Experimental study on the sound exposure when listening to portable audio player in vehicles

Sakae Yokoyama
Institute of Industrial Science,
University of Tokyo
Komaba 4-6-1, Meguro-ku, Tokyo 153-8505 Japan

Hiroo Yano
Chiba Institute of Technology
Tsudanuma 2-17-1, Narashino, Chiba 275-0016 Japan

ABSTRACT
It is popular to enjoy music through portable audio player in vehicles and airplanes. Under such noisy conditions, listening sounds through headphones/earphones with a big volume for a long time can damage the listener’s hearing. To investigate the sound exposure in such cases, experimental studies were performed in this study. As a preliminary study, a field experiment was performed in passenger trains, in which the subjects were asked to listen to music through earphones by adjusting the listening level as they pleased. The level was measured afterward using a head-and-torso simulator with built-in ear-simulators. As a laboratory experiment, the listening condition was simulated in an anechoic room where the environmental noises recorded in trains, buses and an airplane were reproduced by using the 6-channel recording/reproduction technique and listening experiments were performed in the same manner as in the field experiment mentioned above. The experimental results of the listening level were examined with the noise level under the surrounding conditions.

1. INTRODUCTION
It has become a recent fashion among young people to listen to music through earphones by portable audio-players. In such environments as in vehicles and airplanes where the noise level is considerably high, the reproduction volume tends to be high, and there is a possibility of hearing
impairments. In reference [1], usual listening level through personal earphones was examined experimentally, but the influence of the environmental noise surrounding the listener was not considered. Authors have studied the optimum level of radio/music through car-audio system in passenger cars under the condition with running noise by laboratory experiments [2], though earphones were not used to reproduce the sounds. In this study, to investigate the actual condition when listening to music through earphones under such environmental conditions, a preliminary experiment in a passenger train and laboratory experiment using a 3-D sound field simulation system were performed.

2. FIELD EXPERIMENT IN A PASSENGER TRAIN
To investigate the actual condition of listening to music using a portable audio player, a preliminary experiment was performed in real trains as follows.

A. Experimental Procedure
The experiment was performed in passenger trains running at a speed of about 90 km/h. In the train, the test subject stood near a door and was asked to listen to the test music through an intra-concha type earphone-set by controlling the reproduction volume freely as he liked by click-stop type volume controller. The listening time for each subject was about ten minutes. During the experiment, the noise level around the subject in the train was measured using a sound level meter by the experimenter. As the test sound used in this experiment, a popular music (male vocal, 5 minutes 40 seconds) was chosen in order to unify the experimental condition. In the listening test, the music was automatically repeated. After the experiment in the train, the volume position adjusted by respective subjects was recorded. This experiment was performed for three days and ten 20s male university students participated.

B. Environmental Noise in a Passenger Train
After the field experiment, the noise in the passenger train for about ten minutes recorded on a DAT was reproduced and the A-weighted SPL ($L_{pA}$) was analyzed. As a result, the time-averaged $L_{pA}$ was about 75 dB during the steady running, in which not only running noise but also surrounding passenger’s talking was included.

C. Listening Level
To see the listening level adjusted by each subject in the train, the intra-concha type earphones used in the experiment were installed in the outer-ears of ear-simulators (B&K 4158-C for right ear, 4159-C for left ear) of the head and torso system (HATS; B&K 4128-C) as shown in Figure 1a, and the test sound was reproduced from the portable audio player at the same volume as adjusted by each subject in the train. As a result, Figure 2 shows the frequency of the optimum listening level measured in time-averaged $L_{pA}$ ($L_{pA,T}$) during the listening experiment, in which the highest frequency of the listening level was in the range of 65 dB to 70 dB. In the result, the difference among all of the ten subjects was more than 20 dB; the lowest adjusted listening level of music was about 64 dB and the highest one was about 87 dB.
3. LABORATORY EXPERIMENT

To further investigate the listening level when using portable audio players in various transportation vehicles and airplanes, a laboratory experiment was performed as follows.

A. Simulation of Sound Environments in Laboratory

In this experiment, it was aimed to investigate the listening level in various kinds of vehicles. However, it is almost impossible to perform such a field experiment in real vehicles as mentioned above, and therefore a laboratory experiment was performed by applying the 6-channel recording/reproduction technique [3,4] to simulate the sound environments in various vehicles (see Figure 3). In this sound field simulation technique, the sound in a real sound field is recorded through a 6-channel microphone system consisting of six cardioid-type directional microphones and the recorded sound is reproduced through six loudspeakers set in an anechoic room. As a result, the listener sitting at the center of the reproduction system can get natural aural-sensation with real spatial impression.

B. Sounds in Vehicles Used in the Experiment

Using the 6-channel recording technique, the sounds in three passenger trains, three subway trains, a super-express train (Shinkansen), two buses and a passenger jet-plane were recorded.
onto a 8-channel DAT through the 6-channel microphone system (Sanken, CU-6CH). In the vicinity of the system, an omni-directional microphone of a sound level meter was set to measure the sound pressure at the receiving position. When recording these sounds, the receiving system was set at a height of 70 cm above the seat. The recordings in passenger trains, subways and buses were performed during usual service in daytime. Those in the Shinkansen super-express train and the jet-plane were performed under vacant seat condition by getting special permission. Table 1 shows the list of the sounds in these transportation vehicles.

C. Listening Experiment

In the laboratory experiment, two types of earphones were used: an intra-concha type earphone-set (Apple, MA662G/B) and a closed type headphone-set equipped with active-noise-cancelling function (SONY, MDR-NC500D). The listening experiment was performed under respective environmental sound conditions shown in Table 1. These sounds were reproduced from the 6-channel reproduction system for 60 seconds by adjusting the reproduction level at the listening position so as to be equal to the level in respective real environments. Under each environmental sound condition, the subject was asked to listen to the music on the earphones/headphones and to adjust the reproduction level freely as he liked with a remote-control attenuator. As the test music, the same one used in the preliminary experiment was used in this experiment, too. In the experiment, the subjects were asked to image the situation of listening to the music in respective environments. Each condition was repeated twice in random order and 10 second interval was put between respective conditions. After listening, the level adjusted by each subject was recorded for each condition. In the experiment using the intra-concha type earphones, sixteen male university students participated and in that using the headphones, one of them could not join. After the listening experiment, the subjects were asked to answer two questions: (1) Are you satisfied by the volume of the music ? (in 5-step category; “1. extremely satisfied”, “2. very satisfied”, “3. moderately satisfied”, “4. a little satisfied”, “5. not satisfied at all”), and (2) Do you think the sound environment is proper for listening to music with earphones/headphones ? (yes or no).

Figure 3: Outline of the 6-channel recording/reproduction system.
Table 1: Experimental conditions

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Seat Condition</th>
<th>$L_{pA,60s,evrm}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger train “A”</td>
<td></td>
<td>77.0</td>
</tr>
<tr>
<td>Passenger train “B”</td>
<td></td>
<td>74.6</td>
</tr>
<tr>
<td>Passenger train “C”</td>
<td>usual service</td>
<td>66.9</td>
</tr>
<tr>
<td>Subway train “D”</td>
<td></td>
<td>83.8</td>
</tr>
<tr>
<td>Subway train “E”</td>
<td></td>
<td>82.2</td>
</tr>
<tr>
<td>Subway train “F”</td>
<td>usual service</td>
<td>78.5</td>
</tr>
<tr>
<td>Super-express train</td>
<td>vacant</td>
<td>64.8</td>
</tr>
<tr>
<td>Bus “A”</td>
<td>usual service</td>
<td>67.3</td>
</tr>
<tr>
<td>Bus “B”</td>
<td></td>
<td>59.8</td>
</tr>
<tr>
<td>Passenger jet-plane</td>
<td>vacant</td>
<td>72.2</td>
</tr>
</tbody>
</table>

D. Experimental Results

The listening level adjusted by each subject for each experimental condition was reproduced in the same manner as described before by putting the earphones/headphones on the ear-simulators (see Figures 1a and 1b) and the time-averaged A-weighted SPL for 60 seconds ($L_{pA,60s}$) under the condition without the environmental sound was measured. The arithmetical mean of the measurement results was calculated for each experimental condition. As for the effect of the environmental sound on listening to music, Figures 4a and 4b show the relationship between the arithmetic-average of the listening level in time-averaged A-weighted SPL ($L_{pA,60s,music}$) and the level of the environmental sound ($L_{pA,60s,evrm}$) for respective listening conditions using the earphones or the headphones. In these results, it is seen that the listening level increases with the increase of the environmental sound but the gradient of level increase is much less than 45 degrees in both listening conditions; that is the increase in the optimum level of music is about 3.5 dB (earphones) or 3.0 dB (headphones) against 10 dB environmental sound level increment.

![Figure 4: Relationship between the listening level ($L_{pA,60s,music}$) and the environmental sound level ($L_{pA,60s,evrm}$).](image-url)
Figures 5a and 5b show the result of the response to the questionnaire (1), in which it is clearly seen that the degree of satisfaction in listening to music decreases with the increase of the environmental sound in both listening conditions using the earphones and headphones. When comparing the results for these two conditions, the degree of satisfaction when using the headphones is higher than the case using the earphones. In these results, it is seen that the response of category 3, “moderately satisfied”, appears when the environmental sound becomes 76 dB (when using the earphones) or 82 dB (when using the headphones) in $L_{pA,60s,evrm}$. This might be attributed to the effect of active noise cancelling function of the headphones. For the response to the questionnaire (2), as shown in Figures 6a and 6b, the rate of negative response (do not want to listen to the music) is less than 20 % under the conditions where $L_{pA,60s,evrm}$ is lower than 75 dB (earphones) and 80 dB (headphones), respectively, whereas under the condition where $L_{pA,60s,evrm}$ is about 85 dB, the response is over 80 % (earphones) and 50 % (headphones).

**Figure 5:** Relationship between the degree of satisfaction and the environmental sound level ($L_{pA,60s,evrm}$).

**Figure 6:** Relationship between the percentage of negative response and the environmental sound level ($L_{pA,60s,evrm}$).
4. CONCLUSIONS

Regarding the problem of listening to portable audio-players in transportation vehicles and airplanes, a preliminary field test in a real train and a systematic laboratory experiment were performed in this study. As a result of the field experiment, it has been observed that the preferred listening level much varied according to differences among individuals as was expected before the experiment. From the results of the laboratory experiment simulating the sound environments in various kinds of vehicles, it has been found that although the listening level through earphones or headphones increases with the increase of the environmental sound, the rate of increasing the listening level is much smaller than that for the increase of the environmental sound. In the experimental results, it is seen that the sense of disturbance by the environmental sound apt to appear at around 75 dB for using an intra-concha type earphone-set and 80 dB for using a closed type headphone-set.

REFERENCES