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The discomfort model of the micro commercial vehicles interior noise based on the sound quality analyses

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ABSTRACT

The micro commercial vehicles are very popular in the developing areas of China for its capability of loading both cargoes and people. With the demands of customers for improving the comfort of vehicles, it is necessary to develop a discomfort model of noise for the micro commercial vehicles based on the acoustical characteristics of the interior noise, which are different from other passenger cars when they are running in various road conditions. This study investigated the discomfort produced by noise of 3 models of micro commercial vehicles when they are running in 4 types of road conditions, i.e., the asphalt, concrete, gravel and bump road. Seventy-four noise stimuli with the sound pressure levels (SPLs) ranging from 52 to 70 dB(A) were regenerated based on the recorded noise samples for the subjective evaluation experiment. Thirty subjects judged the subjective discomfort of the noise stimuli using the absolute magnitude estimation (AME) method. The relation between the subjective magnitudes of discomfort and the acoustical parameters (i.e., the loudness, sharpness, roughness and articulation index) was analyzed. A tentative equation was obtained by multiple linear regression analysis to predict the discomfort caused by noise of the micro commercial vehicles. The partial correlation analysis was applied to determine the contribution of each psycho-acoustical parameter on discomfort. The results showed that the loudness and sharpness were the influential factors of the discomfort. The subjective magnitudes of discomfort were also transformed into the ratings scales, which were usually employed by car companies.

1. Introduction

The micro commercial vehicles, which can load both cargoes and people, are very popular in the developing areas of China, such as the tier-three cities [1] and towns. Along with the increasing demands of comfort related to the noise and vibration, the design of the NVH (i.e., noise, vibration and harshness) becomes important for the micro commercial vehicles [2,3]. The sound quality analysis plays an important role in the design of NVH of vehicles [2–4].

The sound quality of the passenger cars were extensively researched, including the vehicle interior noise [5–14], engine noise [15,16], and wind buffeting noise [17], *etc*. Brandl and Biermayer developed a software based on the relationship between the subjective evaluations (e.g., annoyance) and objective parameters (e.g., loudness, sharpness, roughness, and articulation index) of passenger car interior noise under all operating conditions [5]. Brizon and Medeiros established a set of comfort index equations of the interior noise between the objective parameters and the subjective numbers based on 5 cars and 2 road conditions [11]. Jiang and Zeng established a quantitative model to describe the sound quality of 8 passenger cars during their accelerating [14]. Duvigneau and Liefold developed a psychoacoustic model of the sound quality of simulated engine noise [16]. Lemaitre and Vartanian proposed an indicator of the unpleasantness of wend buffeting by analyzing relevant data of 19 cars [17]. There were also sound quality studies about other types of vehicles, such as the commercial vehicles [18], heavy commercial vehicles [19,20], electric vehicles [21,22], and hybrid vehicles [23,24], etc.

However, the sound quality of the micro commercial vehicles was rarely studied. As mentioned above, in China most of the micro commercial vehicles are running in the developing areas where the road conditions are complex, including good road conditions such as the asphalt road and concrete road, and poor road conditions such as the gravel road and bump road. The sound quality of the interior noise of micro commercial vehicles are different from that of other types of cars (e.g., passenger cars) because of the differences in structures and driving conditions, so the mature subjective evaluation systems of other types of cars might not be applicable to the micro commercial vehicles directly. Yan and Jiang investigated the contribution of various noise

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sources of the vehicle body panel to the sound quality of interior noise of a micro commercial vehicle running on the asphalt road at constant speeds, and proposed an annoyance prediction model of the micro commercial vehicle based on the A-weighted sound pressure levels (SPLs) [25,26]. However, it might be questionable that the discomfort of noise generated in different road conditions might be different even if the SPLs of the noise are the same, also the discomfort of noise of different models of micro commercial vehicles might be different. It is necessary to investigate the discomfort of noise generated in various types of vehicles when they are running on various types of roads.

The sound quality prediction models are usually established based on the subjective evaluations and the objective measurements. Semantic differential method [8,21,27], rating scale (RS) method [5,7,9–11,13,14,22], paired comparison method [6,16,25,28] and magnitude estimation method [29–33] are commonly used for the subjective evaluation of annoyance and discomfort of noise in vehicles. As one of the magnitude estimation methods, the absolute magnitude estimation (AME) method is straightforward and efficient, and the results are credible and repeatable, and can be transferred to the ranks in the RS systems [30,33].

This study investigated the discomfort produced by interior noise of 3 types of micro commercial vehicles running in 4 types of road conditions (i.e., the asphalt, concrete, gravel and bump road). The hypotheses were: (1) the discomfort increased with increasing SPLs; (2) the discomfort of noise at the same SPLs generated in different road conditions are different; (3) the discomfort of noise at the same SPLs generated in different types of vehicles are different. The AME method was used in the subjective evaluation experiment, and the subjective magnitudes were tested by the non-parametric statistical method. The sound quality of various noise were analyzed and the multiple linear regression method was applied to establish the relationship between the subjective magnitudes and the objective parameters, including the physical parameter such as the SPLs and the psychophysical parameters such as the loudness, sharpness, roughness and the articulation index. Considering that the car companies often use the RS systems, the subjective magnitudes were also transformed to the RS ranks.

2. Methods

2.1. Subjects

Thirty healthy subjects (15 males and 15 females), with median age 24 years (range 21–34 years), stature 1.69 m (range 1.50–1.83 m), and weight 58.5 kg (range 45–80 kg) volunteered to attend the experiment.

The hearing test was carried out in the semi-anechoic room before the formal experiment to insure that all participants had normal auditory. The normal auditory was demonstrated if the subject could perceive the 1000 Hz tone at SPL of 20 dB.

2.2. Apparatus

The experiment was conducted in the semi-anechoic room. Each subject sat on a chair with a pair of headphones (SENNHEISER HD250, Germany) during the experiment (Fig. 1). The software Adobe Audition CS6 in a laptop (Lenovo G470, China) was used to play and control the stimuli. A digital-to-analog converter with headphone amplifier (ORAVA UA01, China) was connected to the laptop to output the stimuli and drive the headphones. The subjects inputted the numerical values of the discomfort via a wireless keyboard (ECOLA NT-21WL, China) connected to a recording laptop (IBM T401, China). The connection diagram of the experiment set-up is shown in Fig. 2.

Fig. 1. Subject on the chair.

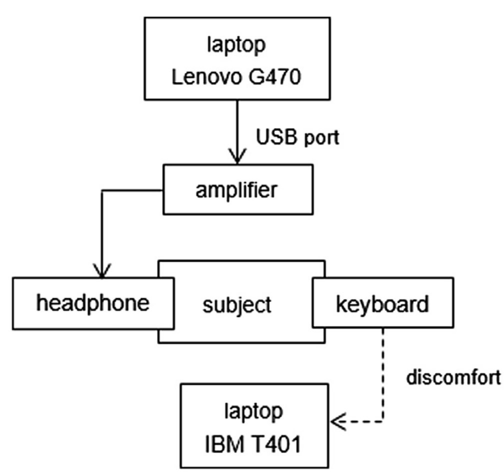

Fig. 2. Connection diagram of the experiment set-up.

2.3. Stimuli

The noise signals were recorded by the artificial head at the ear positions of the co-driver of 3 types of micro commercial vehicles driving in 4 types of road conditions (i.e., the asphalt, concrete, gravel and bump road). The running speeds of the 3 vehicles were 70 km/h on the asphalt road and concrete road, 30 km/h on the gravel road, and 10 km/h on the bump road, respectively. Twelve sound samples were selected from the noise records, with each sample representing a noise condition of one vehicle running in one road condition. The frequency spectra (with the sampling frequency 48,000, FFT length 8192, overlap