AMRL-TR-76-1

A COMPARISON OF THE PERCEIVED INTENSITY OF SINUSOIDAL AND MULTI-FREQUENCY WHOLE-BODY VIBRATION

AEROSPACE MEDICAL RESEARCH LABORATORY

JUNE 1976

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AMRL-TR-76-1

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FOR THE COMMANDER

HENNING E. VON GIERKE
Director
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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: AMRL-TR-76-1	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): A COMPARISON OF THE PERCEIVED INTENSITY OF SINUSOIDAL AND MULTIFREQUENCY WHOLE-BODY VIBRATION	5. TYPE OF REPORT & PERIOD COVERED
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Richard W. Shoenberger Ph.D.	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Aerospace Medical Research Laboratory, Aerospace Medical Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio 45433	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: ~~62202F~~, 7231-01-01
11. CONTROLLING OFFICE NAME AND ADDRESS	12. REPORT DATE: Jun[redacted]76
	13. NUMBER OF PAGES: 11
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Vibration (Whole-Body Vibration), Perception (Vibration), Vibration Criteria, Psychophysical Matching, Human Factors, Biodynamics

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Existing standards for human exposure to whole-body vibration are based heavily on data from experiments in which the vibration inputs were single sinusoids. Yet many operational environments contain complex vibrations composed of multiple sine waves or random disturbances. The preferred method set forth by the standards for assessing such environments is to evaluate each component frequency or each third-octave band independently with respect to the levels specified by a particular criterion curve. Under this procedure,

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if a complex vibration is found to contain several sinusoids (or third octave bands), each with amplitudes at the level of a particular criterion curve, it would be rated the same as any one of the sinusoids alone. However, as more sinusoids (or third-octave bands) are added to the combination the greater will be the total power or force imparted to the man and the greater the possibility for frequency interactions. An intensity matching technique was used to test the independent component method for evaluating complex vibration environments composed of multiple sine waves. Ten subjects adjusted the intensity of a 25 Hz sinusoid to match the subjective intensity of 11, 17, 40, and 63 Hz sinusoids (all with intensities at the same criterion level), presented either singly or in all possible combinations of two, three or four frequencies. The results showed a monotonic relationship between perceived intensity and the number of sinusoids in the stimulus (i.e., the acceleration of the matching response increased significantly as the number of sinusoids increased). These findings indicate (at least for the frequency range sampled) that the "independent frequency" method of evaluating non-sinusoidal vibrations will underestimate the severity of such complex vibration environments, and suggest that the weighting technique recommended by the standards as an alternative evaluation method may more accurately evaluate their effects.

PREFACE

This research was conducted by Richard W. Shoenberger, Vibration Branch, Biodynamics and Bionics Division, Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio. This work supports Project 7231, "Biomechanics of Air Force Operations: Effects of Mechanical Forces on Air Force Personnel," Task 723101, "Effects of Vibration on Air Force Crews and Personnel," Work Unit 72310101, "Aircrew Performance and Subjective Response During Vibration Encountered in Air Force Operations."

INTRODUCTION

The majority of studies investigating human response to whole-body vibration have employed discrete frequency sinusoids as the vibration input stimuli. As a result, existing standards for vibration exposure (1, 4, 6) are all based heavily on data collected using single sinusoids. Yet many operational vibration environments contain complex vibrations made up of multiple sine waves or broadband random disturbances. The vibration standards specify two procedures for evaluating such environments: (a) Evaluate each frequency, for multifrequency inputs, or each third-octave band, for random inputs, *independently* with respect to the level specified for that frequency (or third-octave band) by a particular criterion curve; (b) Use a frequency weighting network, normalized to the most sensitive portion of the curve, to obtain a single weighted RMS acceleration value, which is then evaluated against the same portion of the curve on which the normalization was based. There are indications that neither of these procedures is completely adequate. For example, with respect to perceived vibration intensity, studies by Brumaghim (2) and Dupuis, Hartung, and Louda (3) have produced some evidence indicating that an independent evaluation of individual components would yield an underestimation of the subjective intensity of complex inputs, and the ISO standard (4) points out that in the case where the input spectrum has a shape similar to the criterion curve the weighting procedure would lead to too conservative an evaluation, i.e., the severity of the vibration would be overestimated.

In order to develop more adequate procedures for evaluating nonsinusoidal vibrations, additional information is needed on the relationships between the effects of sinusoidal and more complex vibration environments. The research described in this paper was conducted to provide such information, and was specifically designed to test the independent evaluation method (procedure "a") for evaluating multifrequency vibration. Under this procedure, if a multifrequency vibration is found to contain several sinusoids, each with amplitudes at the level of a particular criterion curve, it would be rated at the same criterion level as any one of the sinusoids alone. However, as more sinusoids are added to the combination, the greater will be the total power or force imparted to the man and the greater possibility for frequency interactions. Therefore, a weighting method such as that specified in procedure "b" might prove to be more advantageous.

In the present experiment, the subjective intensities of several sinusoidal and multifrequency vibrations (composed of from one to four frequencies) were measured by having subjects match their perceptions of the intensities of the various inputs by adjusting the intensity of a single sinusoidal matching frequency.

METHOD

SUBJECTS

The subjects were 10 male Air Force military personnel. They were physically qualified volunteer members of a vibration panel, and received hazard incentive pay for participation in vibration experiments.

APPARATUS

Vibration was produced by an MB Electronics electromagnetic vibrator (Model C-5), which had been modified by the addition of a spring below the moving element so that it could handle the load of a man plus the seat and restraint harness. A lightweight aluminum seat was rigidly mounted to the shaker head and transmitted the vibration directly to the subject without cushioning or padding. The subject was secured to the seat by a lap belt and shoulder harness. Figure 1 shows the subject seated on the shaker and holding the potentiometer with which he controlled the amplitude of the matching vibration.

Five function generators produced the five sinusoidal frequencies used in the experiment, and their outputs were fed to the shaker via an EAI TR-20 analog computer. This provided the necessary gain settings for each frequency and allowed them to be selected singly or in combinations of from 2 to 4 frequencies. Gain settings for the individual frequencies were calibrated for each subject and sample combined frequency spectrums for each subject were analyzed on a Time Data 1923 vibration analyzer to assure that possible frequency interactions did not significantly affect the acceleration levels of the component frequencies making up the combinations. The RMS acceleration of the vibrating seat was also displayed on a meter, and the acceleration of the 25 Hz matching frequency was read from this meter and recorded by the experimenter for each matching response.

VIBRATION

The vibration stimuli were composed of four sinusoidal frequencies (11, 17, 40, and 63 Hz) presented either singly or in all possible combinations of two, three, or four frequencies. Twenty-five Hz (the matching frequency) was also presented as a stimulus to provide a check on possible biases or errors in the matching response when the stimulus and response frequencies were identical. The frequencies used were approximately the preferred center frequencies of every other third-octave band from 10 to 63 Hz. However, slight departures from some of these center frequencies were made to avoid harmonic relationships between frequencies. This resulted in constantly changing phase relationships between the frequencies in all combinations, rather than the fixed phasing that would occur for harmonically related frequencies. All frequencies were presented (whether singly or in combinations) at accelerations corresponding to the ISO 25-min Fatigue-Decreased Proficiency (FDP) level (4). Table 1 lists all of the single- and multi-component stimuli used and specifies their frequencies and RMS accelerations.

PROCEDURE

Each subject was required to match his perception of the intensity of each of the stimulus vibrations listed in Table 1 by adjusting the intensity of a 25 Hz matching frequency until he felt that its subjective intensity matched the subjective intensity of the stimulus vibration he had just experienced. Each match involved a 30-second exposure to the stimulus vibration and a subsequent exposure to the matching frequency that lasted approximately 15 to 30 seconds, depending on how quickly the subject achieved a match.

When each subject arrived at the laboratory, the nature of the experiment and the intensity-matching procedure were explained. The subject was then seated in the vibration chair and given a short practice session by having him match the following series of six single-frequency stimuli: 25, 17, 40, 11, 63, and 25 Hz. He then matched each of the 16 vibration stimuli shown in Table 1 (the stimuli were presented to each subject in a different random order). After a short rest break (about 5-min), the stimulus series was presented again and the subject matched each stimulus vibration a second time.

Figure 1 View of Subject Seated On Vibrator

TABLE 1

VIBRATION STIMULI

NUMBER OF COMPONENTS	*STIMULUS CODE*	*FREQUENCY (Hz)*	*ACCELERATION (RMS Gz)*
	A	11	0.25
	B	17	0.39
One	25	25	0.57
	C	40	0.92
	D	63	1.43
	AB	11 + 17	0.46
	AC	11 + 40	0.95
Two	AD	11 + 63	1.45
	BC	17 + 40	0.99
	BD	17 + 63	1.48
	CD	40 + 63	1.70
	ABC	11 + 17 + 40	1.03
Three	ABD	11 + 17 + 63	1.50
	ACD	11 + 40 + 63	1.72
	BCD	17 + 40 + 63	1.74
Four	ABCD	11 + 17 + 40 + 63	1.76

RESULTS AND DISCUSSION

The 20 matching responses (2 matches for each of 10 subjects) collected for each of the 16 vibration stimuli used in the experiment were averaged to obtain the mean response accelerations shown for each stimulus in Table 2. Also presented in Table 2 are the mean responses for all stimuli containing equal numbers of sinusoidal components (i.e., one, two, three, or four).

Since the acceleration levels of the sinusoidal frequencies were all set at the ISO 25-min FDP boundary, their subjective intensities should have all been approximately equal. Inspection of the mean response accelerations in Table 2 for the single-frequency stimuli indicates some variability in the level of average response. A few subjects felt that the highest frequency stimulus (stimulus D, 63 Hz) was particularly disagreeable, and accordingly set the acceleration of their matching responses rather high compared to the other frequencies. This is reflected in the fact that the mean response for stimulus D in Table 2 is higher than for any other single-frequency stimulus. Further inspection of Table 2 also indicates some differences among the responses for the various stimuli made up of two frequencies as well as among those for stimuli composed of three frequencies. In order to test the significance of these observed differences, three analyses of variance were performed; one based on the data for single frequencies, a second based on the data for double frequencies, and a third based on the data for triple frequencies. The form was the same for all three analyses, a simple treatments x subjects design (5).

TABLE 2

ACCELERATION OF MATCHING RESPONSES (RMS Gz)

STIMULUS CODE	*MEAN RESPONSE (EACH STIMULUS)*	*NUMBER OF COMPONENTS*	*MEAN RESPONSE (BY NO. OF COMPONENTS)*
A	0.56		
B	0.68		
25	0.58	One	0.64
C	0.64		
D	0.76		
AB	0.79		
AC	0.80		
AD	0.93		
BC	0.84	Two	0.88
BD	1.05		
CD	0.89		
ABC	1.02		
ABD	1.14		
ACD	1.06	Three	1.11
BCD	1.20		
ABCD	1.31	Four	1.31

The analysis for single frequencies revealed that none of the observed differences among the single-frequency mean responses were significant ($F_{4,36} = 2.02$; $p > 0.10$), indicating that the mean subjective intensities for the single-frequency stimuli were essentially equivalent, as the ISO standard denotes. However, significant differences were indicated by the analyses for double frequencies ($F_{5,45} = 6.61$; $p < 0.001$) and triple frequencies ($F_{3,27} = 4.08$; $p < 0.05$). Newman-Keuls tests (7) were then performed to determine which stimuli differed significantly within each of these two groups. Results of these tests are presented in Table 3 for the double frequencies and Table 4 for the triple frequencies. Only stimulus BD(17 + 63 Hz) produced a unique response among the double frequencies. Table 3 shows that the response for BD was significantly greater than for all of the other double frequency stimuli. Table 4 indicates only one significant difference among the triple frequencies. The stimulus producing the highest response (BCD: 17 + 40 + 63 Hz) was significantly different from the stimulus producing the lowest response (ABC: 11 + 17 + 40 Hz).

Although the differences for the single-frequency stimuli were not significant, stimulus D and stimulus B had the highest responses among the single frequencies, and the combination of these two frequencies (stimulus BD) had the greatest response for the double frequencies (and the only one significantly different from the others). Moreover, these two frequencies were also included in the triple-frequency stimuli producing the two highest responses (BCD and ABD). Apparently, at least for a significant number of the subjects in the present sample, the combination of certain stimuli, which were judged to be only insignificantly more intense than other stimuli when experienced individually, resulted in a summation effect and produced significantly stronger reactions than similar combinations of other stimuli.

TABLE 5

RESULTS OF NEWMAN-KEULS TESTS FOR
NUMBER OF FREQUENCIES IN COMBINATION

NUMBER OF FREQUENCIES		*1*	*2*	*3*	*4*
Ordered Mean Response (RMS Gz)		0.64	0.88	1.11	1.31
Differences Between Means	1		0.24**	0.47**	0.67**
	2			0.23**	0.43**
	3				0.20**

**$p < 0.01$

The relationship between the number of frequencies in the stimulus and the acceleration of the matching response is presented graphically in Figure 2. The figure shows an essentially linear increase in response acceleration as a function of the number of sinusoids in the stimulus. The data analysis has established the statistical significance of this increase, and the fact that the acceleration of the matching response increases by roughly a factor of two as the stimulus increases from one to four frequencies indicates its practical significance as well. A factor of two increase in acceleration for a given frequency represents a change in severity in terms of the ISO standard from the FDP boundary to the Exposure Limit. Within the limits of the present investigation, these results demonstrate that the "independent frequency" method of evaluating multifrequency vibrations will underestimate the severity of such complex vibration environments and that the degree of underestimation will increase as the number of frequencies in the stimulus increases. The data also tend to support the weighting technique recommended by the standards as an alternative evaluation method.

Continuing investigations in this area will include a similar experiment in which intensity judgments will be made of vibration environments composed of from one to four third-octave bands of random vibration; comparable experiments at lower frequencies extending down into the body resonance range; and, when sufficient data become available, evaluation of the weighting technique recommended by the standards as a secondary method for evaluating complex vibrations and, if necessary, development of alternative weighting procedures.

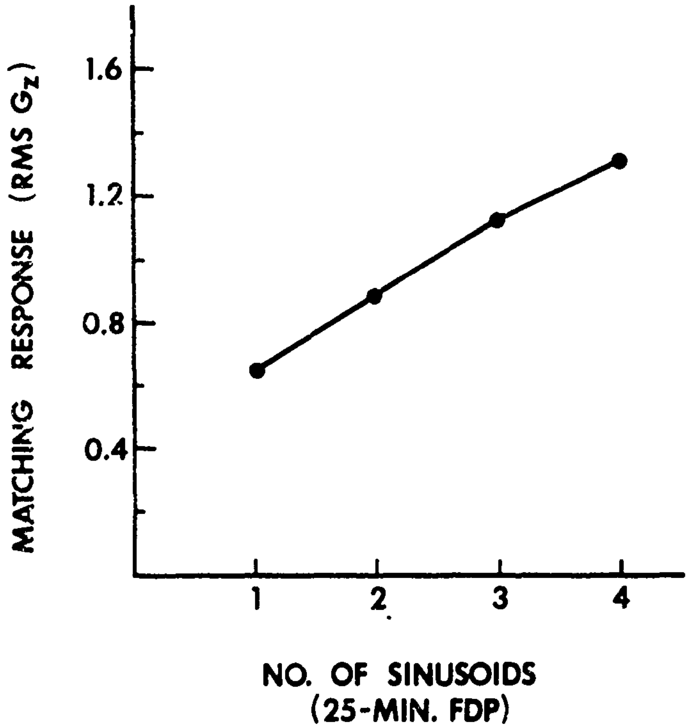

Figure 2. Acceleration of Matching Response as a Function of the Number of Frequencies in the Stimulus

REFERENCES

1. Air Force Systems Command. 1972. *Evaluation of Human Exposure to Whole-Body Vibration.* AFSC Design Note 3E1, Design Handbook 1-3, Series 1-0.

2. Brumaghim, S. H. 1967. *Subjective Reaction to Dual Frequency Vibration.* Wichita Kan.: The Boeing Co., Technical Report D3-7562.

3. Dupuis, H., E. Hartung, and L. Louda. 1972. "Vergleich regelloser Schwingungen eines begrenzten Frequenzbereiches mit sinusförmigen Schwingungen hinsichtlicht der Einwirkung auf den Menschen." ("Random vibrations of a limited frequency range compared with sinusoidal vibrations with regard to its effect on man.") *Ergonomics.* 15:237-265. USAF School of Aerospace Medicine Technical Translation G-1155-0373.

4. International Organization for Standardization. 1974. *Guide for the Evaluation of Human Exposure to Whole-Body Vibration.* ISO 2631-1974.

5. Lindquist, E. F. 1953. *Design and Analysis of Experiments in Psychology and Education.* Boston: Houghton Mifflin Co.

6. U.S. Department of Defense. 1970. Military Standard 1472A; *Human engineering design criteria for military systems, equipment and facilities.* Washington, DC: Government Printing Office.

7. Winer, B. J. 1962. *Statistical Principles in Experimental Design.* New York: McGraw-Hill.

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