Proceedings of 20th International Congress on Acoustics, ICA 2010

23-27 August 2010, Sydney, Australia

Quality Evaluation of Engine Start and Idle Sounds

M. Ercan Altinsoy

Chair of Communication Acoustics, Dresden University of Technology, Germany
ercan.altinsoy@tu-dresden.de

PACS: 43.50.Lj Transportation noise sources: air, road, rail, and marine vehicles, 43.66.Lj Perceptual effects of sound.

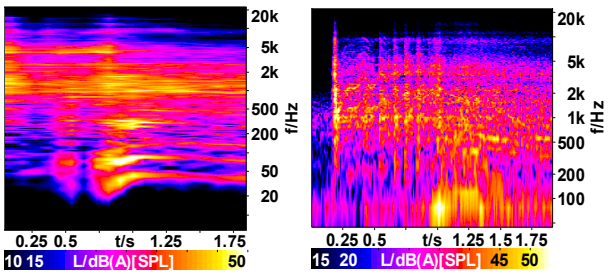
ABSTRACT

One of the interesting questions in vehicle acoustics is how do we evaluate the instationary sounds. What are the relative contributions of the different sequences to the overall quality judgment, if the sounds have two characteristic time sequences? Normal operation of a vehicle covers stationary and instationary sounds depending on driving condition. “Engine start” (instationary) and “Idle” (quasi-stationary) are two examples of these driving conditions which are coupled with each other functionally. Therefore we hear the sounds of these conditions sequentially. Once such a hearing experience is over, we can form an overall evaluation of it. This study deals with the rules behind the evaluation process. We examine the hypothesis stating that the experience over time is not a simple combination of its discrete components. The influences of the extreme part (feature-based), beginning part and the final part of the experience to the overall evaluation are investigated. In order to approach this aim in a systematic way, psychoacoustical experiments were conducted. In the first experiment, the binaurally recorded engine start and the idle sounds of 12 cars from different brands were presented to the nonexpert subjects. They were asked to describe what they like and dislike about engine start and idle sounds. Some of the verbal descriptors which were used by the subjects were selected for the further experiments. In these experiments, the engine start and idle sounds were evaluated separately and variously combined by the subjects using a quasi continues scale. The results of the experiments give some important hints for the experience summation of multiple events.

INTRODUCTION

Quality evaluation of instationary sounds is an important topic for product designers, due to the fact that most of the products have instationary operational conditions and generate instationary vibration and sounds. Recently, different studies have focused on the loudness perception and evaluation of instationary sounds [1,..,9]. Most of them have discussed the suitable pychoacoustical measurement methods for the instationary signal evaluation. Kuwano and Namba have found that instantaneous and global judgments can be well correlated with acoustic level in dBA and Leq, respectively [6]. In another study, the instantaneous and global judgments were well correlated with a specific value of loudness, N4 (ISO 532B [7]). While the results of some investigations show that the global loudness judgment of a time-variant signal is the simple average of the continuous judgments, other studies claim that it is not a simple average. If we take into account the hypothesis of Kundera about our memory, according to which “our memory does not take film, it takes photographs”, it is possible to say that extreme events dominates our experiences, but also our evaluations [10]. Possibly not only extreme parts but also the final part (end) of the signal stimulates our evaluations, because of the short-term auditory memory effect called the "recency effect" [5]. This study focuses on the quality evaluation of complex time-variant vehicle sounds which have two characteristic time sequences, such as engine start and idle. Besides of the loudness, other quality features of the vehicle sounds are in interest of this investigation.

Engine start sound is an important factor influencing the quality impression received from a vehicle. It has a complex nature in time and frequency domain and can emphasize the feeling of a sporty, solid, or a rather cheap, flimsy vehicle. As an example, interior noise spectrograms of two different vehicles that have been recorded during an engine starting condition are shown in Figure 1. Spectrograms were obtained with 32768 FFT points (a: better frequency resolution) and 1024 FFT points (b: better time resolution). Combination and interaction of a number of sources, such as starter motor, intake system and combustion engine cause a number of instationary engine start sounds. A rapid increase of the engine order sound pressure level and frequency gives powerful and sporty feeling (see Figure 1a, time interval: 0.6 – 1.25 sec.). Across a range of engines, there is a large variation of the durations of the different sound source events. Long duration of the starter motor noise and late start of the combustion engine gives impression that the car is powerless and in



a)Vehicle A b)Vehicle B

Figure 1. Interior noise spectrograms during engine start.

need of repair (Figure 1b, time interval:0.25 – 1 sec.). The evaluation of the engine start sound quality is highly interesting and complex because of the interaction of above-mentioned phenomena.

We experience often the idle noise after the engine starting noise in a vehicle, because of their operational order. Combustion engine and ancillary units are mostly dominant sound sources at idle. Therefore one of the characteristic driving conditions which allows to distinguish the kind of combustion engine (diesel/gasoline) is the idle. The vehicles which are equipped with a diesel engine have a typical sound is called "Diesel Impulsiveness". The diesel sound has an impulsive signal component with a periodicity defined by the cylinder firing [11] (Figure 2 a). Another sound character which is typical for the driving condition "Idle" is the rattle. It is mostly caused by the transmission system. Sometimes the combination of transmission system and the engine cause the rattling sound. Besides diesel impulsiveness and rattle, booming is a typical phenomenon for the driving condition idle. The booming noise occurs, when the frequency of excitation from the engine aligns or is very close to an acoustic cavity mode of the vehicle interior (Figure 2b).

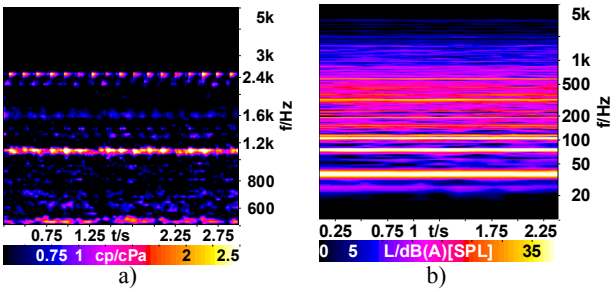


Figure 2. Interior noise spectrograms of two different vehicles that have been recorded during idle condition. a) Relative Approach Analysis. Diesel impulsiveness at 1.1 kHz and 2.5 kHz b) Strongly noticeable engine orders at low frequencies which cause booming.

According to the above-mentioned-background, the following questions arise in this study: what are the relative contributions of the different sound sequences (engine start and idle) to the overall judgment, if we hear these sounds successively? Can one sequence be dominant over the overall assessment? Is the judgment a temporal integration? Do "start", "final" or "extreme" parts of the signal play an important role on the overall judgment? To answer these questions, psychoacoustical experiments were conducted.

EXPERIMENTS AND RESULTS

Twenty subjects, twelve men and eight women, aged between 20 and 47 years, participated in the experiment. The subjects were undergraduate students and university staff. They were paid on a hourly basis.

The binaurally recorded sounds of 12 cars in both driving conditions from different brands with different motorization were selected as stimuli.

To elicit the quality features of the engine start and idle sounds, a free verbalization interview was conducted. In this interview, the sounds were presented and the subjects were asked to describe what they like and dislike about engine start and idle sounds. At the end of the verbalization investigation, 12 different descriptive terms were choosen for the quality evaluation experiments: booming, loud, quiet running, vibrating, rattling, clacking, belling, high (pitch), sporty, grinding, whining, dieselness.

Stimuli were presented in a random order. The engine start and idle sounds were evaluated separately and variously combined. The order of the condition is also randomized between subjects. The questionnaire contained a list of twelve adjectives which are above mentioned. The subjects were asked to describe how they perceive the different attributes on a quasi continuous scale, for which Rohrmann had tested the equidistance of neighbouring categories [12]. A graphical user interface was implemented for the evaluation experiments in Matlab.

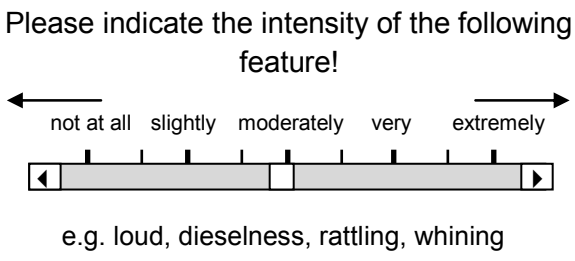


Figure 3. Assesment interface.

RESULTS

The judgments for the attribute rattling on different sound combinations (a: engine start, b: idle and c: engine start & idle) by 20 subjects were averaged and mean scores are shown in Figure 4. The results show that at some stimuli-combinations like vehicle 1 and vehicle 11, the driving condition engine start dominates the overall judgment. At some stimuli-combinations like vehicle 16 or vehicle 14, the driving condition idle dominates the overall judgments. However there are stimuli-combinations, in which the overall judgment is the average of two driving conditions, or additive/subtractive mixtures occur.

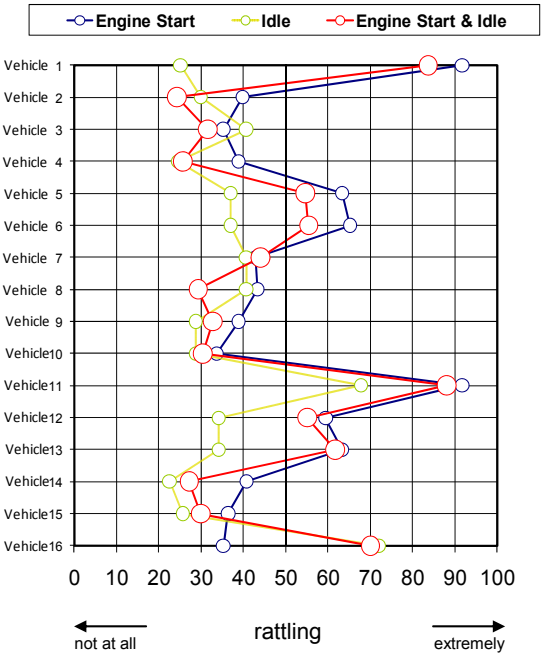
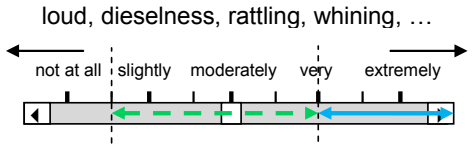


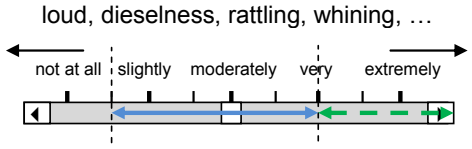
Figure 4. The judgments for the attribute rattling.

The judgments for other attributes show extensive similarities with the results of the attribute "rattling". Therefore it is possible to summarize the results of the investigation and define

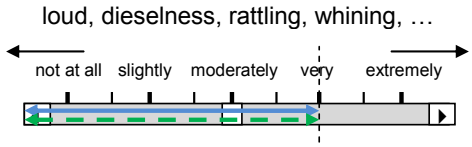
some rules regarding the experience summation of multiple events in Figure 5.



a) If the rating of engine start (⟷) is higher than 75% (~very) and the rating of idle (⟵ ⟶) is between 15% and 75%, engine start dominates the overall judgments.



b) If the rating of idle is higher than 75% and the rating of engine start is between 15% and 75%, the rating of idle dominates the overall judgments.



c) If the ratings of both conditions lower than 75% (~very), different effects like additive, complimentary and subtractive determine the overall judgment.

Figure 5. The rules regarding the experience summation of engine start and idle.

Detailed analysis of the condition c (Figure 5)shows a tendency that if idle obtains a little bit higher rating than engine start, there are often complimentary effects.

It is also possible to observe a tendency that if idle obtains a little bit lower rating than engine start, there are often supplementary effects (Figure 6). Possibly short-term auditory memory is the reason for this supplementary effect, because idle sound was heard always at the end.

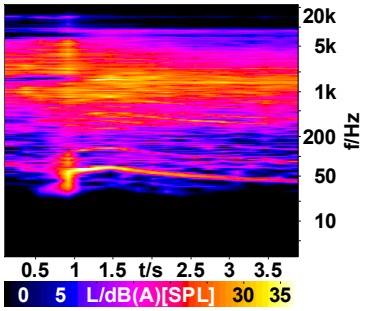


Figure 6. A little bit lower rating for the item booming at the condition idle (68%) than engine start (75%) causes an supplementary effect (overall judgment is 62%).

CONCLUSION

The results of this study show that if the sounds have two characteristic time sequences, the overall judgments are not a priori simple average of two ratings. The weightings of the conditions engine start and idle are dependent on their order and particularly character.

REFERENCES

1 Meunier S. & Marchioni, A. “Loudness of sounds with temporal variable intensity.” In Forum Acusticum 2002- European and Japanese Symposium, 2002

2 Susini, P., McAdams, S. & Smith, B. K., “Global and continuous loudness estimation of time-varying levels”, Acta Acustica, 88, 2002

3 Kuwano, S., Namba, S., Kato T. & Hellbrück, J., “Memory of the Loudness of Sounds in Relation to Overall Impression.“ Acoustical Science and Technology, 2003

4 Susini, P., McAdams, S., and Smith, B. K. “Loudness Asymetries for Tones with Increasing and Decreasing Levels”, Proceedings of ICAD 05-Eleventh Meeting of the International Conference on Auditory Display, Ireland, 2005

5 Teghtsoonian, R., Teghtsoonian, M. Canévet, G. “Sweepinduced acceleration in loudness change and the "Bias for rising intensities" Perception & Psychophysics. 67, 699-712, 2005

6 Kuwano, S. and Namba, S., “Continuous judgment of levelfluctuating sounds and the relationship between overall loudness and instantaneous loudness”. Psychol. Res. 47, 27–37, 1985

7 Fastl, H., “Evaluation and measurement of perceived average loudness.” In: Fifth Oldenburg Symposium on Psychological Acoustics. A. Schick, J. Hellbrück, R. Weber (eds.). BIS, Oldenburg, 205–216. 1991

8 Namba, S., Kato, T., Kuwano, S., “Long-term evaluate on of the loudness of train noise in laboratory situation.” In: 15th International Congress on Acoustics. M. Newman (ed.). Trondheim, Norway, 215–218. 1995

9 Kuwano, S. & Namba S., “On the loudness of road traffic noise of longer duration (20 min) in relation to instantaneous judgment.” J. Acoust. Soc. Am. 64 127–128. 1978

10 Kundera, M., *Immortality*. Grove Press, New York. 1991.

11 Bodden, M. & Heinrichs, R., “Diesel Sound Quality analysis and evaluation” In Forum Acusticum 2005, Budapest, 2005.

12 Rohrmann, B., „Empirische Studien zur Entwicklung von Antwortskalen für die sozialwissenschaftliche Forschung“ Zeitschrift für Sozialpsychologie 9, 1978