inter.noise 2014
MELBOURNE AUSTRALIA
16-19 NOVEMBER

Influence of low SPL and bird twittering sounds on the loudness for road traffic noise

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ABSTRACT

In this study, an influence of the frequency of low sound pressure level (SPL) on the loudness for road traffic noise was investigated. Road traffic noises were recorded and edited to have the same equal equivalent noise level (L_{Aeq}) and having different frequency of low SPL. Through a subjective loudness evaluation test, road traffic noises having more frequency of low SPL were evaluated significantly softer even though all sounds had the same L_{Aeq}. Improvement of the memory to the low SPL sound was considered to be important role for the result. Subsequently, several bird twittering sounds were inserted to a road traffic noise to change the attention and memory of the participants. The twittering sounds were added in high or low SPL section of the road traffic noise and subjective evaluation was performed again. Results show the sound including the twittering sounds were not evaluated softer, oppositely, the loudness decrease effect by the increase of the low SPL frequency was reduced.

Keywords: Loudness, Skewness, Bird twittering sound
I-INCE Classification of Subjects Number(s): 63.1

1. INTRODUCTION

Reduction of environmental noise is important for living comfortably. For the reduction of environmental noise, it is necessary to set and follow an appropriate environmental noise evaluation index. The equivalent continuous A-weighted sound pressure level ($L_{\mathrm{Aeq,T}}$) is employed as the standard environmental noise evaluation index at present. This index is useful index because the value could be obtained easily. However, this index is sometimes reported not to express sensation of human beings accurately according to the frequency characteristic of environmental noise, and suitable evaluation indexes for environmental noise evaluation have been considered until now (1-10). Our research group conducted subjective evaluation tests on loudness using environmental noises having the same L_{Aeq} but different distribution of SPL on the presenting duration for 10 min. As a result, the road traffic noise having more frequency of low SPL was evaluated softer even though all presented sounds had the same L_{Aeq} (11-13). In addition, "skewness" was employed to evaluate the frequency of the low SPL quantitatively and the relationship between the loudness for environmental noise and the skewness was investigated when the skewness was changed from -0.8 (low SPL frequency: small) to 0.8 (low SPL frequency: large). The result shows, the loudness did not change significantly then the skewness was negative but the loudness was decreased depending on the increase of skewness when the skewness was from 0 to 0.8 (increase of low SPL frequency) (13).

In this study, to investigate the dependency of the subjective loudness on the skewness in wider range of the SPL distribution, we prepared road traffic noises having various low SPL distributions and performed subjective loudness evaluation test. Furthermore, the environmental noise does not consist of only traffic noise but also include various natural sounds such as bird twittering sound in general, and people perceive environmental noise including these sounds. Accordingly, we inserted bird twittering sounds in a period of road traffic noise presentation considering the distribution of low SPL frequency (skewness) of the road traffic, and performed additional subjective loudness evaluation test using these sounds.

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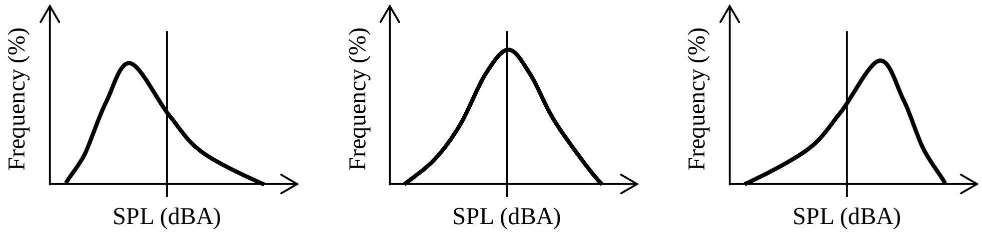
2. EXPERIMENT 1 (Relationship between skewness and subjective loudness)

In the first experiment, to investigate the relationship between subjective loudness and the distribution of low SPL frequency, the distribution was represented by skewness as same as our previous study (13). Skewness is calculated from the cube of the difference between the average and each value, as shown in Eq. (1).

$$S_{k.} = \frac{\sum \left(x_i - \bar{x}\right)^3}{N\sigma^3} \tag{1}$$

Here, N and σ denote the sample number and the variance, respectively. When the distribution is skewed to left side, the skewness becomes positive. This means the frequency of low SPL in the distribution is high as shown in Fig. 1 (a). When the distribution is Gaussian, the skewness becomes zero (Fig. 1 (b)). In case the skewness is negative, the distribution is skewed to the right side, and the frequency of low SPL in the distribution is low as shown in Fig. 1 (c).



(a) Sk. > 0 (b) Sk. = 0 (c) Sk. < 0

Figure 1 – Skewness

In our previous study, the relationship between the loudness and the distribution of low SPL frequency was investigated when the skewness was in a range from -0.8 to 0.8. The loudness was observed to be decreased when the skewness was positive (13). Here, to investigate the dependency of the subjective loudness on the skewness in wider range, we prepared four road traffic noises having four skewness from 0.2 to 1.4 (0.2, 0.6, 1.0 and 1.4). In the preparation of these sounds, four road traffic noises were measured for 10 min and the amplitude of the recorded sounds were adjusted in a part of the duration to meet the skewness of each sound as 0.2, 0.6, 1.0 and 1.4 ± 0.1, respectively. In addition, the amplitude for the entire presentation duration was also adjusted to be the L_{Aeq} of all sounds are 60 ± 1 dBA. For instance of the skewness, the skewness becomes about 0.2 when large SPL event such as vehicles passing occurs about once is ten seconds, also the skewness becomes about 1.4 when the event occurs about once in 20 sec. The calculated L_{Aeq} and the skewness of the adjusted presentation sounds are shown in Table 1.

Table 1 – Parameters of presented sounds

Sound	L_{Aeq} (dBA)	Skewness
Road A1	60.0	0.23
Road A2	60.0	0.60
Road A3	60.0	0.98
Road A4	60.0	1.39

2.1 Stimuli, Procedure and Participants

In the experimental procedure, the environmental noises were saved in a personal computer (PC). One noise sample was selected randomly and presented to the experimental participant via headphones (Sennheiser: HD600) through a playback system (HEAD acoustics: PEQ V).

After the presentation of the 10 min road traffic noise sample, the participant evaluated the overall loudness in prepared categories. Seven major categories “very soft,” “soft,” “relatively soft,” “neither soft nor loud,” “relatively loud,” “loud,” “very loud” and four minor categories among each major category were prepared for the loudness evaluation as shown Fig. 2. In addition, short-term loudness evaluations were performed in each 30 sec sections for the 10 min presentation duration for keeping the participant’s consciousness of the presented sound. For the evaluation, a timer on the PC monitor was used to inform the participant of the evaluation timing. In other words, timing was conveyed without presenting any additional sound. The short-term evaluation for 30 sec was performed a total of 20 times for each evaluation of the 10 min road traffic noise. The subjective loudness was evaluated in the same way as the evaluation of the 10 min noise.

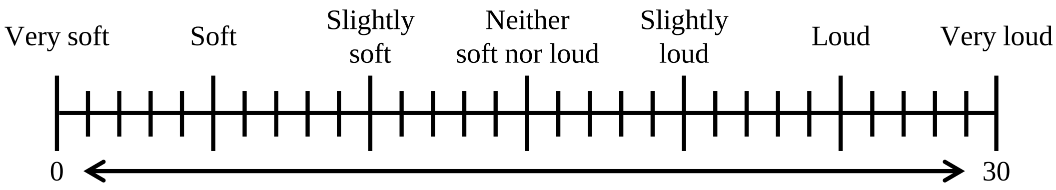


Figure 2 – Evaluation category

Seven males in their 20’s having normal hearing ability participated in the tests. Each participant evaluated loudness of 20 short-term noises at 30 sec sections and evaluated the loudness of entire noise for the duration of 10 min (21 evaluations were performed for one test).

The four samples of road traffic noise with various degrees of skewness were each evaluated three times. Hence, a total of 12 tests (4 samples x 3 repeats) were performed for each participant, and a total of 84 tests (12 tests x 7 participants) were performed in total. As a result, 1764 evaluations (21 evaluations x 84 tests) were performed in total.

2.2 Result

Figure 3 shows the subjective loudness of the 10 min environmental noise averaged for the seven participants and the standard deviation.

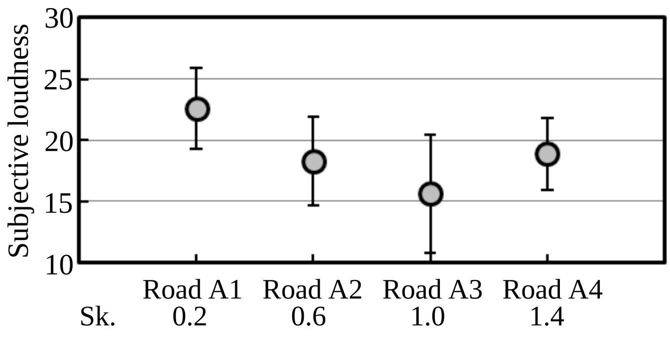


Figure 3 – Subjective loudness for road traffic noise and the standard deviation

Horizontal and vertical axes indicate the presented sounds having various skewness and the subjective loudness, respectively. From the results, the subjective loudness is observed to decrease according to the increase of the skewness when the skewness is in the range from 0.2 to 1.0 even though these sounds had the same L_{Aeq}. The difference among the range was significant ($p<0.01$) by the analysis of variance. This tendency is the same as that obtained in our previous study (13). However, the subjective loudness for Road A4 (skewness: 1.4) was not decreased by comparing with Road A3 (skewness: 1.0) though the skewness was increased. This result indicates that the dependency of the skewness on the subjective loudness is not constant and the influence of the skewness of the subjective loudness disappears when the skewness is over 1.0.

2.3 Discussion 1

In this experiment, an influence of the frequency of low SPL (skewness) on the loudness for road traffic noise was investigated using various road traffic noises. As a result, the subjective loudness was found to be reduced depending on the increase of the skewness at a certain range of the skewness from 0.2 to 1.0. The loudness did not depend on the skewness when the skewness was over 1.0. The reasons of the obtained tendencies were described as follows.

About the loudness decrease trend depending on the increase of the low SPL frequency in case the skewness range was from 0.2 to 1.0, the reason of this tendency is considered to be related to a memory effect discussed in our previous studies (12, 13). In this effect, after a period of hearing environmental noise, the louder sounds are remembered but the softer sounds are forgotten. Thus, the loudness may be evaluated louder when the low SPL frequency was low at the skewness as 0.2 because of the forgetting of the impression of the low SPL sounds. When the skewness became larger, the impression of low SPL sound may be kept strongly in their memory. As a result, the loudness was decreased depending on the increase of the skewness. On the other hand, when the skewness was 1.0, the participants may have memorized the low SPL sounds sufficiently and not forgotten the impression of the sounds any more. Hence, even though the frequency of the low SPL increased more like the skewness as 1.4, the loudness was not decreased.

3. EXPERIMENT 2 (Influence of bird twittering sound on subjective loudness)

In the first experiment, we investigated the influence of low SPL frequency on the subjective loudness and found a tendency in which the loudness was decreased when the skewness was positive and under 1.0. Improvement of memory to the low SPL sounds was considered as one of the factors for the tendency.

In general, the environmental noise does not consist of only traffic noise but also include various natural sounds such as bird twittering sound and people perceive environmental noise including these sounds. Accordingly, we inserted bird twittering sounds in a period of road traffic noise presentation considering the distribution of low SPL frequency (skewness) of the road traffic, and performed subjective loudness evaluation test. The SPL and duration of the inserted bird twittering sound used in the test is much smaller and shorter than the road traffic noise. Hence, L_{Aeq} is not considered to change significantly by inserting the smaller and shorter bird sounds. However, there is a possibility in which these natural sounds are not recognized as noise like road traffic noise, but recognized as a comfortable and relax sound, and the inserted sound may decrease the overall loudness. Also, there is another possibility in which if the participants memorize the inserted bird twittering sound with the back ground traffic noise at low SPL, the subjective loudness for the entire sound may be decreased by the enforced memory to the low SPL sound. On the other hand, if the bird twittering sound is perceived as noisy and uncomfortable, the subjective loudness for the entire sound may be increased by the impression of the bird twittering sound.

3.1 Stimuli, Procedure and Participants

In this experiment, the subjective loudness of environmental noise with or without bird twittering sound was investigated. Three road traffic noises were recorded for 10 min and three bird twittering sounds for 10 sec were also recorded. The L_{Aeq} of the road traffic noises for 10 min were from 60 to 70 dBA and L_{Aeq} of the bird twittering sounds for 10 sec were from 58 to 59 dBA. The synthesized sound of road noise and bird twittering sound were prepared by inserting all three bird twittering sound twice in the road traffic noise of 10 min as shown in Fig. 4.

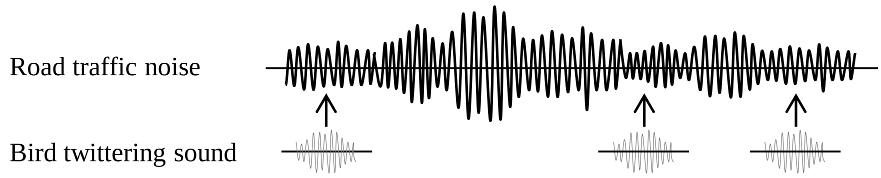


Figure 4 – Synthesized sound of road traffic and bird twittering sounds for presentation

To prepare the presented sound considering the influence of low SPL frequency obtained in the previous section, the bird twittering sounds were inserted to the road traffic noise which skewness was 0, 0.4 or 0.8. The skewness range was in the conditions where the loudness was decreased depending on the increase of skewness in our first and previous studies (11-13). In case the road traffic noise was presented with the bird sound, they were inserted in the high SPL section or low SPL section of each road traffic noise. Hence, there were nine presentation sounds (3 skewness x 3 inserting patterns) in total. The amplitude of the synthesized sounds were adjusted in a part of the duration to meet the skewness of each sound as 0, 0.4 and 0.8 ± 0.1, respectively, and the amplitude for the entire duration was also adjusted to be the L_{Aeq} of all sounds are 65 ± 1 dBA. The calculated L_{Aeq} and the skewness of the adjusted presentation sounds and the inserting pattern are shown in Table 2.

Table 2 – Parameters of presented sounds

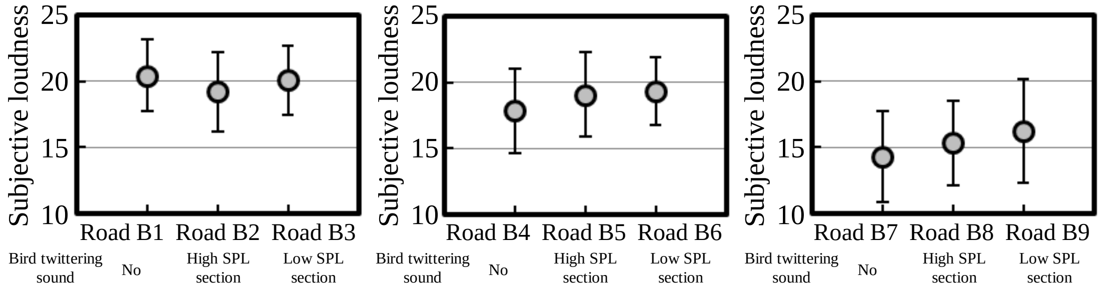
Sound	L_{Aeq} (dBA)	Skewness	Bird twittering sound
Road B1	64.8	0.09	No
Road B2	65.1	0.06	High SPL section
Road B3	65.1	-0.06	Low SPL section
Road B4	65.0	0.37	No
Road B5	65.1	0.39	High SPL section
Road B6	65.1	0.43	Low SPL section
Road B7	64.9	0.77	No
Road B8	65.0	0.82	High SPL section
Road B9	65.0	0.83	Low SPL section

As same as the first experiment, the environmental noises were saved in PC and one sample was selected randomly and presented to the experimental participant via headphones (Sennheiser: HD600) through a playback system (HEAD acoustics: PEQ V). After the presentation of the synthesized noise for 10 min, the participant selected the subjective loudness from 31 levels from 0 (very soft) to 30 (very loud). In addition, the same short-term loudness evaluations were performed in 30 sec sections for the presentation duration of the 10 min synthesized sound presentation. The short-term evaluation for 30 sec was performed a total of 20 times for each overall evaluation. The subjective loudness was evaluated in the same way as the evaluation of the entire sound. In addition, questionnaire asking which sound events are memorized and the impressions about noisiness and comfortableness of the memorized sounds was carried out at the end of the test.

Seven males in their 20’s having normal hearing ability participated in the tests. Each participant evaluated loudness of 20 short-term noises at 30 sec sections and evaluated the loudness of entire synthesized noise for the duration of 10 min (21 evaluations were performed for one test). The nine samples of the synthesized noise were evaluated three times respectively. Hence, a total of 27 tests (9 samples x 3 repeats) were performed for each participant, and a total of 189 tests (27 tests x 7 participants) were performed in total. As a result, 3969 evaluations (21 evaluations x 189 test) were performed in total.

3.2 Result 2

Figure 5 shows the subjective loudness of the 10 min synthesized sound averaged for the seven participants and the standard deviation. Figure 5 (a), (b) and (c) show the subjective loudness with or without bird twittering sound in case the skewness are 0, 0.4 and 0.8, respectively.

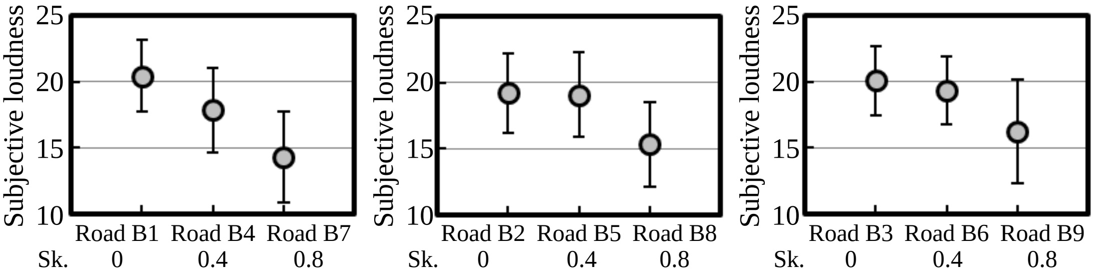


(a) Skewness 0 (b) Skewness 0.4 (c) Skewness 0.8

Figure 5 – Subjective loudness of the synthesized sound with or without bird twittering sound in each skewness and the standard deviation

As shown in this figure, the loudness was not decreased by inserting the bird twittering sound at any conditions of the skewness. Oppositely, the loudness are observed to be slightly increased by inserting bird twittering sounds when the skewness are 0.4 and 0.8 as shown in Fig. 5 (b) and (c).

Subsequently, the obtained subjective loudness were rearranged according to the skewness in each inserting pattern to investigate the relationship between the skewness of the presented sound and the subjective loudness. Figure 6 (a), (b) and (c) show the relationship when the bird twittering sound was not inserted, inserted at high SPL section, and inserted at low SPL section, respectively.



(a) No (b) High SPL section (c) Low SPL section

Figure 6 – Subjective loudness of the synthesized sound in each skewness with or without bird twittering sound and the standard deviation

In case the bird sound was not inserted, the loudness was decreased significantly ($p<0.01$) depending on the increase of the skewness as shown in Fig.6 (a). This tendency is the same as the result obtained in the first experiment and some previous studies (11-13). In case the bird twittering sounds were inserted in high or low SPL section of the presented sound, the loudness were also decreased by the increase of the skewness as same as the sound without the bird sound as shown in Fig. 6 (b) and (c). However, the difference by the increase of the skewness reduced in case the bird sound was inserted by comparing with the difference in case the bird sound was not inserted. This is the reason why the loudness appears to be increased by inserting the bird sound when the skewness was 0.4 and 0.8 as shown in Fig. 5 (b) and (c).

From these experimental results, it was clarified that the influence of the skewness on the subjective loudness was significant when the skewness is positive and under 1.0 but the influence was reduced by inserting a bird twittering sound in a part of a road traffic noise.

3.3 Discussion 2

In this experiment, we performed a subjective loudness evaluation test using road traffic noise and bird twittering sound, and investigated the loudness change by inserting the bird twittering sound. The result indicated the influence of the skewness on the subjective loudness was reduced by inserting the bird sound. We estimated three influences of inserting bird twittering sound on loudness for environmental noise at the beginning of this section as follows.

1. Positive impressions (comfortable or relax) to the inserted bird twittering decreases the subjective loudness for the environmental sound.
2. Participants memorize the inserted bird sound with the back ground traffic noise having low SPL, and the subjective loudness is decreased by the enforced memory of the low SPL sound.
3. Negative impressions (noisy or uncomfortable) to the inserted bird twittering increase the subjective loudness.

On the contrary to these estimated influences, another tendency was observed in this experiment. Loudness decrease effect by the increase of the skewness was reduced by inserting the bird sound. In order to discuss the factor of the obtained findings, responses to the questionnaire about the memorized sound events and the impressions were analyzed. The results show most participants (over 90 %) remembered the inserted bird twittering sound after the evaluation. In addition, the number of the participants having positive impression to the bird sound (40 %) was much more than the participants having negative impression (10 %). However, even though the inserted sound gave positive impression to them, the subjective loudness was not decreased like the first hypothesis. The positive impression of the bird sound in the short duration may not be enough to change the overall impression to the sound. Furthermore, the subjective loudness was not decreased in spite of the existence of the bird sound in their memory like the second hypothesis. Oppositely, the loudness decrease effect by the skewness was reduced by inserting the bird sound. The low SPL section was considered to be memorized more by the increase of the skewness (increase of the low SPL frequency) as we discussed in the first discussion. On the other hand, part of the memory of the low SPL sound may have been lost in order to memorize a new sound event (bird twittering sound) in the evaluation duration. As a result, the loudness decrease effect by the increase of the skewness may be reduced by inserting the bird sound.

4. SUMMARY

In this study, to investigate the dependency of the subjective loudness on the low SPL frequency (skewness) distribution, road traffic noises having various low SPL distributions were prepared and a subjective loudness evaluation test were performed in the first experiment. As a result, the subjective loudness was found to be reduced depending on the increase of the skewness (increase of low SPL frequency) at a certain range (0 to 1.0) of the skewness even though these sounds had the same L_{Aeq}. However, the dependency was not observed when the skewness was over 1.0.

In the second experiment, another subjective loudness evaluation test was carried out using road traffic noise and bird twittering sound. The loudness change by inserting the bird twittering sound was investigated. The result indicated the influence of the skewness on the subjective loudness was reduced by inserting the bird sound.

From the above result, it was found that the loudness decrease effect by the increase of low SPL frequency reported in the previous studies (11-13) occurs in a certain situation. It is necessary to investigate when or where we have to care the effect for evaluating environmental noise in actual condition. On the other hand, the results and discussions show that if an attention is given to the low SPL part in an environmental noise by giving a cue and the impression of the low SPL part could be memorized for a long time, the overall loudness for the environmental noise may be decreased. We will try to find the cue in our future study.

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