Influence of hearing attitude difference on sound quality evaluation of vacuum cleaner sound

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Abstract: Robot vacuum cleaner, which cleans rooms automatically, is a useful appliance that helps house work. The radiated sound should be soft for comfortable living. When we think about hearing situations, we hear sound passively because a robot vacuum cleaner moves automatically without external control indication. On the other hand, when we use a conventional vacuum cleaner, the sound is perceived actively because we operate it ourselves. This hearing attitude difference may affect the perception of sound. In this study, we attempted to clarify the difference in the degree of uncomfortable under different hearing conditions by subjective evaluation tests. In the tests, we prepared the above-mentioned two hearing conditions for the evaluation of the radiated sound. The results showed that the participants felt more uncomfortable under passive hearing condition than under active hearing condition.

Keywords: Vacuum cleaners, Active and passive condition, Subjective evaluation, Uncomfortableness

1. INTRODUCTION

Robot vacuum cleaners (RVCs) are useful appliances that clean rooms automatically without any external control [1–3]. Such vacuum cleaners have become more popular recently. Both cleaning performance and quietness are important features of these vacuum cleaners [4–9] because they are sometimes used when residents are stay at home and the sound may disturb oral communication [10]. On the other hand, the hearing condition for RVCs is different from that for conventional vacuum cleaners. In the case of RVCs, we hear the radiated sound passively because we don’t operate it ourselves. In contrast, we generally operate conventional vacuum cleaners ourselves. Hence, we hear the sound under active condition. This hearing attitude difference may affect the perception of the radiated sound [11–13]. If the difference is marked, the RVCs should be set appropriate target sound level during their development phase.

In this study, we carried out subjective evaluation tests to investigate the perception of the sound radiated by vacuum cleaners under active and passive hearing conditions.

2. SUBJECTIVE EVALUATION TEST

2.1. Active and Passive Hearing Conditions

To carry out subjective tests under active and passive hearing conditions, it is necessary to evaluate identical sound. However, setting up the tests for RVCs sound under active hearing condition is impossible because they move automatically. Therefore, we employed conventional cordless vacuum cleaners having similar radiated sound characteristics with RVC [10] for subjective evaluation tests under active and passive hearing conditions. Figure 1 shows a schematic of subjective evaluation tests for both conditions.

In tests under the active hearing condition, a participants wore headset microphones (Headacoustics BHS I) a few centimeters upper from their ears not to disturb hearing real sound as shown in left part of Fig. 1. The headset did not reproduce any sounds but recorded the sound for the following test under passive hearing condition as shown in right part of Fig. 1. The participants freely cleaned a limited area using a conventional cordless vacuum cleaner and evaluated the real radiated sound.

2.2. Vacuum Cleaners Employed and Stimuli Presented

In the subjective evaluation tests, two conventional cordless vacuum cleaners and two surfaces were prepared. Figures 2(a) and 2(b) show the vacuum cleaners and
surfaces employed for cleaning under the active hearing condition, respectively.

The radiated sound at each vacuum cleaner on each surface (total, four experimental combinations) was evaluated. To investigate the difference in the perception of sound between active and passive hearing conditions, the evaluated sound must be the same. However, the replayed sound under the passive hearing condition may be different from the evaluated sound (real sound) in the test under the active condition due to the slight different microphone attachment point as shown in left part of Fig. 1 and the reproduce frequency characteristic of the headset. Then, we compared the sound under the active and passive conditions using artificial head microphones (Headacoustics HMS2) for each of the four experimental combinations. Figure 3 shows results for two experimental combinations.

Figures 3(a) and 3(b) show the comparison of cleaner A on the carpet surface and cleaner B on wooden surface, respectively. The dashed and solid black lines indicate the sounds under the passive and active hearing conditions, respectively.

2.3. Procedures and Participants

To carry out the subjective evaluation under both hearing conditions, the following procedures were carried out.

**Active test procedure**

Step1: A participant wore headset microphones on his/her ears for recording.

Step2: He/she cleaned a limited area (0.3 m × 0.3 m) for 10 s using a cordless conventional vacuum cleaner and the radiated sound was recorded by the microphones.

Step3: He/she evaluated the uncomfortableness caused by the sound on an answer sheet by checking the box that best indicated the degree of the uncomfortableness among the seven categories shown in Fig. 5. The number corresponding to the checked box was used as the uncomfortable score in the following analysis.

**Passive test procedure**

Step1: A participant wore headset microphones on his/her ears.

Step2: He/she evaluated the uncomfortableness caused by the replayed sound as described in Step3 above.
In the tests, 22 males and two females Japanese in their 20’s participated. Each participant underwent the tests under active and passive conditions in four experimental combinations (two vacuum cleaners × two surfaces) five times in total during each active and passive condition. Hence all 24 participants evaluated total 480 times under each active and passive condition.

### 3. RESULT

#### 3.1. Difference of Uncomfortableness

We analyzed the scores obtained to investigate the difference in the uncomfortableness between the active and passive hearing conditions. Figure 6 shows the average score of all participants under both conditions.

Filled and open bars in Fig. 6 show the average uncomfortable scores under active and passive conditions, respectively. The error bars indicate the standard errors. As shown in the figure, the uncomfortableness score under the passive hearing condition was higher than that under active hearing condition and the difference (0.93) was significant ($p < 0.05$). This result shows that the participants felt more uncomfortable under the passive condition than under the active one significantly even though the presented sound was the same.

Subsequently, we attempted to obtain the uncomfortableness difference in each participant and estimate the difference quantitatively using $L_{Aeq}$ in the following section.

#### 3.2. Relationship between SPL and Uncomfortableness

We evaluated the relationship between $L_{Aeq}$ of the vacuum cleaner sound and the uncomfortable score in each participant under each condition. Figure 7 shows scatter diagrams.

Filled and open circles show the score under active and passive conditions, respectively. As shown in these figures, the uncomfortable scores under the passive condition were generally higher than those under the active condition in most participants and the average score under the passive condition was higher than that under the active condition in 21 participants among 24 participants. However, the relationship between the uncomfortable score and $L_{Aeq}$ was various for participants due to the small sample size and the various $L_{Aeq}$ range of the sound in each participant’s active test. Then, we used all participants’ scores to obtain general tendency under each hearing condition. For estimating $L_{Aeq}$ difference to the same uncomfortable score under different hearing condition, we made the scatter diagram again using all uncomfortable scores and $L_{Aeq}$ for all participants as shown in Fig. 8. And then, we calculated y-intercept under each condition using least mean square method. About the slope, we averaged all slopes obtained from each participant’s scatter diagram as the common slope for both conditions according to the statistical test result about the slope difference between active and passive conditions was not significance. Figure 8 shows the obtained relationship under each condition and the scores for all participants.

Small filled and large open circles show the scores under active and passive hearing conditions, respectively. Gray solid and black dotted lines are their linear regression
fitting results. As shown in the figure, an apparent difference was observed. The line of the passive test (black dashed line) placed about 5 dB left side from the line of the active test (gray solid line). This indicates that even though the $L_{Aeq}$ of the sound under passive hearing condition was 5 dB smaller than that under active hearing condition, the uncomfortableness caused by the sound was similarly evaluated. This also suggests that the target sound level under the passive condition such as RVCs should be decreased by about 5 dB compared with conventional vacuum cleaners during their development phase.

4. CONCLUSIONS

In this study, we investigated the influence of the hearing attitude difference on the degree of uncomfortableness caused by the radiated sound of vacuum cleaners. To this end, subjective evaluation tests were carried out on the participants under the active and passive hearing conditions. In the test under active hearing condition, the participants used the vacuum cleaner and evaluated their degree of uncomfortableness caused by the sound. In the test under the passive hearing condition, they evaluated the replayed sound recorded under the active condition and evaluated the sound quality. The results showed that the degree of uncomfortableness was significantly higher under passive condition than that under active condition. In addition, the uncomfortableness difference was estimated as 5 dB in $L_{Aeq}$. This indicates that when we develop RVCs whose sound is perceived under passive condition, the target level should be decreased by 5 dB compared with that of the conventional vacuum cleaner.

REFERENCES

[1] I. Ulrich, F. Mondada and J.-D. Nicoud, “Autonomous vacuum cleaner,” Rob. Auton. Syst., 19, 233–245 (1997).
[2] E. Prassler and K. Kosuge, “Domestic robotics,” in Springer Handbook of Robotics, B. Siciliano and O. Khatib, Eds. (Springer, Berlin, Heidelberg, 2008), pp. 1253–1281.
[3] E. Prassler, A. Ritter, C. Schaeffer and P. Fiorini, “A short history of cleaning robots,” Auton. Robots, 9, 211–226 (2000).
[4] J. G. Ih, D. H. Lim, S. H. Shin and Y. Park, “Experimental design and assessment of product sound quality: Application to a vacuum cleaner,” Noise Control Eng. J., 51, 244–252 (2003).
[5] H. Yanagisawa, A. Kataoka, T. Murakami, K. Ohtomi and R. Hosaka, “Extraction of latent emotional factors by analyzing human sensitivity towards unexplored design: Application to product sound design,” Proc. ICED 09, pp. 13–24 (2009).
[6] M. Takada, S. Arase, K. Tanaka and S. Iwamiya, “Economic valuation of the sound quality of noise emitted from vacuum cleaners and hairdryers by conjoint analysis,” Noise Control Eng. J., 57, 263–278 (2009).
[7] R. Jurc, O. Jirick and M. Broňánek, “Methods for the assessment of pleasantness in sound quality,” Noise Control Eng. J., 58, 62–66 (2010).
[8] P. Wang, J. Tao and X. Qiu, “Noise control in the exhaust port of a vacuum cleaner,” J. Acoust. Soc. Am., 131, 3471 (2012).
[9] N. A. Jafar, W. M. A. W. M. Ali and L. E. Ooi, “Noise reduction using flax and kenaf for household vacuum cleaner,” J. Eng. Sci. Technol., 13, 3566–3576 (2018).
[10] J. Yoshida, I. Hatta and R. Yamashita, “Noise evaluation method for robot vacuum cleaners and the target setting,” Proc. ICSV 25, pp. 1–8 (2018).
[11] M. Yamaguchi, Y. Watanabe, O. Maeda, N. Okubo and T. Toi, “Impression change of EV driving sound in consideration of audio-visual information and driving intention,” Trans. Soc. Automot. Eng. Jpn., 45(5), 859–864 (2014).
[12] T. Komogawa, A. Arimitsu, C. Kizawa, M. Gunji and T. Toi, “Evaluation of acceleration feel in each acceleration section by the change of acceleration sound,” Trans. Soc. Automot. Eng. Jpn., 47(6), 1381–1386 (2016).
[13] I. Hatta, S. Okuno, J. Yoshida, P. P. Martinez and J. R. Soriano, “Uncomfortableness to vacuum cleaner noise according to the mental state between active and passive situation,” Proc. Internoise 2019, pp. 1–11 (2019).