ON LOUDNESS MATCHING (*Fourth Report*)

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Introduction

In the previous paper, we have reported some discussions concerning the comparison of the subject-control method and the operator-control method on loudness matching. As results of those experiments, the transmission level of any response system which is obtained as being matched is nearly independent of the controlling methods in its measurement. In this report, therefore, experiments are performed by the subject-control method (SCM) alone where its various test-conditions are examined in full, and we have here an occasion to describe about them.

Effect of Duration Time of Testing Stimulus

In the flow of speech sounds, we see their phonetic kinds, their sound intensities and also their lengths all changing in time incessantly. Therefore, it becomes important in loudness matching to determine the most desirable values of duration time of testing condition by which the speech-sounds stimuli are presented to the observers. To check the effect of duration time on the data of loudness matching, experiments are carried out for the case Y (refer to the third report) with three kinds of duration time (1, 2 and 3 seconds respectively). The effect of the duration time upon the mean transmission levels and their standard deviations is tabulated in Table 1. The record is mean value of transmission-level difference of 20 times observation. The mean transmission level thus obtained seems to decrease as the duration time gets short. But these variations are regarded to be insignificant within the extent of five per cent level of confidence. Therefore, the mean transmission level of loudness matching may be nearly independent of duration time of testing stimulus.

The effects of the duration time upon the standard deviations of observed data are evidently significant in loudness matching. These relations are illustrated in Fig. 1.

TABLE 1. Effects of the Duration Time of Testing Stimulus upon the Results of Loudness Matching

Duration time of signal		1 (sec.)		2 (sec.)		3 (sec.)	
Mean values of transmission-level difference ($\bar{x}$) and standard deviation (s)		$\bar{x}$ (db)	s (db)	$\bar{x}$ (db)	s (db)	$\bar{x}$ (db)	s (db)
Frequency band (in c.p.s.)	150~5000 (**W**)	3.9	0.74	5.1	0.74	4.8	1.40
	250~3200 (**M**)	5.8	1.40	6.7	0.94	6.9	1.45
	600~2000 (**N**)	16.3	2.83	17.0	1.56	16.9	1.32

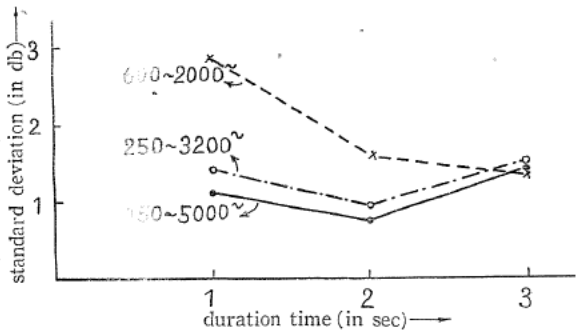

FIG. 1. Relation of the standard deviations in loudness matching with the duration times of stimulus for various frequency bands.

By inspection of this figure, we see the variances being affected not only by duration time, but also by the kinds of testing stimulus. When the timbre of a test pair is resembled, the duration time of about 2 or 3 seconds is more preferable. But the duration time of 3 seconds or more will be more serviceable if the quality resemblances in test sounds come to be lost.

Effect of Combination of the Testing Stimulus

When sounds "x" and "y" are judged as being equal in loudness and also quite so with sounds "x" and "z," then is it possible to induce straightway that the sound "y" matches in loudness with the sound "z"? If it is proved true experimentally that such loudness matching by indirect comparison is applicable to some various types of transmission system, then the testing procedures will be easily more simplified without reducing confidence of observed data.

In the procedure of indirect loudness matching, we take the case X, testing combinations of F-P, F-V and P-V, using the subject-control method. The transmission level of P-V combination, calculated indirectly from the experimental data of F-P and F-V cases, is compared with the directly measured transmission level of P-V combination. These tests are performed in various conditions, namely in three kinds of frequency band and five sorts of voice level. Three young male-observers are employed and 18 times observation are repeated in every test condition. Some of

TABLE 2. Effects of Combination of the Testing Stimulus upon the Results of Loudness Matching for the M Frequency Band

Combination		F-P		F-V		P-V		P-V (calculated)	
Mean values of transmission-level difference ($\bar{x}$) and standard deviation (s)		$\bar{x}$ (db)	s (db)	$\bar{x}$ (db)	s (db)	$\bar{x}_m$ (db)	s (db)	$\bar{x}_c$ (db)	$\lvert \bar{x}_c - \bar{x}_m \rvert$ (db)
Voice level (in db)	35	3.1	2.37	18.17	0.68	17.77	2.6	15.07	2.7
	20	0.06	1.31	17.5	0.96	13.94	2.41	17.44	3.5
	0	−0.6	1.9	17.4	1.2	16.8	2.5	18.0	1.2
	−20	0	1.53	14.33	0.95	13.44	1.68	14.33	0.89
	−35	2.44	2.05	14.44	1.49	9.5	2.62	12.0	2.5

these results are shown in Table 2. In this table, experimental data of F-P, F-V and P-V combinations are shown in the first three columns from the left, the "indirect" matching levels in the fourth column, and the differences between the measured and the calculated levels in the fifth column.

Many results show that the indirectly calculated matching levels are equal, within the variances of subjective measurement, to the directly measured levels. Therefore, such inductive calculation will be pretty available in these sorts of stimulus. As mentioned previously, the variance of experimental data is regarded to be nearly proportional to the psychical strain necessary for the subjective judgement. In this table, the standard deviations of any P-V combination are a little larger than any other one. To make a reduction of the confidence-interval of mean matching level, the selection of reference stimulus should be taken into account in the test of loudness matching.

Effect of Voice Level

Under the consideration of various effects mentioned in the preceding sections, the experiments of loudness matching were as follows. Method of loudness matching is S.C.M. Duration time of testing stimulus is three seconds. As a reference in a matching pair, flat characteristic (F) is always adopted. The judgements in loudness matching are obtained at three different frequency bands (W, M and N in case X) on fixed voice level for each band. This voice level is about 57 db re 0.0002 dyne per square centimeter in the case of non-filtering, flat-response characteristic. This voice level is named, hereafter, referential voice level (0 db). The results of loudness matching in such a reference level are shown graphically for each transmission band in Fig. 2.

It will be worth noting that the relative situation of P and V characteristics for matching changes according to voice levels. The shift values of transmission level for rematching in loudness against every voice level are illustrated in Fig. 3.

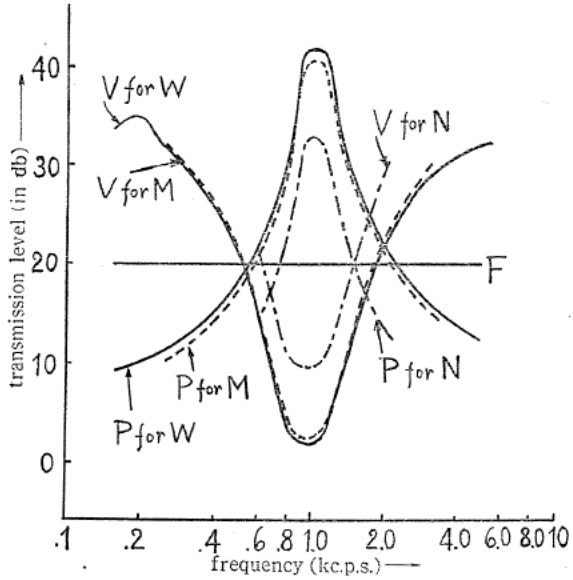

FIG. 2. Level situations of the characteristics of P and V type, brought into the matched condition with reference F type, for all the three frequency bands of W, M and N.

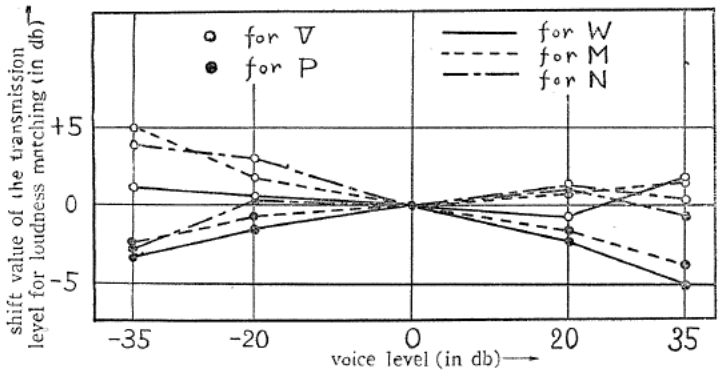

FIG. 3. Shift of the transmission levels necessary for loudness matching, in various frequency bands, at several voice levels.

The effects of voice level on loudness matching are summarized as follows.

(1) In the case of combination **F-P**, the transmission level of **P** system necessary for its rematching, always decreases gradually, as the voice level changes (increases or decreases).

(2) In **F-V** combination, the transmission level of **V** system always increases as the voice level changes.

(3) As the frequency band of transmission system is narrowed, the decrement of the transmission level of **P** system is gradually reduced.

Such shifts of transmission level due to the transition of voice levels are significant at well past the one per cent level of confidence. Fig. 4 shows the fluctuation of the standard deviations of the observed levels affected by the voice levels in the three combinations for **M** frequency band.

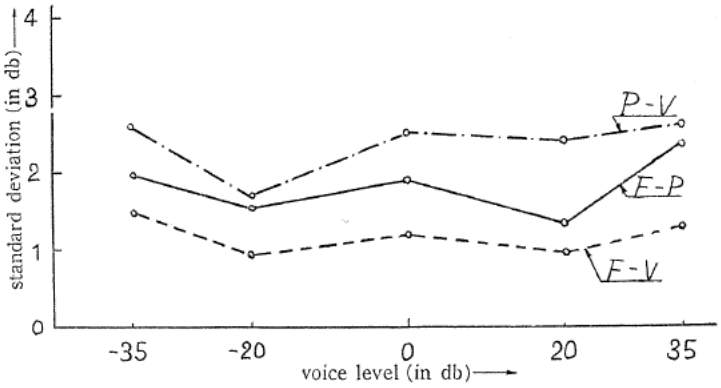

FIG. 4. Relation between voice levels and standard deviations of loudness matching in various types of combination.

The characteristics of variances of experimental data in various testing conditions are as follows.

(1) In the case of **P-V** combination, the variances are large in general. In the **M** and **N** frequency bands, the variances of **F-V** combination get smaller than those

of **F-P** combination, but in the **W** frequency band, the relation comes in reverse.

(2) In the extreme values of voice level (i.e. 35 db and −35 db), the variances are relatively large.

(3) In **F-P** and **F-V** combinations, the standard deviations remain within certain extent.

The analysis of these variances is performed with all testing scores in every frequency bands for the purpose of determining the main factor of variability in the judgement of loudness matching. Table 3 shows the variances of several factors in the case of **M** frequency band.

TABLE 3. Summary of the Analysis of Variance and F-value of α (0.05) and α(0.01)

Source of variance	Mean square of variation		F-value	
	F-P	**F-V**	α (0.05)	α (0.01)
Voice level (L)	50.1	60.3	2.53	3.66
Within-observers (W)	1.8	1.0	3.16	4.99
Between-observers (B)	2.92	3.8	2.37	3.35
L × B	9.35	2.05	1.77	2.24
Error	1.96	0.54		

The variances caused by voice level account for the greater parts of the total. Consequently other factors of variance source come to run lower and some of them become even insignificant at the five per cent of confidence. But in the **W** and **N** frequency bands, the variances caused by differences between-observers and also those within-observers are almost significant at well in every testing condition. In such cases, it is interesting to know which variance is larger, that caused by differences between-observers or that caused by variability within-observers. The percentage of variabilities between-observers and within-observers, in the case of **F-V** and **F-P** combinations are shown in Fig. 5.

In the **W** and **M** frequency bands, the variabilities between-observers are larger than those within-observers, but the situation is reversed in the **N** frequency band. The same tendencies occur in every combination. The analytical result seems to tell us that still the *timbre* quality of testing sounds influences upon the judgement in loudness matching, even when the subjects are forced to perceive the phenomena merely on *loudness* aspect.

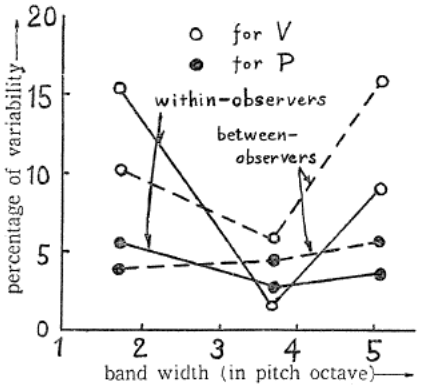

FIG. 5. The percentage of variability between-observers and within-observers as a function of band width, in the case of **F-V** and **F-P** combinations.

Comparison of Loudness Matching with Volume Matching

In the actual communication system, the VU meter is put to use for the indica-

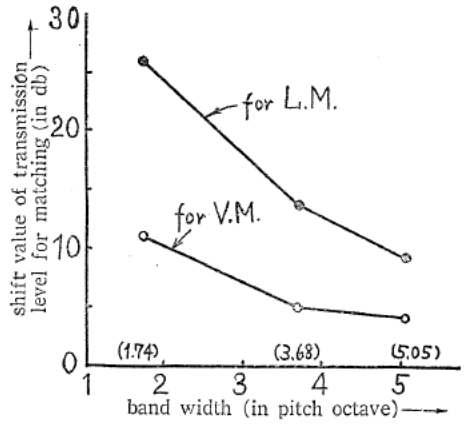

FIG. 6. Comparison of loudness matching (L.M.) with volume matching (V.M.).

tion of voice level, because it is accepted as a handy instrument for that purpose. Here the comparison of the objective volume matching by VU meter with the subjective loudness matching is carried out for the Y case only. Fig. 6 shows the results of volume matching and loudness matching at referential voice level. The ordinate of this figure shows the increment of transmission level necessary for either matchings. From these results, it is found out that the difference between loudness and volume matching increases gradually as the frequency band is narrowed.

Summary

Results of experiment in SCM are summarized here.

(1) The most desirable value of duration time for loudness matching of continuous speech-sounds is about 3 seconds.

(2) The indirect loudness matching is available so far as our experiments are concerned. Thus the selection of reference condition is important for the reduction of the difficulties caused by the timbre difference in direct matching.

(3) The matched level in loudness is influenced by voice level.

(4) The timbre of testing sounds influences upon the judgement of observer.

(5) The difference between loudness matching and volume matching increases considerably as the transmission frequency band decreases in its width.

The object of loudness matching is not for only the consecutive speech-sounds reported here, but also sustained vowels, white noise, interrupted speech-sounds and so on. The authors are intending to extend their reseach hereafter and wanting to catch hold exactly of the meaning of loudness matching in auditory perception.

In concluding the paper, the authors wish to express their gratitude to Mr. Masanobu Watanabe for his earnest and sincere assistance in these experiments.

Comment of Notation

P: Peak characteristic having its resonance point at 1000 c.p.s., with selectivity 2.0.
V: Valley characteristic having its anti-resonance point at 1000 c.p.s., with selectivity 1.8.
F: Flat characteristic, as a reference.
W: With frequency band 150～5000 c.p.s. (5.05 in pitch octave).
M: With frequency band 250～3200 c.p.s. (3.68 in pitch octave).
N: With frequency band 600～2000 c.p.s. (1.74 in pitch octave).

Reference

Y. Ochiai and S. Saito: On Loudness Matching (Third Report). Memoirs of the Faculty of Engineering, Nagoya University, Vol. 4, No. 1. 1952.