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PASSENGER RIDE QUALITY WITHIN A NOISE AND VIBRATION ENVIRONMENT

By

Thomas K. Dempsey, Jack D. Leatherwood, and
Arlene B. Drezek

April 1976

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16. Abstract

The subjective response to noise and vibration stimuli was studied in a ride quality simulator to determine the importance of these two stimuli (or their interaction) in the prediction of passenger ride quality. Subjects used category scales to rate noise discomfort, vibration discomfort, both noise and vibration discomfort, and overall discomfort in an effort to evaluate parametric arrangements of noise and vibration. The noise stimuli were composed of octave frequency bands centered at 125, 250, 2,000 and 4,000 Hz, each presented at 70, 75, 80, and 85 dB(A). The vertical vibration stimuli were 5 Hz bandwidth random vibrations centered at 3, 5, 7, and 9 Hz, each presented at 0.03, 0.06, 0.09, and 0.12 g_{rms}. Analyses were directed at (1) a determination of the subject's ability to separate noise and vibration as contributors to discomfort, (2) an assessment of the physical characteristics of noise and vibration that are needed for prediction of ride quality in this type of multifactor environment, and (3) an evaluation of the relative contribution of noise and vibration to passenger ride quality.

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INTRODUCTION

Passenger discomfort in transportation vehicles is attributable to a host of physical and psychological factors. A model (ref. 1) has been developed at NASA Langley Research Center which provides a framework to account for the effect of both multifrequency and multiaxis vibratory stimuli, as well as nonvibratory factors, on these human comfort responses. To date, the studies (ref. 2-5) based on this model have concentrated on the influence of vibratory factors upon ride quality. This paper represents an extension of this work and is directed at providing information for the prediction of comfort within a combined noise and vibration environment. Despite the fact that several studies (ref. 7 and 8) have investigated the influence of these combined factors (noise and vibration) upon performance and physiological measures, there is a dearth of systematic information regarding the influence of these factors upon ride quality. Prior to the development of noise and vibration criteria for ride quality, which could be either composite or separate criteria (either hierarchical or successive in nature), several problems of a methodological nature must be considered. These problems are addressed by the present paper and include: (1) a determination of the subject's ability to separate noise and vibration as contributors to discomfort, (2) an assessment of the physical measures of noise and vibration that optimize ride quality prediction in this type of multifactor environment, and (3) a determination of the relative contribution of noise and vibration to passenger ride quality.

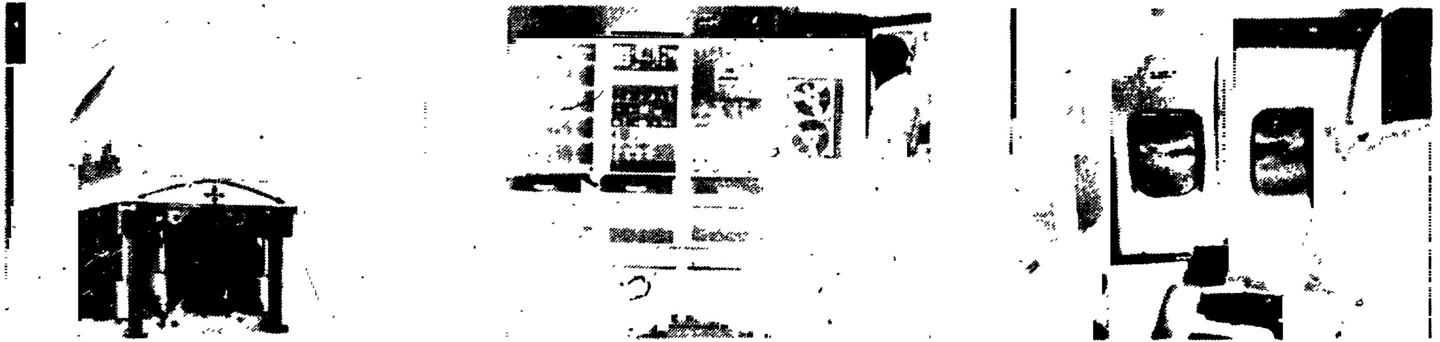
METHOD

The objectives of the investigation were achieved through exposure of subjects to noise and vibration combinations. The following sections provide a review of the NASA Langley Passenger Ride Quality Apparatus (PRQA) which was used in the investigation as well as a short description of the subjects, task, and procedure.

Simulator

The apparatus used was the Langley Passenger Ride Quality Apparatus (PRQA). The PRQA is described briefly in this section and a detailed description can be obtained from references 9 and 10. The PRQA and associated programing and control instrumentation are shown in the photographs of figure 1 on the next page. Figure 1(a) shows the waiting room where subjects are instructed as to their participation in the experiment, complete questionnaires, etc. Figures 1(b) and 1(c) are photographs of the exterior of PRQA, and it should be noted that the actual mechanisms which drive the simulator are located beneath the pictured floor. Shown in figure 1(d) is a model of the PRQA indicating the supports, actuators, and restraints of the three-axis drive system. The control console is shown in figure 1(e) and is located at the same level as the simulator to allow the console control operator to constantly monitor subjects within the simulator. An interior view of PRQA fitted with tourist-class aircraft seats is shown in figure 1(f). Additional interior views (with front or back panels removed) of PRQA are displayed in figures 1(g), 1(h), and 1(i). Noise was produced by a noise generator and played through an octave filter into a sound system.

(A) WAITING ROOM (B) ENTERING CABIN (C) EXTERIOR VIEW



(D) THREE AXIS DRIVE (E) INSTRUMENT CONSOLE (F) VISUAL SIMULATION

(G) FIRST CLASS CABIN (H) REAR VIEW (I) SUBJECTS

FIGURE I.– PASSENGER RIDE QUALITY APPARATUS

SUBJECTS

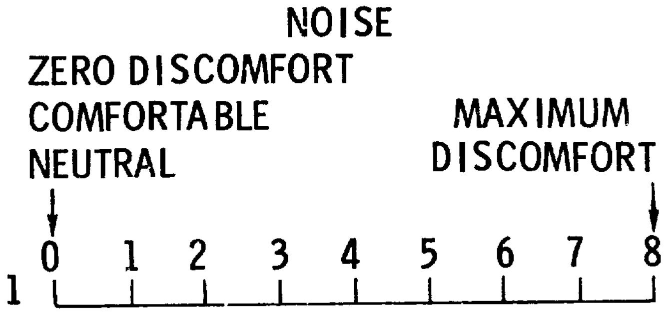
A total of 48 subjects (9 males and 39 females) participated in the study. The volunteer subjects were obtained from a contractual subject pool and were paid for their participation in the study. The ages of the subjects ranged from 18 to 54 years, with a median age of 33 years. The mean weight of the subjects was 63.88 kg (140.84 lb), with a standard deviation of 13.74 kg (30.30 lb). All subjects were audiometrically screened and had normal hearing.

Subjective Evaluation Scales

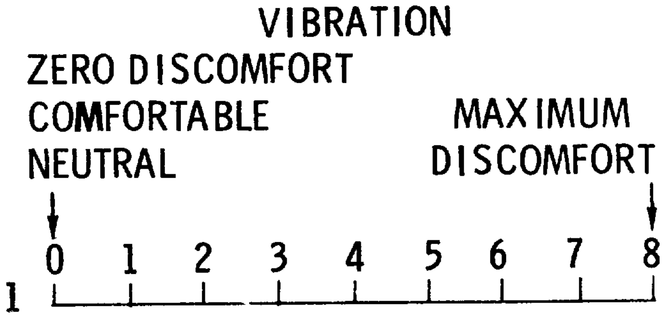
The same set of noise and vibration combinations were evaluated according to the three different types of subjective scales displayed in table 1. The three scales were used to obtain four sets of evaluations of (1) noise discomfort only, (2) vibration discomfort only, (3) simultaneous but separate noise discomfort and vibration discomfort, and (4) overall discomfort (including noise and vibration in combination). A particular subject evaluated ride segments according to one scale condition. Each scale was a nine-point unipolar scale, with associated numerical integers. The scales were each anchored at zero with the words "comfortable," "neutral," or "zero discomfort." The anchor at the opposite end of the scale was "maximum discomfort." Thus, the scale continuum of increasing numbers was interpreted as representing increasing degrees of discomfort (for noise, vibration, or their combination). The subjects were instructed to interpret the scale in an equal-interval fashion.

TABLE I.– LIST OF SUBJECTIVE SCALES

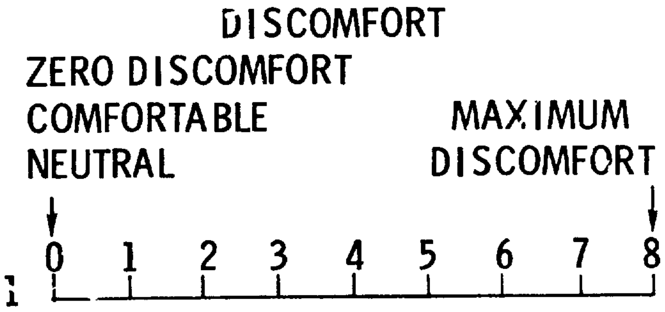
(A) NOISE DISCOMFORT



(B) VIBRATION DISCOMFORT



(C) OVERALL DISCOMFORT



PROCEDURE

The task for each subject (six subjects concurrently) was an evaluation (according to one of the previously-mentioned scales) of successive "ride segments." Table 2 displays the design of the present investigation and indicates a ride segment is defined as a particular experimental condition that resulted from a parametric combination of selected vibrations and noise. The vibrations were all of 5 Hz bandwidth and random in nature, at center frequencies of 3, 5, 7, or 9 Hz, at 0.03, 0.06, 0.09, or 0.12 g_{rms}. The noises were all random in nature of octave bandwidth, at center frequencies of 250, 500, 2,000 and 4,000 Hz, at 70, 75, 80, or 85 dB(A). Through the use of a red indicator light, the subjects were informed of the time period (ride segment) on which to base their evaluation. The subjects were instructed to ignore rise and decay vibrations (and noise) that occurred prior to and subsequent to illumination of the indicator light. Each ride segment lasted 15 seconds, with an additional 5 seconds each of rise and decay time, and a 5 second time period between successive ride segments.

Each subject was exposed to a total of 368 ride segments, composed of the 256 parametric combinations of table 2, and 112 repeated ride segments of that same table (included within the dashed lines). These ride segments (368) were randomized and divided in half for presentation to subjects on 2 days of testing (separated by 48 hours).

TABLE 2.– EXPERIMENTAL DESIGN

dB$_A$		70				75				80				85			
rms g	Hz	250	500	2 K	4 K	250	500	2 K	4 K	250	500	2 K	4 K	250	500	2 K	4 K
.03	3																
	5																
	7																
	9																
.06	3																
	5																
	7																
	9																
.09	3																
	5																
	7																
	9																
.12	3																
	5																
	7																
	9																

VIBRATION = 5 Hz BW
NOISE = 1 octave BW

RESULTS AND DISCUSSION

This section provides results and discussion related to the three methodological problems addressed in the introduction. In order to provide an overall summary of the various types of subjective responses, a total of five analyses of variance were computed. Each analysis of variance was four dimensional (4 x 4 x 4 x 4, corresponding to four levels and frequencies of noise (dB(A), and four levels (rms) and frequencies of vibration) with repeated measures on all dimensions. A summary of these analyses is provided in table 3. Note that for each analysis of variance, the physical measure main effect corresponding to the type of response, e.g., dB(A) for noise ratings, was significant. However, more importantly many of the other main effects and interactions of the same analysis of variance were significant. The implication of these analyses are discussed in successive sections that address each type of scale response. Interpretation of these results needs to consider the fact that these analyses are based on a within-subject-design as well as a large number of degrees of freedom. Consequently, through increased sensitivity of the design relatively small systematic differences between certain experimental conditions may be over emphasized if not considered relative to total response variation. Successive sections address each type of scale response in terms of the subject's ability to separate noise and vibration, as well as physical measures that optimize ride quality predictions. A final section addresses the relative contribution of noise and vibration to ride quality judgments.

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TABLE 3.- SUMMARY OF ANALYSES OF VARIANCE FOR SINGLE SCALES OF NOISE DISCOMFORT, VIBRATION DISCOMFORT, AND OVERALL DISCOMFORT, AS WELL AS FOR THE DUAL SCALE CONDITIONS OF NOISE DISCOMFORT AND VIBRATION DISCOMFORT

Source	Single Scale							Dual Scale			
	Noise Discomfort			Vibration Discomfort		Overall Discomfort		Noise Discomfort		Vibration Discomfort	
	df	Mean Sq.	F	Mean Sq.	F	Mean Sq.	F	Mean Sq.	F	Mean Sq.	F
A Noise Level, dB(A)	3	1211.75	361.43*	2.2[illegible]	1.15	253.63	57.65*	1510.12	91.07*	6.80	4.14*
Error (AXS)	33	3.52		[illegible]		4.40		16.58		1.64	
B Octave Bands	3	635.81	35.08*	15.5	[illegible].60*	88.56	22.60*	324.16	31.67*	11.20	7.15*
Error (BXS)	33	18.13		2.05		3.92		10.23		1.57	
C Vibration Level	3	2.80	3.09*	1019.31	117.28*	390.92	100.77*	.56	.34	1184.02	84.15*
Error (CXS)	33	.91		8.69		3.93		1.64		14.07	
D Center Hz-Vibration	3	3.49	3.31*	61.60	29.34*	34.82	9.51*	3.27	1.74	71.57	10.68*
Error (DXS)	33	1.05		2.10		3.66		1.88		6.70	
S Subjects	11	362.85		228.12		93.37		189.29		161.45	
AXB Interaction	9	10.22	3.80*	1.87	1.89	12.25	7.92*	5.58	1.69	1.86	2.35*
Error (AXBXS)	99	2.69		.99		1.55		3.31		.79	
AXC Interaction	9	1.74	1.75	7.67	6.99*	15.02	9.91*	1.92	2.07*	5.61	4.49*
Error (AXCXS)	99	.99		1.10		1.52		.92		1.25	
BXC Interaction	9	.96	1.08	5.97	7.90*	4.47	5.59*	6.47	5.95*	3.33	2.86*
Error (BXCXS)	99	[illegible]		.75		.80		1.09		1.17	
AXD Interaction	9	2.04	2.48*	5.04	5.56*	2.01	1.99*	2.77	2.59*	5.86	5.60*
Error (AXDXS)	99	.82		.91		1.01		1.07		1.05	
BXD Interaction	9	2.37	2.45*	2.89	2.69*	6.55	8.10*	3.13	3.68*	2.46	2.72*
Error (BXDXS)	99	.97		1.07		.81		.85		.91	
CXD Interaction	9	3.20	3.25*	13.57	10.64*	12.25	15.87*	1.56	1.64	14.63	12.06*
Error (CXDXS)	99	.98		1.84		.77		.95		1.21	
AXBXC Interaction	27	2.06	2.17*	5.41	4.23*	4.21	3.67*	2.87	2.38*	6.11	6.27*
Error (AXBXCXS)	297	.95		1.28		1.15		1.23		.98	
AXBXD Interaction	27	2.63	3.33*	2.81	2.78*	2.75	2.94*	2.51	2.67*	3.53	3.56*
Error (AXBXDXS)	297	.79		1.01		.94		.94		.99	
AXCXD Interaction	27	2.06	2.48*	4.22	3.97*	3.07	3.74*	2.89	3.34*	4.79	5.62*
Error (AXCXDXS)	297	.83		1.06		.82		.86		.85	
BXCXD Interaction	27	2.55	2.81*	2.63	2.76*	2.99	3.90*	2.48	2.02*	4.38	4.07*
Error (BXCXDXS)	297	.91		.95		.77		1.23		1.08	
AXBXCXD Interaction	81	2.68	3.36*	4.52	3.91*	4.26	4.73*	4.13	3.69*	5.31	4.97*
Error (AXBXCXDXS)	891	.80		1.16		.90		1.12		1.07	

*$p<0.05$

NOISE DISCOMFORT

Figures 2 through 5 display the noise discomfort ratings as a function of the major physical measures. These responses clearly varied as a function of both noise level, dB(A), and octave band of the noise. An initial implication of these results is that information of both the intensity level and spectrum content of a noise are needed for the prediction of ride quality noise discomfort responses.

Figures 4 and 5 (the lower figures on the next page) display the noise discomfort responses as a function of the physical vibration measures. The analysis of variance did indicate that the rms vibration level main effect was significant. However, due to the small relative variability between rms vibration levels and almost lack of variability between these levels in comparison to those for noise levels, the significance of the vibration level main effect is only of theoretical importance. A practical implication of these results for ride quality research is that subjects can quite accurately separate the influence of noise from vibration for noise discomfort evaluations.

NOISE DISCOMFORT

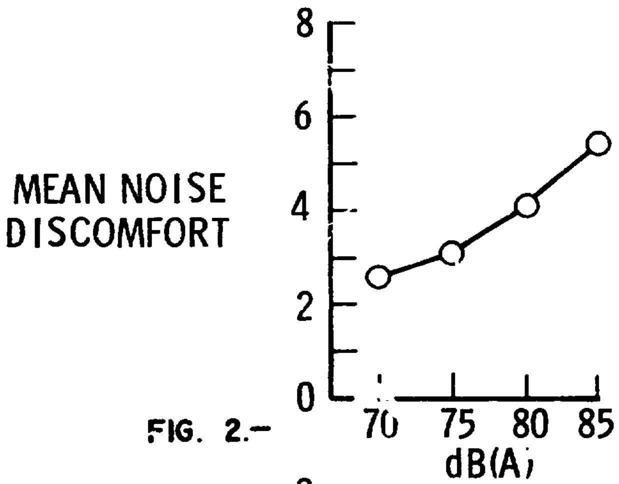

FIG. 2.–

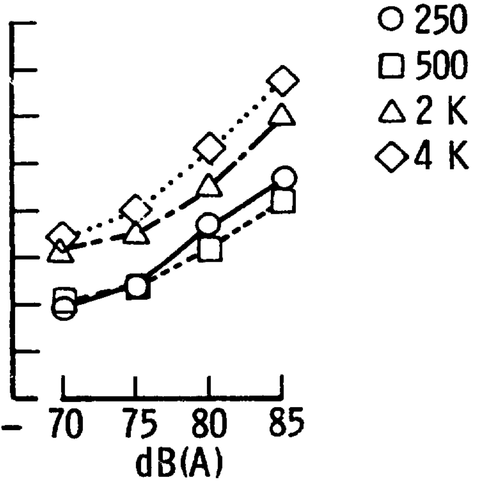

FIG. 3.–

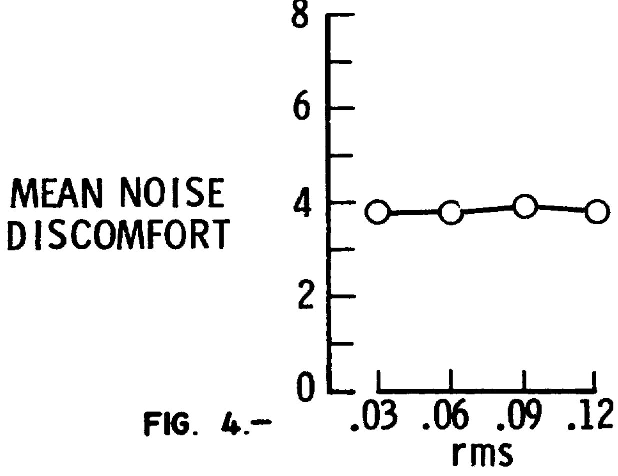

FIG. 4.–

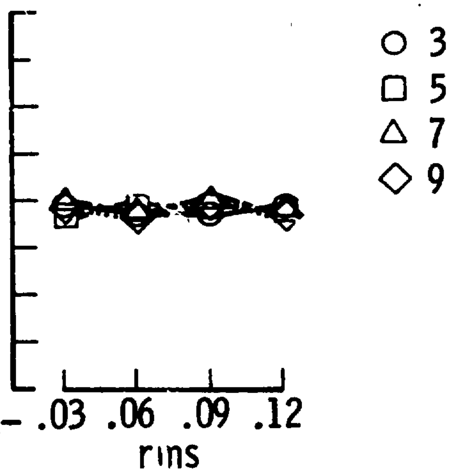

FIG. 5.–

VIBRATION DISCOMFORT

Figures 6 through 9 display the vibration ratings as a function of the major physical measures. These figures display for vibration discomfort results similar to those for noise discomfort. These results show (1) that information is needed of both the vibration level, rms, and spectrum content of a vibration for the accurate prediction of vibration discomfort, and (2) from a practical standpoint, subjects can separate the relative contribution of noise and vibration for vibration discomfort evaluations.

VIBRATION DISCOMFORT

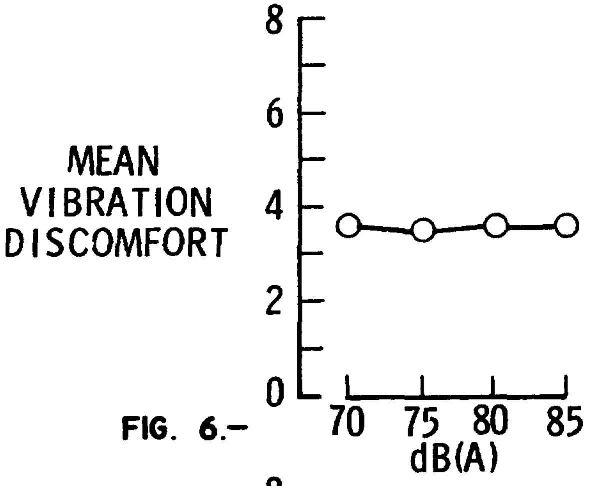

FIG. 6.–

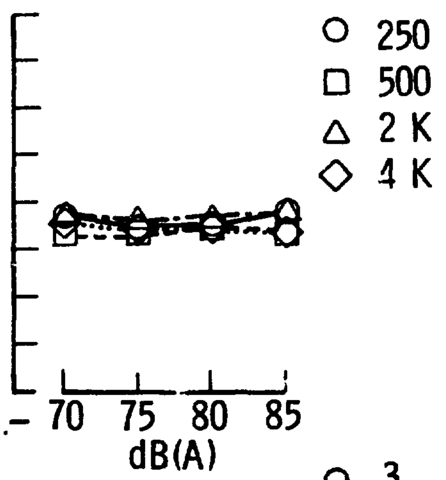

FIG. 7.–

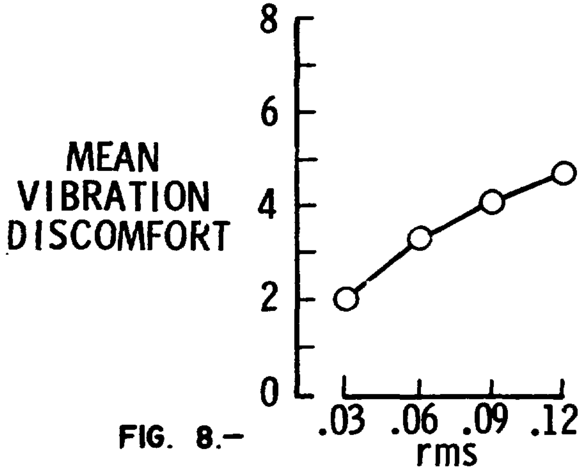

FIG. 8.–

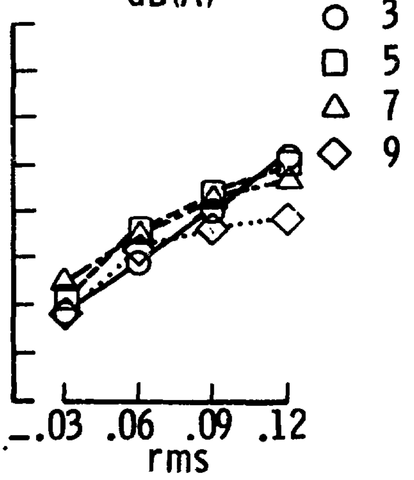

FIG. 9.–

NOISE DISCOMFORT: DUAL SCALE CONDITION

The noise discomfort responses obtained when the subjects simultaneously, but separately, evaluated vibration and noise discomfort are discussed in this section. Figures 10 through 13 display these evaluations as a function of the physical measures. The response trends in these figures essentially conform to those in which the subjects provided only noise discomfort evaluations (figures 2 through 5). However, comparison of the two sets of figures indicates that the absolute discomfort level of this type of response was higher when subjects simultaneously provided vibration discomfort responses. An implication of these differences is discussed in the section that addresses the relative importance of noise and vibration to ride quality judgments.

NOISE DISCOMFORT — DUAL SCALE

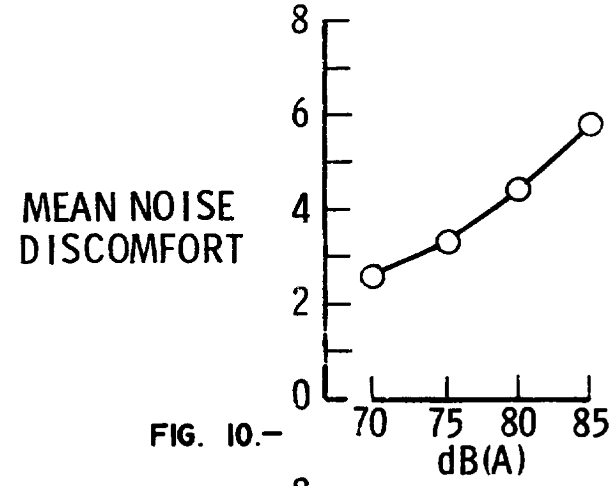

FIG. 10.–

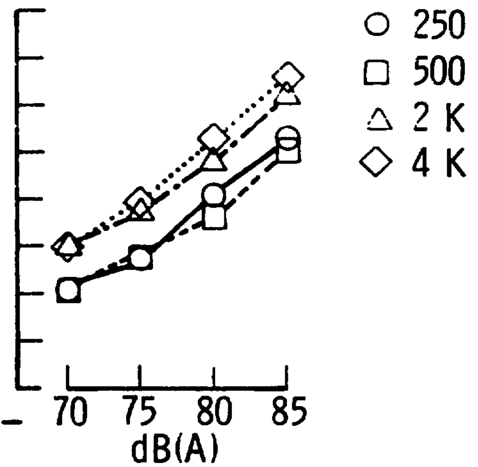

FIG. 11.–

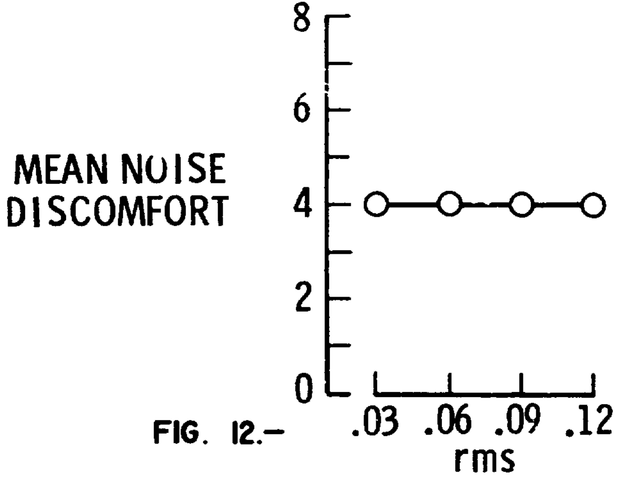

FIG. 12.–

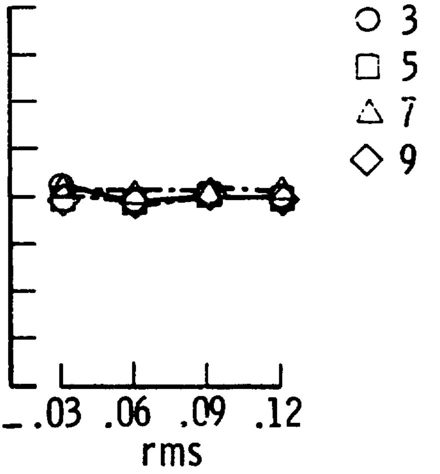

FIG. 13.–

VIBRATION DISCOMFORT: DUAL SCALE CONDITION

This section addresses the vibration responses obtained when the subjects simultaneously, but separately, evaluated noise and vibration. Figures 14 through 17 display these vibration ratings as a function of the physical measures. The comparison of vibration discomfort for single and dual scale conditions display similar trends. However, particular notice should be given to the fact that vibration discomfort was systematically higher for the dual scale condition than for the vibration discomfort only condition. A possible explanation of this result is discussed later in the paper.

In summary, the results for vibration discomfort in the dual scale condition are similar to those of the single scale case. The point of primary interest is that subjects, when appropriately instructed, can separate the influence of noise and vibration when using separate scales of noise and vibration discomfort.

VIBRATION DISCOMFORT — DUAL SCALE

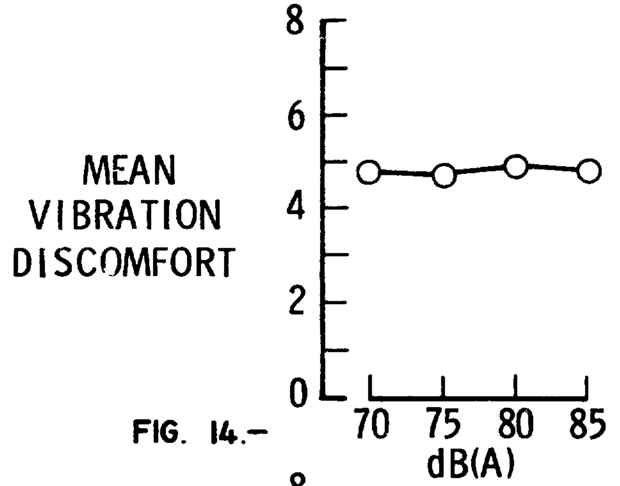

FIG. 14.—

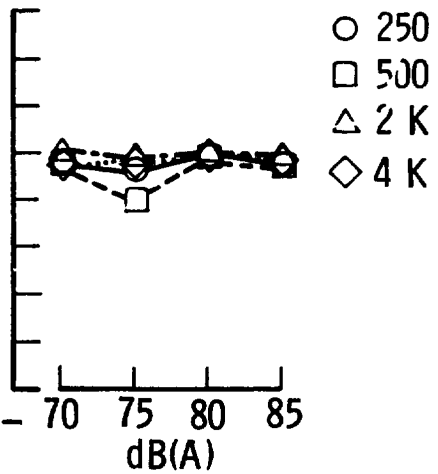

FIG. 15.—

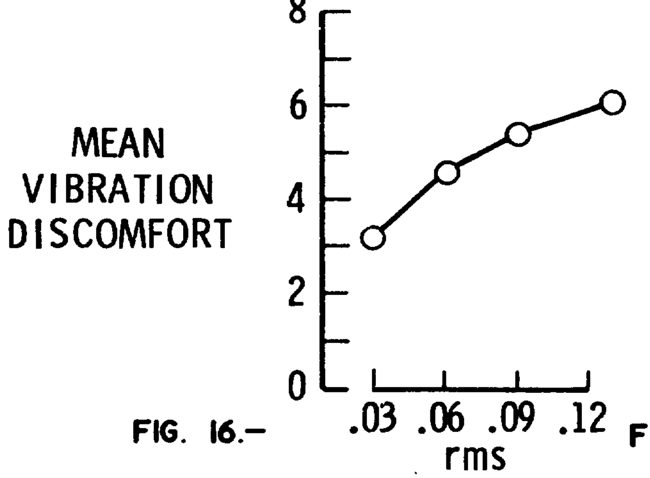

FIG. 16.—

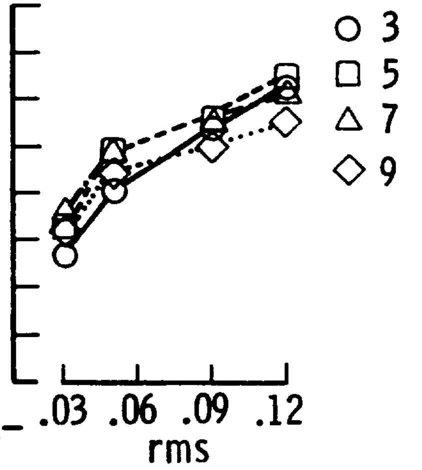

FIG. 17.—

OVERALL DISCOMFORT

The subjective evaluations considered in this section are overall discomfort evaluations that include effects of both noise and vibration. Figures 18 through 21 display these overall responses as a function of the physical measures. The figures consistent with the analysis of variance (from table 2) for these overall responses display expected trends. Specifically, the discomfort responses, except for minor fluctuations, vary as a function of both noise and vibration measures. An implication of these analyses is that ride quality criteria development could be based on the use of a single subjective scale. Consequently, the relative importance of various physical measures to ride quality would be based upon multiple regression analyses rather than simple regression analyses for each separate noise and vibration discomfort scale. An important question that results from these analyses is whether or not there is a differential accuracy in discomfort response prediction that results from the use of dual scales versus an overall scale and, in fact, is addressed in a later section.

OVERALL DISCOMFORT

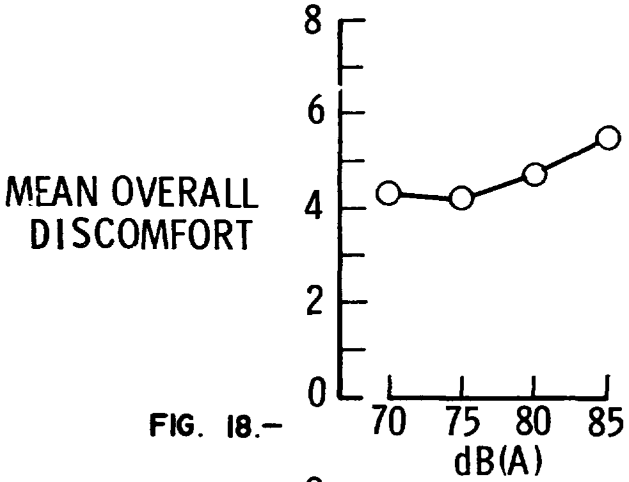

FIG. 18.–

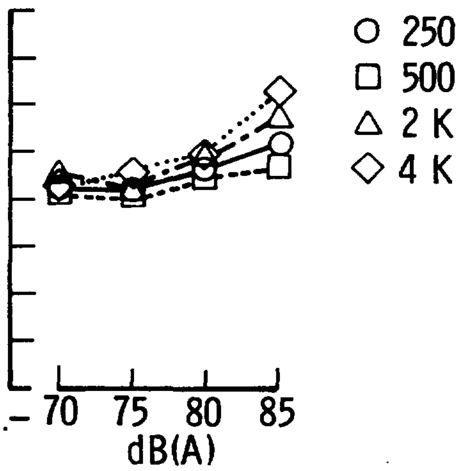

FIG. 19.–

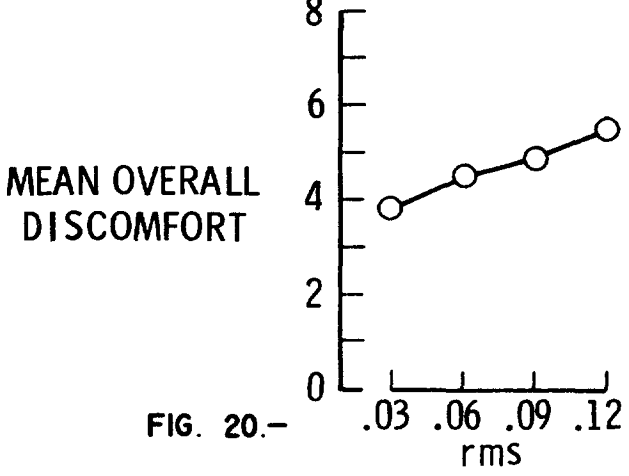

FIG. 20.–

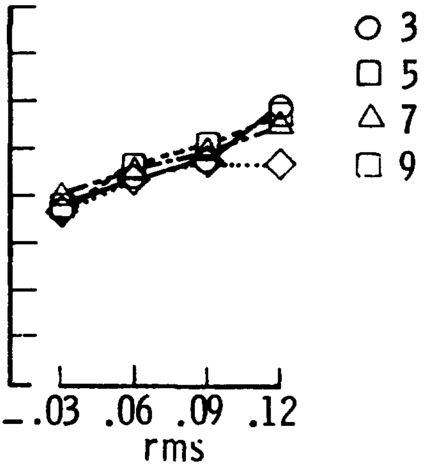

FIG. 21.–

NOISE AND VIBRATION CONTRIBUTIONS

This section addresses the question of the contribution of noise and vibration measures to ride quality discomfort. Table 4 on the next page provides a summary of multiple correlation analyses for each type of scale response. The multiple correlations were computed between responses for each individual and the four independent physical measures (due to design) in a stepwise regression. The table provides the multiple correlations, explained variance, and cummulative explained variance associated with the extraction of successive physical measure predictors.

The multiple correlation analyses of overall discomfort responses are of primary interest for determining the relative contribution of noise and vibration measures to the prediction of ride quality reactions. The four physical measures each account for a degree of response variation. The vibration measures account for greater than four times the response variation as do the noise measures. Additional implications of these analyses include the following: (1) The physical measures associated with the same type of subjective response, e.g., dB(A) and octave bands associated with noise discomfort, almost exclusively account for the explained variance of a particular scale. The other physical measures are of minor importance in terms of explained variance. (2) The prediction accuracy of noise discomfort and of vibration discomfort are improved when subjects provide simultaneous evaluations of noise and vibration rather than single evaluations. (3) Comparison of the total explained variance of the different scales indicates that the dual scale evaluations allow the most comprehensive prediction of discomfort in this multifactor environment.

TABLE 4.- A SUMMARY OF MULTIPLE CORRELATION ANALYSES OF THE
VARIOUS TYPES OF DISCOMFORT RESPONSES

Scale	Descriptor	Extraction Order			
		1	2	3	4
Noise Discomfort	Predictor Measure	dBA	OCT	C-Hz	RMS
	Multiple Correlation	.4521*	.5521*	.5744*	.5946*
	Explained Variance	.2044	.1004	.0251	.0236
	Cummulative Variance	.2044	.3048	.3299	.3535
Vibration Discomfort	Predictor Measure	RMS	C-Hz	dBA	OCT
	Multiple Correlation	.5743*	.6397*	.6398*	.6398*
	Explained Variance	.3298	.0794	.0001	
	Cummulative Variance	.3298	.4092	.4093	.4093
Overall Discomfort	Predictor Measure	RMS	C-Hz	dBA	OCT
	Multiple Correlation	.4848*	.5661*	.6099*	.6253*
	Explained Variance	.2360	.0845	.0515	.0190
	Cummulative Variance	.2360	.3205	.3720	.3910
Noise Discomfort (dual scale)	Predictor Measure	dBA	OCT	C-Hz	RMS
	Multiple Correlation	.5192*	.5676*	.5936*	.6124
	Explained Variance	.2696	.0526	.0302	.0226
	Cummulative Variance	.2696	.3222	.3524	.3750
Vibration Discomfort (dual scale)	Predictor Measure	RMS	C-Hz	OCT	dBA
	Multiple Correlation	.6116*	.6957*	.6960*	.6962*
	Explained Variance	.3741	.1099	.0004	.0003
	Cummulative Variance	.3741	.4840	.4844	.4847

*P < 0.05

CONCLUDING REMARKS

Several major conclusions that can be derived from this investigation are: (1) Information of the intensity level and spectrum content of both noise and vibration is needed for the accurate prediction of ride quality. (2) From a practical point of view, subjects can separate the influence of noise and vibration measures on different discomfort scales. (3) The most comprehensive prediction of discomfort in a noise-vibration environment appears to result from the collection of subjective responses on separate, but simultaneous, noise discomfort and vibration discomfort scales. (4) Initial results indicate that vibration measures account for as great as four times the amount of explained variance as do noise measures.

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