QUALITY OF NOISE

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1. INTRODUCTION

In our daily life, we are given much benefit from machinery civilization. This means that there are many machines in our surroundings and most of them make noise. The sound level from recently developed machines shows remarkable reduction. On the other hand, however, a reduction of a given sound may produce other by-products. For example, reduced machinery noise may make other sounds audible, which were previously masked, and cause another noise problem. The spectrum shape of noise affects the effect of masking and also affects the timbre of noise. When noise if reduced sufficiently, close examination of the quality of noise may be necessary.

It should be added that noises in daily life usually have complicated and irregular frequency components and are level fluctuating. Every noise has its own timbre and loudness. For noise assessments, research using such complicated noise is important. Traditionally, in a psycho-physical study of timbre, steady-state musical tones are used, because of their simplicity and regularity. It is unneccessary to limit stimuli to musical tones.

A psychological study of timbre faces many difficulties when irregular and complicated stimuli are used. Firstly, many factors may affect the impression of timbre. Secondly, timbre is multi-dimensional. In instructions to subjects, it is difficult to arrive at a clear concept and definition of timbre. Therefore, the control of experimental conditions is very important in the study of timbre.

The definition of timbre given by the Americal Standard Association describes it as the "attribute of auditory sensation in terms of which a listener can judge that two sounds similarly presented and having the same loudness and pitch are dissimilar". Comparable definitions of timbre can be found in many dictionaries of acoustical terms and in schedules of regulations. According to such definitions, all the characteristics of a sound other than loudness and pitch are included in timbre and all its physical properties are related to timbre. The definition is so open as to be ambiguous. It is not well viewed by researchers. A more practical definition would help to avoid confusion.

According to Helmholtz1), "timbre" as a quality of a tone has two applications: one is for discriminating between sound sources, and the other is for describing the subjective impression of musical instruments.

Following Helmholtz, I would therefore like to propose a redefinition of timbre2). I suggest that "timbre" should be employed to cover the following

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attributes of sounds:

(1) A characteristic which gives a clue to the identity of the sound source.

(2) The quality of a sound which corresponds to the emotive impression which can be verbally expressed as timbre. These impressions are multi-dimensional and combine attributes of sensation and feeling.

The definition of timbre is divided into two aspects, but they are closely related. The identification of a sound source may affect the impression of timbre. When a listener likes a sound source, the timbre of the sound may appear pleasant. In daily life situations, depending on the attitude of a listener and the context of stimuli, the two aspects of timbre will be inseparable. I would therefore like to emphasize that it is very difficult to arrive at a strict definition of imbre. The signification of the term, "timbre" in everyday language is extremely unclear.

In the case of sensory evaluation of noise, however, the proposed division of timbre into two aspects is very useful.

Concerning (1), the subjects' task is to discriminate or identify the stimuli by reference to timbre, not to judge timbre itself. In instructions to subjects, it is not necessary to use the term "timbre".

Concerning (2), we have to find the minimum number of descriptive terms sufficient to describe timbre. It is essential that the descriptive terms can be used for different kinds of stimuli. To find the minimum number of descriptive terms, it is necessary to determine the orthogonal(independent) relationship between proposed terms. To determine which terms are sufficient, it is necessary to discover the stability of this orthogonal relation after employing a wide range of stimuli. To find the minimum number, factor analysis is suitable; to find sufficient terms, it is necessary to confirm "the generality of factor structure" of "factorial invariance" which has been discussed by L.L.Thurstone[3].

Semantic differential is a typical method for this purpose. This techinique has been developed for the measurement of the connotative or affective meanings of verbal expressions by C.E.Osgood and his colleagues[4]. When semantic differential is adopted in experiments on timbre, sound sources are used as concepts and pairs of adjectives which are antonyms of each other are used for scales.

I should now like to consider the terms found to cover the expression of a response to timbre and the factors governing the use of the term "timbre". According to our previous experiments, in spite of the variety of conditions, three constant factors were normally evident. The scales having a high loading on Factor 1 were "beautiful-ugly", "pure-impure" and "tasteful-dry". Factor 1 can be denominated the "pleasant" factor. The scales having a high loading on Factor 2 were "powerful-weak", "rich-poor" and "loud-soft". Factor 2 can be denominated the "powerful" factor. The scales having a high loading on Factor 3 were "calm-shrill", "metallic-deep" and "high-low". This factor can be denominated the "metallic" factor.

If this factorial incariance is constantly manifest even where there is a wide variety of sound sources, adjective scales and subjects, it should be possible to express impressions of timbre by employing the scales assigned to the three factors.

2. APPLICATION OF SEMANTIC DIFFERENTIAL TO NOISE RESEARCH

For the assessment and the control of noise in every day situations, it is important to know the physical properties of sounds. Everyday sounds would include transportation noise and noise from electric appliances. They have complicated frequency components and level-fluctuation. It is interesting to examine whether "factorial invariance" can be found in the case of such stimuli. It is also interesting to consider the relation between factors and the physical properties of the sounds.

The results from our experiments using a variety of everyday noises are summarized in the followings.

Oil tanker noise[5),6)]

Experiments and questionnaire surveys were conducted on an oil tanker during the voyage from Japan to Kuwait. The sites where measurements were conducted were the living room, the dining room, the working room and the engine room. Each subject moved to each site and judged his impression of the noise using adjective scales. The subjects were the officers and the crews of the tanker. The results of factor analysis are shown in Figs.1 and 2. Three factors were extracted which can be interpreted as "pleasant", "powerful" and "metallic".

Rumble noise[7),8)]

The same three factors were also found in an experiment with rumble noise generated in the acceleration of a car. Impressions of the timbre of actual and simulated rumble noise were judged using semantic differential. The results are shown in Figs.3 and 4. The same three factors, "pleasant", "powerful" and "metallic" can be found.

Helicopter noise[9)]

We conducted experiments concerning the timbre of the noise from helicopters in three flight modes: landing, taking off and level flight. The results of factor analysis are shown in Figs.5 and 6. The same three factors, "powerful", "metallic" and "pleasant", were found to be prominent in this experiment.

Air-conditioner noise[10)]

A similar experiment was conducted concerning the timbre of air-conditioner noise containing a prominent frequency component. The same three factors, "pleasant", "powerful" and "metallic", were found to be prominent, as shown in Figs.7 and 8.

Environmental noise[11)]

The timbre of nine kinds of sound source; aircraft noise, super express train noise, ordinary train noise, road traffic noise, speech, music, impulse noise, artificial level fluctuating noise and steady state pink noise, all with four different levels, was judged using semantic differential. The results of factor analysis are shown in Figs.9 and 10. The same three factors were dominant. They are "pleasant", "metallic" and "powerful".

Similar results have also been reported by other researchers in Japan, e.g. by Yamashita et al.[12)], Ishiyama et al.[13)] and Okuda[14)].

It may be concluded from these results that the timbre of everyday sounds can be expressed and measured by means of a small number of common factors. Using these, we can estimate the subjective impression of the timbre of various sounds. I am convinced of the generality of factor structure where the descriptive terms are drawn from the Japanese language. However, there are several problems which gave to be discussed.

Firstly, the relation between impression of timbre estimated by Semantic Differential and the physical values of stimuli used should be considered. Secondly, some discussion of possible criticism of the use of verbal responses to describe timbre cannot be omitted.

3. RELATION BETWEEN TIMBRE AND PHYSICAL VALUES

Essentially, timbre is multi-dimensional. Many physical values affect timbre. Therefore, multi-variate analysis is necessary. One way is to employ a multi-dimensional diagram where each point represents the timbre of a sound source measured by Semantic Differential.

In the case of impulsive noise[15], the impressions denominated "sharp" or "metallic" and "loud" or "powerful" vary systematically according the duration, the rise-time and the sound pressure level of stimuli as shown in Fig.11.

Another way to display the result of semantic differential is to make profiles of the adjective scales. An example is shown in Fig.12[10]. This profile shows the effect of prominent frequency components on impressions of timbre. Here, "metallic" impression varies systematically according to signal to noise ratio, i.e. the relation of prominent components to background noise. Scales having high loadings on "powerful" and "pleasant" factor do not vary system according to S/N. The impression "metallic" also varies according to the carrier frequency. Higher frequencies produce more "metallic" impression.

By examining the points in a multi-dimensional diagram or the profiles of adjective scales, we can consider the relation between impression of timbre and physical values. Where semantic differential is used, such multi-dimensional representations are essential. However, they make it very difficult to detect the relation between timbre and physical values and it is tempting to simplify the results. For this purpose, it is convenient to examine the relation between one of the scales of semantic differential and physical values. In the case of helicopter noise, the relation between "loud-soft" and Leq is shown in Fig.13[9]. It is very easy to understand the good correspondence between them.

The results of factor analysis of air-conditioner noise[10] are shown in Table 1 with the coefficient of correlation between LLz[16),17] and each category of adjective scales. It is clear that there is high correlation between LLz and scales having high loadings on the "powerful" factor.

Adjective scales having high loading on the "metallic" factor show a high coefficient of correlation with "sharpness" as it is defined by von Bismarck[18]. Roughly speaking, "sharpness" is calculated on the basis of the balance between the loudness of the higher frequency components and the total loudness.

Perhaps, then, "sharpness" and the "metallic" factor represent much the same aspect of sounds. It must be taken into account, however, that the calculation of "sharpness" proposed by von Bismarck does not include time correction. Both rise time and duration affect impressions which produce the "metallic" impression as is shown in Fig.11. In short, the "metallic" factor is affected by both frequency and time domain. It is necessary to find an appropriate index for the impressions from which the "metallic" factor is extracted.

Concerning the "pleasant" factor, it is very difficult to find an appropriate index based on physical measurement. The meaning or subjective value of sounds may affect the responses from which the "pleasant" factor is derived.

For example, the brand image of cassette tape strongly affects evaluation of the sound quality of the tapes[19]. We recorded music on cassette tapes as stimuli. In condition 1, subjects judged the timbre of stimuli using semantic differential without information about the brand of the tapes. In condition 2, subjects judged the timbre looking at the name of the cassette tape. Therefore, they could recognize the brand of the tape.

An example of the results is shown in Fig.14. The horizontal line shows the upper limit of frequency range of the tapes and the vertical line shows the category rating, "pure-impure". This scale has high loadings on "pleasant factor". Fig.14-b shows the result of condition 1, i.e. blind condition. In this condition, the coefficient of correlation between frequency characteristics of the tapes and subjective ratings is only .115 and not significant. Fig.14-a shows the result of condition 2, i.e. brand condition. In this case, a fairly high correlation can be seen. This fact suggests that the brand image may affect the evaluation of timbre. The good image may bring about good evaluation. In the case of the scale having high loadings on "powerful factor", the effect of brand image was not found as shown in Fig.15.

The objectives and conditions of experimental investigation must be carefully defined if a useful relationship is to be found between the "pleasant" factor and physical measurements. Otherwise, it might be necessary to establish a composite index.

In the case of cassette tapes, the market price is a good index of the sound quality described by the scale of "beautiful-ugly" as shown in Fig.16. The market price under highly competitive condition may reflect the total quality of tapes. Various properties(physical and other) may affect the "pleasant" factor, depending on the purpose of experiments. We can see, then, that the physical properties which affect the "pleasant" factor cannot be considered without taking experimental situations into account.

4. USEFULNESS OF VERBAL RESPONSE

There has been much criticism of the use of verbal responses to describe timbre because of the ambiguity in the terms available. Although this is so, verbal expression is nevertheless a useful tool for understanding the characteristics of timbre. It is possible to place sound sources in a multidimensional space without using verbal expression and to examine the physical factors which determine the clusters, but it is really impossible to express the subjective properties of the sounds in a cluster without using verbal expression.

The effectiveness of verbal expression has been examined in a study involving five contries, using the method of "selected description"[20]. Subjects were asked to select adjectives which they thought appropriate for expressing the impression of sounds. Cluster analysis was conducted on the basis of commonly selected adjectives. An example of a dendrogram for sound sources is shown in Fig.17. As these figures show, similar sound sources gathered in close trees. Clear configurations of sound sources were found in the experiment, in which stimuli were not directly compared but assessed independently using verbal expressions. The results suggest that there is an area of common agreement when impressions of a sound are expressed verbally. It would be desirable to establish a clearer definition of the terms to be used to express impressions of timbre on the basis of results of experiments. The terms could be defined by making examples of sounds for which the terms are an appropriate expression.

5. SUMMARY

A definition of timbre was proposed which suggested its application to two attributes of sound: "a characteristic which gives a clue to the identity of the sound source, and the quality of sounds which corresponds to the emotive impression expressed by "timbre"". The emotive aspects of timbre are multidimensional. Using semantic differential, the factorial invariance of timbre was investigated and it was found that three factors were dominant: "pleasant", "powerful" and "metalli c". The generality of these three factors has been confirmed in Japan. The relation between timbre and physical values was examined. Finally, the usefulness of verbal expression concerning timbre has also been discussed.

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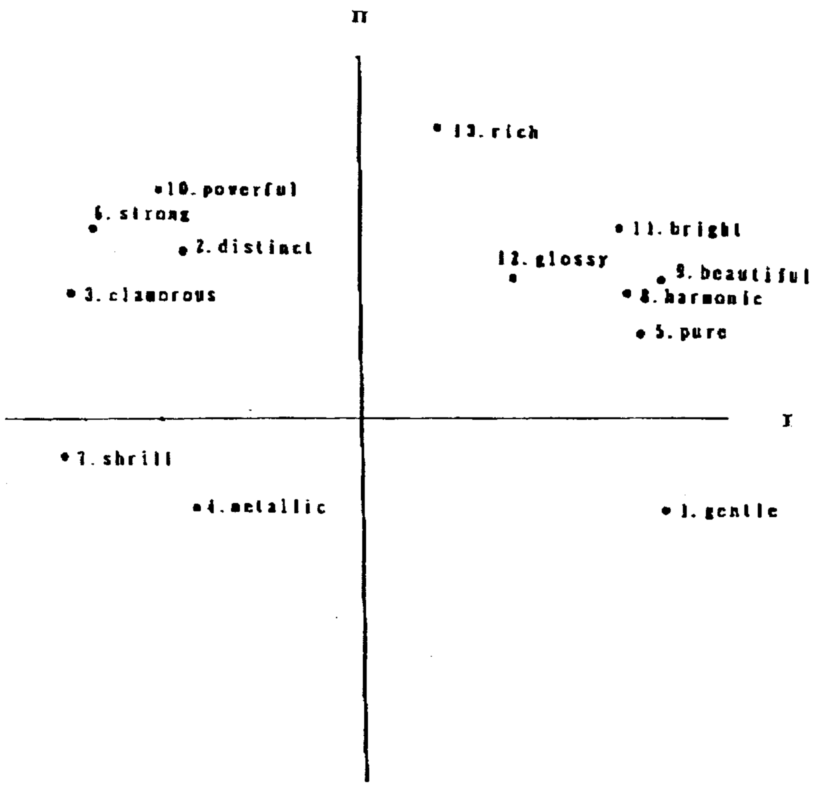
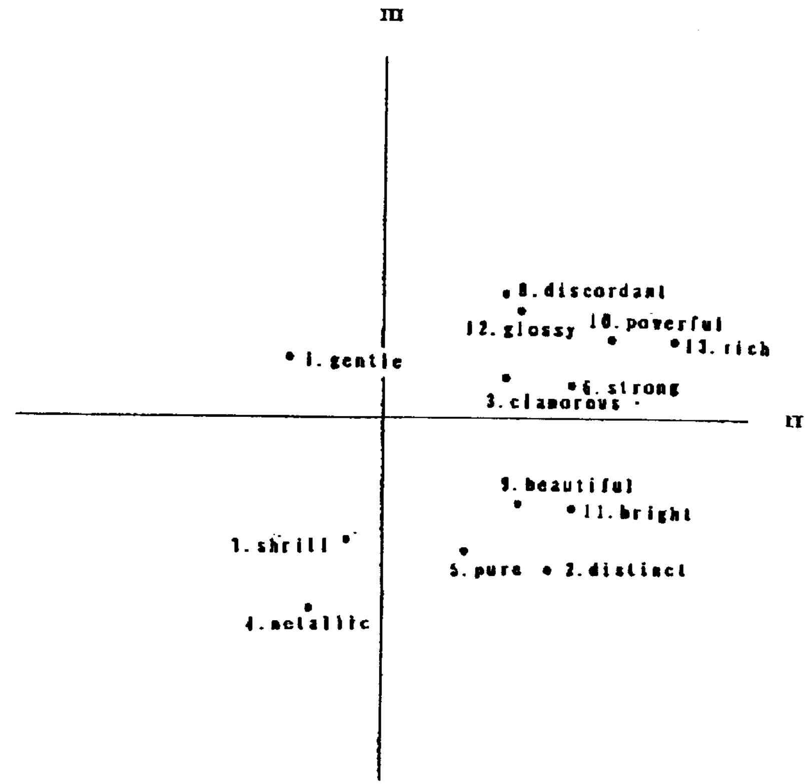


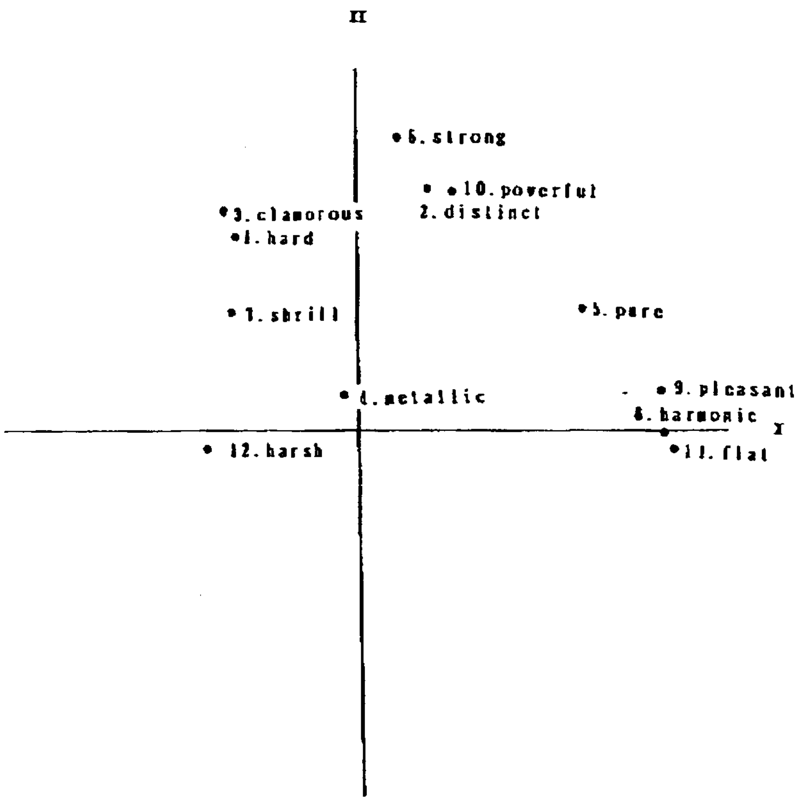


tanker noise

Fig.1

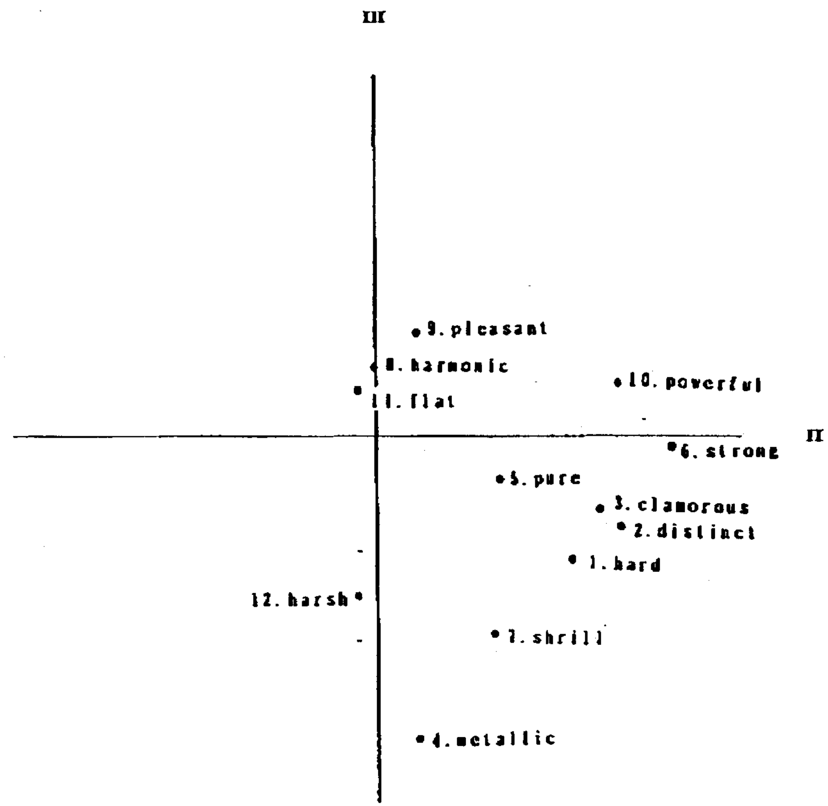
Fig.2

(Manabe et al., 1968)



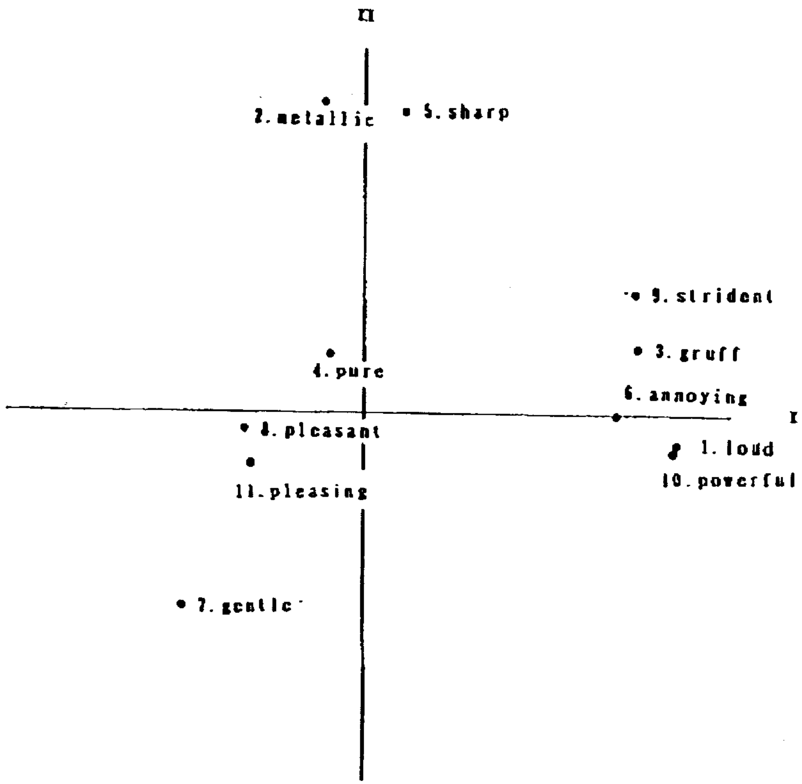
rumble noise

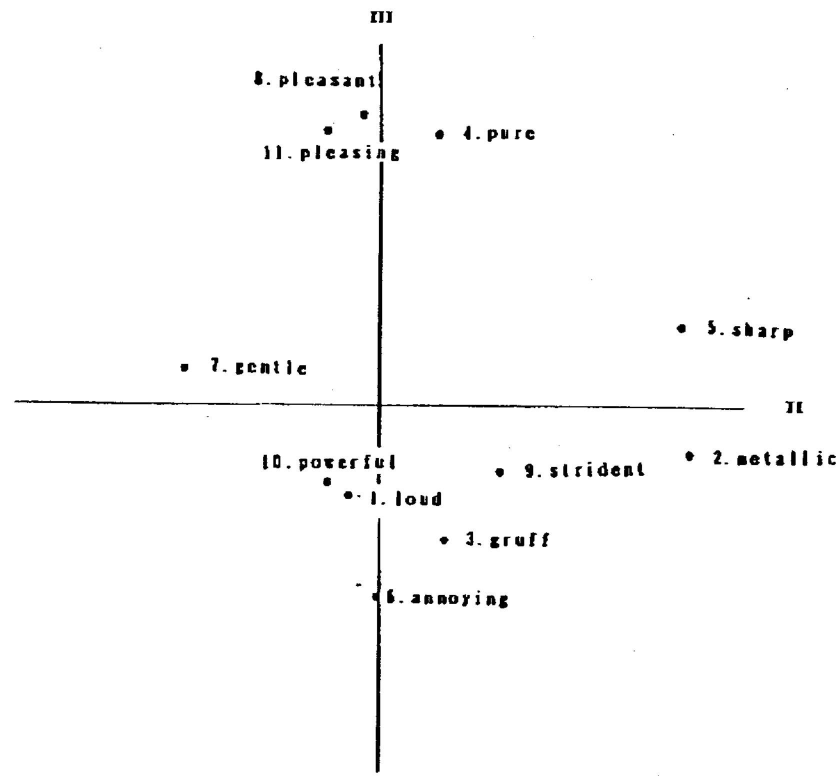
Fig. 3



(Hashimoto et al., 1988)

Fig. 4



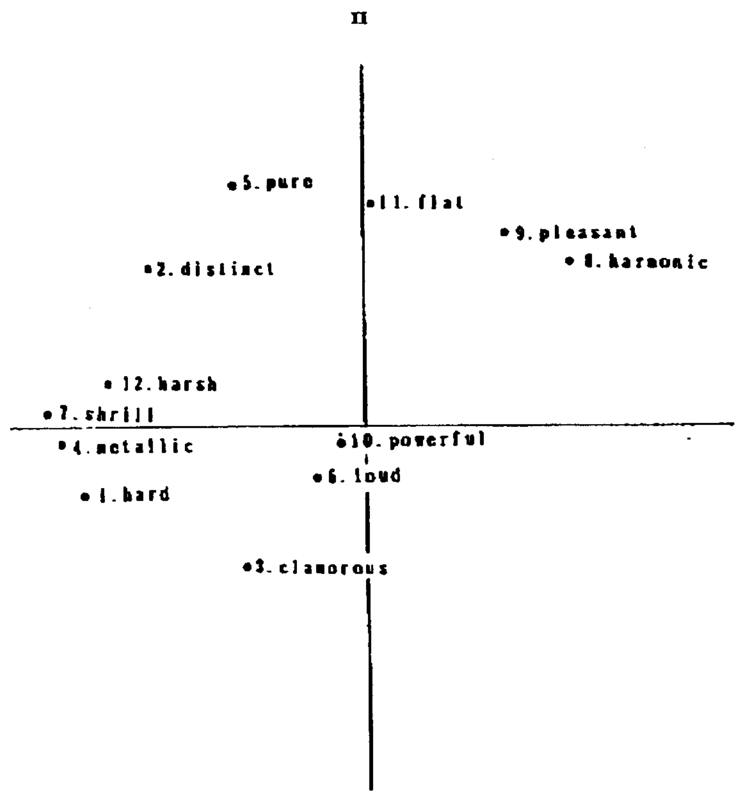


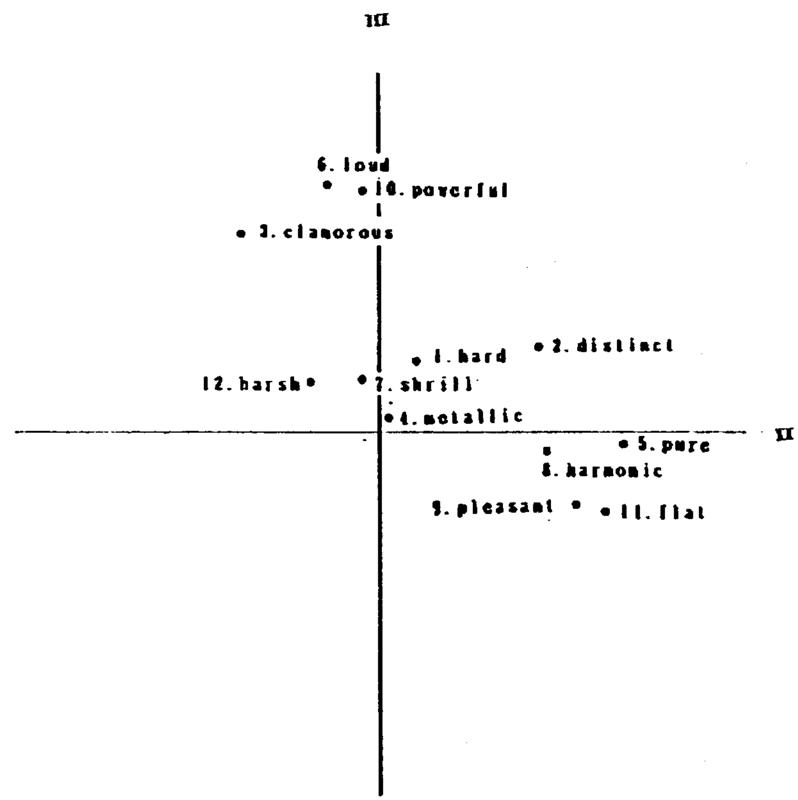
helicoper noise

(Namba and Kuwano, 1989)

Fig.5

Fig.6





aircondltioner noise

(Namba et al., 1992)

Fig.7

Fig.8

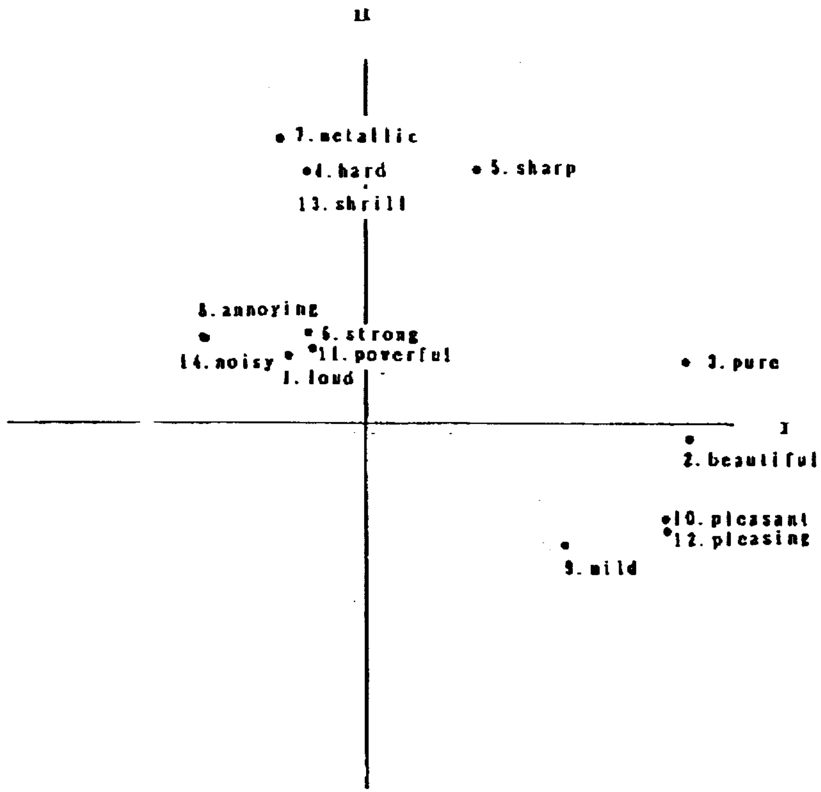
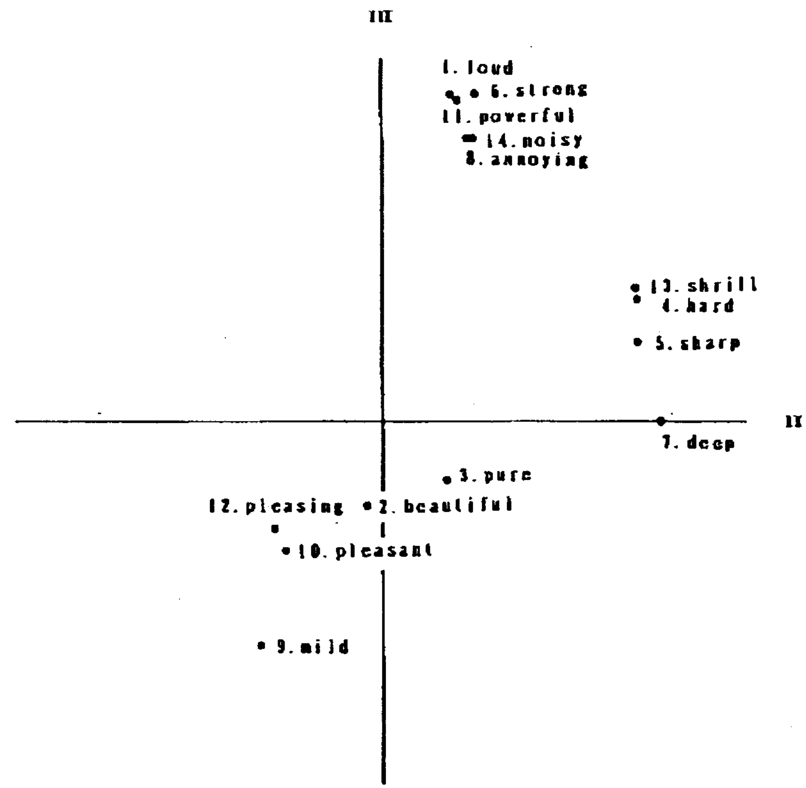


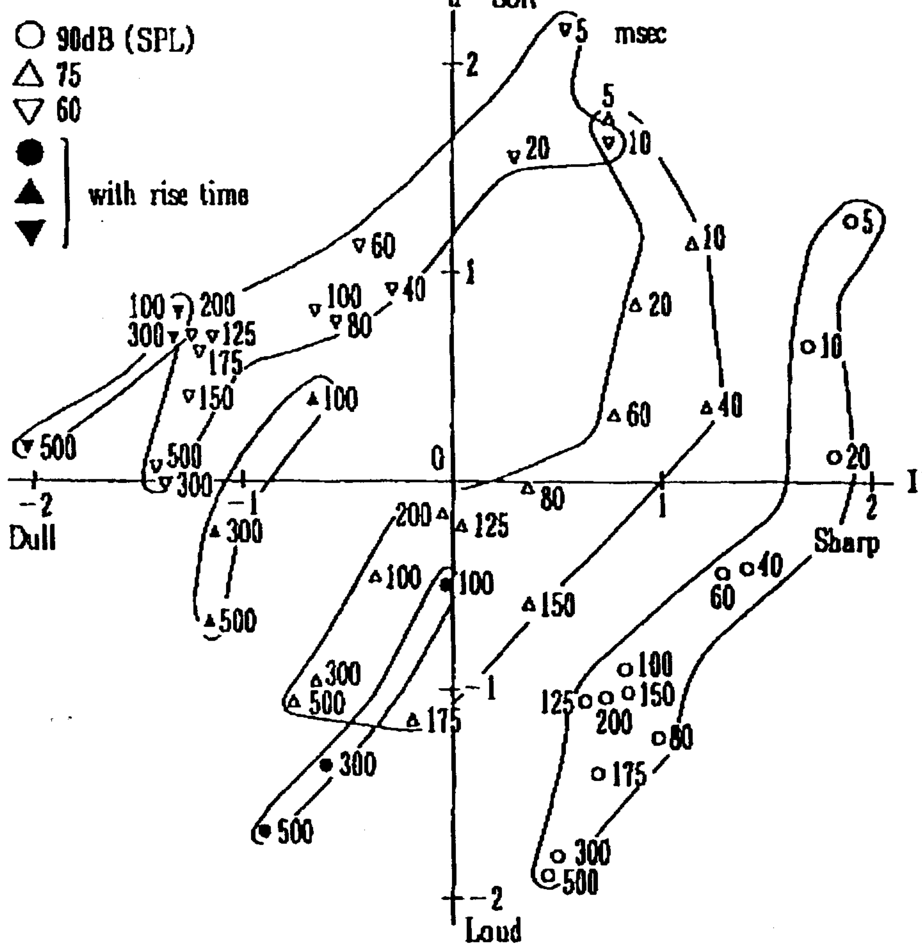
Fig.9



environmental noise

(Namba and Kuwano, 1989)

Fig.10



(Namba et al., 1974)

Fig.11

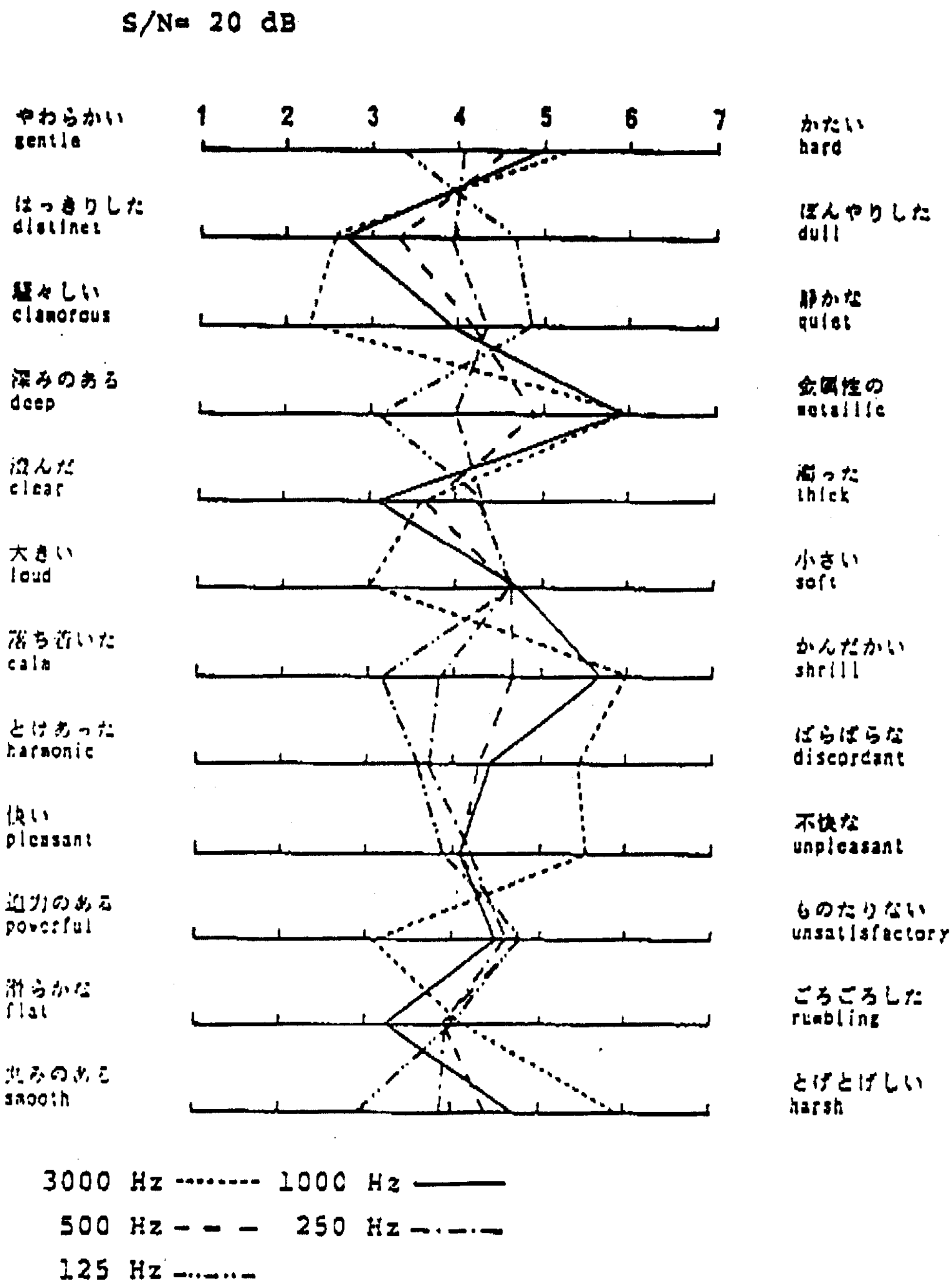
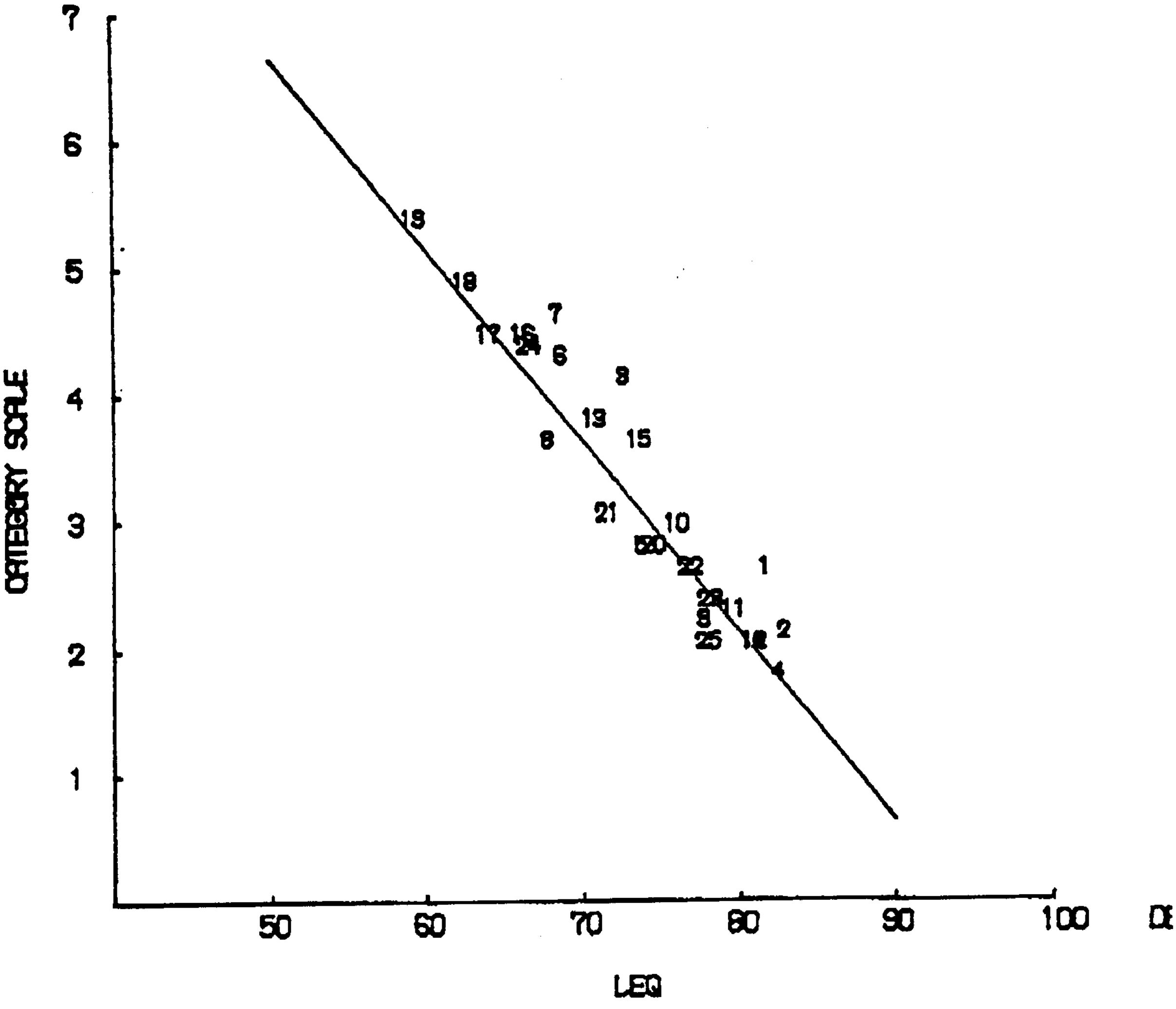


Fig.12 An example of semantic profiles for S/N of 20 dB.



ADJECTIVE NO. 1 (R= -.942)

大きい ——— 小さい

Fig.13

(Namba and Kuwano, 1989)

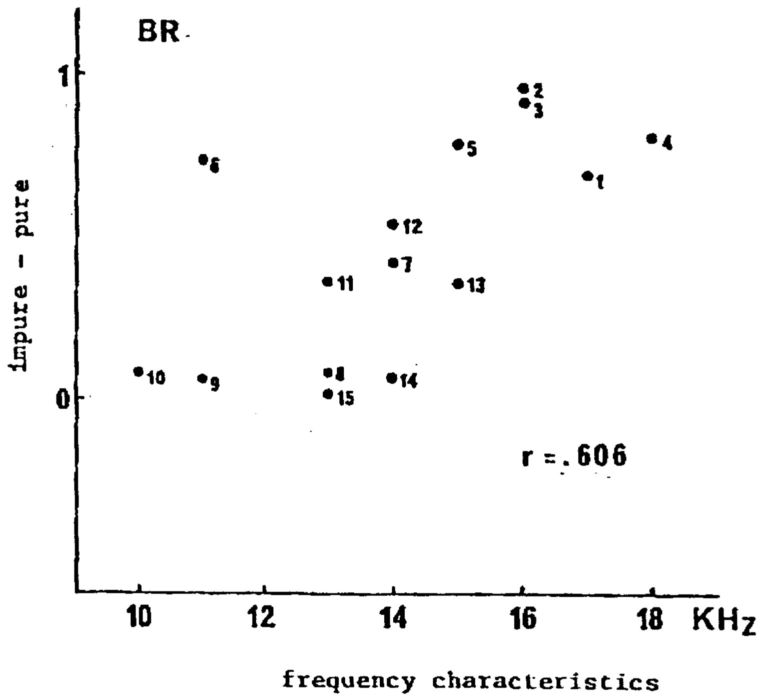


Fig.14-a

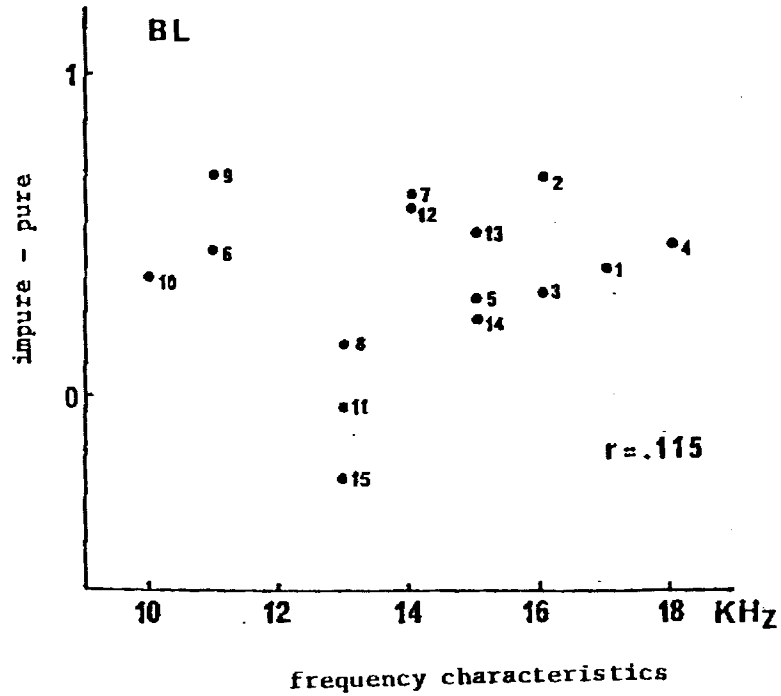


Fig.14-b

(Kuwano et al., 1978)

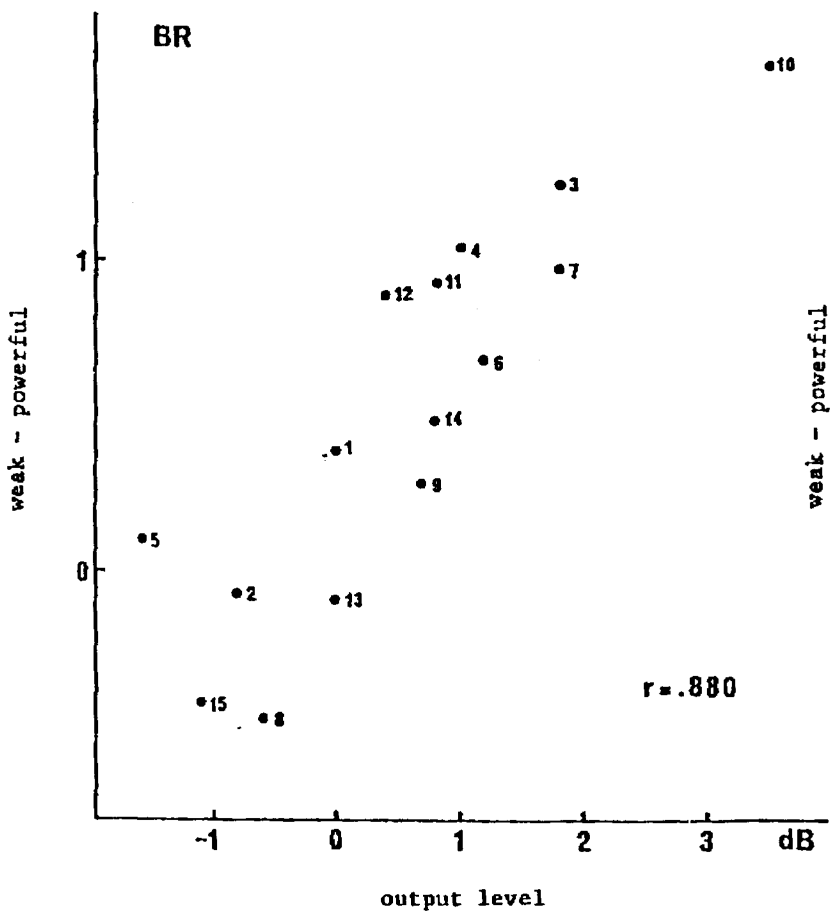


Fig.15-a

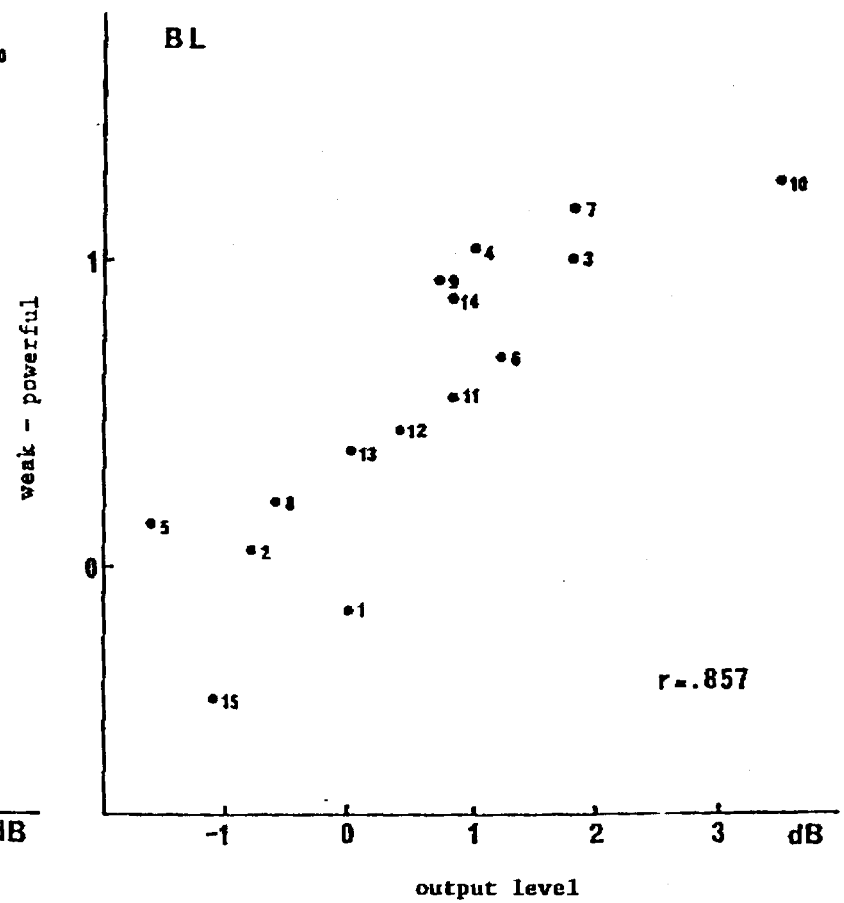


Fig.15-b

(Kuwano et al, 1978)

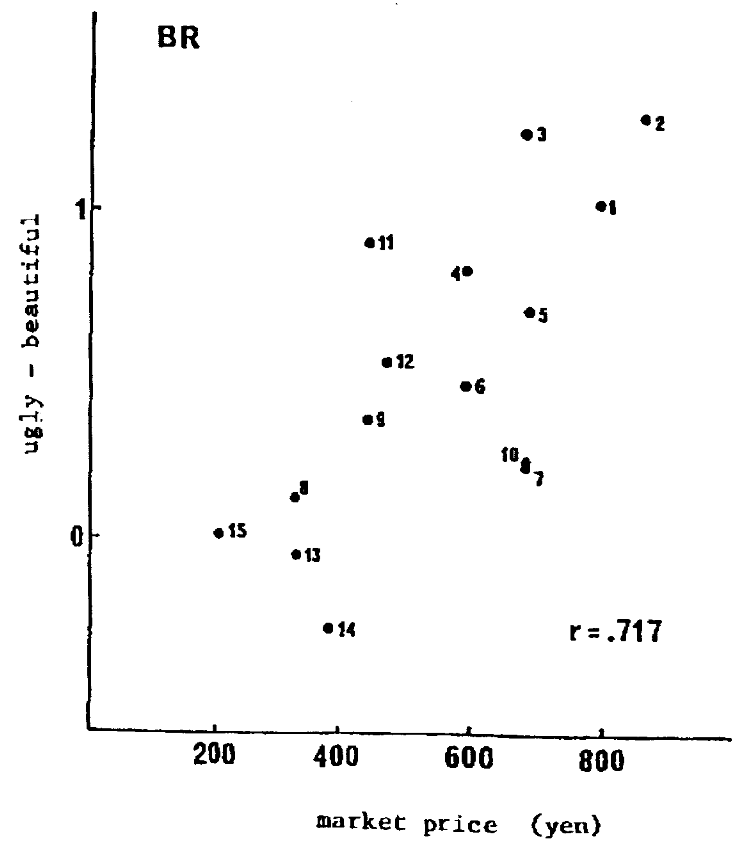


Fig. 16-a

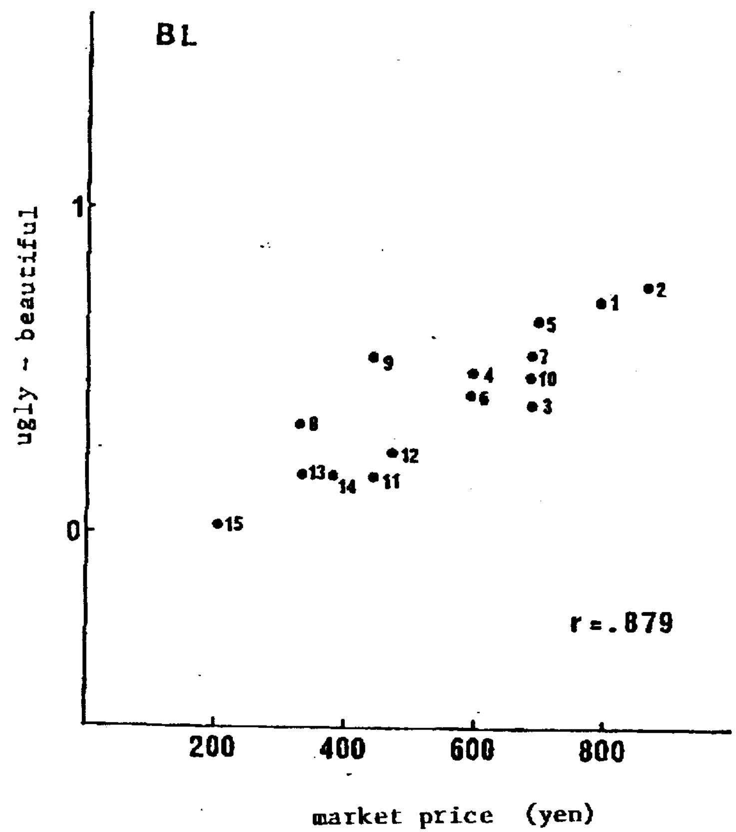
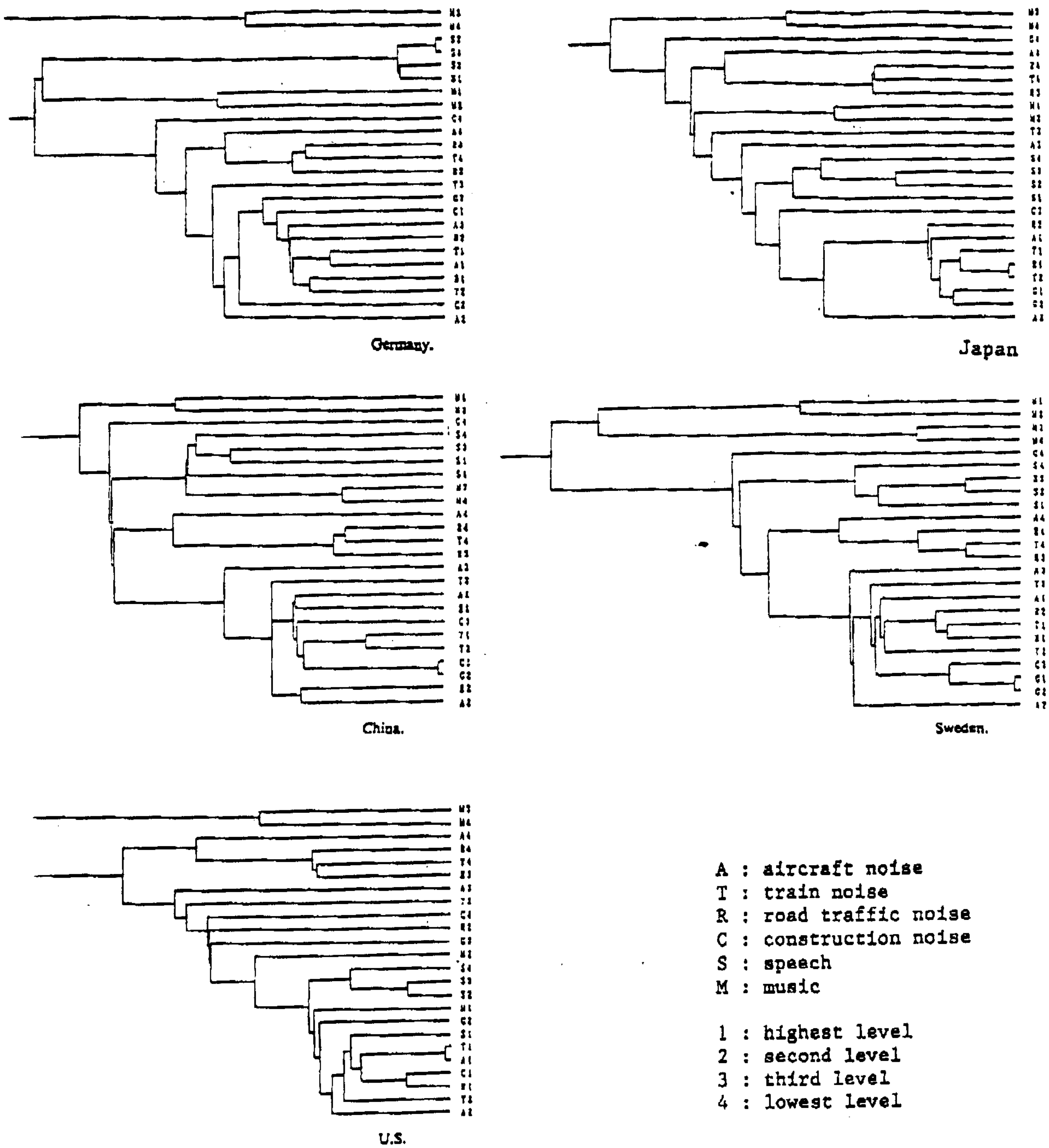


Fig. 16-b

(Kuwano et al., 1978)



A : aircraft noise
T : train noise
R : road traffic noise
C : construction noise
S : speech
M : music

1 : highest level
2 : second level
3 : third level
4 : lowest level

Fig.17

Table 1

Results of factor analysis in Experiment 4. The coefficient of correlation between each adjective scale and estimated values based on physical measurement (S/N, *LLz* and sharpness) are also shown in the right-hand columns.

	Adjective	Factor 1	Factor 2	Factor 3	r (S/N)	r (*LLz*)	r (Sharpness)
1.	Gentle	0.725	−0.114	−0.224	0.621	0.008	0.796
2.	Distinct	−0.615	0.425	0.229	−0.723	0.120	−0.722
3.	Clamorous	−0.342	−0.387	0.546	0.061	−0.707	−0.742
4.	Deep	0.878	−0.036	−0.051	0.578	0.041	0.831
5.	Clear	−0.371	0.660	−0.040	−0.799	0.362	−0.571
6.	Loud	−0.139	−0.148	0.684	0.273	−0.819	−0.590
7.	Calm	0.842	0.044	−0.160	0.553	0.086	0.871
8.	Harmonic	0.553	0.445	−0.060	0.346	0.321	0.838
9.	Pleasant	0.374	0.528	−0.204	0.023	0.712	0.737
10.	Powerful	−0.073	−0.054	0.667	0.297	−0.834	−0.582
11.	Flat	0.016	0.611	−0.223	−0.683	0.549	−0.200
12.	Smooth	0.788	0.186	−0.161	0.436	0.291	0.892

(Namba et al., 1992)