DOI: 10.61782/fa.2023.0639

SOUND ANNOYANCE EVALUATION OF SINGLE PASS-BY VEHICLE NOISE

Vincent Grimaldi[1*] **Thach Pham Vu**[1] **Hervé Lissek**[1]
[1] Acoustic Group - Signal Processing Laboratory LTS2, EPFL, Lausanne, Switzerland

ABSTRACT

Noise radars can be used to track the noise emitted by a single vehicle. Acoustic metrics, such as A-weighted equivalent continuous sound level are typically used to monitor traffic noise. However, equivalent sound level may not be the most relevant metric to predict the sound annoyance generated by a single vehicle. In this study, listeners were asked to rate the perceived annoyance when listening to single pass-by vehicle sounds excerpts. The correlation of the subjective annoyance ratings with several psychoacoustic metrics of the literature was investigated. The results suggest that A-weighted equivalent continuous sound level and Zwicker's model of sound annoyance may not be the best indicators of the actual annoyance perceived for this type of sounds. The averaged instantaneous loudness, computed with either Zwicker's or Moore-Glasberg's model, provided the best correlation with the subjective ratings.

Keywords: *annoyance, traffic, vehicle noise*

1. INTRODUCTION

Traffic noise monitoring usually relies on acoustic metrics, such as A-weighted equivalent continuous sound level (L_{Aeq}). With the current development of noise radars, the noise emitted by a single vehicle can be tracked from a fixed position close to the road. However, equivalent sound level may not fully explain the sound annoyance generated by each single vehicle. Such sound can be considered short and time-varying. The goal of this experiment is to evaluate the annoyance perceived by listeners when exposed to various noises from single pass-by vehicles. From these ratings, the goal is to investigate which psychoacoustic metrics of the literature could reliably help to predict the subjective annoyance of the listeners. In particular, Zwicker and Fastl' model of sound annoyance [1], Zwicker's model of loudness and Moore and Glasberg's model of loudness [2] are considered.

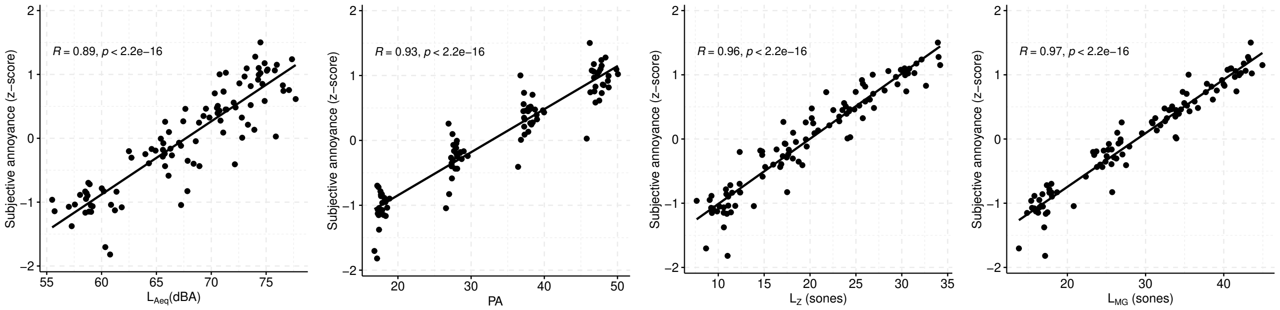
*__Corresponding author__: *vincent.grimaldi@epfl.ch.*

2. LISTENING TEST DESIGN

50 naive young normal hearing listeners took part in the listening experiment (25 female, 25 male, $\bar{x}$ = 22.6 y.o.; 18≤x≤27 y.o.). The experimental setup was installed in a listening room (V = 125 m^3; RT_{60} = 0.17 s). All stimuli were played through a single loudspeaker (Genelec 1032a) located in front of the listener, at a distance of 1.5 m.

The stimuli for this experiment were a selection of 25 audio samples of duration 3 s of vehicles passing by, recorded from a fixed position from the road. The recordings include a variety of vehicle types (cars, trucks, motorbikes) and speed behaviors. The sounds were chosen to cover a wide range of values in terms of roughness and fluctuation strength. Each of those 25 samples was played at four fixed levels of percentile loudness N_5 during the experiment: 15, 24, 33 and 42 sones. Those samples were equalized using N_5, as suggested by the computation of Zwicker's model of sound annoyance. The N_5 was measured and tuned at the position of the listener.

The listeners were asked to listen to 3-s vehicle noise samples played by the loudspeaker. After listening to each sound, they graded the subsequent perceived annoyance using a 11-points numerical scale with ticks equally spaced from 0 (not annoying at all) to 10 (extremely an-



(a) (b) (c) (d)

Figure 1. Spearman's correlation with average subjective annoyance z-score ratings, for: (a) L_{Aeq}: A-weighted equivalent continuous sound level, (b) PA: Zwicker psycoacoustic annoyance, (c) L_Z: average of Zwicker's time-varying loudness, (d) L_{MG}: average of Moore and Glasberg's time-varying loudness.

noying). Each of the 25 audio samples was played at the four fixed N_5 levels, forming a block of 100 samples. Three repetition blocks were presented to the listeners, leading to a total of 300 sounds to evaluate. The order of the sounds within each block was randomized for every participant to mitigate the effect of presentation order by overall averaging.

3. RESULTS

Spearman's correlation coefficients and associated p-values are reported in Figure 1 for L_{Aeq}, PA (Zwicker psycoacoustic annoyance), L_Z (average of Zwicker's time-varying loudness) and L_{MG} (average of Moore and Glasberg's time-varying loudness).

The correlation coefficient comparison test of Meng was evaluated for each pair. L_{Aeq} was significantly less correlated with the subjective annoyance compared to all the other metrics considered in this work. PA had a smaller correlation with the ratings compared to L_{MG} and L_Z. L_{MG} was slightly better correlated with subjective annoyance compared to L_Z.

4. DISCUSSION

This study shows the limitation of sound pressure level for understanding how humans perceive annoyance of short time-varying sounds. L_{Aeq} indeed correlated more poorly with the subjective annoyance compared to the other metrics based on loudness estimations, confirming the results in [3]. The results suggest that N_5 and consequently Zwicker's PA might not be the best predictors for the annoyance of pass-by vehicle sounds. Indeed pass-by vehicle noise is inherently time-varying, even within 3 s as in this test, and thus N_5 might not be the best indicator of loudness, as suggested in [4]. This is the case in particular for pass-by noise containing revving sounds.

In application, the small improvement in correlation observed with L_{MG} compared with L_Z is probably not worth the significant computational cost increase.

In this work, the targeted range of N_5 values as well as the resulting range of loudness values experienced by the listeners was large. The subsequent evident difference in intensity perception might have hidden more subtle effect that could have affected annoyance, such as e.g. roughness or fluctuation strength.

5. CONCLUSION

The results from the listening experiment suggest that using a loudness model of the literature such as Zwicker's or Moore-Glasberg's might be a reliable method to predict the subjective annoyance from single pass-by vehicle sounds. For this type of sounds, Zwicker's model of psychoacoustic annoyance did not correlate as well with the subjective ratings. A-weighted equivalent sound level (L_{Aeq}) did not yield to precise predictions either.

In further works, sounds could be played in randomized blocks of equalized time-varying loudness. This could remove the dominant effect of loudness, and enable to better understand the role of psychoacoustic attributes such as fluctuation strength or roughness on subjective annoyance.

Aknowledgements: The work reported in this paper has been co-financed by Innosuisse under Grant agreement 43941.1 IP-ICT.

6. REFERENCES

[1] E. Zwicker and H. Fastl, *Psychoacoustics: Facts and Models.* 3rd Edition, Springer, 1999.

[2] I. 532-1:2017(E), *Acoustics – Methods for calculating loudness*. International Organization for Standardization., 2017.

[3] M. E. Nilsson, "A-weighted sound pressure level as an indicator of short-term loudness or annoyance of road-traffic sound," *J. Sound Vib.*, vol. 302, no. 1, pp. 197–207, 2007.

[4] J. Schlittenlacher, T. Hashimoto, S. Kuwano, and S. Namba, "Overall judgment of loudness of time-varying sounds," *J. Acoust. Soc. Am.*, vol. 142, no. 4, pp. 1841–1847, 2017.