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Review Article

Necessary Research for Standardization of Subjective Scaling of Whole-Body Vibration

Setsuo MAEDA

Department of Human Engineering, National Institute of Industrial Health, 21-1 Nagao 6-Chome, Tama-ku, Kawasaki 214-8585, Japan

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Abstract: Researches into the relationship between the physical quantity of vibration and the subjectively perceived quantity become important in designs for the vibration environment. Subjective experimental methods to obtain the relationship between the physical quantity of vibration and the subjectively perceived quantity are different depending on the design objectives which consider the human sense of vibration characteristic. In this review, the following are outlined: (i) fundamental methods for obtaining the design objectives for vibration environments; (ii) reported findings on the physical quantity of vibration environments and the human characteristics of sense vibration; and (iii) problems with and limits of the ISO 2631-1 standard, which defines the subjective response of the ride comfort in public transportation. Finally, the directions of research into the subjective experimental methods for obtaining design objectives in the vibration environment considering of the human characteristics of sense vibration are described.

Key words: Whole-body vibration, Subjective scaling, Ride comfort, ISO 2631-1

Introduction

The purpose of using experimental subjectively perceived methods is: to understand grasp human subjective characteristics of physical characteristics of vibration; to determine the relationship between the subjectively perceived value and the good evaluation index of the physical vibration characteristics; and the establishment of the target values in the design of vibration environments in considering the human sense of vibration characteristics.

In order to clarify the relationship between the physical quantity and the subjectively perceived quantity of the vibration environment, the various experimental methods shown in Table 1 have been used[1].

The constant measurement method of Table 1 is mainly a method for measurement of the threshold of human sense. The subjective scaling method is one of the methods for obtaining subjective scaling or proportional scaling between the subjectively perceived quantity and physical quantity.

In this review, the fundamentals thinking of experimental method for obtaining the target values in the design of vibration environments, and the different findings between the subjectively perceived method evaluating human sense to vibration characteristic and physical quantity of vibration environment are summarized. The problems with and limitations of the ISO 2631-1[2] standard that defines the subjective scaling of the ride comfort in public transportation are clarified. Also, future researches needed for the experimental psychological method for providing the target values in the design of vibration environments considering the vibration characteristics of the human senses are described.

Table 1. Psychophysical methods

Constant Measurement Method	Constant Method Method of Adjustment Method of Limits Adaptive Psychological Method
Subjective Scaling Method	Interval Scale Paired Comparison Method Category Judgment Method Proportional Scale Magnitude Estimation

Fundamentals of Subjective Scaling

The relationship between the experimental psychological methods for providing target values in the design of the vibration environments and the physical quantities is shown in Fig. 1.

For the vibration characteristics that arise from the vibration of vehicles, it is necessary to link the relationship between the sensory threshold of human reaction and the physical characteristics of the source of vibration, in order to clarify what kind of reaction the researchers want to get.

The constant measurement method of Fig. 1 is used, when the researchers want to get the human sensory and perceptual changes to the physical quantity. Subjective scaling, such as an interval scale or the proportional scale, have been used, when subjective scaling between the physical quantity and the subjectively perceived quantity is being considered.

The ME (Magnitude Estimation) method is a subjective scaling method for obtaining a proportional scale and seems to be suitable for clarifying whether the evaluation index of the physical quantity corresponds to the subjectively perceived quantity. The category judgment method, or the method of adjustment by subjects, seems to be suitable as a method for obtaining the correspondence between "Phrase" or "Words" and the physical quantity.

The subjectively perceived experimental method is a different way which has choices depending on what it wants to clarify as the target characteristics of the experimental design. Therefore, researchers have to choose the experimental subjectively perceived method carefully.

Subjective Response and Psychometrics

Thresholds

As a method for determining the threshold of the target characteristics of the experimental design whether or not humans sense the vibration, the constant measurement method is mainly used, Fig. 1. The method of adjustment by the subjects is used and many researchers have been reported the results of vibration thresholds[3–14].

The example of vibration thresholds for discrete frequency by the method of adjustment in supine posture is shown in Fig. 2. By the elucidation of these values, it seems possible to contribute for target characteristics of the design of the habitability to the building vibration.

Figure 2 shows the thresholds of whole-body vibration obtained by using the method of adjustment by the subjects. These results were obtained by laboratory experiments using a single axis vibrator and discrete frequencies and stationary vibration stimuli in the frequency range of 1–80 Hz. Although a small number of researches have been performed to get the thresholds of whole-body vibration, the threshold data however, were referenced to the threshold value of the ISO 2631-1 standard. It is not clear, whether these threshold

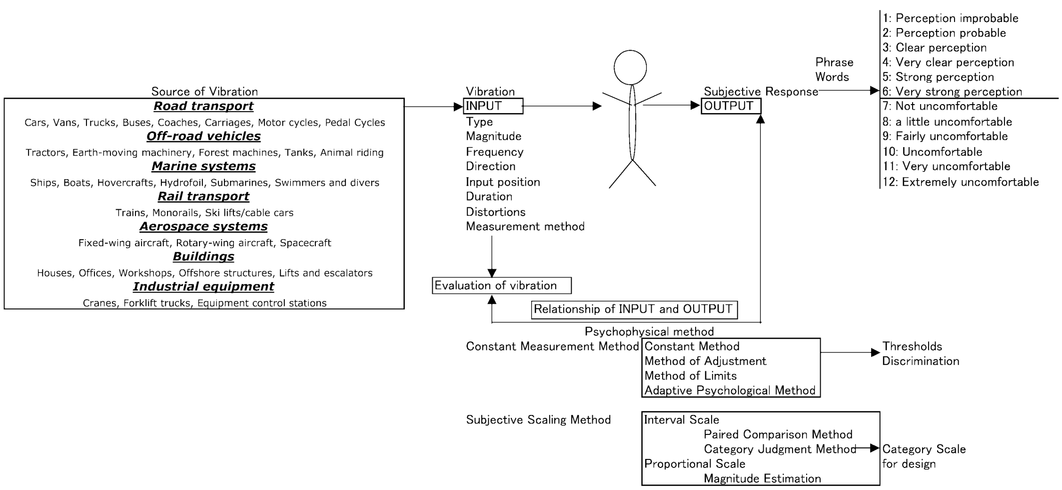

Fig. 1. Relationship between vibration and subjective responses.

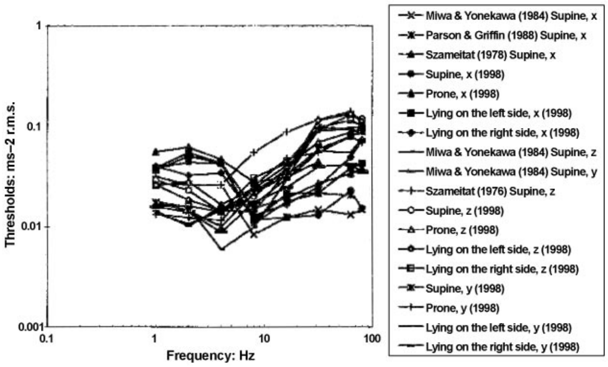

Fig. 2. Thresholds of whole-body vibration by using the method of judgment by subjects[4].

data are consistent with the threshold value of the frequency-weighted r.m.s. acceleration value according to the ISO 2631-1 standard. Therefore, we have to find out the threshold values of stationary and non-stationary vibration at multiple-frequencies, and in multiple-axes to contribute to the target values of the design.

Difference thresholds

The difference threshold is the difference in magnitude between two stimuli which is just sufficient for their difference to be detected.

Usually, difference thresholds are determined using the UD (The Up-and-Down) method or the UDTR (The Up-and-Down Transformed Response) method of the adaptive subjectively perceived method in constant measurement method[15–17]. In Fig. 3, the measurement results of difference threshold values of vibration at discrete frequencies are shown[18].

It seems to become the target values in the design in considering whether it may deal with the change of how much vibration as an effect of the shock absorber as the vibration travels in the seat through shock absorber from the tire of the automobile by lying by clarifying these results. Reduction in vehicle vibration that may contribute to improvements in overall vehicle ride could individually be too small to be detected by drivers or passengers.

As shown in Table 3, researches into difference thresholds have been very few. Difference thresholds have only been clarified at discrete frequencies and real vehicle seat vibration in the z axis. Therefore, much research is needed to find out difference thresholds in real situations for designing vehicles.

Magnitude estimation

The ME method is a subjective scaling method for discrimating between physical quantity and subjectively perceived quantity. This method was proposed by Stevens[19].

Table 2. Results of thresholds researches

Thresholds

	Stationary vibration						Non-stationary vibration	
	Axis	Standing	Sitting on the chair	Sitting on the floor	Recumbent supine		Standing sitting chair & floor	Recumbent all postures
1–80 Hz; Sinusoidal	x y z	■ ■ ■	■ ■ ■	■ ■ ■	■ ■ ■	1–80 Hz Single Shock	□ □ □	■ ■ ■
1–80 Hz; Sinusoidal	Multi-Axis x + y or x + z y + z	□	□	□	□	1–80 Hz Single Shock	□	□
1–80 Hz; 1/1, 1/3 Octave	x y z	□ □ □	□ □ □	□ □ □	□ □ □	1–80 Hz 1/1 or 1/3 octave	□ □ □	□ □ □
Multi-Frequency Spectrum	x y z	□ □ □	□ □ □	□ □ □	□ □ □	Multi-Frequency	□ □ □	□ □ □
Multi-Frequency Spectrum	Multi-Axis 3 or 6 Axis	□	□	□	□	Multi-Frequency and Axis	□	□

■ Researches done, □ Future research, Single Shock: Single Cycle Sinusoidal Shock.

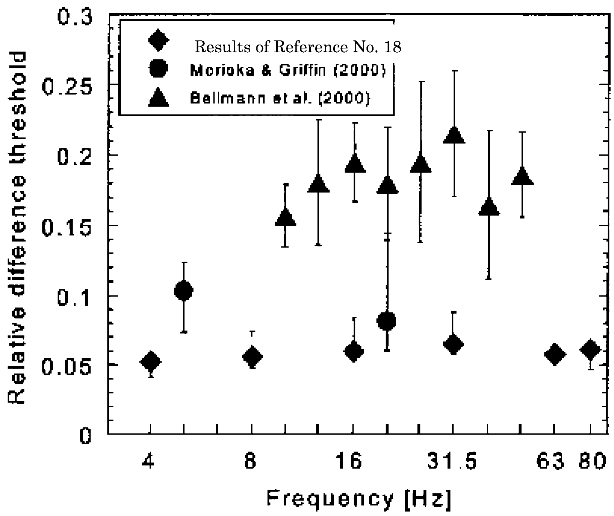

Fig. 3. The difference thresholds of whole-body vibration by using the UDTR method[18].

The psychophysical magnitude, Ψ, of the stimulus is related to its physical magnitude, ϕ, by the expression

$$\Psi = k\phi^n$$

where the constant k depends on the units employed. The growth of sensation is determined by the value of the exponent n, which is expected to be constant for each type of stimulus. The value of the exponent may be determined by the ME method. Many researchers have used the ME method, in order to clarify the correspondence of a human subjective characteristic with a change in physical quantity[20–42].

One study examined the effect of the physical quantity which was applied to humans with changes in the exponent ‘n’[43], in order to clarify the change of the subjectively perceived quantity with the change of the physical quantity. Also, the ME method has been used as a method for clarifying whether the evaluation index of the subjectively perceived evaluation result corresponds with the evaluation index of the physical quantity[44]. Some results of the ME method are shown in Fig. 4 as an example.

In Fig. 4, the physical quantity in which the correspondence with the subjectively perceived evaluated quantity is most taken as the evaluation method of the shock vibration was cleared. This result can be used as an index of the physical quantity for obtaining the subjective scaling at the next stage.

Category judgment

The category judgment method, a subjective scaling method, is used in the setting of the target characteristics of the design. When subjects receive stimulus, their reaction is captured in “Phrases” or “Words”, such as “very

Table 3. Results of difference thresholds researches

Difference thresholds

	Stationary vibration						Non-stationary vibration	
	Axis	Standing	Sitting on the chair	Sitting on the floor	Recumbent supine		Standing sitting chair & floor	Recumbent all postures
1–80 Hz; Sinusoidal	x	☐	☐	☐	☐	1–80 Hz	☐	☐
	y	☐	☐	☐	☐	Single	☐	☐
	z	☐	■	☐	☐	Shock	☐	☐
1–80 Hz; Sinusoidal	Multi-Axis x + y or x + z y + z	☐	☐	☐	☐	1–80 Hz Single Shock	☐	☐
1–80 Hz; 1/1, 1/3 Octave	x	☐	☐	☐	☐	1–80 Hz	☐	☐
	y	☐	☐	☐	☐	1/1 or 1/3	☐	☐
	z	☐	☐	☐	☐	octave	☐	☐
Multi-Frequency	x	☐	☐	☐	☐	Multi-Frequency *	☐	☐
	y	☐	☐	☐	☐		☐	☐
	z	☐	■	☐	☐		☐	☐
Multi-Frequency	Multi-Axis 3 or 6 Axis	☐	☐	☐	☐	Multi-Frequency and Axis*	☐	☐

■ Researches done, ☐ Future research, *Shock on Random (Multi-Frequency). Single Shock: Single Cycle Sinusoidal Shock.

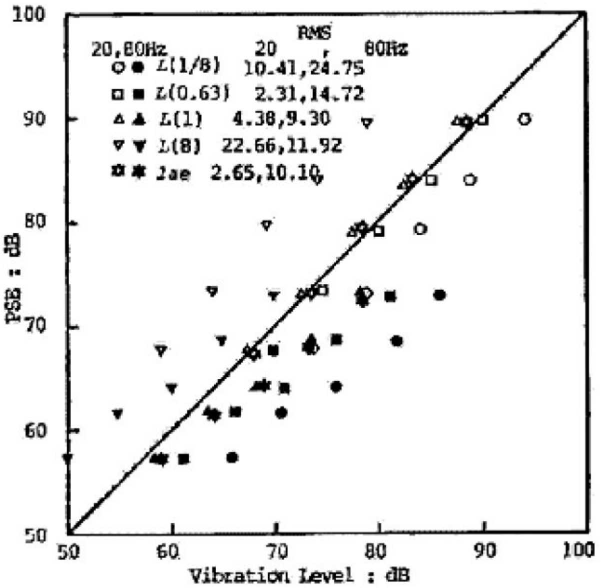

Fig. 4. The results of magnitude estimation methods[44].
L(1/8): peak response of R.M.S. detector of 125 ms time-constant; L(0.63): peak response of R.M.S. detector of 0.63 s time-constant; L(1): peak response of R.M.S. detector of 1 s time-constant; L(8): peak response of R.M.S. detector of 8 s time-constant; Lae: Square-Integration Method, 1 s time of reference time.

uncomfortable" or "uncomfortable", Fig. 1. In the ME method human judgment is not involved. It seems to be impossible to decide the target characteristics of the design, if the relation between physical stimulation quantity and image of the phrase or words cannot be established.

As an example, in order to obtain the relationship between physical quantity and phrase or words, research using the method of adjustment by subjects of the constant measurement method has been reported. In that research, each subject sat on the excitation vibrator, and was asked to adjust the level of vertical vibration until experiencing one of categories of sensation relating to the degree of comfort or discomfort experienced. The scaling between the physical quantities of the measured vibration of the vibrator table and the psychologically evaluated quantity was carried out. From the results of that experiment, it is clear that a problem of the physical quantity overlapping categories occurs. A representative example of this kind of result is the subjective response scale in the Annex of the ISO 2631-1 standard. For solving such problems, the category judgment method seems to be optimal.

Until now, few subjective scaling data have been published as shown in Table 4. Also, published data have only been obtained from experiments using a single axis vibrator. In the future, we need to find out the relationships among

Table 4. Results of subjective scaling researches

Subjective scaling

	Stationary vibration						Non-stationary vibration	
	Axis	Standing	Sitting on the chair	Sitting on the floor	Recumbent supine		Standing sitting chair & floor	Recumbent all postures
1–80 Hz;	x	■	■	□	■	1–80 Hz	□	□
Sinusoidal	y	■	■	□	■	Single	□	□
	z	■	■	□	■	Shock	□	□
1–80 Hz; Sinusoidal	Multi-Axis x + y or x + z y + z	□	■	□	□	1–80 Hz Single Shock	□	□
1–80 Hz;	x	□	□	□	□	1–80 Hz	□	□
1/1, 1/3 Octave	y	□	□	□	□	1/1 or 1/3	□	□
	z	□	□	□	□	octave	□	□
Multi-Frequency	x	□	□	□	□	Multi-Frequency *	□	□
	y	□	□	□	□		□	□
	z	□	■	□	□		□	□
Multi-Frequency	Multi-Axis 3 or 6 Axis	□	■	□	□	Multi-Frequency and Axis*	□	□

■ Researches done, □ Future research, *Shock on Random (Multi-Frequency). Single Shock: Single Cycle Sinusoidal Shock.

multiple-frequency, random vibration, shock vibration, multiple-axis, translational or rotational, continuous or intermittent, vibration.

Subjective Response of ISO 2631-1

Problems with subjective scaling of ISO 2631-1

Quantitative evaluation of a "degree of comfort" is an important aspect to consider when evaluating the nature of products, or the establishment of target characteristics of design during vehicle development. ISO2631-1, which defines an acceptable standard of bodily vibration, is the generally accepted evaluation criteria for evaluating whole-body vibration as part of overall in-vehicle comfort.

ISO2631-1 defines whole-body vibration in the seated position as the vibration received from the seat, the seat back, and the feet. Meanwhile, the comfort of a seated person is evaluated in terms of frequency-weighted r.m.s. acceleration that is calculated as the sum of the recorded vibration on a total of twelve axes after weighting based on the frequency-weighting curve. The twelve axes include translational vibration axes for the seat back and feet areas (x, y, and z), translational vibration axes for the seat (x, y, and z) and the rotational vibration axes (r_x, r_y, r_z), while the vibrations in question are periodical, random and transient in nature, ranging from 0.5 to 80 Hz. In the attached document C.2.3. entitled Comfort Reactions to Vibration Environments of ISO 2631-1, the following values as shown in Table 5 (5) are given as approximate indications of the likely reaction to various degrees of whole-body vibration experienced in public transport vehicles.

There are areas of overlap between the two reaction groups covered by the ISO2631-1 scale and their presence is problematic in determining the appropriate presumed reaction concerning the degree of comfort based on the physically recorded vibration level. For example, if the frequency-weighted r.m.s. acceleration is 1.5 m/s^2, this cannot just be independently assessed as an "Uncomfortable" or "Fairly uncomfortable" level. This problem exposes a partial inability to perform quantitative evaluation of a degree of comfort and makes the evaluation of the nature of the products or establishment of a target characteristic value of design more difficult.

The establishment of the values contained in the ISO2631-1 scale is thought to be based on a reference to BS 6841[45)] which was established from the research performed by Fothergill[46)], Jones and Saunders[47)], Oborne and Clarke[48)], Fothergill and Griffin[49)] and others. The results of these studies were compared in Fothergill and Griffin and are presented in Table 5 (1)-(4).

Fothergill conducted an experiment whereby each subject was asked to adjust the level of 8 Hz vertical sinusoidal vibration until they experienced one of five categories of sensation relating to the degree of comfort experienced. Based on these experiments he reported the average values selected and the standard deviations.

The four aforementioned research projects all used the subjective adjustment method that can be classed as one involving constant measurement to establish a relationship between the level of vibration stimulus and the perceived degree of comfort. Since this method applies the average values and standard deviations of the overall experimental assessment results based on a pre-determined scale, overlapping between adjacent categories may be inevitable.

Consequently, it can be surmised that the problem of category overlap will persist in ISO2631-1 since it depends on experimental results obtained from this means of measurement.

One solution to the problem of overlapping categories

The methods of measurement for material not directly observable, such as human reaction to stimuli, are categorized as subjectively perceived measurement, roughly divisible into two types, namely scaling and constant measurement. While the scaling method involves "the creation of a scale" to measure the subjectively perceived concepts involved, the constant measurement method involves an assignation process linking suitable evaluation to a pre-determined scale. Since the four research projects mentioned above all used the subjective adjustment method, ISO2631-1 is thought to include considerable degrees of overlap between categories.

The presence of such overlap leads to a problematic situation in which the corresponding human reaction in relation to comfort cannot be ascertained over a vibration stimulus of a certain strength according to the ISO2631-1 scale. However, no research has been performed on this problem and no solution has yet been presented to resolve the overlap issue. Consequently, this review project includes an attempt to resolve the problem using the category judgment method, one of the scaling methods.

The establishment of the scale involves the problem of unequal intervals since comfort is basically expressed using an order scale. However, according to the category judgment method, which implies that the reaction to a stimulus is normal distribution on a subjectively perceived continuity, the interval of the scale can be accurately defined and, from a single experiment, achieve a scale that connects physical values with continuous categories that represent subjectively

Table 5. Comparison of ISO 2631-1 scale and other researches obtained by using the method of adjustment by subjects

	Source (yr)	Scale	Mean magnitude	Standard deviation	Situation
(1)	Fothergill (1972)	Very unpleasant	2.5	1	Seated subjects
		Unpleasant	1.7	0.83	Levels of 8 Hz sinusoid
		Mildly unpleasant	1.1	0.5	
		Not unpleasant	0.7	0.35	
		Noticeable	0.3	0.14	
(2)	Jones and Saunders (1974)	Very unpleasant	3.7	–	Seated subjects
		Very uncomfortable	2.2	–	Equivalent levels of
		Uncomfortable	1.2	–	8 Hz sinusoid
		Mean threshold of discomfort	0.7	–	
		Not uncomfortable	0.33	–	
(3)	Oborne and Clarke (1974)	Very uncomfortable	> 2.3	–	Standing subjects
		Uncomfortable	1.2–2.3	–	Levels of 10 Hz sinusoid
		Fairly uncomfortable	0.5–1.2	–	
		Fairly comfortable	0.23–0.5	–	
		Very comfortable	< 0.23	–	
(4)	Fothergill and Griffin (1977)	Very uncomfortable	2.7	0.91	Seated subjects
		Uncomfortable	1.8	0.77	Levels of 10 Hz sinusoid
		Mildly uncomfortable	1.1	0.47	
		Noticeable, but not uncomfortable	0.4	0.16	
(5)	ISO2631-1 (1997)	Extremely uncomfortable	Greater than 2	–	
		Very uncomfortable	1.25–2.5	–	
		Uncomfortable	0.8–1.6	–	
		Fairly uncomfortable	0.5–1	–	
		A little uncomfortable	0.315–0.63	–	
		Not uncomfortable	Less than 0.315		

The unit of Mean magnitude and Standard deviation is m/s^2 r.m.s.

perceived values without overlapping. Although the width of a category is adjusted in the category judgment method so that the distribution of the judgment category to a stimulus is a normally distributed, it cannot be measured directly or can it be investigated whether the reaction of the subject corresponding to the judgment itself is a normal distribution. Therefore, the distribution of the reaction to the stimulus by a subject is assumed to be a normal distribution, and the value of a category boundary is decided from the obtained category.

Maeda *et al*.[50] successfully composed a scale to evaluate the localized vibration transmitted to hands and arm using the category judgment method, showing a clear relationship between the frequency and level of vibration acceleration and the respective subjectively perceived values. Moreover, Sumitomo *et al*.[51] used the category judgment method to successfully identify changes in the subjectively perceived values of perceived vibration from Shinkansen bullet trains in subjects before and after the Kobe Earthquake of 1995.

The vibration stimuli, which were used in the experiments by Fothergill and Griffin, Fothergill, Jones and Saunders and Oborne and Clarke comprised combinations of single frequency sine waves. ISO2631-1, which is thought to have been established based on these experiments, implies that this scale can be suitably applied to frequency-weighted r.m.s. vibration acceleration. However, no research has been performed to clarify the relationship between a subjective scale and frequency-weighted r.m.s. vibration acceleration, which attributes a physical value to whole-body vibration. Therefore, other reseraches[52, 53] included an experiment using the category judgment method to establish a scale using vibration stimuli with three kinds of spectrum in the direction of the Z (vertical) axis, and scrutinized the applicability of the ISO2631-1 scale to frequency-weighted r.m.s. vibration acceleration.

In their reports, experiments were carried out using the

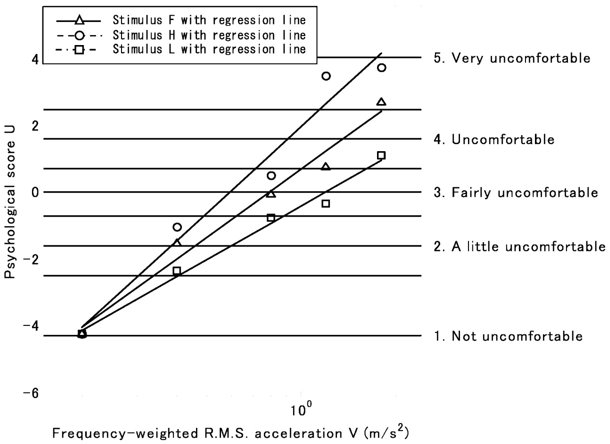

Fig. 5. The results of the category judgment method[52, 53].
○: stimulus H with PSD, which became 20 dB higher at 100 Hz than at 1 Hz; △: stimulus F, with flat PSD (Power Spectrum Density) ranging from 1 to 100 Hz; □: stimulus L that had a PSD 20 dB lower at 100 Hz.

category judgment method in respect of the subjective response of whole-body vibration with different frequency spectrums and equal frequency-weighted r.m.s. vibration acceleration values with vertical vibration exposure[52, 53]. And the problem that was including for frequency-weighting method was clarified. The experimental results using the category judgment method are shown in Fig. 5.

When the frequency-weighted r.m.s. vibration acceleration value was an equal value, although ISO2631-1 and Griffin and Fothergill appeared to obtain the same psychophysical value, the results of current experiment[52, 53] differed from them.

There was a rectilinear relation between the psychophysical quantity U and the logarithm of the frequency-weighted r.m.s. vibration acceleration value V, as shown in Fig. 5. However, the tendency was different with spectrum composition of the vibration stimuli. In the case of a smaller frequency-weighted r.m.s. vibration acceleration, such as 0.2 m/s^2, no significant difference was noticed in response to the vibration stimuli. As the values increased however, the difference in the perceived degree of comfort also increased correspondingly, to the point that at 1.2 m/s^2 all three stimuli types provide different results, with the F stimulus designated "Uncomfortable", the H stimulus "Very uncomfortable" and the L stimulus "Fairly uncomfortable". This result shows that when random signals are applied as vibration stimuli, even if the r.m.s. acceleration frequency-weighted by the ISO2631-1 W_k is the same, signals made up of different frequency spectra will elicit differing evaluations of the degree of comfort. Therefore, this may indicate the need to re-examine the method used for frequency-weighting. In Fig.5, stimulus F had flat PSD (Power Spectrum Density) ranging from 1 to 100 Hz, stimulus H had with PSD which became 20 dB higher at 100 Hz than at 1 Hz, and stimulus L had a PSD 20 dB lower at 100 Hz.

Major Remaining Issues and Topics for Further Studies

The flow of noise evaluation is shown in Fig. 6.

In noise evaluation, the A frequency-weighting is utilized for the difference in audibility by frequency. Good relationships between L_{Aeq} based on the energy mean value and the impression of the environmental noise, which consists of wide-band frequency components on level variation in A frequency-weighting, have been established[54].

However, the A frequency-weighting is a simple method, and it has been shown that the subjective impression does not correspond well with L_{Aeq} in evaluating of time-variant noise. Alternative methods to the A frequency-weighting method have been proposed by Zwicker[55], Stevens[19] and Preis *et al.*[56], such as Sharpness, Roughness, Fluctuation, Strength, Tonality, and SEN (Sound Exposure Loudness). These evaluation methods are based on a loudness level calculation method, which proposed by Zwicker and Steven. It would be due to seem to market the measuring instrument which calculated software and loudness level calculated by the computer in order to use this method in recent years.

On the other hand, in the human vibration evaluation,

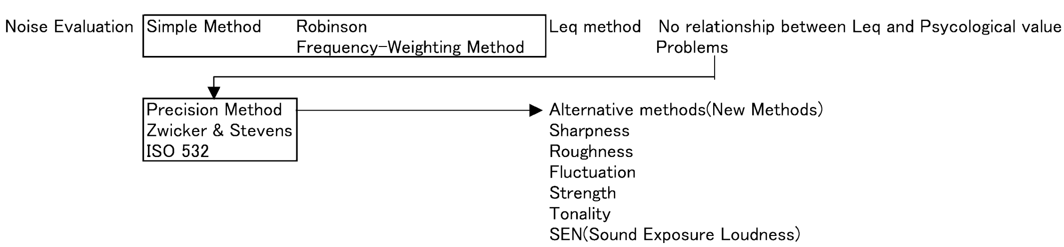

Fig. 6. Research flow of the noise evaluation.

Griffin and Fothergill and Griffin *et al.* showed the usefulness of the frequency-weighting method to stationary vibration with multiple frequencies from the comparison of VG (Vibration Greatness) method[57] that Miwa proposed, Fig. 7.

The frequency-weighting method using the frequency-weighting curve is the mainstream of human vibration evaluation, and it is stipulated in fundamental requirements of the measuring evaluation of the present ISO2631-1 standard of whole-body vibration.

In recent years it has been indicated that there are problems with the average evaluation method by the frequency weighting method and some a new calculation methods have been proposed[58].

Lewis & Paddan[59] measured the vibration of the bicycle, and commented that the degree of unpleasantness was often extremely sensed in the running from measurement result and subjects. They compared the average measured value with the comfort and unpleasantness curve of the ISO from the viewpoint of frequency-weighted r.m.s. vibration acceleration value during the measuring time without taking into account the degree of unpleasantness experienced by the subject. Therefore, it seems to require the evaluation method that Zwicker or Steven proposed for human vibration in which the level at every moment will differ from vibration spectrum in future.

The method of the laboratory experiment using the vibrator has advanced from experiments using a single axis vibrator to those using a six-axis vibrator which is similar to the real vibration environment[60]. The results of an experiment using a 6 axis vibrator have recently been reported. A problem with the frequency-weighting method has been raised, as shown in the experimental result using the category judgment method[61].

In the noise evaluation method, although the frequency-weighting method proposed by Robinson as a simple method had been used, a problem with the time-variant signal was indicated by Zwicker and Stevens, who proposed not the simple method but a precision method, which was issued as ISO532 standard[62]. Also, in vibration evaluation, problems with the frequency-weighting method have been indicated already. It seems necessary to investigate the applicability of the time-variant vibration proposed by Zwicker and Steven. Miwa's proposed VG method might be adaptable to single axis vibration in stationary vibration with different spectrum in the laboratory experiment, but a new method is necessary for the actual environment vibration evaluation method of time-variant vibration of multi-axis vibration. A new evaluation method of the physical quantity, and new subjective scaling for the target characteristics of design in actual environments is needed in the future. Furthermore, the environment, the physical characteristic, the health situation, and the characteristics of the seat, etc. are not considered in the schema of Fig. 1. Therefore, it will be necessary to have the target characteristics of design considering these factors.

Summary

In this review, the following were outlined: the basic thinking of experimental psychological methods for providing target characteristics in design of vibration environments, and the comparison of results between physical quantity of vibration environments and the experimental psychological method. Problems concerning ISO 2631-1 which defines the scale of public ride comfort were clarified, and also, the direction of research into the calculation method of target characteristics in design of vibration environments which consider human characteristics of sense of vibration was described.

In addition, it will be necessary to conduct new experiments for the design of vehicles in the future. In order to resolve the problems of the new experimental design, it will be necessary to find out the relationship between the human biodynamic response to whole body vibration and subjective responses to multi-axis subjective scaling.

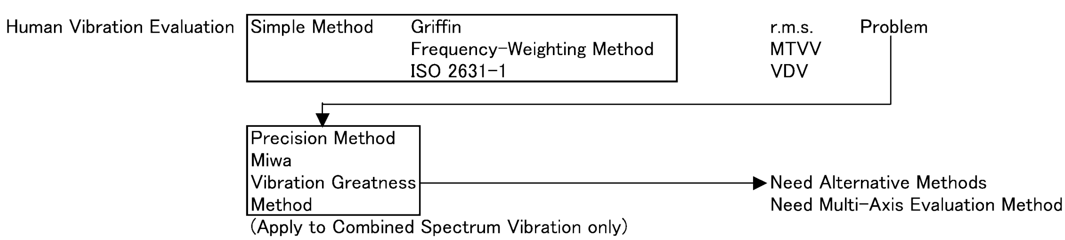

Fig. 7. Research flow of vibration evaluation.

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