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PSYCHOLOGICAL EVALUATION OF NOISE IN PASSENGER CARS—THE EFFECT OF VISUAL MONITORING AND THE MEASUREMENT OF HABITUATION

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The instantaneous impression of the loudness of internal car noise was judged by using the method of continuous judgment by category. The effect of visual monitoring while driving and the habituation to noise were examined. The following results were found: (1) the instantaneous impression of loudness showed a high correlation with L_{Aeq}, which suggests that instantaneous loudness can be approximately estimated by L_{Aeq}, (2) visual information has a great effect on the impression of loudness; it was suggested that comfortable driving softens the sounds, while uncomfortable driving makes the impression of the sounds more negative; (3) in the group of subjects who tried the condition without visual monitoring after trying the condition with visual monitoring, the number of responses decreased; this suggests that, when other information about the change of sounds does not exist, habituation to sounds occurs with the elapse of time and it is reflected in the number of responses to noise events.

1. INTRODUCTION

Internal car noise varies temporally according to driving situations. In a driving situation, visual information gives important clues for recognizing driving situations. Therefore, from an ecological point of view, in the evaluation of internal car noise, it is necessary to examine the interaction between visual and auditory information by comparing the results with the conditions in which both visual and auditory information is presented and those in which only one type of information is presented. It is also necessary to examine subjective responses to temporally varying stimuli along the temporal stream since the recognition in driving situations depends not only on the stimuli presented at that moment,

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but those already presented and those that are to come: i.e., the stimulus context plays an important role.

When long-term sound is presented, habituation may occur. Habituation to noise is a phenomenon that occurs when a stimulus is presented continuously or repeatedly to auditory organs such that the response to that stimulus gradually diminishes and finally disappears. Though the habituation is often experienced in daily life situations, it is difficult to measure it by conventional psychophysical methods, in which subjects are required to pay attention to the stimuli they judge. One possible method for measuring habituation is "the method of continuous judgment by category", developed by Namba and Kuwano *et al*. [1, 2]. The main advantages of this method are as follows; (1) subjects are not compelled to pay attention to specific stimuli; (2) stimuli of longer duration can be used.

As concerns advantage (1), subjects are given a certain freedom in making their responses, and the absence of a response is a meaningful part of the data gathered; the number of responses or "no responses" is an index of habituation.

As concerns advantage (2), a longer duration of stimuli is necessary for habituation to take place; with the "method of continuous judgment by category", stimuli of very long duration can be used [3].

In the present study, the loudness of the noise audible in a passenger car while driving was continuously evaluated by using the method of continuous judgement by category, and the effect of visual monitoring on loudness and habituation to internal car noise in driving situations was examined.

2. EXPERIMENT

2.1. STIMULI

Four kinds of internal car noise while driving were used as stimuli. Stimulus 1 was recorded on a busy road in a city with a great deal of traffic. The duration was 22·5 min and the L_{Aeq} was 57·2 dB(A). Stimulus 2 consisted of three parts: a mountain area, a residential area and a resort area; the duration was 18·5 min and the L_{Aeq} was 60·8 dB(A). Stimulus 3 was recorded on a narrow road in a residential area; the duration was 17 mins and the L_{Aeq} was 60·7 dB(A). Stimulus 4 was recorded on a highway; the duration was 10 min and the L_{Aeq} was 66·6 dB(A).

2.2. PROCEDURE

The instantaneous impression of loudness was judged by using the method of continuous judgment by category. Subjects were instructed to judge the impression of loudness continuously using seven categories from very loud to very soft by touching a key on a computer keyboard corresponding to the category. Two conditions were used: in condition 1, sounds were presented without visual monitoring and, in condition 2, visual monitoring was used. After the continuous judgment to each stimulus was over, the subjects were asked to fill in a questionnaire that focused on the overall impression of loudness and noisiness, the impressive things in visual monitoring, etc. The subjects experienced the two conditions on different days. Half of the subjects had condition 1 first and the other half condition 2 first.

2.3. APPARATUS

Sounds were reproduced with a video recorder (Victor Video Cassette Recorder HR-D725) and presented to subjects via headphones (Stax Ramda pro). Visual monitoring was reproduced with the same video recorder and presented on a 32-inch monitor television (Victor AV-M320S) in a sound proof room.

2.4. SUBJECTS

Five female and three male subjects, aged between 23 and 43, with normal hearing ability participated in the experiment.

3. RESULTS AND DISCUSSION

3.1. INSTANTANEOUS JUDGMENTS OF LOUDNESS

3.1.1. *Relation between subjective judgments and physical values*

Subjective responses were sampled every 100 ms and correlated to the L_{Aeq} of every 100 ms ($L_{Aeq,100ms}$) by sliding the interval between them. The time lag when the highest correlation was found was regarded as a reaction time. Taking the reaction time into account, the responses were averaged for the values of $L_{Aeq,100ms}$ of a 1 dB step. An example of the relation between mean subjective responses and the values of $L_{Aeq,100ms}$ of a 1 dB step is shown in Figure 1 with standard deviations. A high correlation can be seen between them. There is a statistically significant difference between the responses of adjacent $L_{Aeq,100ms}$ values from 42 to 68 dB(A), as shown in Table 1. This suggests that a 1 dB difference can be discriminated from a statistical view point.

3.1.2. *Comparison between two conditions*

A high coefficient of correlation was found between instantaneous judgments and $L_{Aeq,100ms}$ in both conditions ($r = 0{\cdot}981$ for condition 1, $r = 0{\cdot}988$ for condition 2). This suggests that, in both conditions, subjects carefully listened to sound. However, sounds were judged to be louder in condition 1 (without visual monitoring) than in condition 2

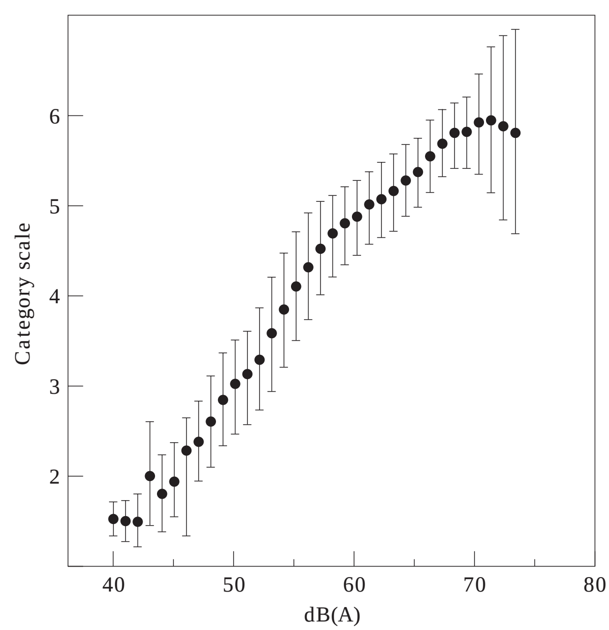

Figure 1. Relation between $L_{Aeq,100ms}$ and the average of instantaneous judgments for the values of $L_{Aeq,100ms}$ of every 1 dB step with their standard deviation. Stimuli; 1–4, conditions 1 and 2; $r = 0{\cdot}935$.

TABLE 1

Results of t-test between the averages of instantaneous judgments to each value of $L_{Aeq,100ms}$

$L_{Aeq,100ms}$(dB)		$L_{Aeq,100ms}$(dB)		$L_{Aeq,100ms}$(dB)	
40–41	ns	51–52	***	62–63	***
41–42	ns	52–53	***	63–64	***
42–43	***	53–54	***	64–65	***
43–44	***	54–55	***	65–66	***
44–45	***	55–56	***	66–67	***
45–46	***	56–57	***	67–68	***
46–47	***	57–58	***	68–69	*
47–48	***	58–59	***	69–70	***
48–49	***	59–60	***	70–71	ns
49–50	***	60–61	***	71–72	ns
50–51	***	61–62	***	72–73	***

*** $p < 0{\cdot}005$; ** $p < 0{\cdot}01$; * $p < 0{\cdot}05$; ns, not significant.

(with visual monitoring) in the higher level portions and vice versa in lower level portions, as shown in Table 2. That is, the slope of the psychophysical function between $L_{Aeq,100ms}$ and the average of instantaneous judgments was steeper for condition 1 than for condition 2. This suggests that visual information may make subjects perceive the sound as being neither extremely loud nor extremely soft.

3.1.3. *Comparison between stimuli*

The dynamic ranges of the sound levels of the four stimuli used were almost equal to each other. However, stimulus 2 was judged to be louder than the other stimuli. This may be the results of low frequency components originating from rough road conditions in mountain areas. This effect may be underestimated with A-weighting. The high level portions of stimulus 4 were also judged to be louder than the other stimuli. This may possibly be due to the impression of sounds based on aerodynamics.

TABLE 2

Results of t-test between two conditions

$L_{Aeq,100ms}$(dB)	cond.†		$L_{Aeq,100ms}$(dB)	cond.†		$L_{Aeq,100ms}$(dB)	cond.†	
40		ns	52		ns	64	1	*
41	2	***	53		ns	65	1	***
42	2	***	54		ns	66	1	***
43	1	***	55	1	*	67	1	***
44	2	***	56	1	***	68	1	***
45	2	*	57	1	***	69	1	***
46	2	***	58	1	***	70	1	***
47	2	***	59	1	***	71		ns
48		ns	60	1	***	72		ns
49	2	***	61	1	***	73		ns
50	2	***	62		ns			
51	2	*	63		ns			

† The number in the condition column indicates the conditions in which the average of instantaneous impressions was judged louder than in the other condition. For example, sounds of 41 dB in $L_{Aeq,100ms}$ was judged louder in condition 2 than in condition 1, and there is a statistically significant difference between the judgments in two conditions. *** $p < 0{\cdot}005$; ** $p < 0{\cdot}01$; * $p < 0{\cdot}05$; ns, not significant.

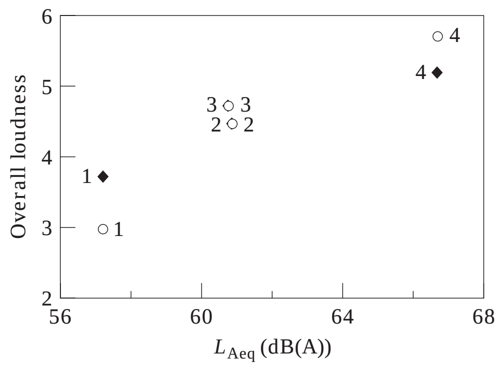

Figure 2. Relation between overall loudness and L_{Aeq} in the group of subjects who had condition 1 first. ○, condition 1, $r = 0{\cdot}951$; ◆, condition 2, $r = 0{\cdot}844$.

3.2. OVERALL IMPRESSION

The relation between overall loudness or noisiness and L_{Aeq} is shown in Figures 2–5. A higher coefficient of correlation can be seen between them in condition 1 (without visual monitoring) than in condition 2 (with visual monitoring). Especially in the group of subjects who experienced condition 2 first, there was little correlation between overall loudness or noisiness and L_{Aeq}. This suggests that the visual effect was so great that the impression of sounds became weakened in overall impressions.

The loudness of stimulus 1 was judged to be greater in condition 2 than in condition 1. This may be due to the effect of heavy traffic. The uncomfortable impression of heavy traffic may make the impression of sounds more negative. The opposite effect can be seen in stimulus 4, whose loudness was judged to be softer in condition 2 than in condition 1. Comfortable highway driving may make the sounds be perceived as being softer.

3.3. HABITUATION

To examine habituation, it is important to find appropriate indices of habituation. In our former experiments [3], "no response" was found to be a good index of habituation.

In this experiment, fairly long stimuli were used and it was examined whether habituation can be found by using the number of responses as an index of habituation. Since visual monitoring has a great effect on the perception of sounds, habituation was examined in the stimulus condition 1 in which sounds were presented without visual monitoring. The number of responses to the stimulus condition 1 was compared between

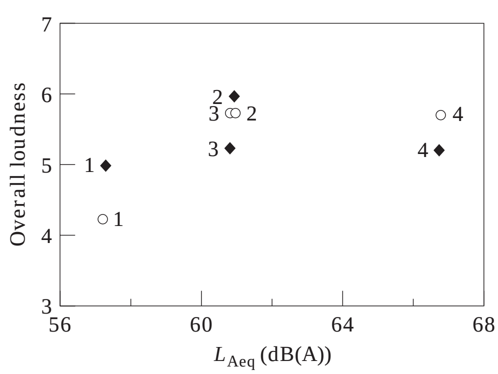

Figure 3. Relation between overall loudness and L_{Aeq} in the group of subjects who had condition 2 first. ○, condition 1, $r = 0{\cdot}706$; ◆. condition 2, $r = 0{\cdot}126$.

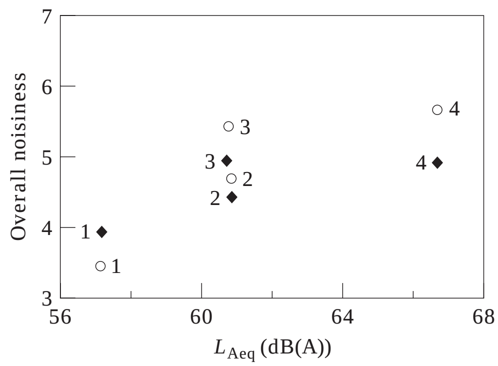

Figure 4. Relation between overall noisiness and L_{Aeq} in the group of subjects who had condition 1 first. ○, condition 1, $r = 0{\cdot}844$; ◆, condition 2, $r = 0{\cdot}794$.

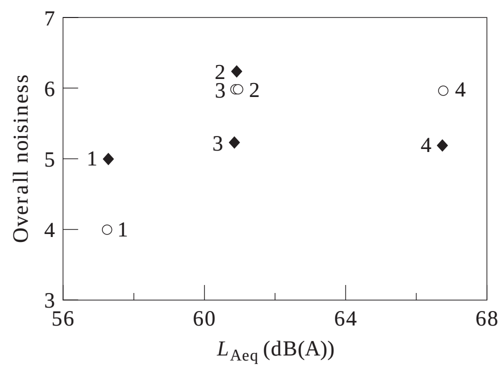

Figure 5. Relation between overall noisiness and L_{Aeq} in the group of subjects who had condition 2 first. ○, condition 1, $r = 0{\cdot}706$; ◆, condition 2, $r = 0{\cdot}078$.

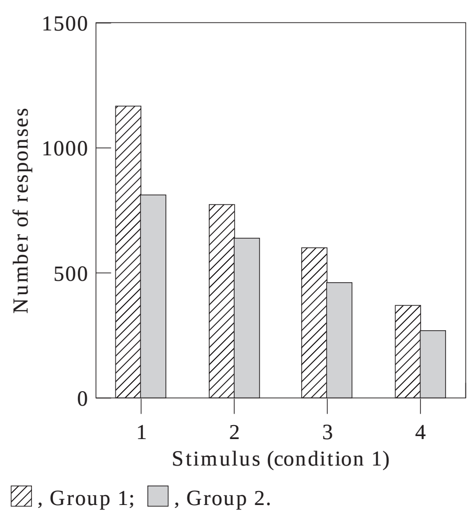

Figure 6. The number of responses to the stimulus condition 1 in which visual monitoring was not presented is compared between two groups. The number of responses was smaller for the group 2, who had condition 1 after condition 2, than for the group 1, who had condition 1 first.

two groups and the result is shown in Figure 6. The number of responses was smaller for group 2, who had condition 1 after condition 2, than for the group 1, who had condition 1 first, as shown in this figure. When subjects listened to the same sound in the second trial, they may not have a fresh impression of the sound, which may be reflected in habituation to the sound. This suggests that, when there is no other information about the change of sounds, habituation to sounds occurs as time elapses and is reflected in the number of responses. Similar results were also found in another experiment [4].

It would be important to find that habituation could be found by using the number of responses as an index of habituation.

4. CONCLUSION

In the evaluation of long-term effects of noise in daily life, it is important to examine the interaction between visual and auditory stimuli and the effect of habituation. In this experiment, it was found that visual stimuli have a great effect on the overall impression of loudness and that habituation to noise can be measured using the number of responses as an index of habituation.

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