and vfo_5 +vfo_5 +pfo_1: F(1,32) = 3.77; p = 0.06; for dfo_4 +dfo_4 +pfo_1 and pfo_1 +dfo_4 +dfo_4: F(1,32) = 3.62; p = 0.07). From Figure 12, it is apparent that sequences with the same pass-by noises presented in different orders were not significantly different. This result is in agreement with the tendency observed in experiment I (*cf.* section 4.2). Such a result was obtained in experiment I in which the pass-bys of a noise sequence stemmed from the same perceptual categories of Morel's typology [14] and were presented at the same L_{Aeq}. Experiment II confirms this result by considering more differences between the used pass-by noise events as the pass-by noises within a sequence stemmed from different perceptual categories of the typology and were presented at different L_{Aeq}. The pass-bys also differed in temporal evolution of loudness (*cf.* Figures 5 and 6) and were rated differently (*cf.* Figure 2).

Finally, according to t-tests, it can be observed that the annoyance ratings of the sequences were inversely correlated with the number of light vehicles appearing within the sequences: sequences without light vehicles were significantly more annoying than sequences with one light vehicle, which were significantly more annoying than sequences with two light vehicles. According to experiment B and Figure 2, the PTW at constant speed (dfo_4) and the heavy vehicle at constant speed (pfo_1) were more annoying than the light vehicle at constant speed (vfo_5). It seems that the vehicle type and the specific annoyance due to these single pass-by noises influenced the total annoyance of the sequence but the order of these different pass-by noises within the road traffic sequence did not have any influence.

6. Discussion

6.1. Influence of the noise events

The experiments were designed to study the influence of acoustical factors which emerged in literature on noise annoyance due to urban road traffic noise (*e.g.* [11]). The studied urban road traffic consisted of PTWs, buses, heavy and light vehicles, as it may be observed in cities.

6.1.1. Influence of the source

Experiment A dealt with annoyance due to different urban road vehicles equalized in L_{Aeq}. The different urban road vehicles led to different annoyance ratings: PTWs were judged among the most annoying pass-by noise sources and light vehicles among the least annoying. Experiment B confirms these expected results, as PTWs are usually cited among the most annoying noise sources (*e.g.* [11, 10]). Experiment I also showed that the noise sequences comprising PTWs were more annoying than the noise sequences with buses and heavy vehicles. The sequences comprising only buses and heavy vehicles were more annoying than the noise sequences with buses, heavy and light vehicles. This result was confirmed by experiment II (*cf.* Figure 12), showing that the noise sequences without light vehicles were judged more annoying than sequences with light vehicles. Experiments I and II indicated that the total annoyance ratings of the sequences seem to be influenced by the specific annoyance of a particular annoying noise event, in the same way as louder elements receive higher weights during global loudness assessment [17]. Considering these results, it seems necessary to pay a particular attention to the PTWs in road traffic noise management. It must be noted that in the recent modified common noise assessment methods [33], the European Commission recommends to consider PTW in a special category of vehicles, thus PTW will no longer be aggregated with the light vehicles.

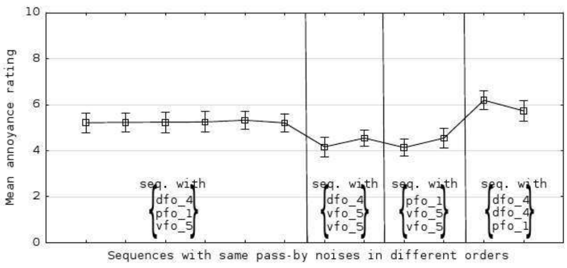

Figure 12. Experiment II – Mean annoyance rating as a function of the sequences (denoted by seq.) composed of 3 pass-by noises at constant speed and corresponding standard errors (vertical error-bars).

6.1.2. Influence of the number of events

Experiment I and experiment II showed that annoyance increased with the number of vehicles. This result was expected since the influence of the number of noise events, even for noise sequences with similar L_{Aeq}, has been previously highlighted for aircraft noises [34] and for road traffic noises [35]. Furthermore, in the current experiments, an increase in the number of vehicles appearing in one sequence implies an increase of the equivalent sound pressure level of the sequence, which is an important acoustical factor of annoyance. The aim of experiment II was to compare the results obtained by Björkman [12] with the city traffic studied under laboratory conditions considering different urban vehicles (PTWs, buses, heavy and light vehicles). Björkman [12] showed that annoyance increased with the number of heavy vehicles a day up to a breakpoint of around 2,000 heavy vehicles a day. In experiment II, the number of vehicles increased from 10 to 50 for 3-minute sequences. Considering the proportion of each vehicle type in the traffic, urban road traffic noise sequences with 1 to 5 heavy vehicles in 3 minutes were tested. This was equivalent to a traffic composed of 480 to 2400 heavy vehicles a day.

Figure 11 showed that the increase between 10 and 30 vehicles in 3 minutes (*i.e.* between 1 and 3 heavy vehicles in 3 minutes or between 480 and 1440 heavy vehicles a day) is steeper than the increase between 30 and 50 vehicles (*i.e.* between 3 and 5 heavy vehicles in 3 minutes or between 1,440 and 2,400 heavy vehicles a day). The breakpoint in this study seemed therefore to be of the same order of magnitude as the one found by Björkman [12]. However, it should be pointed out that the number of heavy vehicles in the noise sequences increases in the same proportion as the number of light vehicles, the number of PTWs and the total number of vehicles. It is therefore not possible to conclude that the breakpoint observed in Figure 11 is only due to the heavy vehicles. It may also be due to the presence of other types of vehicles, in particular PTWs, as they are known to be very annoying.

6.1.3. Influence of the order of the noise events

Since loudness appears to be an underlying basis of judged annoyance [13], confirmed by high correlation between loudness and annoyance [7, 27, 28, 29], it was expected that literature results concerning loudness judgments can also be observed for noise annoyance judgments. For example, the evaluated global loudness of an increasing and a decreasing time-intensity profile with the same maximum sound pressure level is inversely correlated to their steepness [26]. Since the different pass-by noises did not exhibit the same temporal profiles (*cf.* Figures 5 and 6), we expected the sequences with steeper time-intensity slopes at the beginning of the sequence to be judged less annoying than the sequences with shallower time-intensity slopes. For example, in experiment I, for pass-by noises equalized in L_{Aeq}, vfo_5 had an increasing slope of 7 dB(A)/s, whereas bfu_3 had an increasing slope of 10 dB(A)/s. Thus, the sequences with bfu_3 at the beginning (3bpv) was expected to be judged less annoying than the sequence with vfo_5 at the beginning (3bpv_bis). But this was not the case. Experiment II with L_{Aeq} differences between vehicles led to the same result: sequences with the same pass-by noises presented in a different order were not significantly different.

Furthermore, studies dealing with the evaluation of loudness for increasing and decreasing time-intensity profiles showed that increasing profiles are judged louder than decreasing profiles [16]. Because of the relation between loudness and annoyance [13, 7, 27, 28, 29], it was expected that sequences with the most annoying (or the loudest) pass-by noise appearing at the end would be judged more annoying than sequences with pass-by noises occurring at the beginning. Three different types of pairs of urban road traffic noise sequences were studied:

- Sequences differing only in the order of pass-by noises with same L_{Aeq} but with different specific annoyance ratings (rated in experiment A) led to the same total annoyance judgment in experiment I (*e.g.* 3bpv compared to 3bpv_bis; bfu_3 and vfo_5 had the same L_{Aeq}, but bfu_3 was judged more annoying than vfo_5, *cf.* Figure 1);
- Sequences differing only in the order of pass-by noises with the same specific annoyance but different L_{Aeq} led to the same annoyance judgment in experiment II (*e.g.* dfo_4+dfo_4+pfo_1 compared to pfo_1+dfo_4+dfo_4; the two pass-by noises dfo_4 and pfo_1 did not have the same L_{Aeq} but were equally annoying, *cf.* Figure 2);
- Sequences differing only in the order of pass-by noises with different specific annoyance ratings and different L_{Aeq} led to the same total annoyance judgment in experiment II (*e.g.* dfo_4+vfo_5+vfo_5 compared to vfo_5+vfo_5+dfo_4; the two pass-by noises dfo_4 and vfo_5 did not have the same L_{Aeq} neither the same specific annoyance, *cf.* Figure 1).

Both experiment I and experiment II led to the conclusion that sequences with the same pass-by noises presented in a different order were not significantly different. It seems that annoyance evoked by an urban road traffic sequence was determined by the presence of a noticeable event in the sequence instead of its position within the sequence. This result supports the findings of Schreiber and Kahneman [36]: the most annoying part of a negative episode influences its retrospective judgment. This hypothesis was confirmed by the verbalizations of the participants who noticed the presence of particularly annoying pass-by noises: *"the aggressive sounds are the mopeds and the trucks."* (*"les sons agressifs, ce sont les mobylettes et les camions"*.)

6.2. Influence of the quiet periods

Experiment I showed that the urban road traffic noise sequences with quiet periods were significantly less annoying than the ones without quiet periods. However, experiment I showed that the quiet period duration between noise events (3 or 6 seconds) and the cumulative quiet period duration within the sequence did not have any effect on noise annoyance. For example, regarding 4-event sequences, the sequences D2 and D1 had a quiet period duration between noise events of 3 seconds and 6 s, respectively, and a cumulative quiet period duration of 9 s and 18 s, respectively. Despite these differences, the annoyance ratings of these sequences were not significantly different.

Moreover, several studies on the evaluation of global loudness showed that the beginning [8, 37] and/or the end [8, 37, 15] of a stimulus influence loudness judgments more than the middle of the stimulus. According to Dittrich and Oberfeld [8], the influence of the end of a stimulus is more pronounced when the loudness of the end corresponds to the maximum loudness of the sequence. Considering these results, it was hypothesized that the position of the quiet period within the sequence may have an effect on annoyance ratings. For example, it was hypothesized that noise sequences with quiet periods at the beginning (*i.e.* D4 and D7) or at the end of the sequences (*i.e.* D3 and D6) would be judged less annoying than sequences of the same duration but with noise events at the beginning and at the end (*i.e.* D1). Experiment I showed that this hypothesis was not confirmed: sequences with different positions of quiet periods did not get significantly different annoyance ratings.

It should be noted that studies dealing with loudness judgments usually consider artificial noise sequences [8, 37, 16, 26] or sounds of accelerating vehicles recorded inside the vehicles [15]. The sequences studied in this paper were very different as they contained several pass-by noises, each having one increasing and one decreasing time-intensity slope. Furthermore, other temporal features (*e.g.* the slope of the signal envelope, *cf.* [11]) or spectral features (*cf.* [21]) contributed to the annoyance judgment of the different pass-by noises of the sequence. In addition, the sequences implied cognitive phenomena, since the pass-by noises were real sounds experienced everyday by participants (*cf.* [14, 29]). The complexity of these sequences may partly explain the differences observed between the results and the hypothesis derived from findings concerning loudness and based on the fact that loudness appears to be an underlying basis of judged annoyance [13], dominant over the other acoustical features [38].

7. Conclusion

The objective of this work was to study the influence of different acoustical factors on annoyance due to urban road traffic composed of different urban road vehicles (PTWs, buses, heavy and light vehicles). The experiments led to the following results:

- The type of vehicle and the number of pass-by noises explained an important part of the variance in annoyance judgments: the PTWs, buses and the heavy vehicles are more annoying than the light vehicles. This shows the importance to consider PTWs in further studies dealing with urban noise environments (*e.g.* soundscapes or road traffic modeling) and particularly with noise annoyance due to urban road traffic.
- It seems that noise annoyance due to an urban road traffic comprising PTWs increased with the number of vehicles, up to a breakpoint, after which it saturated and increased more slowly.
- The order of the different urban vehicle pass-by noises (PTWs, buses, heavy and light vehicles) within an urban road traffic sequence had no influence on annoyance.
- It seems that participants' ratings were more influenced by the presence of a very specific pass-by noise rather than by its position. The latter result, expressed in terms of specific annoyance due to noise events and its relation to annoyance due to successive noise events, may be of interest for combined noise source studies dealing with different transportation noise events and the understanding of dominance effects.
- The presence of quiet periods in an urban road traffic noise sequence decreased annoyance, compared to sequences without quiet periods.
- The position of quiet periods and their cumulative duration had no influence on annoyance ratings of sequences composed of the same pass-by noises.

These different results highlighted in this work contribute to i) the understanding of the influence of the studied acoustical factors on noise annoyance due to urban road traffic with PTWs, ii) and to the perspective of enhancing noise annoyance models.

Acknowledgement

This work was supported by the Labex CeLyA of Université de Lyon, operated by the French National Research Agency (ANR-10-LABX-0060 / ANR-11-IDEX-0007).

References

[1] European Parliament and Council: Directive 2002/49/EC of june 2002 related to the assessment and management of environmental noise.

[2] H. M. E. Miedema, C. G. M. Oudshoorn: Annoyance from transportation noise: relationships with exposure metrics DNL and DENL and their confidence intervals. Env. Health Persp. **109** (2001) 409–416.

[3] E. A. M. Franssen, J. E. F. Dongen, J. M. H. Ruysbroek, H. Vos, R. K. Stellato: Hinder door milieufactoren en de beoordeling van de leefomgeving in Nederland (Nuisance by environmental factors and the evaluation of the living environment in The Netherlands). RIVM-report no. 815120001/2004, Dutch National Institute for Public Health and Environment, Bilthoven, The Netherlands, 2004.

[4] B. Berglund, M. E. Nilsson: Total annoyance and perceptually discernible noise sources. Proc InterNoise 2000, Nice, France, 2000.

[5] P. Lercher, M. Sölder: Exposure by motorbike noise in alpine residential areas - a case study in public health risk assessment. Proc Euronoise 2009 on CD-Rom, Edinburgh, UK, 2009.

[6] R. F. S. Job: Community response to noise: a review of factors influencing the relationship between noise exposure and reaction. J. Acoust. Soc. Am. **83** (1988) 991–1001.

[7] M. Alayrac, C. Marquis-Favre, S. Viollon, J. Morel, G. Le Nost: Annoyance from industrial noise: indicators for a wide variety of industrial sources. J. Acoust. Soc. Am. **128** (2010) 1128–1139.

[8] K. Dittrich, D. Oberfeld: A comparison of the temporal weighting of annoyance and loudness. J. Acoust. Soc. Am. **126** (2009) 3168–3178.

[9] T. Kaczmarek, A. Preis: Annoyance of time-varying road-traffic noise. Archives of Acoustics **35** (2010) 383–393.

[10] J. Vos: Noise annoyance caused by mopeds and other traffic sources. Proc InterNoise 2006, Honolulu, USA, 2006.

[11] M. Paviotti, K. Vogiatzis: On the outdoor annoyance from scooter and motorbike noise in the urban environment. Science of The Total Environment **430** (2012) 223–230.

[12] M. Björkman: Community noise annoyance: importance of noise levels and the number of noise events. J. Sound Vib. **151** (1991) 497–503.

[13] R. P. Hellman: Loudness, annoyance, and noisiness produced by single-tone-noise complexe. J. Acoust. Soc. Am. **71** (1982) 62–73.

[14] J. Morel, C. Marquis-Favre, D. Dubois, M. Pierrette: Road traffic in urban areas: a perceptual and cognitive typology of pass-by noises. Acta Acustica united with Acustica **98** (2012) 166–178.

[15] P. Susini: Perception évolutive et globale de sons non-stationnaires (Progressive and global perception of non-stationary sounds). PhD dissertation, Université du Maine, Le Mans, France, 1999.

[16] E. Ponsot, P. Susini, G. Saint-Pierre, S. Meunier: Temporal loudness weights for sounds with increasing and decreasing intensity profiles. J. Acoust. Soc. Am. **134** (2013) EL321–EL326.

[17] D. Oberfeld, T. Plank: The temporal weighting of loudness: Effects of the level profile. Attention, Perception & Psychophysics **73** (2011) 189–208.

[18] A. Klein, C. Marquis-Favre, R. Weber, A. Trollé: Spectral and modulation indices for annoyance-relevant features of single urban road vehicle pass-by noises. J. Acoust. Soc. Am. **137** (2015) 1238–1250.

[19] C. Guastavino, V. Larcher, G. Catusseau, P. Boussard: Spatial audio quality evaluation: comparing transaural, ambisonics and stereo. Proc 13th International Conference on Auditory Display, Montreal, Canada, 2007, 53–59.

[20] R. Paulsen: On the influence of the stimulus duration on psychophysical judgment of environmental noises taken in the laboratory. Proc InterNoise 1997, Budapest, Hungary, 1997, 1175–1178.

[21] J. Morel, C. Marquis-Favre, L.-A. Gille: Noise annoyance assessment of various urban road vehicle pass-by noises in isolation and combined with industrial noise: A laboratory study. App. Acoust. **101** (2016) 45–57.

[22] A. Trollé, C. Marquis-Favre, A. Klein: Short-term annoyance due to tramway noise: Determination of an acoustical indicator of annoyance via multilevel regression analysis. Acta Acustica united with Acustica **100** (2014) 34–45.

[23] A. Trollé, C. Marquis-Favre, J. Faure: An analysis of the effects of structural parameter variations on the auditory perception of environmental noises transmitted through a simulated window. App. Acoust. **69** (2008) 1212–1223.

[24] S. Bech, N. Zacharov: Perceptual audio evaluation - Theory, method and application. Wiley & Sons, Chichester, England, 2006.

[25] D. C. Howell: Statistical methods for psychology cengage learning. Belmont, 2010.

[26] E. Ponsot, P. Susini, S. Meunier: The role of duration in global loudness evaluation of rising and falling-intensity sounds. Proc 30th Annual Meeting of The International Society for Psychophysics, Lund, Sweden, 2014.

[27] B. Berglund, M. E. Nilsson: Total and source-specific loudness of singular and combined traffic sounds. Archives of the Center for Sensory Research (Stockholm University, Sweden) **6** (2001) 71–93.

[28] C. Marquis-Favre, E. Premat, D. Aubrée: Noise and its effects: a review on qualitative aspects of sound. Part II: Noise and annoyance. Acta Acustica united with Acustica **91** (2005) 626–642.

[29] J. Morel: Caractérisation physique et perceptive du bruit routier urbain pour la définition d'indicateurs de gêne sonore en situation de mono-exposition en présence de bruit industriel (Physical and perceptual characterization for indicators of annoyance due to urban road traffic noise in isolation and combined with industrial noise). PhD dissertation, ENTPE, Vaulx-en-Velin, France, 2012.

[30] DIN 45631: Berechnung des Lautstärkepegels und der Lautheit aus dem Geräuschspektrum; Verfahren nach E. Zwicker (Procedure for calculating loudness level and loudness). 1991.

[31] Code de la route, article R412-12 (Road code). available on www.legifrance.fr.

[32] Mairie de Paris, Direction de la Voirie et des Déplacement: Composition du trafic PIM 2008 (Traffic composition in Paris intra-muros in 2008). 2011.

[33] European Commission: Commission Directive (EU) 2015/996 of 19 May 2015 establishing common noise assessment methods according to Directive 2002/49/EC of the European Parliament and of the Council.

[34] J. Lambert, P. Champelovier, R. Blanchet, C. Lavandier, J. Terroir, F. Márki, B. Griefahn, U. Iemma, K. Janssens, R. Bisping: Human response to simulated airport noise scenarios in home-like environments. App. Acoust. **90** (2015) 116–125.

[35] G. Labiale: Laboratory study of the influence of noise level and vehicle number on annoyance. J. Sound Vib. **90** (1983) 361–371.

[36] C. A. Schreiber, D. Kahneman: Determinants of the remembered utility of aversive sounds. J. Exp. Psychol. **129** (2000) 27–42.

[37] B. Pedersen, W. Ellermeier: Temporal weights in the level discrimination of time-varying sounds. J. Acoust. Soc. Am. **123** (2008) 963–972.

[38] W. G. Cermak, P. C. Cornillon: Multidimensional analyses of judgments about traffic noise. J. Acoust. Soc. Am. **59** (1976) 1412–1420.