Does the order of different successive vehicle pass-bys have an influence on the annoyance due to an urban road traffic noise?

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Summary
Noise annoyance is mainly predicted by mean energy-based indices. But such indices only explain a small part of the annoyance expressed by individuals. This is, however, necessary to enhance the understanding of perceptual phenomena involved in annoyance responses. We propose to study the influence of the acoustic characteristics of an urban road traffic on noise annoyance. Several studies showed that loudness is a basis of annoyance; other studies showed that differences in time-intensity profiles lead to different loudness judgments. An urban road traffic is composed of different vehicles which present different time-intensity profiles. Thus, considering one traffic composition, a question may arise: does the successive vehicle order have an effect on the annoyance due to the traffic noise? We studied such potential effect for an urban road traffic composed of powered-two-wheelers, heavy and light vehicles. Annoyance was assessed in laboratory conditions. The participants evaluated the annoyance due to noise sequences composed of three pass-by noises presented in different orders. The noise sequences were constructed from *in situ* recordings. This experiment showed that the order of vehicles does not have any effect on the noise annoyance ratings due to urban road traffic composed of powered-two-wheelers, heavy and light vehicles.

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1. Introduction

The European directive 2002/49/EC demands 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 Lden -- the day-evening-night level -- is used for the construction of noise maps. As several annoyance models are based on this index [1], noise maps may be interpreted as annoyance maps. But, it is well known that acoustical energy-based indices, such as the Lden, explain only a small part of variance in noise annoyance (*e.g.* [2]). Indeed, different acoustical factors (*e.g.* temporal and spectral noise characteristics) and non acoustical factors (*e.g.* noise sensitivity) are known to influence noise annoyance responses (*e.g.* [3]). Taking into account these other factors is also necessary to improve noise annoyance prediction.

Morel *et al.* [4] realized a free categorization test of single urban road vehicle pass-by noises. They proposed a physical and perceptual typology of these noises, structured according to the type of vehicle and the driving condition. For each category of the typology, Morel *et al.* [9] studied noise annoyance due to the single urban road vehicle pass-by noises and proposed annoyance indicators, based on different indices such as loudness, roughness, etc. Temporal and spectral characteristics are taken into account in the proposed annoyance indicators. These works contribute to the understanding of noise annoyance due to single urban vehicle pass-by noises, which constitutes a necessary step for improving noise annoyance knowledge. But noise annoyance due to an urban road traffic may be different. In order to improve the evaluation and the prediction of noise annoyance due to an urban road traffic, it is necessary to study how some acoustical factors of urban road traffic may influence noise annoyance ratings. In this paper, we will focus on the influence of the vehicle order within a traffic on noise annoyance.

Indeed, loudness is well known to be a basis of noise annoyance ([6], [7]). Several studies ([8], [9]) showed a better correlation between loudness and annoyance than between energetic indices and annoyance. Furthermore, studies on loudness assessment ([10], [11]) have demonstrated that sounds with different time-intensity profiles lead to different loudness ratings. Differences in time-intensity structure might contribute to urban road traffic noise annoyance. As the different pass-by noises within urban road traffic have different slopes of loudness as a function of time, the order of the different pass-by noises within an urban road traffic sequence may have an influence on annoyance. Such potential influence will be studied in this paper for urban road traffic with powered-two-wheelers.

The paper is organized as follows: the experiment is described in section II, the results are presented and discussed in section III.

2. Experiment

The influence on short-term noise annoyance of the order of the urban road vehicle pass-by noises within a traffic is studied under controlled conditions. During the experiment carried out, the influence of the number of vehicles is also studied. The whole experiment will be presented but just the results about the order of the urban road vehicle pass-by noises will be exposed in this paper.

2.1. Stimuli

2.1.1. Noise recording

The urban road vehicle pass-by noises used in the experiment were recorded by Morel *et al.* [4] and the urban background noise was recorded by Trollé *et al.* [12] early in the morning without distinguishable noise events. All the noises were recorded in Lyon and its neighborhood using the same procedure and apparatus. Simultaneously, a monophonic and a stereophonic recordings were performed ([4], [12]). The stereophonic recording was done using the ORTF technique. 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 [13]. The monophonic recording was done using a calibrated omnidirectional microphone, in order to measure the recording noise level.

The microphones were placed at a height of 1.5 m and perpendicularly to the axis of the road. The distance between the microphones and the vehicles varied from 3 m to 10 m, due to the urban architecture of the recording locations, and respecting 2 m away from any reflecting wall [4]. (For more details, *cf.* [4], [12])

2.1.2. Noise sequences

The experiment is composed of 17 noise sequences. Twelve sequences are composed of 3 urban road vehicle pass-by noises and 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. The noise level of these 5 latter sequences varies from 55.4 to 62.5 dB(A).

The 12 sequences designed to study the influence on noise annoyance of the order of the urban road vehicle pass-by noises within a traffic are presented in details. These sequences are composed of 3 pass-by noises of vehicles at constant speed. The pass-by noises stemmed from 2 of the 7 categories of the physical and perceptual typology of Morel *et al.* [4].

Table 1 presents the 12 sequences, their duration and their A-weighted equivalent sound pressure level (L_{Aeq}). The sequences are composed as follows: (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. The code (xyz_N) used to refer to the pass-by noises is as follows: x for "vehicle type" (b = bus; d = powered-two-wheelers; 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). N is an arbitrary number to differentiate stimuli. The noises of vehicles passing by at constant speed were chosen within the 1st perceptual category (powered-two-wheelers at constant speed) or the 3rd perceptual category (buses, heavy and light vehicles at constant speed) according to their most representative rating in their category: dfo_4 for category 1 and vfo_5 for category 3 (*cf.* Morel *et al.* [4]). In order to also consider a heavy vehicle at constant speed, the pass-by noise pfo_1 was usedas all heavy vehicles within the 3rd category present the same annoyance rating (*cf.* Klein [14]). These sequences are also constructed in a reverse order, to study the influence on annoyance of the order of pass-by noises within each road traffic sequence.

Table I. Duration and A-weighted equivalent sound pressure level (L_{Aeq}) of the sequences.

Sequence	*Duration (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 + pfo_1 + pfo_1 pfo_1 + pfo_1 + dfo_4	13.5	64.9

The pass-by noises have differences in L_{Aeq} according to mean differences calculated between the average L_{Aeq} measured *in situ* for light vehicles at constant speed (vfo) and the average L_{Aeq} measured *in situ* for other vehicles in different driving conditions (*cf.* [5]). The pass-by with the lowest L_{Aeq} is vfo_5, the light vehicle at constant speed, with L_{Aeq} equal to 58 dB(A). The heavy vehicle and the powered-two-wheeler have a higher noise level of 7.3 dB(A) and 5.3 dB(A) respectively (*cf.* [5]). The urban background noise is equalized to 40 dB(A), in order to be masked by the light vehicle at constant speed.
Figure 1 represents the loudness as a function of time for the single pass-by noises.

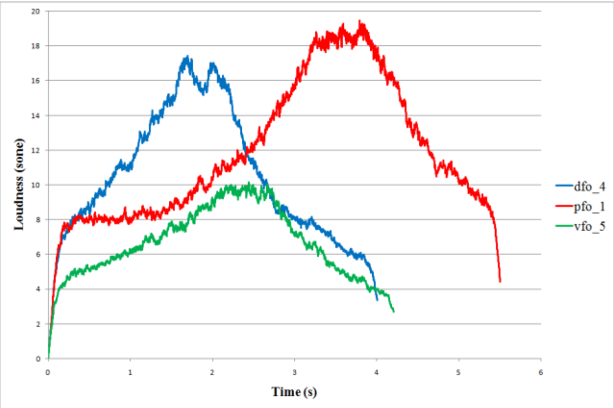

Figure 1: Loudness as a function of time for the urban road vehicle pass-by noises used for the construction of urban road traffic sequence.

2.1.3. Sound reproduction

No filter simulating facade transmission is applied to the stimuli as wall material and window types have an effect on auditory judgments [15] and the choice of one kind of facade might have been too limiting. Thus, the worst noise exposure is considered (*e.g.* [16]) such as being in private outdoor spaces at a certain distance from the road.

2.2. Apparatus

The experiment takes place in a quiet room with a background noise measured at 19 dB(A). The stimuli are reproduced employing a 2.1 audio reproduction system consisting of two active loudspeakers (Dynaudio Acoustics BM5A) and one active subwoofer (Dynaudio Acoustics BM9S).
The center of the interaural axis of the participant and the loudspeakers form an equilateral triangle. This is in accordance with the recommendations given by Bech and Zacharov [17]. The loudspeakers are placed at a height of 1.20 m from the floor, and the subwoofer is placed on the floor between the loudspeakers. The user interface is programmed using MATLAB©.

2.3. Procedure

Participants are 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 ([9], [12]). Prior to each experiment, the participants are trained. The stimuli are presented one by one in random order.
After each stimulus, the participants are asked: "During your relaxing activity, you hear this noise. Does this noise annoy you?". The participants give 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").
At the end of the test, the participants perform a verbalization task concerning the description of the noise sequences they have heard. They answer to a questionnaire concerning several non acoustical factors, such as the noise sensitivity.
The experiment lasts 30 minutes.

2.4. Participants

Thirty three participants took part in Exp. 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.

3. Results and discussion

The annoyance ratings for the sequences with the same pass-by noises in different orders are not significantly different according to t-tests. The order of the pass-by noises has thus no influence on the annoyance due to urban road traffic noise sequences. The pass-by noises composing these sequences stemmed from two different perceptual categories of Morel *et al.* typology [4] and are set at different L_{Aeq}.

Comparing the noise sequences dfo_4 + pfo_1 + vfo_5 and dfo_4 + vfo_5 + pfo_1, the pass-by noise pfo_1 has a L_{Aeq} higher than the L_{Aeq} of the pass-by noise vfo_5. The positions of these two pass-by noises is reversed within the two noise sequences. Concerning loudness assessment for 1-second sounds, Pedersen and Ellermeier [18] showed that the beginning and the end of the stimulus influence the loudness assessment more than the middle of the stimulus does. Because of the relation between loudness and noise annoyance ([3], [5], [6], [16]), it was expected that the sequence dfo_4 + vfo_5 + pfo_1 will be judged more annoying than the sequence dfo_4 + pfo_1 + vfo_5. However, the present experiment denies this hypothesis.

Moreover, the pass-by noises differ in temporal evolution of loudness. The evaluated global loudness of sounds with an increasing and a decreasing time-intensity profile and with same maximum sound pressure level is inversely correlated to their loudness slope [19]. Since the different pass-by noises do not exhibit the same temporal profiles (*cf.* Figure 1), we expected the sequences with steeper slopes at the beginning of the sequence to be judged less annoying than the sequences with shallower slopes. For example, vfo_5 has an increasing slope of 2.8 sone/s, whereas dfo_4 has an increasing slope of 7.0 sone/s. Thus, the sequence dfo_4 + vfo_5 + pfo_1 was expected to be judged less annoying than vfo_5 + dfo_4 + pfo_1. But the two sequences were not judged significantly different.

Furthermore, Dittrich and Oberfeld [20] showed a primacy and a recency effects on annoyance for 900-ms wide-band sequences and varying every 100 ms. Schreiber and Kahneman [21] showed that retrospective judgments of a negative episode are highly influenced by the worst part and the final part of the episode. According to Dittrich and Oberfeld [20], the annoyance evaluation implies negative emotions, that is why the observed recency effect on the annoyance may be explained by the peak-end rule. Hence, we may expect that sequence beginning or ending with a louder pass-by noise would be judged more annoying than sequence with a softer pass-by noise at its beginning or at its end. For example, as dfo_4 and pfo_1 are louder than vfo_5, we expected dfo_4 + vfo_5 + pfo_1 to be judged differently from dfo_4 + pfo_1 + vfo_5. The experiment demonstrates that it is not the case.

There is significant differences in annoyance ratings only between sequences presenting different urban road traffic compositions, as can be seen on Figure 2. It can be noticed that the sequences comprising two powered-two-wheelers are the most annoying sequences whereas the sequences comprising two light vehicles are the least annoying ones.

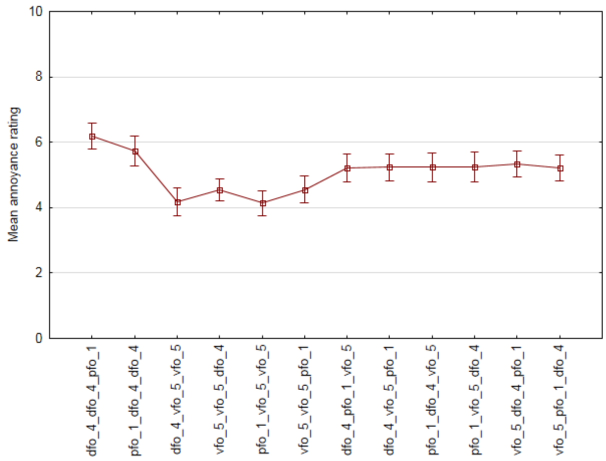

Figure 2: Mean annoyance ratings and standard error for the different urban road traffic sequences.

Therefore, it seems that annoyance due to an urban road traffic noise sequence is more influenced by the presence of a remarkable pass-by noise than by its position within the sequence. This hypothesis reminds the one of Schreiber and Kahneman [21]. This hypothesis is confirmed by the verbalizations of the participants who noted 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.")

It should be noted that studies dealing with loudness judgments usually consider artificial noise sequences ([18], [19]) or sounds of accelerating vehicles recorded inside the vehicles [11]. The sequences studied in this paper are very different as they contain several pass-by noises, each having one increasing and one decreasing slope. Furthermore, within noise sequences, the pass-by noises vary not only in time-intensity structure but also in other auditory attributes (*e.g.* [9], [14]). The complexity of these sequences may explain the differences observed between our results and our hypothesis derived from findings concerning loudness and based on the fact that loudness appears to be an underlying basis of judged annoyance [7].

4. Conclusion

The experiment shows that the order of the urban road vehicle pass-by noises within an urban road traffic noise sequence does not have any influence on the noise annoyance ratings. This result is unexpected, since literature shows an effect of the loudness slopes on loudness assessment and since loudness is well known to be a basis of noise annoyance. As the different urban road vehicle pass-by noises do have neither the same A-weighted equivalent sound pressure level nor the same loudness slope, we expected an effect on noise annoyance of the order of the urban road vehicle pass-by noises within an urban road traffic noise sequence.

This result improves the understanding of the perceptual mechanisms of noise annoyance due to urban road traffic, with different vehicle types such as powered-two-wheelers, heavy and light vehicles. This result is interesting from a practical point of view for *in situ* study: the order of the urban road vehicle pass-by noises within urban road traffic has not to be taken into account in a perspective of improving noise annoyance models.

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References

[1] H. M. E. Miedema and C. G. M. Oudshoorn, "Annoyance from transportation noise: relationships with exposure metrics DNL and DENL and their confidence intervals", Environ. Health Perspect., vol. 109 (4), 409–416, 2001.

[2] R. F. S. Job, "Community response to noise : a review of factors influencing the relationship between noise exposure and reaction", J. Acoust. Soc. Am., vol. 83 (3), 991–1001, 1988.

[3] C. Marquis-Favre, E. Premat, and D. Aubrée, "Noise and its Effects - A review on qualitative aspects of sound. Part II: Noise and annoyance", Acta Acust. united with Acust., vol. 91, 626–642, 2005.

[4] J. Morel, C. Marquis-Favre, D. Dubois, and M. Pierrette, "Road traffic in urban areas: A perceptual and cognitive typology of pass-by noises", Acta Acust. united with Acust., vol. 98, 166–178, 2012.

[5] J. Morel, "Caractérisation physique et perceptive du bruit routier urbain pour la définition d'indicateurs de gêne sonore en situation de mono-exposition et de multi- exposition en présence de bruit industriel", Ph.D. thesis, ENTPE, 2012.

[6] C. A. Powell, "A summation and inhibition model of annoyance response to multiple community noise sources", 20 p., 1979.

[7] R. P. Hellman, "Loudness, annoyance, and noisiness produced by single-tone-noise complexes", J. Acoust. Soc. Am., vol. 72 (1), 62–73, 1982.

[8] T. Kaczmarek and A. Preis, "Annoyance of time-varying road-traffic noise", Arch. Acoust., vol. 35 (3), 383–393, 2010.

[9] J. Morel, C. Marquis-favre, M. Pierrette, and L. Gille, "Physical and perceptual characterization of road traffic noises in urban areas for a better noise annoyance assessment maps", Proc. Acoustics 2012, 1679–1684.

[10] E. Ponsot, P. Susini, G. Saint Pierre, and S. Meunier, "Temporal loudness weights for sounds with increasing and decreasing intensity profiles", JASA Express Lett., vol. 134 (4), EL321–EL326, 2013.

[11] P. Susini, "Perception évolutive et globale de sons non-stationnaires", Ph.D. thesis, Université du Maine, 1999.

[12] A. Trollé, C. Marquis-Favre, and A. Klein, "Short-term annoyance due to tramway noise: determination of an acoustical indicator of annoyance via multilevel regression analysis", Acta Acust. united with Acust., vol. 100, 34–45, 2014.

[13] C. Guastavino, V. Larcher, G. Catusseau, and P. Boussard, "Spatial audio quality evaluation : Comparing transaural, ambisonic and Stereo", Proc.of the 13th International Conference on Auditory Display, 7p., 2007.

[14] A. Klein, "Annoyance indicators for various urban road vehicle pass-by noises and urban road traffic noise combined with tramway noise", Ph.D. thesis, ENTPE, 2015.

[15] A. Trollé, C. Marquis-Favre, and J. Faure, "An analysis of the effects of structural parameter variations on the auditory perception of environmental noises transmitted through a simulated window", Appl. Acoust., vol. 69, 1212–1223, 2008.

[16] M. Alayrac, C. Marquis-Favre, S. Viollon, J. Morel, and G. Le Nost, "Annoyance from industrial noise: Indicators for a wide variety of industrial sources", J. Acoust. Soc. Am., vol. 128 (3), 1128–1139, 2010.

[17] S. Bech and N. Zacharov, Perceptual audio evaluation - Theory, method and application. Wiley, 2006.

[18] B. Pedersen and W. Ellermeier, "Temporal weights in the level discrimination of time-varying sounds", J. Acoust. Soc. Am., vol. 123 (2), 963–972, 2008.

[19] E. Ponsot, P. Susini, and S. Meunier, "The role of duration in global loudness evaluation of rising and falling-intensity sounds", Proc. of the 30th Annual Meeting of The International Society for Psychophysics, 2014, 1 p.

[20] K. Dittrich and D. Oberfeld, "A comparison of the temporal weighting of annoyance and loudness", J. Acoust. Soc. Am., vol. 126 (6), 3168–3178, 2009.

[21] C. A. Schreiber and D. Kahneman, "Determinants of the remembered utility of aversive sounds", J. Exp. Psychol. Gen., vol. 129 (1), 27–42, 2000.