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Effect of Vibration Duration on Human Discomfort

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SUMMARY

A laboratory investigation was conducted to examine the duration effects of random vertical vibration on passenger discomfort. The study was performed in a simulated section of an aircraft cabin configured to seat six persons in tourist-class style. Variables of the study included four specific rms amplitudes of vibration up to 0.100g and nine specific durations up to 1 hr. The vibrations had the characteristics of a white noise spectrum with a bandwidth of 10 Hz centered at 5 Hz. Data indicate that the discomfort threshold for this study occurred at an rms vertical acceleration level of 0.027g for all durations of vibration. However, for acceleration levels that exceeded the discomfort threshold level, a systematic decrease in discomfort occurred as a function of increasing duration of vibration. Further, for the range of accelerations used in this study, the magnitude of the discomfort decrement was shown to be independent of acceleration level. The fact that the subjective discomfort produced by typically uncomfortable vertical vibrations decreased as exposure time increased indicated that the subjects apparently adapted to vibrations of longer durations. This adaptation process apparently operated to reduce the perceived discomfort associated with the vibration. This observed trend is the opposite of current recommended standards.

INTRODUCTION

Passenger comfort in various transportation vehicles is known to be influenced by a host of environmental factors including those of vibration, noise, temperature, seat dimensions, etc. (See refs. 1 to 3.) Two of the most important factors in terms of passenger comfort as well as vehicle design are noise and vibration. These factors consistently operate to reduce human comfort in transportation systems (refs. 1 to 3). Furthermore, from an engineering standpoint, noise and vibration are the most difficult and expensive factors to control.

Because of the importance of these factors, a number of experimental studies (refs. 4 to 10) have been conducted to develop an improved understanding of the effect of these factors on passenger discomfort. A major goal of these studies is the development of a comprehensive model for use in the prediction and/or assessment of ride comfort in diverse transportation systems. However, a possible limitation of these studies results from the fact that the noise and/or vibrations investigated were experienced by passengers for very short durations (less than 1 min) rather than longer trip durations, which is typical of most transportation vehicles. Consequently, a question arises concerning the effect of exposure duration on ride comfort. Unfortunately, very few investigations have directly addressed this question, and the literature that is available presents an inconsistent picture of the duration effect. For example, the International Organization for Standardization (ISO) has issued a document (ref. 11) in which it is recommended that acceptable levels of vibration acceleration corresponding to a "reduced comfort boundary" be decreased as the duration of vibration is increased. Other investigators (refs. 12 to 15), however, indicate that no effect of vibration duration on discomfort exists. Consequently, it is the purpose of this study to examine in a systematic manner, and under controlled conditions, the effect of duration of vibration on passenger discomfort. The results will provide additional information for prediction of passenger comfort in vehicles having long trip durations.

SIMULATOR

The apparatus used to expose passengers to vibration was a three-degree-of-freedom motion simulator (fig. 1) called the Langley passenger ride quality apparatus (PRQA). The simulator is described in detail in references 16 and 17, and the reader is referred to those references for detailed information related to the system operation, capabilities, and design. For this investigation, only the vertical degree-of-freedom capability of the simulator was utilized, and the interior of the simulator was fitted with tourist-class (three-abreast) aircraft seats. Characteristics of the seats are given in reference 18.

EXPERIMENTAL METHOD

Subjects

A total of 210 paid volunteer passenger-subjects (male and female) obtained from a contractual subject pool participated in the study. The ages of the subjects ranged from 18 to 62 yr, with a median age of 30 yr. The mean weight of the subjects was 64.3 kg (141.7 lb), with a weight range of 42.2 to 120.2 kg (93 to 265 lb). It should be noted that a previous study (ref. 7) indicated that the factors of age, weight, and sex did not have a significant effect upon discomfort responses for this type of study. Thus, these factors are not considered to be important in the present study.

Subjective Evaluations

Passenger subjective reactions to the vibration stimuli used in this investigation were obtained by use of the magnitude estimation method (ref. 19). This method was selected because, in addition to providing an efficient and reliable measure of the duration effect, its ratio properties allow the results of this study to be used to develop duration correction factors for direct incorporation into a ride comfort research model, that is, the subjective response units had identical meanings. Since the discomfort scale developed in the comfort model studies at Langley Research Center was a ratio scale derived from application of the magnitude estimation technique, and is referenced to the discomfort threshold, it was necessary to use the same procedure in this investigation. Some of the details related to the application of the magnitude estimation procedure within the context of this study are described in the following paragraphs.

The task for each subject (six subjects concurrently) was to provide magnitude estimations of successive "comparison ride segment vibrations" relative to "standard ride segment vibrations" which were assigned the numerical value of 100 (the vibrations are described in the next sections). For this task the subjects were required to assign numbers to the comparison ride segments to reflect how much greater or less the discomfort of that ride was, relative to the discomfort of the standard ride segment. For example, if the discomfort of a comparison ride segment was felt to be twice the discomfort of the standard ride segment, the subjects would give the ride a value of 200. The subjects were instructed not to use zero or negative numbers in making their subjective evaluations. Through the use of a two-way auditory communication system, the subjects were instructed as to the beginning and end of a ride segment (either standard or comparison) by the words "start" and "stop," respectively. Subjects were further instructed to ignore rise and decay vibrations that occurred prior to and subsequent to the words "start" and "stop." The exact instructions given to subjects are reproduced in the appendix.

Vibration Stimuli

Comparison ride segments were random vertical vibrations with a 10-Hz bandwidth centered at 5 Hz. This type of vibration spectrum was used because (1) it is typical of most transportation systems, and (2) it contains the range of vibration frequencies known to produce significant discomfort in humans. These vibrations were presented to subjects at one of four rms acceleration levels (0.025, 0.050, 0.075, or 0.100g). ($1g = 9.807 \text{ m/sec}^2$.) Figure 2 shows representative spectra of these vibrations for each of the acceleration levels investigated. These vibrations were experienced by subjects for one of nine time durations (0.25, 1, 2, 3, 5, 10, 15, 30, or 60 min). On the other hand, a standard ride segment consisted of a 9-Hz vertical sinusoidal vibration and was presented at an rms acceleration level of 0.100g for 10 sec. This particular vibration condition was selected as the standard because it has been shown to produce minimum variability in subjective ratings of discomfort and is the frequency at which the seat transfer function (transmission characteristics) is unity; that is, the seat does not amplify the floor vibration. A rise and decay time of 5 sec was used for both standard and comparison rides. The time between vibrations was 10 sec.

Test Procedures

A typical day of testing consisted of instructing each group of six subjects in the use of the magnitude estimation procedure and then exposing them to about a $2\frac{1}{2}$-hr test period composed of the standard and comparison ride segments. Each group of subjects within a particular test period was exposed to only one of the nine durations for the comparison rides. This procedure was followed in order to insure that subjects based their evaluation upon the discomfort due to a vibration of a specified duration, rather than merely to elapsed time. A consequence of this experimental design procedure was that subjects exposed to different comparison ride durations received a different number of standard and comparison ride segments during testing. Table I shows the number of standard and comparison rides (of various acceleration levels) experienced by subjects that were assigned (randomly) to each vibration duration condition. The vibration acceleration levels within a particular duration condition were randomized for a single group of subjects, or counterbalanced across subject groups (e.g., for longer vibration durations) in order to reduce subjects bias due to presentation order. The second column of table I indicates the number of subjects that participated in the experiment for each of the duration conditions.

For the subject groups that evaluated the 0.25-, 1-, and 2-min duration conditions, the experimental test sequence consisted of a standard ride segment followed by two comparison rides prior to another standard ride. In this case, each subject made a magnitude estimation of the discomfort of a comparison ride immediately after experiencing the comparison ride. For the remaining duration conditions, the experimental test sequence consisted of a standard ride followed by a comparison ride and then another standard ride, after which the subjects rated the discomfort of the comparison ride. This test sequence was followed in order to insure that subjects exposed to the longer comparison ride durations had not forgotten the discomfort associated with the standard ride. It should be noted that during the test sequences the ambient noise level never exceeded 70 dB(A). Consequently, noise is not considered to be at a sufficient level to influence subjective evaluations.

RESULTS AND DISCUSSION

The following sections present an overview of the results of the present study. Included in this overview is a comparison of the results of the present study with the duration effect recommendation of the ISO.

Experimental Results

The effects of acceleration level and duration of vibration on passenger discomfort are shown in figures 3 and 4, respectively. Note that the discomfort responses are presented in terms of both magnitude estimates and DISC values (discomfort units). The DISC values (where DISC = 1 is the threshold of discomfort) represent an anchoring of the magnitude estimations relative to the standard ride segment, which was selected to have a DISC value equal to 2.22 based upon previous research (refs. 20 and 21). This transformation procedure permits the results of the investigation to be interpreted within the framework of the NASA ride comfort model. Figure 3 displays the mean DISC values (and magnitude estimations) that occurred as a function of rms vertical acceleration, g. The DISC values presented in this figure are the mean discomfort responses averaged across all subjects and all durations of vibration for a particular acceleration level. These results are consistent with previous research (e.g., refs. 20, 21, and 22), which indicates discomfort increases linearly with acceleration level. Furthermore, for the specific vibration spectrum investigated, the threshold of discomfort (defined as DISC = 1) was found to occur at an rms vertical acceleration level of approximately 0.027g. This implies that transportation vehicles possessing similar frequency spectrum characteristics will be comfortable if the spectrum level is less than 0.027g and will provide increasingly more discomfort as the level is increased.

The overall effect of vibration duration on human discomfort responses is indicated in figure 4. This figure shows the mean DISC values (and mean magnitude estimations) that were obtained in the study for various durations of vibration. The DISC values of the figure were obtained by averaging responses across subjects and acceleration levels for each of the durations investigated. As indicated in figure 4, a linear least-squares line was used to represent the trend of these data. The rationale for the decision to use a straight line is discussed in detail in subsequent paragraphs. The slope of the least-squares line shown in figure 4 is negative and differs significantly from zero ($t = -3.927$, Degrees of freedom = 7, Probability $\leqq 0.05$; $2.365 \leqq t \leqq -2.365$ is needed to achieve statistical significance; see ref. 23 for procedures needed for computation of t). These results indicate that a significant systematic decrease in the discomfort (i.e., increasing comfort) occurs as the duration of vibration is increased. The amount of this discomfort decrease is discussed subsequently in this section.

First, however, two interrelated questions concerning the data of figure 4 must be addressed. The first question concerns whether a straight line (as opposed to a polynomial curve) can be justified to represent the duration trend. The second question concerns whether the duration trend, however represented, remains constant for the individual vibration acceleration levels that were used to compute the average trend given in figure 4. Information pertinent to these questions can be extracted from the data shown in figure 5. This figure presents the DISC values (and magnitude estimations) that occurred for each level of rms acceleration (0.025, 0.050, 0.075, and 0.100g) as a function of vibration duration. Thus, it represents a breakdown of figure 4 into the four component acceleration levels from which figure 4 was derived. The vertical bars represent the standard error of the mean discomfort responses. As noted in figure 5, each of the component acceleration levels was also fitted by a linear least-squares line. The first question mentioned above, considered from a statistical point of view, is whether the data points of figure 5 represent true or random variation about the least-squares lines for each acceleration level. In other words, if the data points represented true (significant) variations from the least-squares predictions, a polynomial curve would be needed to track the fluctuations of the discomfort responses across duration. On the other hand, a straight line (rather than a polynomial) would be sufficient to represent the duration effect if the data points merely represented random fluctuations (not significant differences) from the least-squares predictions.

Table II provides a summary of t-test values (see ref. 23) that were computed to determine whether the fluctuation of data points about the linear least-squares lines for each acceleration level represents true or random fluctuations. These single sample t-tests were computed between the mean DISC response corresponding to a data point and the predicted response based on the straight-line least-squares estimate. These results indicate that, from a statistical point of view, a straight-line least-squares fit of the response data is more appropriate than a polynomial fit. Except for the t-tests computed for the 0.25-min duration vibrations, the t-tests were either not significant or did not display a systematic effect. The lack of a systematic effect is displayed by two of the t-tests computed for the 5-min duration vibrations which indicated response differences in an opposite direction. The only data, therefore, that could be considered to represent true variation from the straight-line predictions are those for the 0.25-min vibration duration. Since these variations are relatively small and occur for only one duration condition, it is questionable from a practical point of view whether the type of curve selected to represent the duration effect should be modified to account for these minor variations. For example, the use of higher order polynomial fits (i.e., quadratic, cubic, quartic) provided only a minimal increase in explained variance (less than 2 percent maximum) which is not considered to be of practical importance. A least-squares straight line was therefore used to represent the duration effect for each level of vibration acceleration.

In order to address the second question of whether the duration trend remains constant with increases of rms acceleration level, an additional series of statistical tests were conducted based on the data of figure 5. The slope of the least-squares line fitted to the response data of the 0.025g level of rms vibration was analyzed by a t-test (see ref. 23) and found not to differ significantly from zero. Recall that a DISC of 1 equals 0.027g. Consequently, these results imply that the threshold of discomfort remains constant at an rms level of approximately 0.027g regardless of vibration duration. The slopes of the least-squares lines fitted to the response data for the 0.050, 0.075, and 0.100g levels of acceleration, however, were each negative and each differed significantly from zero ($t = -3.011$, -4.040, and -2.506 for the 0.050, 0.075, and 0.100g levels of rms vibration, respectively; for each comparison, the Degree of freedom = 7, Probability $\leqq 0.05$, and $2.365 \leqq t \leqq -2.365$ is needed to achieve statistical significance).

The results of these tests indicate that a systematic decrease of discomfort occurred for increases in vibration duration for each acceleration level above the threshold value. However, the question remains as to whether the absolute amount of discomfort decrease, for increases in vibration duration, is the same for the various acceleration levels. To answer this question, additional t-tests were computed to determine whether any of the slopes for each possible pair of lines in figure 5 differed. The results of these t-tests indicated there was no statistical difference between any of the slopes ($t = 0.505$, -0.645, and -0.305 for slope comparisons of rms acceleration values of 0.050g as opposed to 0.075g, 0.050g as opposed to 0.100g, and 0.075g as opposed to 0.100g, respectively). Therefore, the amount of discomfort decrease for increases of vibration duration is the same for the three levels of vibration acceleration above threshold. This implies that if the vibration acceleration level of a ride environment exceeds the threshold of discomfort, subjects tend to adapt to this environment and the resultant decrease in subjective discomfort is independent of the level of vibration, at least for the range of vibration accelerations of this study. Consequently, the results of this study suggest that a single function can be derived to represent the effects of rms vibration duration up to levels of 0.100g. To be meaningful, however, such a function must be referenced to the discomfort associated with a particular vibration duration. Since it is intended that the function also serve as a duration correction for the NASA ride quality model, it is expedient to reference it to the discomfort due to a 0.25-min vibration. The reasons for this are (1) discomfort decreases systematically with increases of vibration duration in excess of 0.25 min, and (2) the majority of previous investigations conducted for development of the NASA model have involved 0.25-min vibration durations. Thus, the duration correction is defined as the difference between discomfort due to a ride segment of duration T ($T > 0.25$ min) and the discomfort due to a ride segment of 0.25-min duration. The duration correction can mathematically be expressed as

$$DISC_{DURATION} = DISC_{T=T_i} - DISC_{T=0.25\ min} \tag{1}$$

where

$DISC_{DURATION}$	incremental change in discomfort due to duration
$DISC_{T=T_i}$	discomfort at Time = T_i
$DISC_{T=0.25\ min}$	discomfort at Time = 0.25 min

Using equation (1) and the fact that the slopes of the lines of figure 5 did not differ, the $DISC_{DURATION}$ values for durations greater than 0.25 min were computed and are shown in figure 6. Since the duration effect was shown to be independent of acceleration level, the $DISC_{DURATION}$ values of figure 6 represent an average of these values across acceleration level at each of the vibration durations. The final duration correction function is given by the following equation, which corresponds to the line shown in figure 6:

$$DISC_{DURATION} = -0.011969(T) + 0.003137 \tag{2}$$

where T is vibration duration in minutes. This function clearly illustrates the fact that the subjects adapted to the longer duration vibration environment. This result is consistent with comments made by the subjects upon completion of the experimental testing each day. An important implication of the duration effect displayed in figure 6 (and eq. (2)) is the possibility that it may account for some of the inconsistencies (refs. 1 and 2) observed when comparing the results of various ride quality studies that exposed passengers to similar vibration stimuli but of varying durations.

The major results and implications discussed in this section can be summarized as follows: (1) for rms vibration levels below discomfort threshold (<0.027g), passenger discomfort was independent of vibration duration (up to 1 hr); (2) for rms vibration levels in excess of discomfort threshold (>0.027g) up to 0.100g, a systematic decrease in passenger discomfort occurred as vibration duration increased; and (3) the absolute amount of discomfort decrease was independent of acceleration level for the particular acceleration levels tested.

Comparison With ISO

The recommendations of the ISO as to the effect of vibration duration are presented in reference 11. These recommendations indicate that the effects of vibration duration are independent of acceleration level, vibration frequency, and the axis of vibration. The document defines a "reduced comfort boundary" as the acceleration level (at each frequency) below which a ride is considered to be comfortable and above which a ride is treated as uncomfortable. The effect of duration is incorporated as a modification in the acceleration level required to provide "reduced comfort." The ISO duration effect can be illustrated by defining a parameter called acceleration ratio R_a which is defined as follows:

$$R_a = \frac{a_T}{a_{ref}} \tag{3}$$

where

a_T permissible rms acceleration level at time T for no reduced comfort

a_{ref} permissible rms acceleration for 1 min exposure for no reduced comfort

A plot of the acceleration ratio as a function of vibration duration (Time $\geqq$ 1 min) for the ISO recommendation is given in figure 7. As shown in the figure, the ISO trend indicates that the acceleration level should be reduced for increases in duration in order not to exceed the reduced comfort boundary. For comparison purposes, the values of R_a for this study are also displayed in figure 7 and show an opposite trend, namely, that an increase in acceleration level is required to maintain a constant level of discomfort. Thus, the results of this study imply that the passenger-subjects tend to adapt to a continuously applied ride environment, whereas the ISO recommendation indicates that subjective tolerance decreases (no adaptation). One possible explanation for the difference between the two results is that the ISO trend was derived from performance-oriented investigations and hence may be valid for very high levels of acceleration, whereas the duration effect of the present investigation applies only to the lower level vibrations typical of passenger transportation vehicles. In other words, the ISO recommendation may apply to extreme vibration environments such as may be found in certain military vehicles.

CONCLUDING REMARKS

An investigation was conducted to systematically examine the effects of vibration duration on passenger discomfort. A realistic laboratory simulator was used to expose subjects to random vertical vibrations. Variables included the time of exposure (0.25 to 60 min) and the amplitude of rms vibration (0.025 to 0.100g). The vibration was characterized by a white noise spectrum with a bandwidth of 10 Hz centered at 5 Hz. Data indicate that for rms acceleration levels greater than the threshold of discomfort (0.027g), a systematic decrease in discomfort occurred as a function of increasing duration of vibration. The magnitude of the discomfort decrement was shown to be independent of acceleration level. These results were opposite to the duration correction recommended by the International Standard ISO 2631-1974 (E) "Guide for the Evaluation of Human Exposure to Whole-Body Vibration." One possible reason for the difference in trend between the results of this study and the International Organization for Standardization (ISO) recommendation could be the fact that the ISO trend was derived from data related to human performance (or proficiency) under vibration stress. Consequently, the levels of vibration upon which the ISO trend is based are substantially higher than the levels required to produce decrements in subjective comfort. The validity of extrapolations from performance data, or the ISO fatigue-decreased proficiency boundary curve, to the case of reduced comfort is questionable and remains to be demonstrated. This is an area that is certainly worthy of additional well-planned research.

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APPENDIX

PASSENGER INSTRUCTIONS FOR DISCOMFORT TESTS

Discomfort Instructions

You have volunteered to participate in a research program to investigate the quality of rides. Specifically, we wish to identify the types of vibration in transportation vehicles which most influence a person's sense of well-being. To assess the influence of these vibrations, we have built a simulator which can expose passengers to realistic ride motions. The simulator essentially provides no risk to passengers since it has been designed to meet stringent safety requirements such that it cannot expose subjects to motions which are known to cause injury. It contains many built-in safety features which automatically shut the system down if it does not perform properly.

The vibrations that you will receive today are representative of vibrations you may experience in an airplane. You will enter the simulator, take a seat, fasten the seatbelt, and assume a comfortable position with both feet on the floor. Selected vibrations will then be applied to the cabin. You are to make yourself as comfortable and relaxed as possible while the test is being conducted; however, you must keep your feet on the floor and keep your seatbelts fastened at all times. During the tests you will at all times be in two-way communication with the test conductor.

You have the option at any time and for any reason to terminate the tests in any one of three ways: (1) by pressing overhead button labeled "STOP," (2) by voice communication with the test conductor, or (3) by pressing downward on toggle switch located at front of each right-hand armrest. Because of individual differences in people, there is always the possibility that someone may find the motions objectionable and may not wish to continue. If this should happen to you, please do not hesitate to stop the tests by one of the above methods.

Instructions for Comfort Ride Estimations

The task you will now be required to perform is to evaluate the vibration of a ride segment. The discomfort evaluation you make of a particular ride segment will always be in comparison to a standard ride segment. I will specify the start of a ride segment with the word "start," and I will specify the end of a ride segment with the word "stop." After you hear the word stop, you are to evaluate the ride segment in comparison with the standard ride segment.

Task.- I will present a ride segment, termed the standard, at the beginning and intermittently throughout your evaluations. The standards will be the same throughout the testing. The discomfort of the standard ride segment is to be assigned the number 100. I will present ride segments that provide less or more discomfort than the standard 100. Your task will be to assign numbers to each of these ride segments above and below the standard 100. Try to assign the appropriate number to each ride segment regardless of what you may have called the previous ride segment. If, for example, the ride segment seems to provide twice the discomfort of the standard, say 200. If the ride segment provides one-tenth the discomfort, say 10. If the ride segment provides one-fourth the discomfort of the standard, say 25. As you know, there are infinite numbers above as well as below the standard of 100. You may use decimals, fractions, or whole numbers. Do not use zero or negative numbers.

Evaluation marks.- You should record your evaluation (number) of the ride segment on the blank space next to the ride segment number. For example, the data sheet for you to record your evaluation of a ride segment will look like the following:

STANDARD (100)		STANDARD (100)
RIDE 2, RATE _____		RIDE 2
	OR	
RIDE 3, RATE _____		STANDARD (100)
STANDARD (100)		RATE RIDE 2 _____

Evaluations.- There are two requirements you should use in your evaluations.

First, your evaluations should be based upon vibration. Certainly, you could evaluate a ride based on other factors such as temperature, pressure, etc. However, restrict your evaluations of a ride segment to variations of vibration.

Second, base your evaluation of a ride upon comfort of a vibration, not only upon variations of vibration. In other words, rate a ride segment in terms of comfort of a vibration, not on whether you notice differences of vibration. This requirement is important because we are interested in differences of comfort, not merely your ability to detect differences of vibrations.

Consistency.- It is typical for participants in the study to "try and be consistent." Instead of trying to be consistent with previous ride segments, try and evaluate each segment without looking at evaluations of previous ride segments. Please do not be concerned about whether your ratings agree with the others in the simulator with you. Remember we want to know how different people feel about the ride. You may talk between the segments you are to rate, but please do not talk during them. It is also typical for participants to feel that they are not doing well at this task. It is usually true, however, that participants are doing better than they think they are, so don't be discouraged if you find the task difficult or monotonous at times.

Remember.-

1. Listen for the words "Start" and "Stop."

2. Evaluate only the discomfort of vibrations.

3. Place your evaluation number on the appropriate blank.

Are there any questions?

APPENDIX

Simulator Instructions

(Upon entering the simulator, the subject should be told:) Please be seated and fasten your seatbelt. (Wait until all the subjects are ready.) Now, the mirror you see in front of you is a two-way mirror to allow the operator to monitor any discomfort you may have during a ride. In addition, as I told you before, the test conductor will be able to hear everything you say. Also, if you wish to end the test, you can push the toggle switch, press one of these little buttons (point to both), or you can ask the test conductor to stop the test and let you out. The first part of the test will take about an hour.

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TABLE I.- A SUMMARY OF THE NUMBER OF STANDARD AND COMPARISON RIDE SEGMENTS THAT EACH SUBJECT EXPERIENCED FOR A VIBRATION DURATION

Comparison duration, min	Number of subjects tested at each duration	Number of times each subject exposed to each rms level				
		Comparison				Standard (0.100g)
		0.025g	0.050g	0.075g	0.100g	
0.25	18	36	36	36	36	48
1	12	24	24	24	24	96
2	12	16	16	16	16	64
3	24	10	10	10	10	80
5	24	5	5	5	5	40
10	12	3	3	3	3	24
15	12	2	2	2	2	16
30	24	1	1	1	1	8
60	12	1	1	---	---	4
60	12	1	---	1	---	4
60	12	1	---	---	1	4
60	12	---	1	1	---	4
60	12	---	1	---	1	4
60	12	---	---	1	1	4

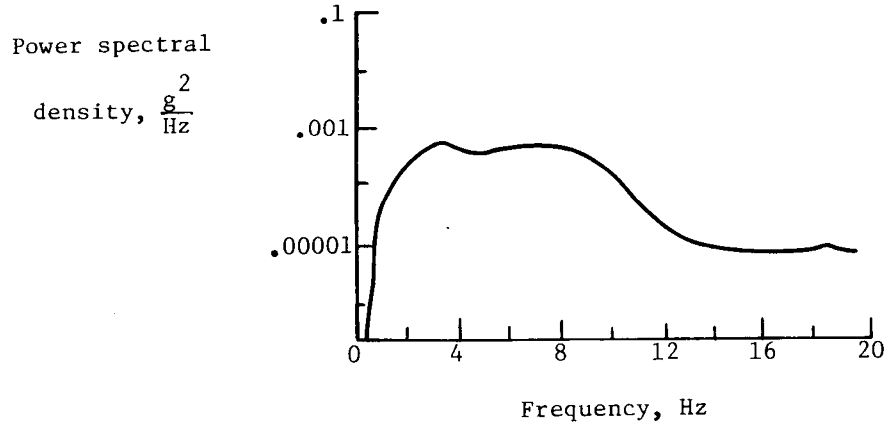
TABLE II.- A SUMMARY OF SIGNIFICANT t-VALUES[a] COMPUTED BETWEEN THE MEAN DISCOMFORT RESPONSE FOR EACH DURATION AND ACCELERATION LEVEL AND THE PREDICTED RESPONSE BASED ON LEAST-SQUARES CURVE-FITTED ESTIMATES FOR EACH ACCELERATION LEVEL

Duration, min	rms acceleration level, g units				Degrees of freedom	Significant ($P \leqq 0.05$) t-value
	0.025	0.050	0.075	0.100		
0.25	[a]7.7771	[a]8.4418	[a]2.7947	[a]2.0862	647	-1.96 > t > 1.96
1	-1.7231	.0681	-.4165	-.8514	287	-1.96 > t > 1.96
2	-.0311	-1.2668	-.8412	-1.0201	191	-1.96 > t > 1.96
3	.8121	.2436	-.1866	-.7863	239	-1.96 > t > 1.96
5	[a]-2.1019	-.5201	.7896	[a]3.2626	119	-1.98 > t > 1.98
10	-1.1719	-.1448	-.5202	.1604	35	-2.042 > t > 2.042
15	.5304	-.4269	-.6659	-1.5931	23	-2.069 > t > 2.069
30	-1.4629	-1.4299	.7083	.8256	23	-2.069 > t > 2.069
60	.5712	1.4131	-.3788	-.1933	35	-2.042 > t > 2.042

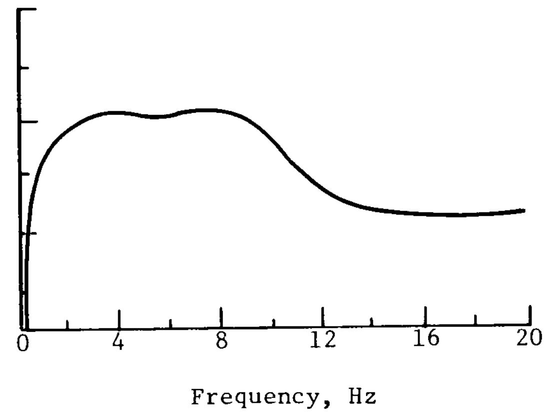
[a]Probability (P) $\leqq$ 0.05.

L-78-600

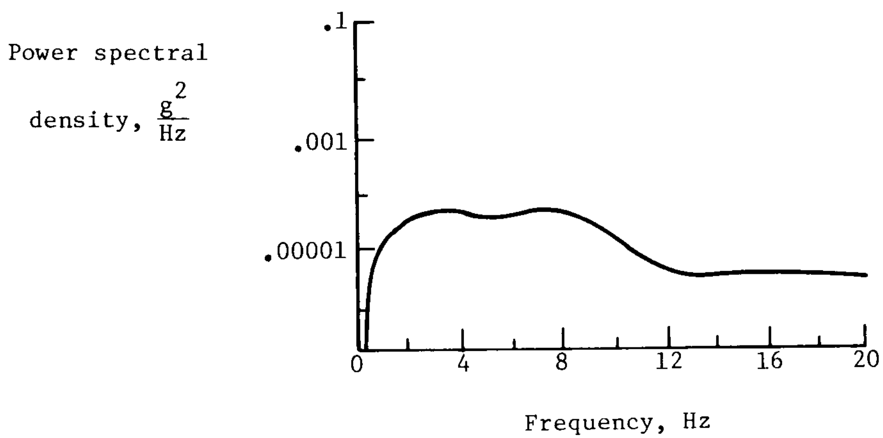
Figure 1.- Langley passenger ride quality apparatus.



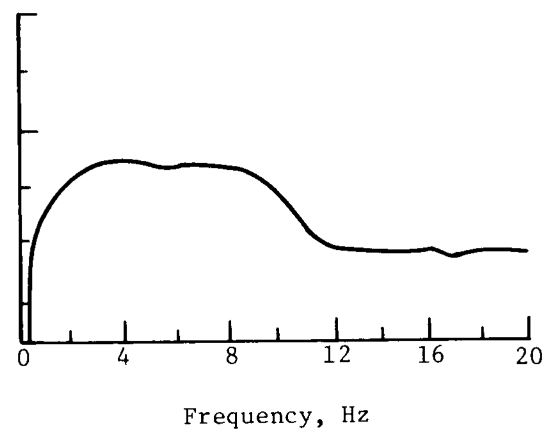
(a) rms vibration amplitude, 0.075g.



(b) rms vibration amplitude, 0.100g.



(c) rms vibration amplitude, 0.025g.



(d) rms vibration amplitude, 0.050g.

Figure 2.- Vibration spectra for the four floor vibration levels.

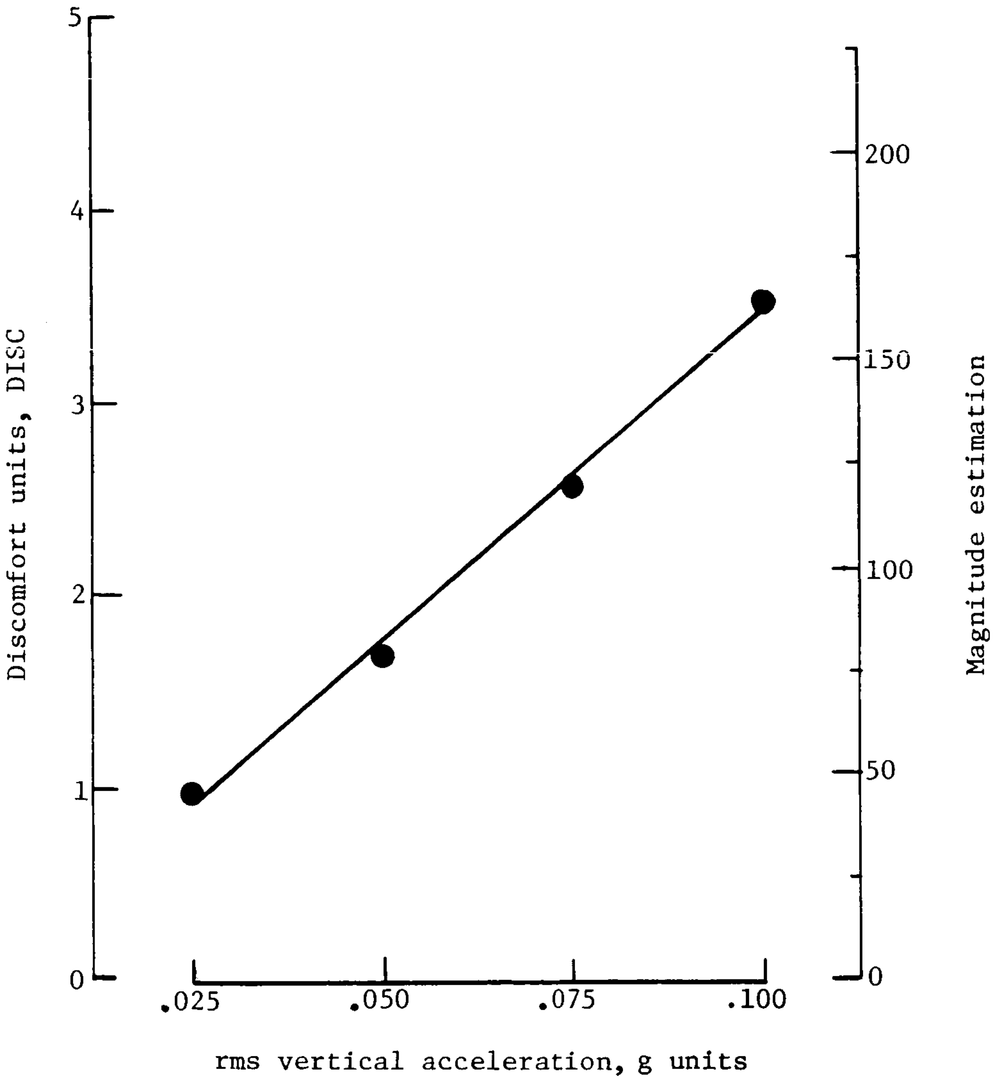


Figure 3.- Values of DISC and magnitude estimations of discomfort (averaged over all subjects and durations) as a function of floor acceleration level.

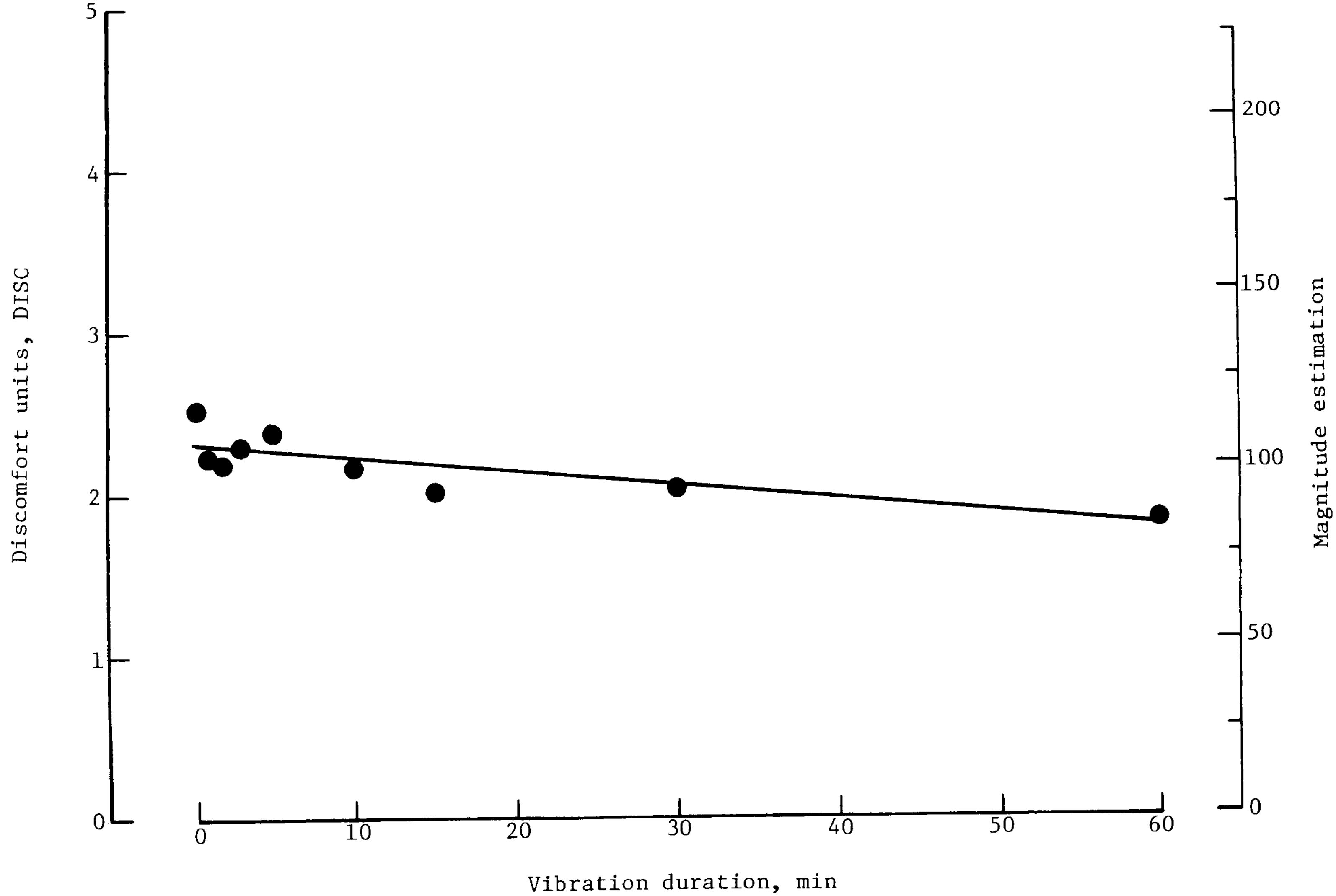


Figure 4.- Values of DISC and magnitude estimations of discomfort (averaged over all subjects and acceleration levels) as a function of vibration duration.

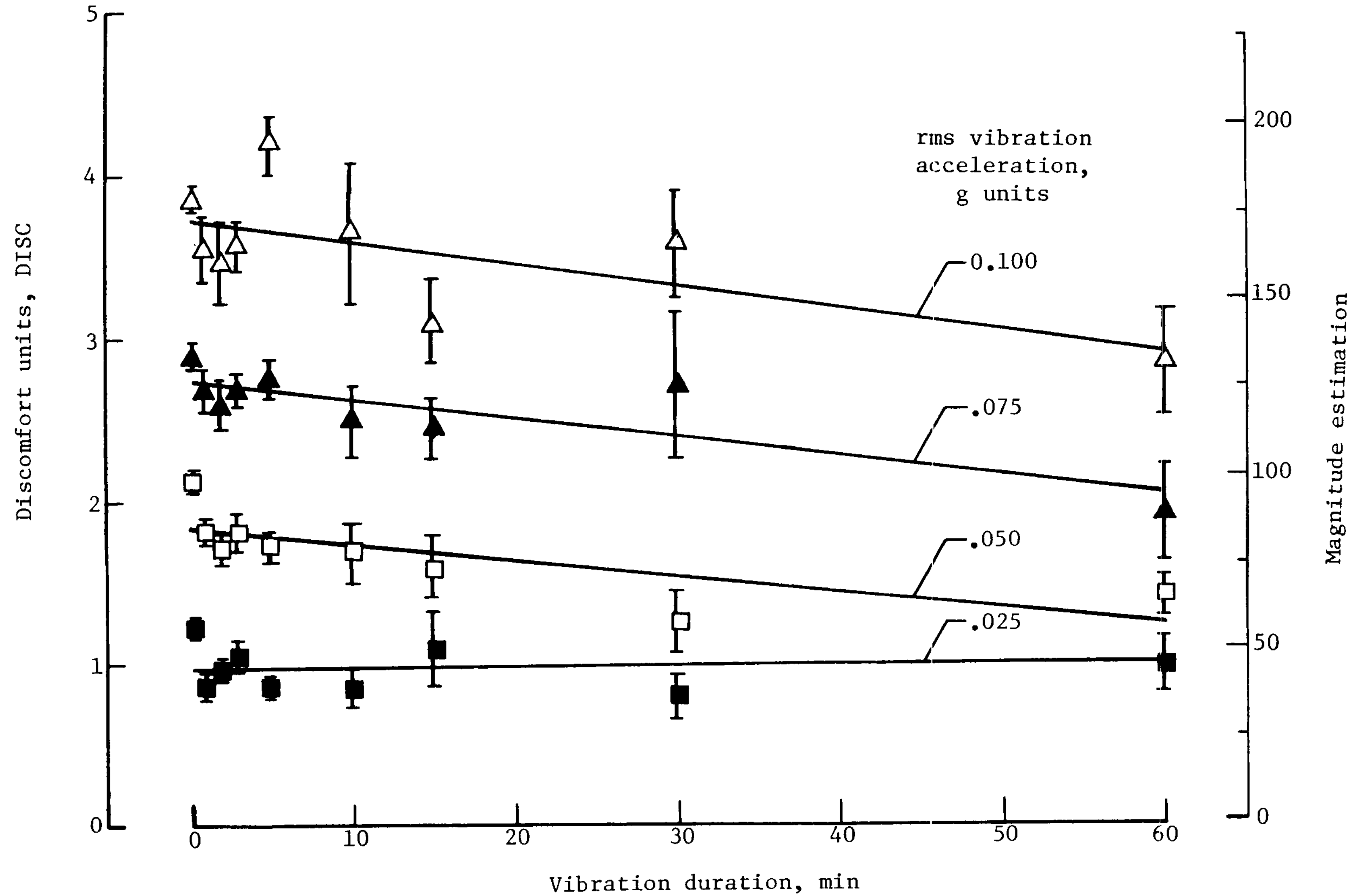


Figure 5.- Mean values of DISC and magnitude estimations of discomfort for the 0.025, 0.050, 0.075, and 0.100g levels of vibration acceleration as a function of vibration duration.

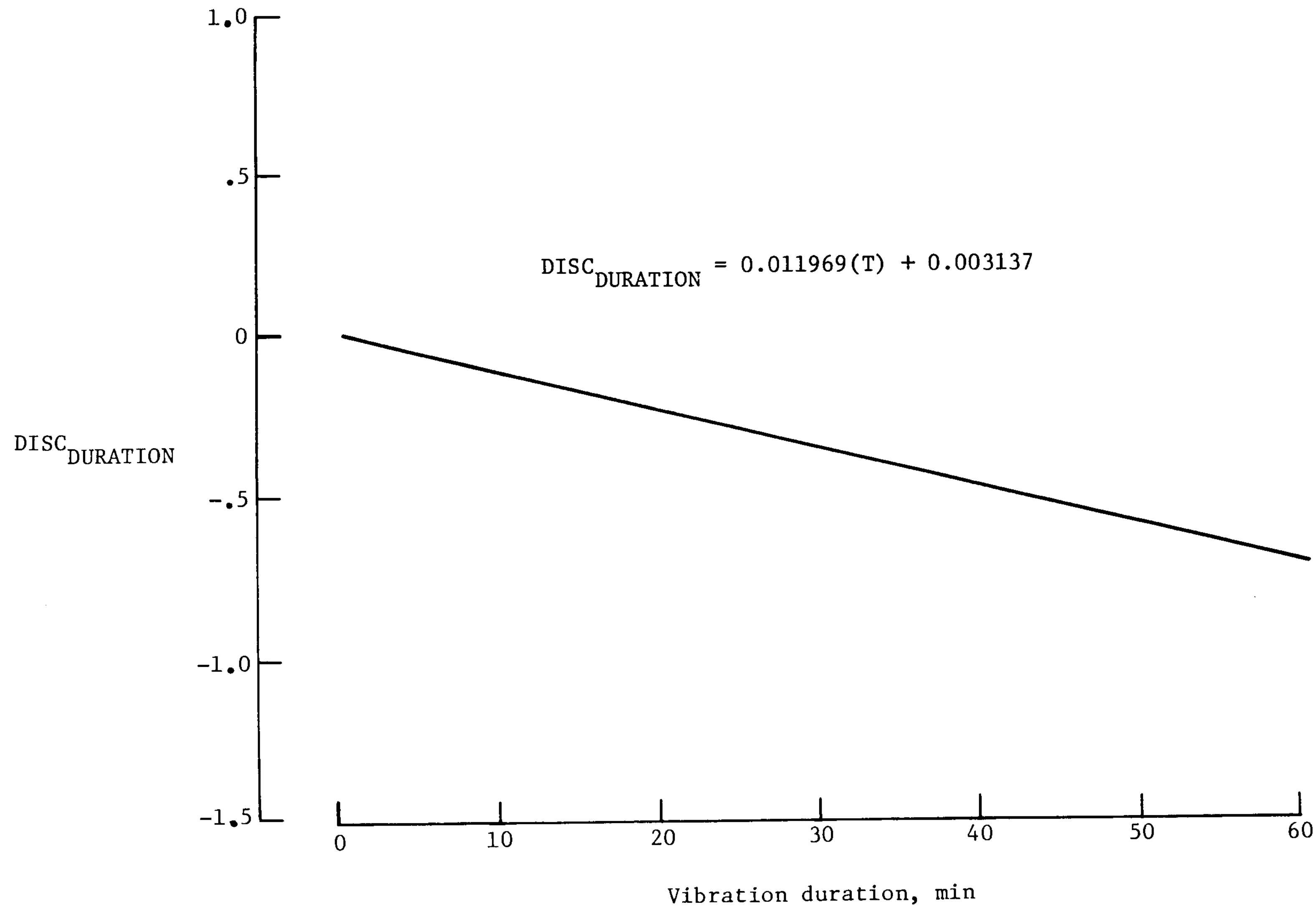


Figure 6.- Values of $DISC_{DURATION}$ as a function of vibration duration. $DISC_{DURATION}$ = Incremental change in discomfort due to duration.

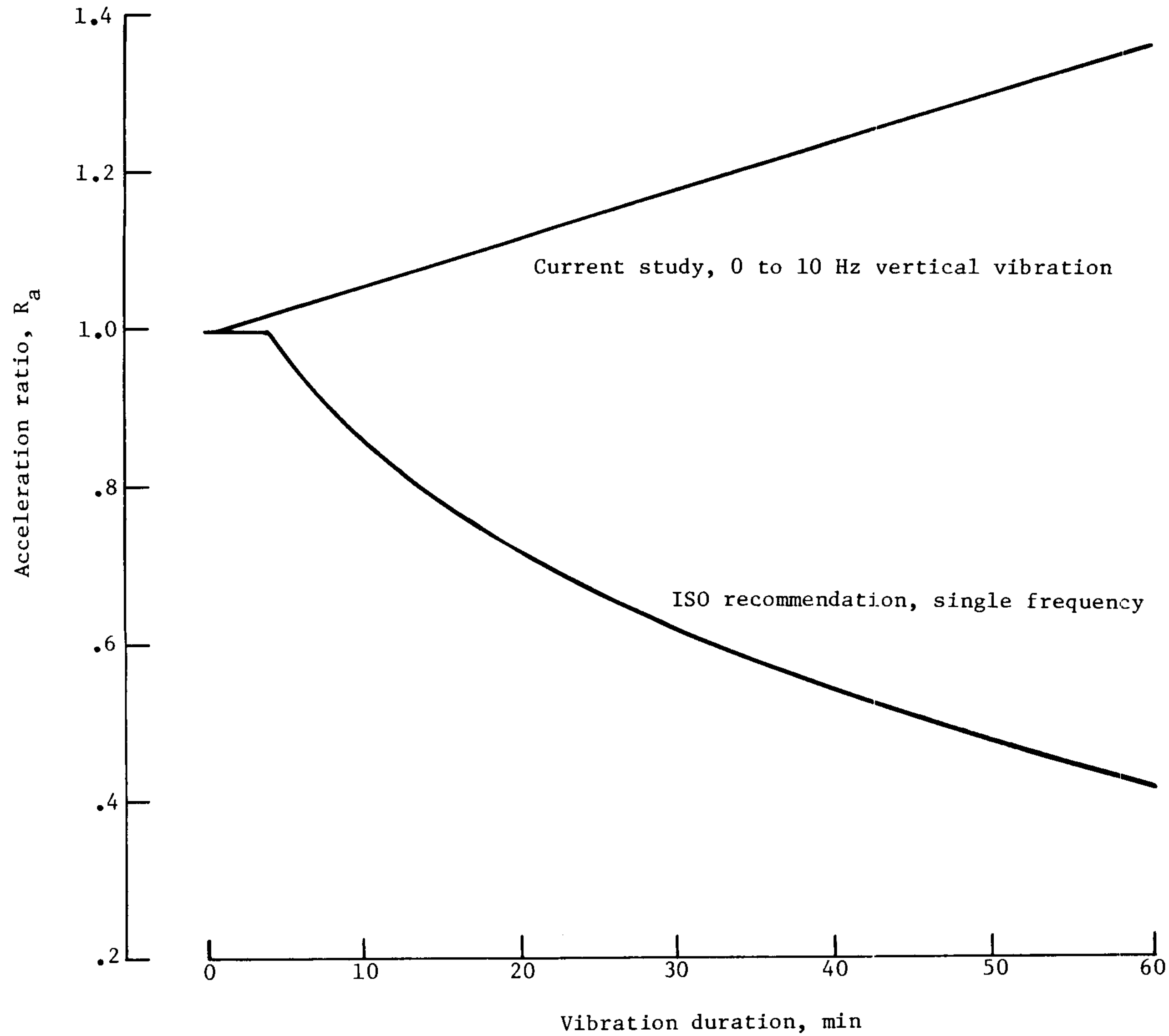


Figure 7.- Values of R_a (see eq. (3)) for present study and those of ISO document as a function of vibration duration.

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15. Supplementary Notes

16. Abstract

A laboratory investigation was conducted to examine the duration effects of random vertical vibration on passenger discomfort. The study was performed in a simulated section of an aircraft cabin configured to seat six persons in tourist-class style. Variables of the study included time of exposure (0.25 min to 60 min) and the rms amplitude of vibration (0.025g to 0.100g). The vibrations had a white noise spectrum with a bandwidth of 10 Hz centered at 5 Hz. Data indicate that the discomfort threshold for this study occurred at an rms vertical acceleration level of 0.027g for all durations of vibration. However, for acceleration levels that exceeded the discomfort threshold, a systematic decrease in discomfort occurred as a function of increasing duration of vibration. Further, for the range of accelerations used in this study, the magnitude of the discomfort decrement was shown to be independent of acceleration level. The results suggest that discomfort from vertical vibration applied in the frequency range at which humans are most sensitive decreases with longer exposure, which is the opposite of the recommendation of the International Standard ISO 2631-1974 (E) "Guide for the Evaluation of Human Exposure to Whole-Body Vibration."

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