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Uncomfortableness to vacuum cleaner noise according to the mental state between active and passive situation

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ABSTRACT

Robot vacuum cleaner which cleans rooms automatically is useful products to reduce house work time. At the development phase of vacuum cleaners including the robot cleaners, the radiated noise reduction is essential. Generally, when we are exposed by the radiated noise of conventional type cleaners, the noise is perceived actively because we clean room by ourselves and we can expect the motion. On the other hand, robot vacuum cleaner moves automatically without our indication, hence we hear the noise passively. Therefore, this difference of mental state may make difference of uncomfortableness to the vacuum cleaner's noise. If there is significant difference between them, the target level of the radiated noise of robot cleaners should be set considering the difference. In this study, the aim is to reveal the difference in uncomfortableness of different mental state using subjective evaluation test. In the test, we prepared the above mentioned 2-mental state using cordless type vacuum cleaners and the participants evaluated the uncomfortableness in each condition. The result showed the participants felt more uncomfortable in passive condition than active condition. Consequently, we found that lower target sound pressure level had better to be set for robot vacuum cleaners than the conventional cleaners.

Keywords: Vacuum cleaners, Active and passive condition, Subjective evaluation, Uncomfortableness
I-INCE Classification of Subject Number: 61, 63

1. INTRODUCTION

Robot vacuum cleaners (RVCs) are known to be useful appliances which clean room automatically without any indications[1-2]. Recently, the cleaners are becoming more popular all over the world[3]. Accordingly, requirements about the performance will

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increase by the increase of the popularity. Concerning with the performance of the robot vacuum cleaners, not only the cleaning performance but also the quietness is one of the important performances because the cleaners are sometime used when the resident stay at home and the noise has a possibility to disturb the auditory communication[4-6]. On the other hand, the hearing situation of RVCs is quite different from those of conventional type cleaners. In the situation when we use RVCs, we hear the radiated noise passively because we don't operate it by ourselves. On the contrary, the conventional vacuum cleaners are generally operated by the users. Hence, they hear the noise in active mental situation. This mental state difference in the hearing condition may affect the impression to the radiated noise. If the difference is not negligible, we had better to set appropriate the target noise level of the RVCs considering the influence in the development phase.

In this study, we carried out subjective evaluation tests to investigate the impression to the radiated noise of vacuum cleaners in the different mental state (active and passive hearing). In addition, we carried out this subjective evaluation test in Japan and Spain to investigate and compare the influence in different countries.

2. PREPARATION OF SUBJECTIVE EVALUATION TEST

2.1 Active and passive hearing situation

To carry out subjective tests in different mental state (active and passive haring conditions), it is necessary to evaluate the same noise in different hearing situation. However, preparing the situation for hearing RVC noise in active condition is impossible because RVC moves automatically and does not need our operation. Accordingly, we decided to employ cordless vacuum cleaners for the subjective evaluation test to make both active and passive hearing conditions. Figure 1 shows the subjective evaluation test image for the both conditions.

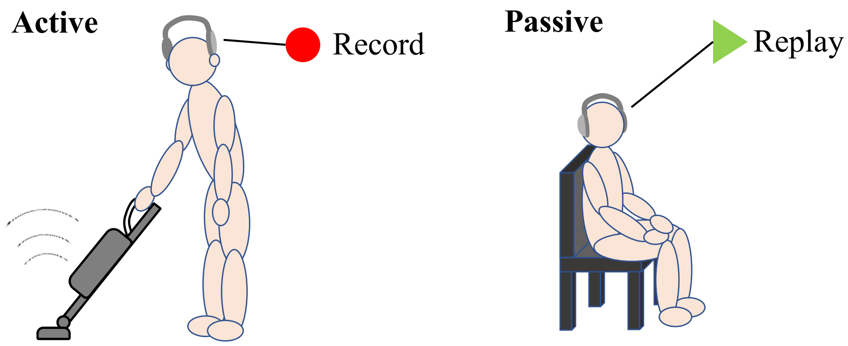
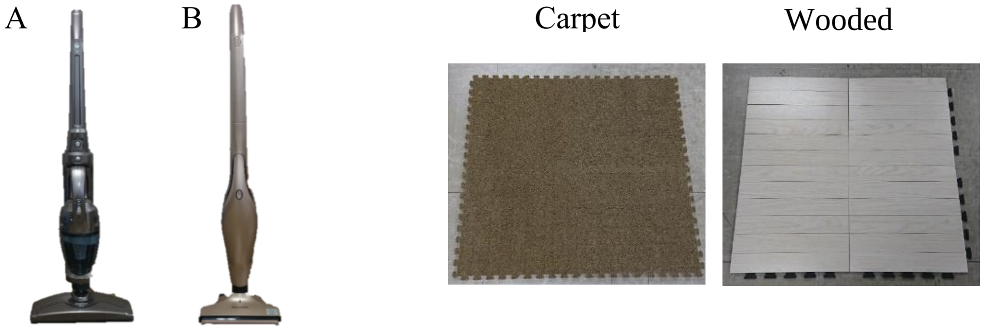


Fig. 1 Image of subjective evaluations test for active and passive hearing conditions.

In the active situation test, the participant wearing head-set type microphones (HEAD acoustics BHS Ⅰ) cleaned a limited area as they like using the cleaner and evaluated the radiated noise as the active situation evaluation. In addition, the radiated noise was recorded by the microphones as shown in left side of Fig. 1 and the noise was replayed to the participant in the passive situation test as shown in right side of Fig. 1.

2.2 Employed vacuum cleaners and presented stimulus

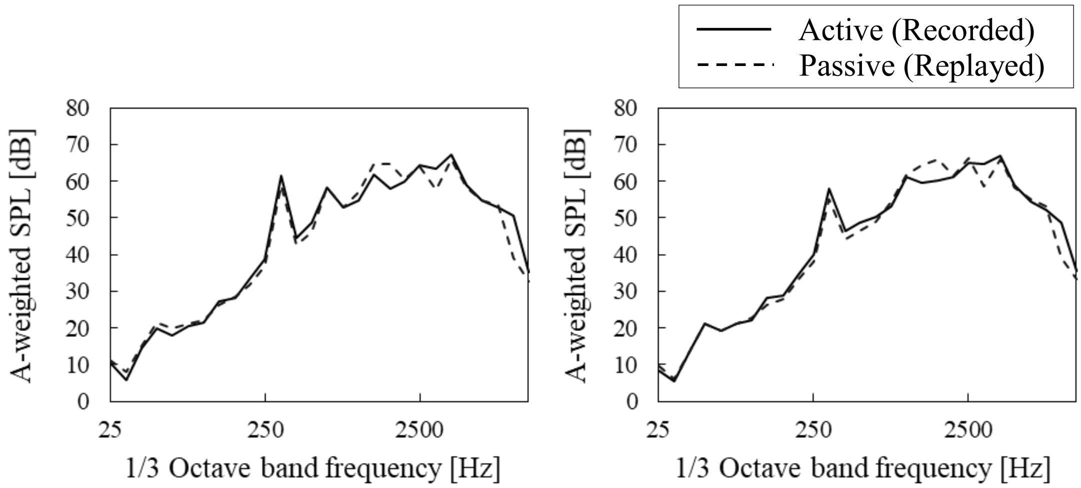
In the subjective evaluation test, two vacuum cleaners and two surfaces were prepared. Figure 2 (a) and (b) show the employed cleaners and surfaces for cleaning in the active test, respectively.



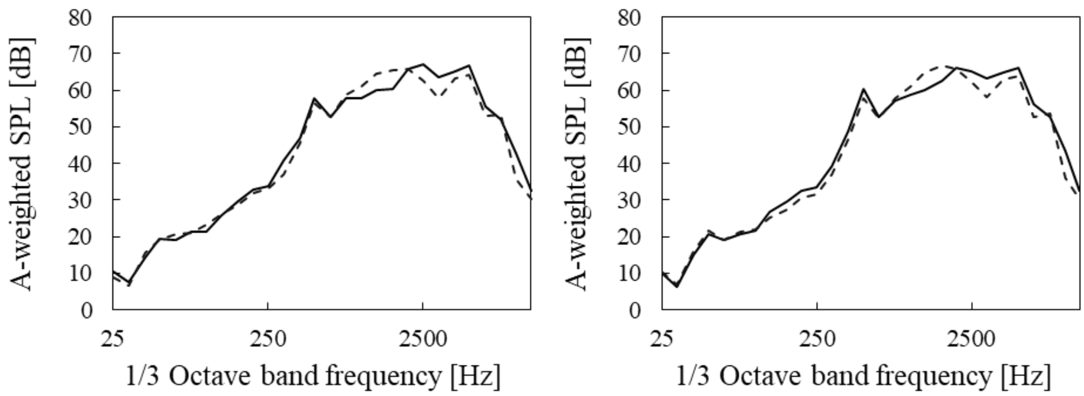
(a) Employed cleaners *(b) Employed surfaces*

Fig. 2 Employed cleaners and the surfaces for evaluation.

The radiated noise at each vacuum cleaner on each surface (total four sounds) was evaluated in the test. To investigate the impression difference to the noise between active and passive hearing conditions, the evaluated noise at both conditions must be the same. However, the replayed noise in the passive test may be different from the evaluated noise in the active test by the slightly different positions of their ear and the head-set microphone attachment position as shown in Fig. 1. Then, we compared the noise at the active condition and the passive condition using an artificial head microphone (HEAD acoustics HMS2) in each four condition. Figure 3 shows the comparison.



(a) Cleaner A on the carpet *(b) Cleaner A on the wooded*



(c) Cleaner B on the carpet *(d) Cleaner B on the wooded*

Fig. 3 Comparison of recorded and replayed sound.

Figure 3 (a), (b), (c) and (d) show the comparison of cleaner A on the carpet surface, cleaner A on wooded surface, cleaner B on carpet surface and cleaner B on wooded surface, respectively. The dotted and solid black curves indicate the noise at the passive and active situation, respectively.

As shown in these figures, the noise were observed to be almost same between the different mental state conditions. However, slight difference were found at around 1000 and 3150 Hz bands. Then, FIR filter was made to compensate the difference and the filter was applied to the recorded noise at the active condition to make equal stimulus at the passive condition. Figure 4 shows the FIR filtering and Fig. 5 (a), (b), (c) and (d) shows the comparison of the sound at all conditions after applying the FIR filtering to the noise at the passive condition.

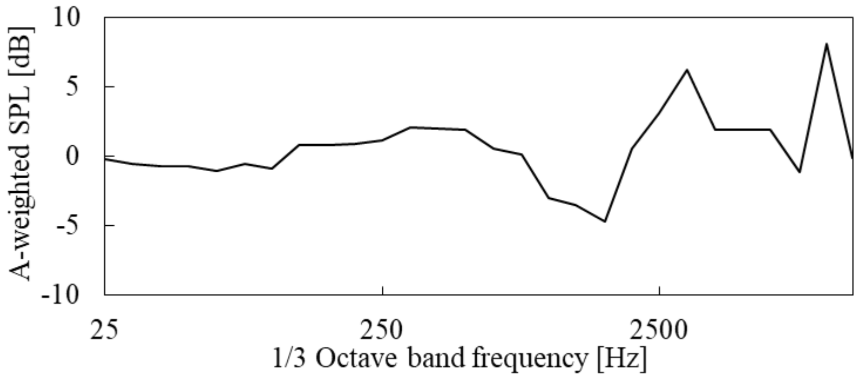
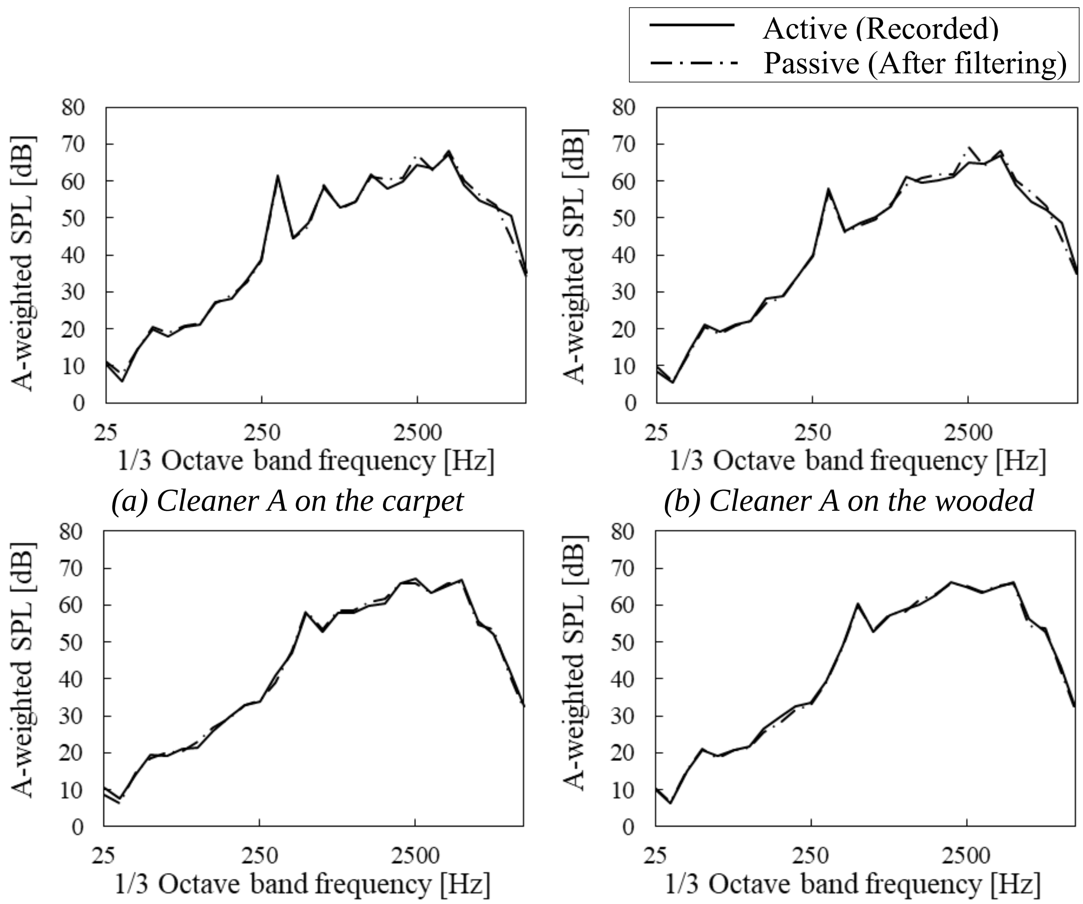


Fig. 4 FIR filter for equalization.



(a) Cleaner A on the carpet *(b) Cleaner A on the wooded*

(c) Cleaner B on the carpet *(d) Cleaner B on the wooded*

Fig. 5 Comparison of recorded and replayed sound after applying FIR filter.

As shown in the figure, the SPL difference between passive and active conditions became very small and the overall A-weighted SPL difference between them was less than 1 dB, hence this filter was used in the actual subjective evaluation test.

2.3 Procedure and Participants

To carry out the subjective evaluation at the both mental conditions, the following procedure was prepared in each condition.

Active test procedure

Step1: The participant wore the head-set type microphones at upon his/her ears for recording.

Step2: He/she cleaned the limited area (0.6 m x 0.6 m) for 15 s using the cordless cleaner and the radiated noise was also recorded by the microphones.

Step3: He/she evaluated uncomfortableness of the noise on the answer sheet by choosing from the seven categories as shown in Fig. 6. The selected number was used as the uncomfortable score in the following analysis.

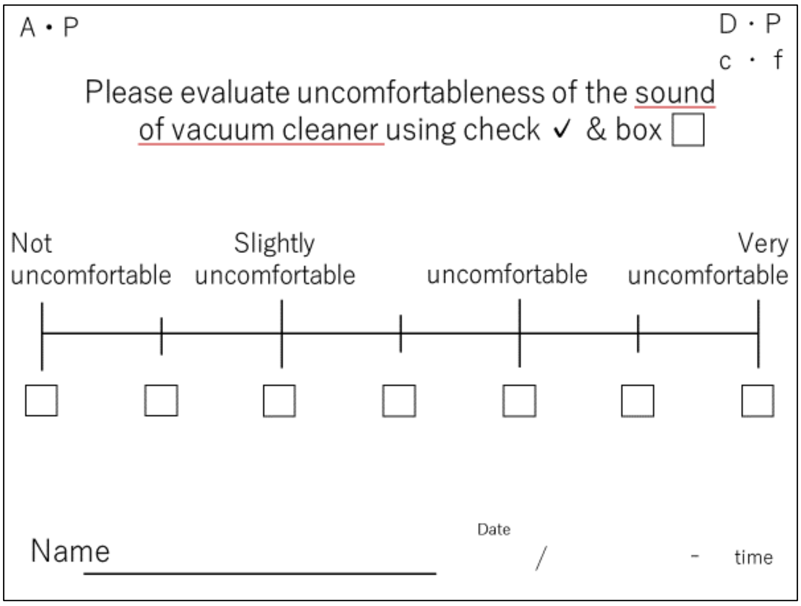


Fig. 6 Evaluation sheet and categories.

Passive test procedure

Step1: The participant wore the head-set type microphones on his/her ears.

Step2: He/she evaluated uncomfortableness of the replayed noise on the same way of the active test procedure.

In the Japanese test, 22 male and 2 females in 20's participated. Each participant carried out the above mentioned active and passive tests in the four conditions (2 vacuum cleaners x 2 surfaces) as a session. Total five sessions were repeated in each participant, hence total 480 evaluations were carried out to each sound for all Japanese participants.

In the Spanish test, 13 male and 6 females in 20 to 30's participated. And the number of the session was identical with the Japanese test. Hence, total 380 evaluations were carried out to each sound among all Spanish participants.

3. RESULTS OF JAPANESE TEST

3.1 Difference of uncomfortableness

At first, we analysed the result of subjective evaluation scores about the uncomfortableness to investigate the difference of the uncomfortableness between the active and passive hearing conditions in Japanese participants. Figure 7 shows the averaged uncomfortableness score among all Japanese participants in each condition.

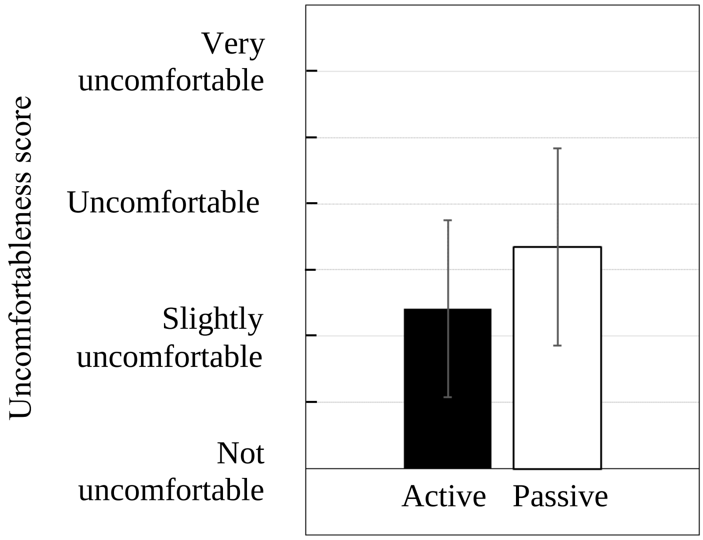


Fig.7 Averaged uncomfortableness score (Japanese).

Filled and opened bars in Fig. 7 shows the averaged uncomfortable scores in active and passive conditions, respectively. And the error bars indicate the standard deviation of them. As shown in the upper figure, the uncomfortableness score in passive condition was observed to be higher than that in active condition and the difference between active and passive condition was significant ($p < 0.05$) at 0.93. This result shows the participants felt more uncomfortable in passive condition than active condition even though the presented noise was the same. Subsequently, we attempted to obtain the uncomfortableness difference according to the mental state quantitatively using A-weighted SPL in the following section.

3.2 Relationship between SPL and uncomfortableness

Here, we obtained the uncomfortableness difference quantitatively by the mental state. We firstly evaluated the relationship between A-weighted SPL and the uncomfortableness score in each participant. Figure 8 shows the scatter diagram of A-weighted SPL of the noise and the uncomfortableness score in each participant.

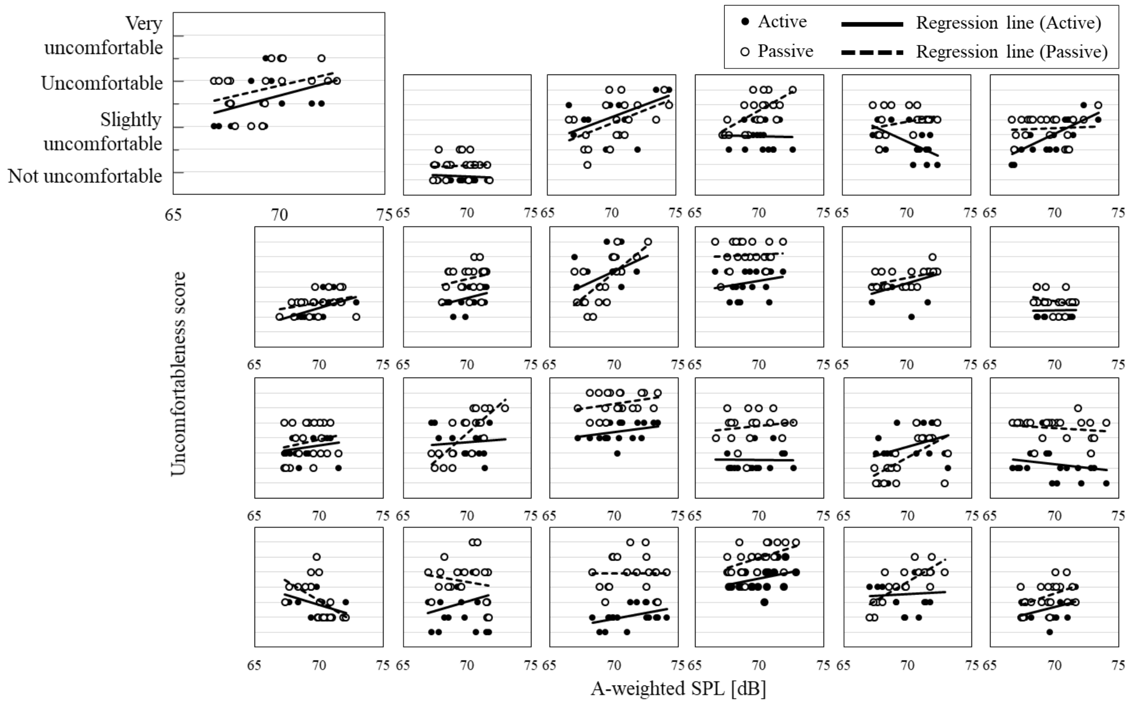


Fig.8 Uncomfortableness score in each participant (Japanese).

Filled and opened circles show the data at active and passive test, respectively in each graph. Solid and dotted lines are the regression line of them.

As shown in these figures, the uncomfortableness scores at of the passive condition were generally higher than those at the active condition as indicated in the previous section. On the other hand, the slope of them varies among participants and there was no significant difference between at the active and passive tests. Then, we averaged the slope among all participants at both conditions and calculated the y-intercept in each condition to minimize the error to obtain general tendency between the A-weighted SPL and the uncomfortableness score in each condition. Figure 9 shows the obtained relationship in each condition.

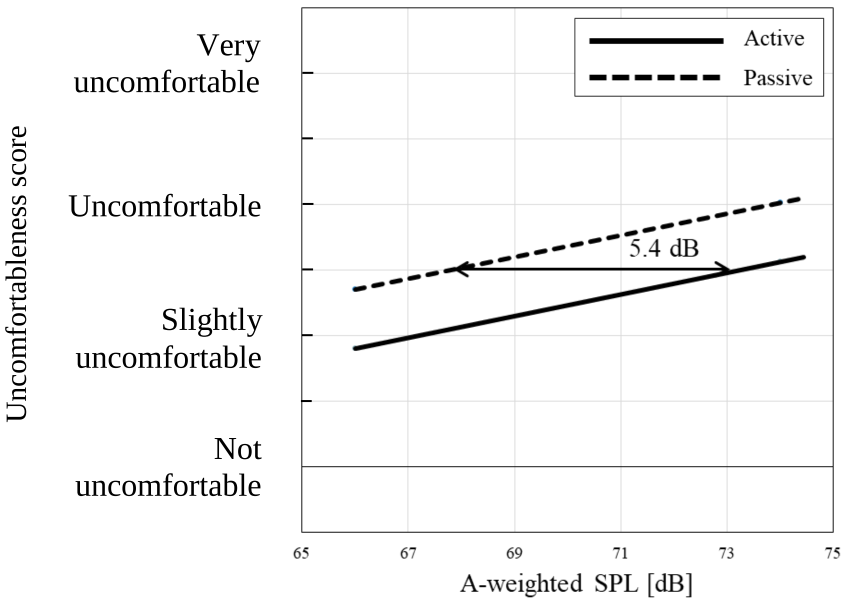


Fig. 9 General relationship between the A-weighted SPL and the uncomfortableness (Japanese).

Solid and dotted lines are the obtained lines of the data at active and passive test, respectively. As shown in the figure, apparent difference of the relationship between at the active and passive conditions was observed. The line of the passive test (dotted line) placed about 5 dB left side from the line of the active test (solid line). This means that even though the SPL of the noise in passive condition was 5 dB smaller than that in active condition, the noise were evaluated almost the same uncomfortable. Hence, this also suggests that the noise at the passive condition such as RVCs had better to be decreased about 5 dB than that at the active condition such as conventional vacuum cleaners in the development phase for Japanese.

4. RESULTS OF SPANISH TEST

4.1 Difference of uncomfortableness

As same as the Japanese test, here we analysed the uncomfortable score in Spanish test. Figure 10 shows the averaged uncomfortableness score among all Spanish participants in each condition.

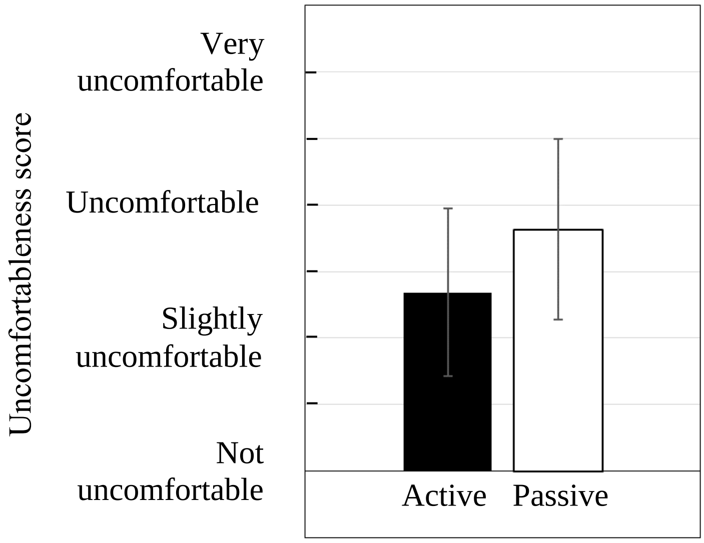


Fig.10 Averaged uncomfortableness score (Spanish).

Filled and opened bars in Fig. 10 shows the averaged uncomfortable scores in active and passive conditions, respectively. Error bars indicate the standard deviation of them. As shown in the upper figure, the uncomfortableness score in passive condition was observed to be about 0.95 higher than that in passive condition ($p < 0.05$) as same as the Japanese test. Subsequently, we obtained the uncomfortableness difference according to the mental state quantitatively using A-weighted SPL in the following section.

4.2 Relationship between SPL and uncomfortableness

The uncomfortableness difference by the mental state in Spanish test was calculated quantitatively in this part. Figure 11 shows the scatter diagram of A-weighted SPL of the noise and the uncomfortableness score in each participant.

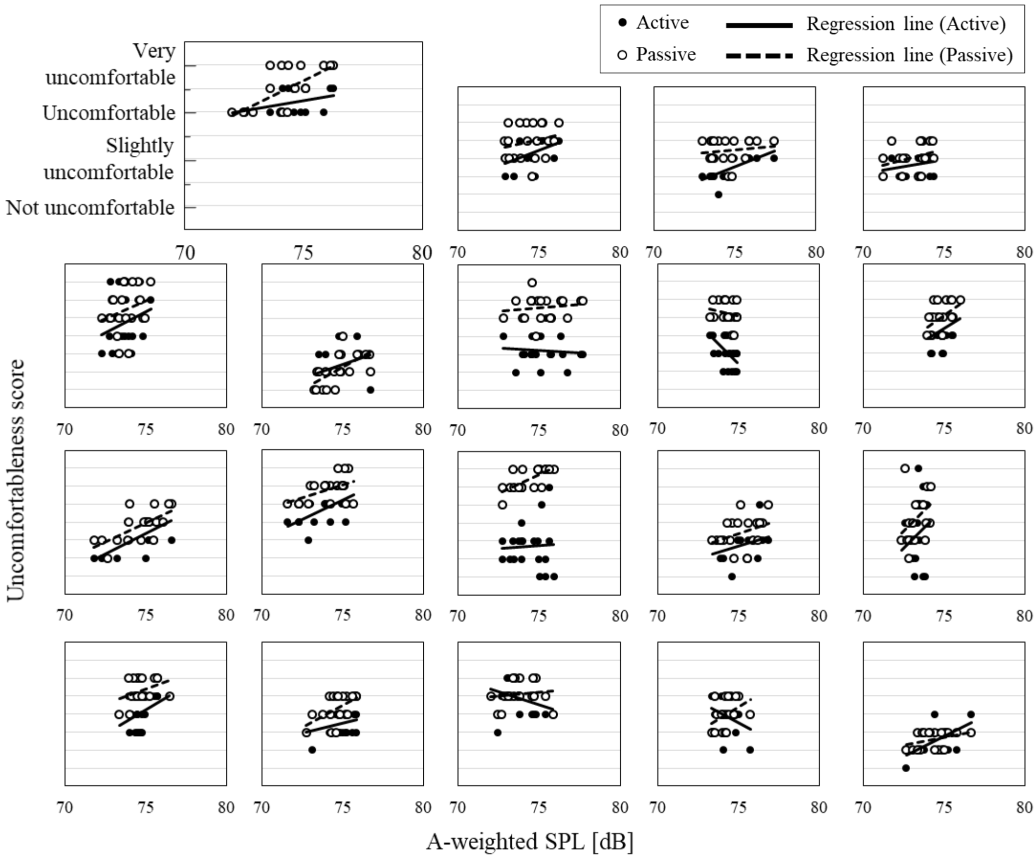


Fig.11 Uncomfortableness score in each participant (Spanish).

Filled and opened circles show the data at active and passive test, respectively in each graph. The solid and dotted lines are the regression line of them. As same as the analysis for Japanese result, we averaged the slope among all participants at both conditions because there was no significant difference between them and calculated the y-intercept in each condition to minimize the error. Figure 12 shows the obtained relationship in each condition.

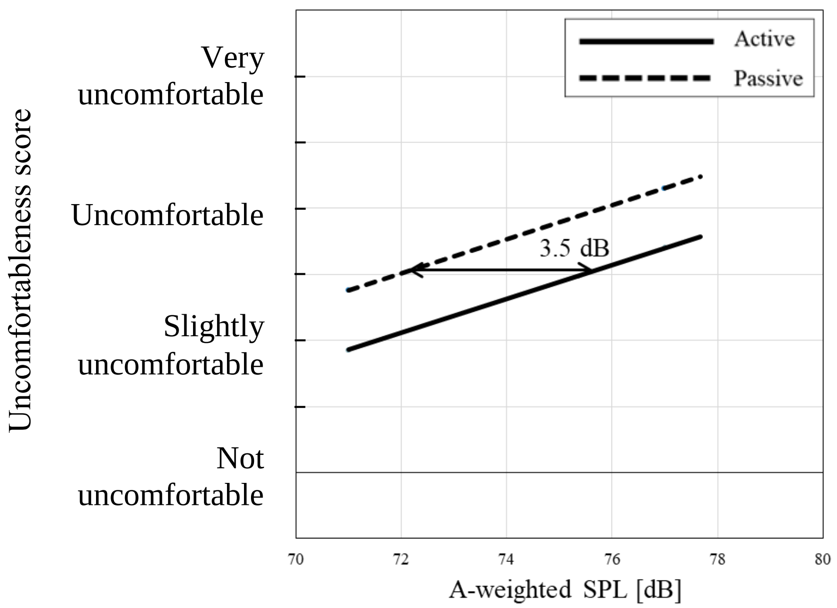


Fig.12 General tendency between the A-weighted SPL and the uncomfortableness (Spanish).

Solid and dotted lines are the obtained lines of the data at active and passive test, respectively. As shown in the figure, a certain difference of the relationship between at the active and passive conditions was observed. The line of the passive test (dotted line) placed about 4 dB left side from the line of the active test (solid line). This shows even though the SPL of the noise in passive condition was 4 dB smaller than that in active condition, the noise were evaluated almost the same uncomfortable in Spanish participants.

From these analytical results, the uncomfortableness to the radiated noise at the passive condition was clarified to be evaluated as higher than that at the active condition in both countries. In addition, the target level of the radiated noise of RVC was also found to be necessary to be set much lower than the level of conventional type vacuum cleaners for both countries.

5. CONCLUSIONS

In this study, we investigated the influence of the mental state between active and passive hearing condition on the uncomfortableness of the radiated noise of vacuum cleaners. To obtain the difference for two countries in Japan and Spain, subjective evaluation tests were carried out in both countries when the participants heard the radiated noise in active or passive hearing situation. In the active test, participants used the vacuum cleaner and evaluated the uncomfortableness of the noise. In the passive test, they evaluated the replayed noise recorded at the active test and evaluated the sound quality. The result showed that the uncomfortableness was significant higher at the passive condition than that at the active condition in both countries. In addition, the uncomfortableness difference between the mental states was evaluated in A-weighted SPL using the relationship between SPL and the uncomfortable score in each condition. The result was obtained as 5 dB in Japan and 4 dB in Spain. This reveals that when we develop RVCs which noise is perceived in passive condition, the SPL had better to be decreased 5 dB smaller than that of the conventional vacuum cleaner for both countries.

6. REFERENCES

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