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Cross-cultural study on feasible sound levels of possible warning sounds for quiet vehicles

Katsuya Yamauchi[1], Daniel Menzel[2], Hugo Fastl[2],
Masayuki Takada[3], Koji Nagahata[4] and Shin-ichiro Iwamiya[3]

[1] Division of Electrical Engineering and Computer Science, Faculty of Engineering, Nagasaki University
Bunkyo-machi 1-14, Nagasaki 852-8521 JAPAN

[2] AG Technische Akustik, MMK, TU München
Archisstrasse 21, München 80333, GERMANY

[3] Communication Design Science, Faculty of Design, Kyushu University
Shiobaru 4-9-1, Minami-ku, Fukuoka 815-8540, JAPAN

[4] Department of Human Support System, Faculty of Symbiotic Systems Science, Fukushima University
1, Kanayagawa, Fukushima 960-1296, JAPAN

ABSTRACT
Electric and hybrid electric vehicles (EV/HEV) have the advantage of being more environmentally friendly and quieter than internal combustion engine vehicles. However, reduced noise can also lead to potentially dangerous situations for pedestrians when an oncoming vehicle is inaudible due to background noise (e.g. Kerber and Fastl, internoise 2007). The installation of devices that produce warning sounds in vehicles to alert pedestrians is being considered in various countries. Because this is a global topic, it is of vital interest to determine whether there exist cross-cultural differences. Pilot studies on this topic were performed in Japan (Yamauchi *et al.*, internoise 2010) and, with improved input devices and test procedure, in Germany (Menzel *et al.*, DAGA 2011). The level of three possible warning sounds (engine noise, car horn, and band-pass noise) were adjusted in presence of four different urban background sounds (busy street, residential area, heavy traffic, and shopping area) in laboratory environments. In the first part of the experiments, subjects were asked to adjust the level of the warning sounds so that they were clearly audible and could be reliably detected in the background noise. In the second part the goal was to adjust the level so that the warning sounds were just audible. The results of the adjustments showed no significant difference between the two subjects groups. The results were discussed in view of inter-individual and intra-individual differences. Moreover, the results were compared to current recommendations for sound levels of warning sounds in quiet vehicles.
Keywords: Quiet vehicles, warning sound, cross-cultural comparison

1. BACKGROUND OF THE STUDY —QUIET VEHICLE PROBLEM

Electric and hybrid electric vehicles (EV/HEV) are rapidly becoming common. Plugin hybrid, fuel cell and hydrogen cell vehicles are also becoming a reality. The number of these next-generation vehicles is expected to increase following the social demands of greenhouse gas reduction and the realization of a low-carbon society. Actually, the Japanese government has announced their diffusion target for these vehicles and a roadmap in the "Next-Generation Vehicle Strategy 2010" so that these vehicles should account for up to 50% of new vehicle sales in 2020. The German and U.S. governments have established targets of reaching 1 million electric vehicles by 2015.

In addition to being more environmentally friendly, these vehicles are also quieter than internal combustion engine vehicles (ICEV), especially when they are driven at slower speed propelled by

[1] yamauchi@cis.nagasaki-u.ac.jp

electric motors. Therefore, these vehicles are sometimes called "quiet vehicles." The reduce noise is beneficial in environments with high levels of noise. Noise control engineers and automobile manufacturers have been working for many decades to reduce noise generated by these vehicles. This quietness is one of the goals on the noise reduction history of vehicles.

On the other hand, reduced engine noise can also lead to potentially dangerous situations for pedestrians when an oncoming vehicle is inaudible over the background noise (e.g., [1]). The quietness could reduce the audible information used to predict and understand the vehicle behavior. This is of particular concern to the blind community. The National Federation of the Blind (NFB) and the World Blind Union (WBU) have been stated their concerns[2,3]. The Japan Federation of the Blind has stated that many of their members have pointed out the danger of quiet vehicles; for example, many members were startled when a driver of the a hybrid vehicle suddenly honked at them because they were not aware of the vehicle. Moreover, it has been pointed out the possibility of abuse the quietness for crimes. In fact, a snatching incident that a hybrid vehicle were used to sneak up quietly occurred in Japan in 2010. Ironically, we are now facing to new noise problem—a quietness problem.

The installation of a device to provide sound as loud as the conventional vehicles has been discussed as a counter action against the quietness problem. One possible solution to this problem involves using sounds that are emitted from the vehicle to alert pedestrians. There is a considerable amount disapproval of the use of these warning sounds. However, considering the fact that the governments and automobile manufacturers are under a great deal of pressure to take measures to solve the quietness problem immediately, it could be said that providing audible information is one of the most reasonable and realistic solution at the moment. In addition to the fundamental discussions, realistic actions are being taken, such as determining the relevance of sound compensation in quiet vehicles.

Measures to deal with the quietness problem are currently being discussed by many governments. The Japanese and U.S. governments have set up a task force to address this issue. Towards the end of January 2010, the Japanese Ministry of Land, Infrastructure, Transport and Tourism (MLIT) formulated a guideline for the measure against the quietness problem at the end of January, 2010 [4]. The Pedestrian Safety Enhancement Act was approved in December 2010 in United States. As an international agreement of these actions, a special informal group called "Quiet Road Transport Vehicles (QRTV)" was established in 2010 to deal with this problem within the Working Party on Noise (GRB), a subsidiary body of the UN/ECE/WP.29 (World Forum for Harmonization of Vehicle Regulations). The objective of QRTV is "to consider essential to determine the viability of 'quiet vehicle' audible acoustic signaling techniques and potential need for their global harmonization."[5] The QRTV proposed an international guideline on measures to ensure the audibility of hybrid and electric vehicles at the GRB session in February 2011[6]. According to the international guideline, the system is called the "Acoustic Vehicle Alerting System (AVAS)." The guideline proposed by QRTV is essentially based on the Japanese guideline.

According to the Japanese guidelines, an external acoustic warning system should be provided to the vehicle. The system should automatically emit a sound when the vehicle is driven at a speed of less than 20 km/h; the sound should be a continuous sound that evokes the running condition of a vehicle. The guideline does not clearly define the sound level; it just states that "it should not exceed the sound level of the ICEV running at a speed of 20 km/h." The sound level can be read from the subsidiary documents of the guideline so that it should not exceed approximately 60 dB at a 2m distance from the center of the vehicle.

On another front, the automobile industry also has been working to develop a sound device. For example, in 2010, some Japanese automobile manufacturers launched warning systems for their EV/HEVs.

2. AIM OF THIS STUDY

To develop standards or guidelines for a warning system or to design the system itself, a wide range of knowledge on acoustics is needed. Although some studies have been performed to examine the effect of adding sounds to quiet vehicles qualitatively in limited conditions[7–9], the acoustical properties of ideal audible information, including basic issues such as adequate sound levels, are still not known sufficiently. Sekine *et al.* [7] showed the effectiveness of adding sound to the awareness of quiet vehicles. Their experiment was conducted in the very quiet environments (L_{Aeq}=44, 50, and 56 dB). It is still unclear whether the sound level suggested by the guidelines, the warning sounds in such sound level, sound level of the ICEV running at a speed of 20 km/h, can be effective in a real urban environment.

A pilot study on this topic was performed in Japan[10]. The level of three possible warning sounds was adjusted in four different urban background sounds in a laboratory environment. Similar experiments were performed in Germany with an improved input device and test procedure[11]. Since the vehicles are usually sold not only in local market but also worldwide, it is of vital interest to determine whether there exist cross-cultural differences. The authors have designed a cross-cultural examination of sound levels of possible warning sounds for quiet vehicles. In this study, the cross-cultural differences between German and Japanese subjects were examined through experiments similar to the pilot examination. In one experiment, subjects were asked to adjust the level of the warning sounds so that they were clearly audible and could be reliably detected in the background noise. In a second experiment, the goal was to adjust the level so that the warning sounds were just audible. The results of the adjustments for the two subject groups are compared and discussed. Moreover, they are compared to current recommendations for sound levels of warning signals in quiet vehicles.

3. EXPERIMENTAL METHOD

3.1 Stimuli

Four environmental background sounds were recorded in Fukuoka, Japan: a two-lane busy street in downtown area, a two-lane road in a residential area, heavy traffic on six-lane heavy traffic road, and a narrow road in a shopping area. The recordings were performed binaurally using a head and torso simulator (HATS) located on the sidewalk. The A-weighted equivalent sound levels (LAeq) were also measured simultaneously. The measured sound levels and road environmental conditions are shown in Table 1.

Three potential warning sounds were used in this study: a car horn, the sound of an idling gasoline engine, and bursts of band filtered white noise. These sounds were played back over a loudspeaker in an anechoic room and re-recorded binaurally via the HATS to simulate a position 2m diagonally behind the subject. The characteristics of each target stimulus source are shown below.

3.1.1 Horn

The horn sound was obtained from a commercially available CD containing a compilation of sound effects. The duration of the horn was approximately 300 ms.

3.1.2 Engine sound

The idling sound of a 1500 cc gas engine vehicle was recorded in the open air under quiet condition without surrounding buildings. The microphone was set up 2 m behind the vehicle and 1.2 m height avobe the ground. The source duration was 20 s with a 250 ms linear rise and decay.

3.1.3 Broadband noise

The source was filtered white nose with a high-pass filter (with a cutoff frequency of 1 kHz and a slope of 12 dB/octave), and a low-pass filter (with a cutoff frequency of 10 kHz and a slope of 12 dB/octave). The source was then given a temporal pattern consisting of four bursts and a 1400 ms pause. Each burst had a 350 ms onset and a 350 ms pause duration with a 25 ms rise and decay.

3.2 Set-up and procedure

The experiments were performed in a darkened soundproofed booth in TU München in Germany and in a darkened soundproofed room in Nagasaki University in Japan. The experimental setup is shown in Figure 1. The signals were presented dichotically over Sennheiser HD-650 headphones. The input voltage to the headphones was measured, so that, taking into account the headphones' sensitivity, the playback level could be calibrated. Subjects could adjust the level of the warning sounds using a slider visible on a computer screen (Figure 1). The sound presentation was repeated until a button was pressed by the subjects indicating a satisfactory level adjustment.

First, one of the background stimuli was presented, and then about 10 s later one of the warning sounds was overlapped. The subjects were asked to imagine that they were on a road and that the vehicle providing the warning sound positioned 2 m behind them diagonally to the right, as shown in Figure 2. There were two tasks in each experimental session. One task was to adjust the warning sounds so that they were clearly audible and could be safely recognized in the different background sounds even without concentrating. The other task (performed for two of the four background sounds)

Table 1 – Noise level and road environmental conditions of each environmental sound

	L_{Aeq}	Condition
Env.1	65.9	two-lane busy street in downtown, including sound of crowd, female announcement, and ambient music from shops
Env.2	67.8	two-lane street in a residential area
Env.3	73.2	six-lane heavy-traffic road
Env.4	60.4	narrow street in a shopping area

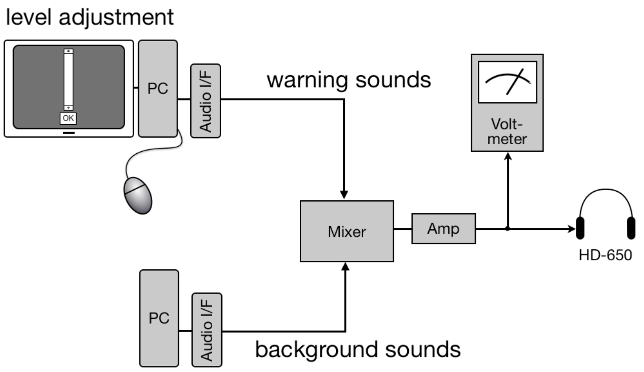

Figure 1 – Experimental setup

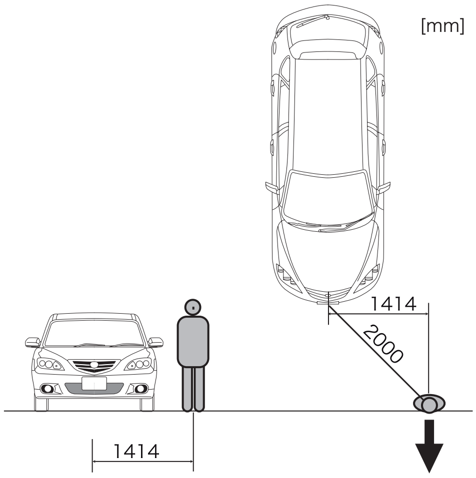

Figure 2 – Assumed relative position between the pedestrian and the vehicle providing warning sounds

was to adjust the warning sounds so that they were just audible. The order of these tasks was switched for each new subject. All stimulus combinations were presented once in pseudo-random order. All subjects took part in a second trial some days later to check for intra-individual differences.

3.3 Subjects

A total of 15 German subjects (4 females, 11 males) between the ages of 26 and 49 years (median 31.3, median 30) participated in the experiment performed in Germany. A total of 16 Japanese subjects (5 females, 11 males) between ages of 23 and 55 years (mean 30.2, median 30) participated in the experiments performed in Japan. None of the subjects had ever been diagnosed with hearing auditory abnormalities during prior routine physical examinations.

4. RESULTS

Figure 3 shows the medians and interquartile ranges of the averaged adjusted levels between two trials per person. The adjusted levels of the Japanese subjects are shown with circle symbols, and those of the German subjects are shown with squared symbols. White symbols indicate warning signals that were adjusted to be clearly audible, and black symbols show warning signals that were just audible. Additionally, the A-weighted equivalent noise levels of the background sounds are marked by horizontal lines. Both the adjusted sound levels for clearly audible and just audible were analyzed by analysis of variance (ANOVA).

The adjusted levels of the German and Japanese subjects are not significantly different for each stimulus condition. The result of ANOVA showed that the main effect of the subjects group (German/Japanese) was not statistically significant. No significant difference between the subjects groups for each background and warning sound combination was found through Tukey's multiple comparison procedure.

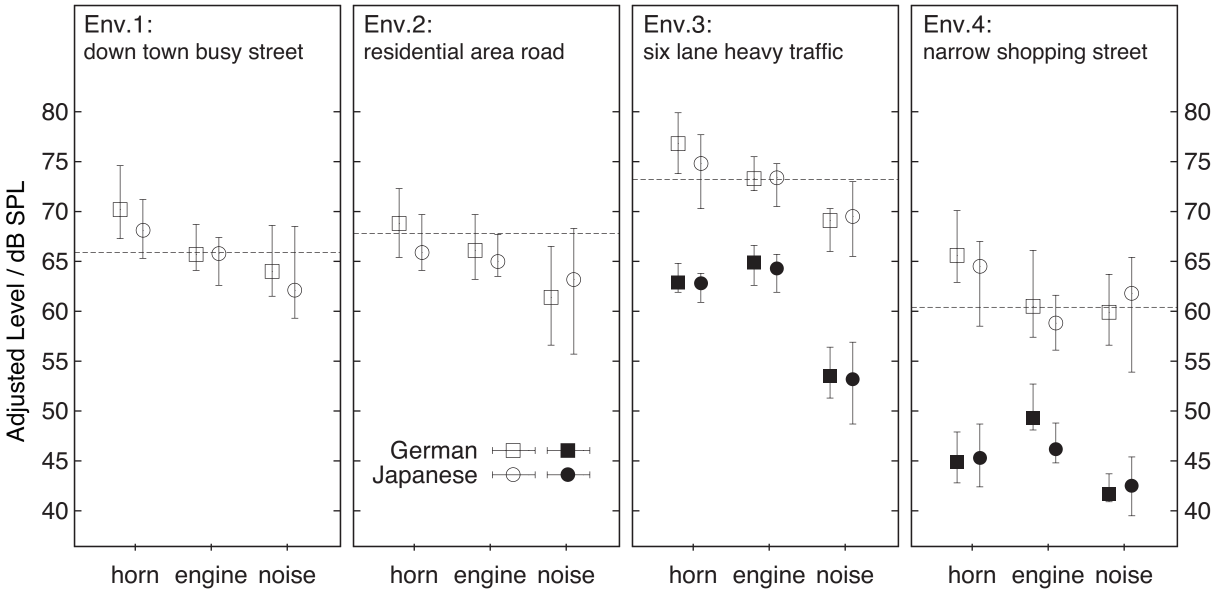

Figure 3 – Medians and interquartile ranges of the averaged adjusted levels between two trials per person. White symbols: warning sounds clearly audible. Black symbols: warning sounds just audible. Horizontal lines: level of environmental background sound.

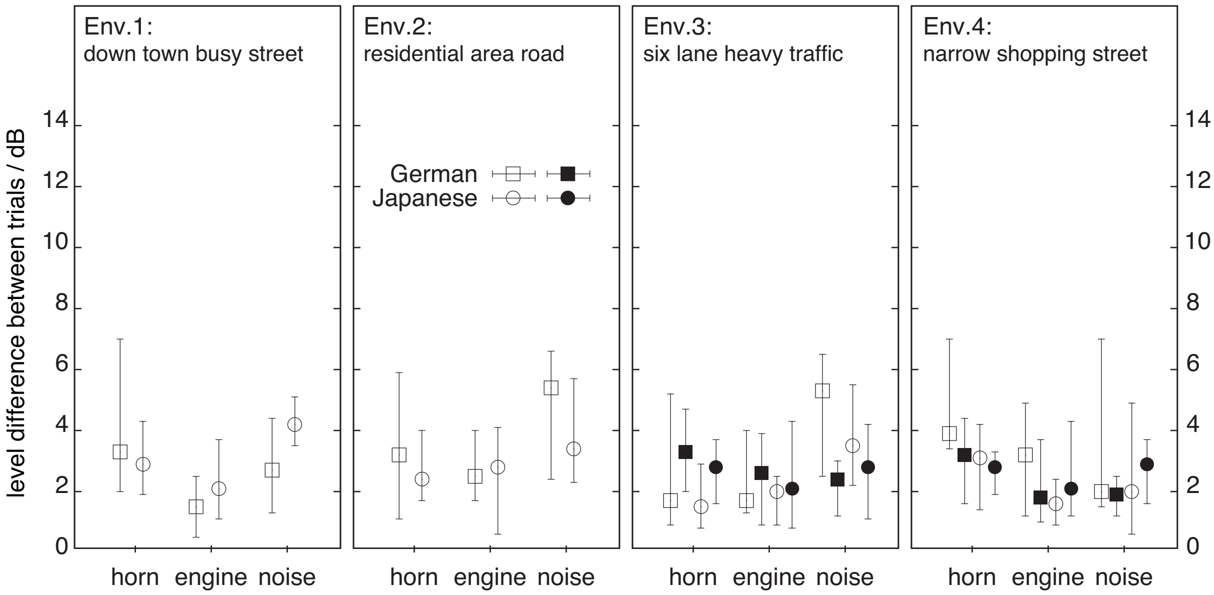

Figure 4 – Medians and interquartile ranges of the absolute level difference between two trials per person. White symbols: warning sounds clearly audible. Black symbols: warning sounds just audible.

The result of ANOVA showed that the main effects of the background and the warning sound conditions were statistically significant ($p < 0.001$). The adjusted levels depend strongly on the level of the background sounds. Differences between adjusted levels for each background sound correspond to the respective differences between the environmental sound levels. It can also be seen that the type of warning sound plays an important role. In each case, a car horn needed a higher level than the other sounds to be clearly audible, while band-limited noise was detectable more easily. The levels of clearly audible warning signals were about 10 to 20dB higher than their respective audibility thresholds.

Inter-individual interquartile ranges can reach 10dB. This rather large variability is likely caused by the strong level fluctuations of the environmental background sounds (e.g. varying numbers of cars passing by on the road). These fluctuations are probably also the reason for the large intra-individual differences between the two trials (Figure 4). Subjects frequently adjusted a sound in the second trial to a level that differed by 5dB or more from the same sound in the first trial.

5. DISCUSSION

The results shown in Fig.3 indicate that there was no significant difference in the adjusted sound levels for warning sounds between two subjects groups. No cross-cultural difference was found in the sound level evaluation. Note that these experiments only deal with the audibility in the environment. Differences in sound quality with regard to such things as annoyance and preference are still open to discussion.

The results also indicate that there is a strong influence of the type of warning sound as well as the background sound on the necessary level of the potential warning signal. A sound with an adequate level that is clearly audible in one environment (e.g., engine sound in a narrow shopping street) may be at the detectability threshold in another background (e.g., car horn in heavy traffic). In the case of engine sound, the levels that are clearly audible are about 10–15 dB higher than the audibility threshold; therefore the sound emitted at an adequate level in a quieter environment might be undetectable in an environment that is 10–16 dB louder.

The adjusted differences in sound level between the two trials frequently reached 5 dB or more. It is thought that there are similar fluctuations in the evaluation of sound level in a realistic scenario. We should consider this 5 dB fluctuation in the discussion of sound level.

It can be seen that recommending only one fixed sound level could be problematic when establishing guideline for the sound levels of warning sounds radiated by vehicles. For example, the Japanese guideline recommends that a warning sound should not exceed the sound level of the ICEV running at a speed of 20 km/h [6], which, according to the subsidiary documents, is below approximately 60 dB at a 2 m distance. Such a sound level might be adequate in one particular environment, but the sound might become inaudible and therefore ineffective in the presence of higher background levels.

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REFERENCES

[1] S. Kerber and H. Fastl, “Perceptibility of approaching vehicles in urban background noise,” Proc. Inter-noise 2007, CD-ROM (2007).

[2] “Key Stakeholders Agree on Measures to Protect Blind Pedestrians from Silent Cars—Urge Passage as Part of Motor Vehicle Safety Act,” National Federation of Blind http://www.nfb.org/nfb/NewsBot.asp?MODE=VIEW&ID=594 (2010)

[3] “World Blind Union comments on Japanese guidelines,” Informal document of UNECE/WP29/GRB/QRTV, QRTV-04-03 (2010).

[4] “Guideline for measure against quietness problem of HV, etc.,” Informal document of UNECE/WP29/GRB/QRTV, QRTV-03-01 (2010).

[5] “Terms of Reference and Rules of Procedures for the GRB working group on Quiet Road Transport Vehicles (QRTV),” Informal document of UNECE/WP29/GRB/QRTV, QRTV-01-02 (2010).

[6] “Proposal for guidelines on measures ensuring the audibility of hybrid and electric vehicles,” Informal documents for the 53rd GRB session, GRB-53-09-Rev.1 (2011).

[7] M. Sekine, T. Tanaka, I. Sakamoto, K. Morita, “Research on the Acceptability Evaluation of Sounds to Warn the Approach of an Electric Vehicle,” Proc. Inter-noise 2009, Paper No.336 (2009).

[8] P. Nyeste, M. S. Wogalter, “On Adding Sound to Quiet Vehicles,” Proc. Human Factors and Ergonomics Society 52nd Annual Meeting, 1747–1750 (2008).

[9] P. Goodes, Y. B. Bai, E. Meyer, “Investigation into the detection of a quiet vehicle by the blind community,” Proc. of Sound Quality Symposium, SQS08-023 (2008).

[10] K. Yamauchi, M. Takada, K. Nagahata, S. Iwamiya, “An Examination on Required Sound Levels for the External Acoustic Sign for Quiet Vehicles,” Proc. Inter-noise 2011, Paper No. 530 (2010).

[11] D. Menzel, K. Yamauchi, F. Völk, H. Fastl, “Psychoacoustic experiments on feasible sound levels of possible warning signals for quiet vehicles,” Fortschritte der Akustik, DAGA 2011, CD-ROM (2011).