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Boeing Wichita
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Visual-Motor
Performance
during
Whole-Body
Vibration

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Technical Report D3-3512-5
Contract NONR 2994(00)
Office of Naval Research

Technical Report No. 5

VISUAL-MOTOR PERFORMANCE
DURING
WHOLE-BODY VIBRATION

R. E. Chaney
and
D. L. Parks

Research Accomplished Under
Office of Naval Research
Contract Nonr-2994(00)

"Research On
Low Frequency Vibration Effects
On Human Performance"

Principal investigator
J. E. Beaupeurt

HUMAN FACTORS STAFF

THE BOEING COMPANY
Wichita, Kansas

D3-3512-5

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ABSTRACT

Seven male employees of the Boeing Company were tested in the company's human vibration facility to determine the effect of whole body vibration on visual-motor performance. Six controls; a large and a small knob; a horizontal and a vertical lever; and a horizontal and a vertical thumbwheel were used to adjust a standard 3 inch dial indicator to a prescribed setting. Independent variables included variations in vibration frequency and severity, control force requirements, and task complexity. Speed and accuracy of task accomplishment were recorded for each condition.

A high work load condition, vibration independent of frequency and level, and control force requirements, individually affected the speed and accuracy of operator adjustment. The type of control used did not influence accuracy, and had only minor influence on adjustment time with mounting position apparently producing the noted differences.

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REFERENCES

1. Boeing document D3-3301, "Boeing Human Vibration Facility", 28 September 1960.
2. Boeing document D3-3512-1, "Human Reaction to Low Frequency Vibration", D. L. Parks and F. W. Snyder, 24 July 1961.
3. Boeing document D3-3512-2, "A Comparison of Sinusoidal and Random Vibration Effects on human Performance", D. L. Parks, 28 July 1961.
4. Boeing document D3-3512-3, "Human Hearing and Speech During Whole-Body Vibration", R. J. Teare, April 1963.
5. Boeing document D3-3512-4, "Visual Performances during Whole-Body Vibration", R. J. Teare and D. L. Parks, November 1963.
6. AFSC Manual 80-1, Vol. III, "Handbook of Instructions for Aircraft Designers", 1 April 1963.
7. Magid, E. G. & Coermann, R. R., "The Reaction of the Human Body to Extreme Vibrations", 1960 Proceeding of the Institute of Environmental Sciences.
8. Boeing document D3-4937, "Analysis of the Human Vibration Table", T. M. Cate, January 1963.

INTRODUCTION

Definition of operator performance capability, as influenced by system environmental conditions, is becoming increasingly important as modern manned systems become more complex. To the system designer, the accuracy and speed with which an operator can accomplish assigned visual-motor and tracking tasks within the operational environment is probably the largest contributing factor to the selection of a final display-control configuration.

Low frequency vibration is an important part of many operational environments, and is perhaps the most difficult to design out of the system. Consequently, a critical need exists for data concerning vibration effects on human ability to perform perceptual and motor control activities, and design features which will enhance their accomplishment.

The program reported herein is the fifth in a series of Boeing conducted research studies designed to expand the fund of data on the effects of vibration on these various types of operator activity. Previously reported experiments (Refs. 2, 3, 4, 5) have considered the establishment of subjective levels of vibration and the effects of these levels on hearing, speech and vision. Future studies will be concerned with their effect on operator tracking and additional vibration effects on relatively complex behavior.

This report is concerned with four vibration performance relationships:

1. Vibration effects on the accuracy of visual-motor task accomplishment using various types and sizes of controls.
2. Vibration effects on the speed of visual-motor task accomplishment using various types and sizes of controls.
3. The effects of various control forces on the performance of visual-motor tasks in a vibration environment.
4. The effects of increased work load on the speed and accuracy of visual motor task accomplishment under vibration.

It is divided into three major sections. The first is concerned with the general experimental conditions; the second describes results of the first three specified relationships and the third examines performance differences as affected by increased operator work load.

METHODOLOGY

Experimental Subjects

The subjects of the study were seven male Boeing employees who had participated in previous phases of the vibration program and had qualified for this phase by passing an extensive physical examination. Individual descriptions are included in Appendix A.

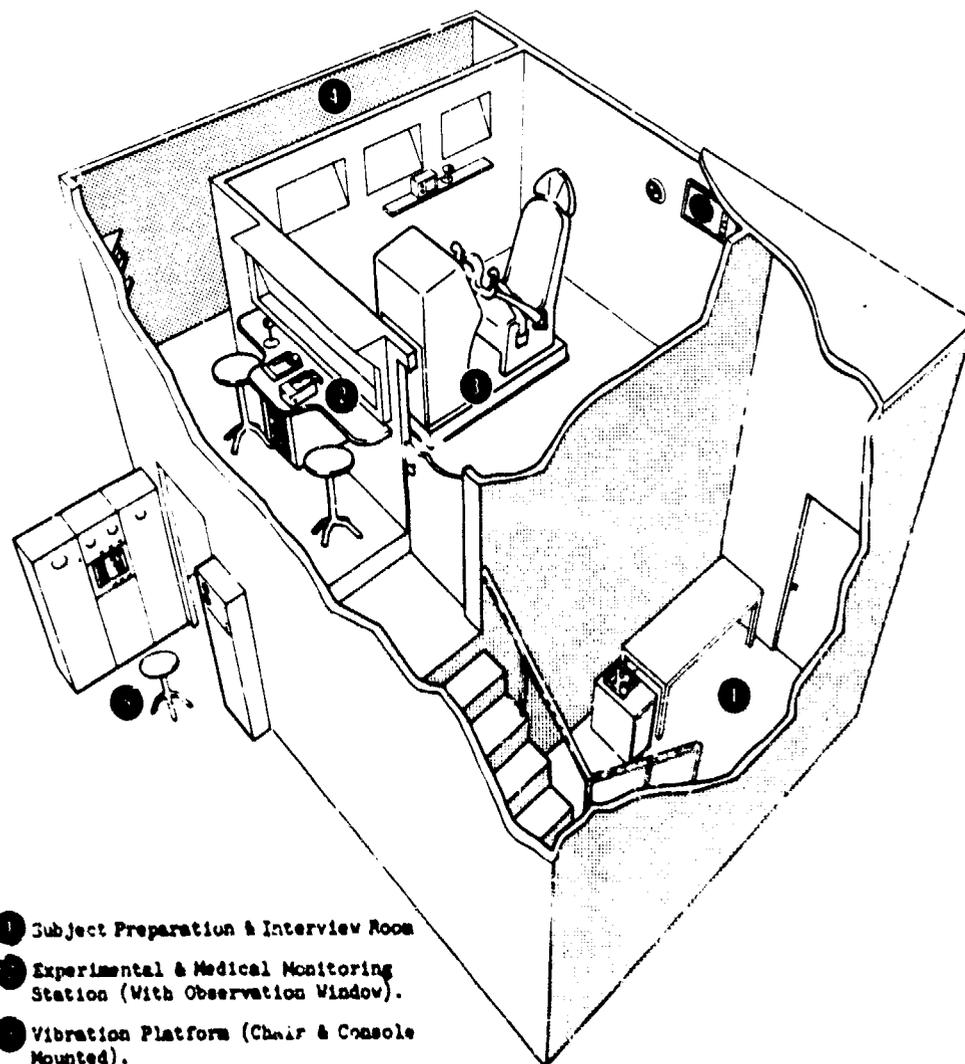
Vibration Apparatus and the Vibration Environment

The Boeing Human Vibration Facility (Figure 1) provided the vibration conditions required for these experiments. A detailed description of the facility is contained in reference 1.

The subject's general test configuration for the study is shown in Figure 2. A reinforced standard aircraft seat was used to provide vibration inputs to the subjects. To increase fidelity of vibration transmission, plywood inserts covered with 3/4 inch hard felt were used in preference to the standard survival kit, cushions and parachute pack. Subject restraint was accomplished by means of a military type lap belt. No shoulder harness was used.

A variety of controls and displays were provide for these experiments. An illustration of what was available to the subject may be seen in Figure 3. An aircraft control column and wheel were mounted in the proper control position (reference 6), and a throttle type control was provided for use by the operator's left hand. An instrument display and control panel was mounted 28 inches in front of the average subject eye position, with the display center located 10° below and perpendicular to the average line of sight. Included on the panel were:

1. Two toggle switches
2. A clock
3. Five 5-digit counter readouts
4. An airspeed indicator
5. A cathode ray tube
6. A heading indicator
7. A 360° manual task indicator
8. A large control knob
9. A small control knob
10. A horizontal control lever
11. A vertical control lever
12. A horizontal thumbwheel
13. A vertical thumbwheel
14. Jeweled indicator lights adjacent to most controls and displays



- ① Subject Preparation & Interview Room
- ② Experimental & Medical Monitoring Station (With Observation Window).
- ③ Vibration Platform (Chair & Console Mounted).
- ④ Observation Area (With 3 One-Way Viewing Windows)
- ⑤ Equipment Operator's Station (Signal Generation, Feed back, & Monitoring).

FIGURE 1. BOEING HUMAN VIBRATION FACILITY

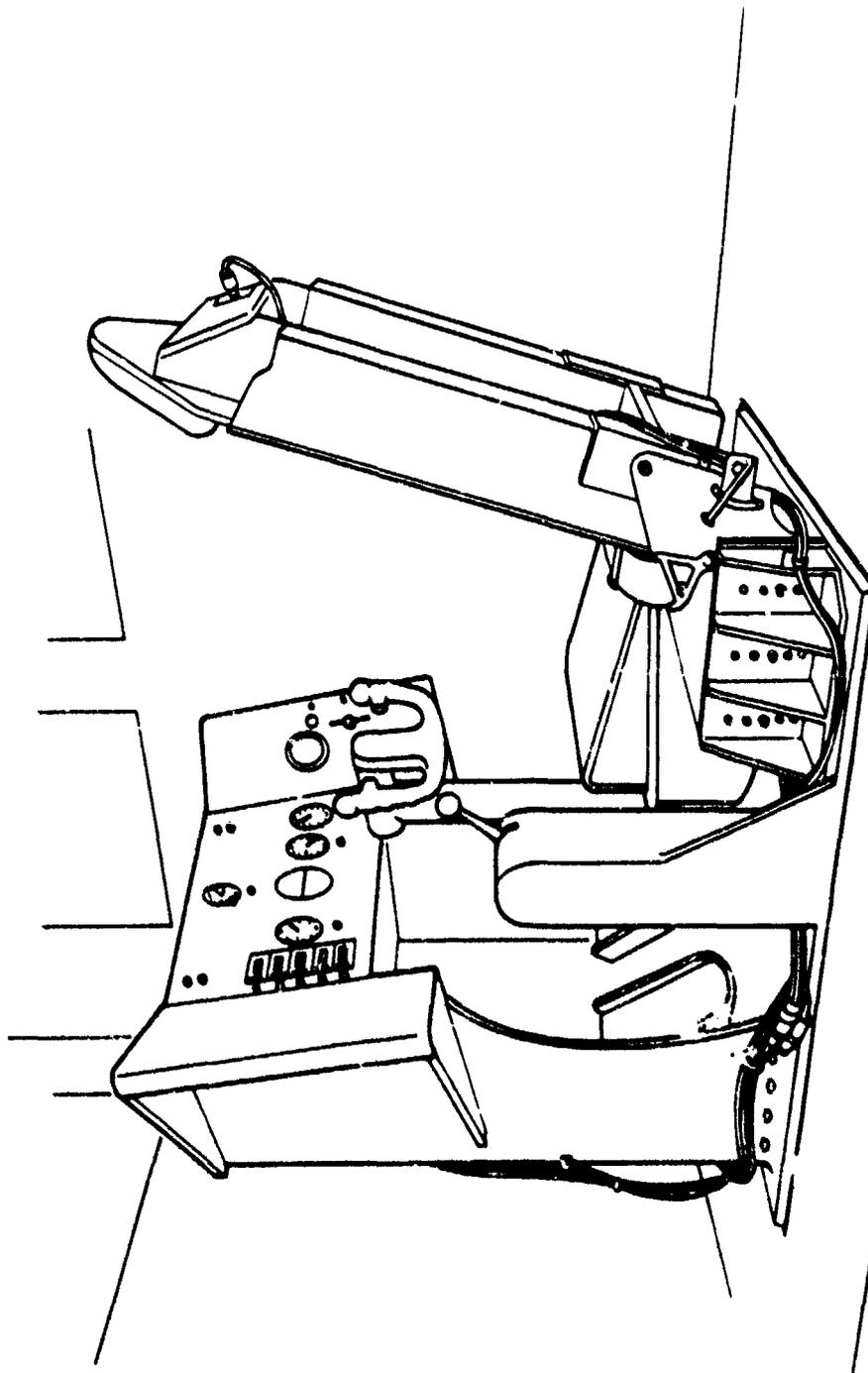


FIGURE 2. TEST STATION CONFIGURATION

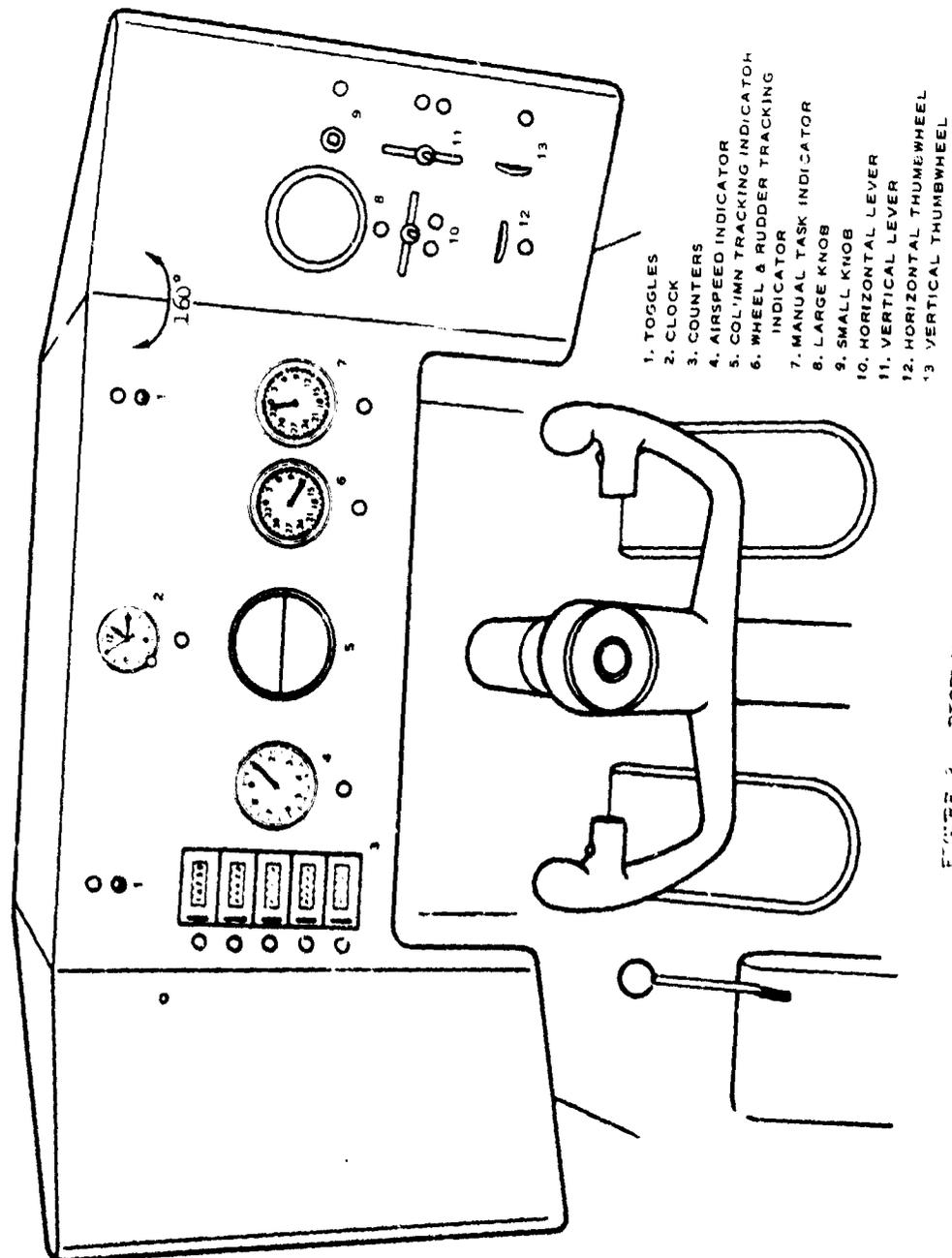


FIGURE 3. DISPLAY-CONTROL PANEL

Control Column and Wheel

The control column and wheel used for these tests were the standard heavy aircraft type and had been used in a previous program (experiment (reference 3)). The only modification made for this phase was to provide an additional cut-off switch on the back of the right handgrip similar to that on the left, so that vibration would continue when either hand was grasping the wheel. Fore and aft movement of the column was used for compensatory tracking of a projected horizontal line on the cathode ray tube (CRT), and the wheel control was utilized for compensatory tracking of the needle on a modified heading indicator located to the immediate right of the CRT.

Vertical Tracking Indicator

The centrally located CRT was a five inch display tube with a horizontal crosshair etched on the face. When being used in the tests, a projected horizontal line of light .05 inch wide was programmed to move between top and bottom of the display at a rate which varied sinusoidally. Display response to control column movement was delayed by a two second time constant to simulate "aircraft" response to control action. Control action requirements were patterned after a terrain following type display with forward movement of the column required to bring the projected light beam up to the desired position, and aft column movement required when the projected line was above the position desired. An additional feature built into the response system would drive the projected line off the CRT if the subject failed to maintain reasonable alignment control. Full 7-1/4 inches forward and full 9-1/2 inches aft column movement required 64 and 84 pounds force respectively.

Lateral Tracking Indicator

To the right of the CRT display were two standard 3 inch aircraft heading indicators with all identifying markings except graduation marks and numbers removed from the faces. Both were north oriented indicators with heading numbers located every 30° and graduation marks each 2°. The one on the left, nearest the CRT, served as the display for control wheel or "rudder" movement with the servo regulated needle programmed to move at a sinusoidally varying rate, 15° to right and left of the 360° position. Clockwise rotation of the control wheel or depression of the right foot pedal when appropriate, produced clockwise rotation of the needle with no incorporation of control feedback delay. Control wheel force ranged essentially linearly from zero to ten pounds through left or right rotation of 65°, and foot pedal force could be set at 40 pounds, 100 pounds or 150 pounds, as desired, for a maximum forward displacement of four inches with either foot. Forward movement of either pedal produced an equal and opposite movement of the alternate pedal.

Right Hand Manual Task Indicator and Controls

The heading indicator on the right of the panel served as the display for controls located on the right wing of the control-display panel. The servo driven needle was displaced in each case $1/3$ the distance of the active control at the location of applied force. Included in the controls were a large and a small knob, a horizontal and a vertical lever and a horizontal and a vertical thumbwheel. Operating force requirements at the point of application could be set at $2/3$ pound, $1-1/3$ pound or 2 pounds for each.

Knobs

The two knurled knobs were the uppermost controls of the series and were located side by side with the small knob on the right. They were $5/8$ inch thick with skirts added at the base; diameters were 3 inches and $3/8$ inch. Clockwise rotation produced a similar movement of the display.

Levers

The center controls were the levers, located side by side with the vertically moving lever to the right. Diameters of the levers were $3/8$ inch, heights were 1 inch and skirts were again provided at the base. Right and upward movement respectively produced clockwise rotation of the indicator needle.

Thumbwheels

The final controls of the series were the thumbwheels located at the lower right console position. They were $1/4$ inch wide and protruded $1/4$ inch above the panel surface which subtended a $1-1/2$ inch chord on the control. Control edges were serrated. Right movement of the horizontal control and downward movement of the vertical control were necessary to move the pointer of the indicator in a clockwise direction. The vertical control was located to the right.

Left Hand Indicators and Controls

To the left of the CRT on the display panel were five 1-digit counter readouts and an airspeed indicator. The airspeed indicator was controlled by "throttle" movement with 3 inches control movement required to produce 1 inch needle movement on the display. Forward throttle adjustment increased indicated "airspeed".

The throttle consisted of a 5-1/2 inch lever on top of an aisle stand located adjacent to the left hand side of the seat. In the rear position the tip of the lever was 16 inches forward of the subject elbow position and 24 inches from the floor. Force requirements could be set at 1/2, 5, or 10 pounds.

At the upper portion of the central display panel were two toggle switches located toward each edge, and a centrally located clock. Jeweled indicator lights adjacent to these, and all panel displays and controls except the tracking indicators, served to inform the subject of the action required in the testing sequence.

Vibration Conditions

Vibration conditions used in this phase of the study, as in the case of earlier program performance studies, were selected from four subjective reaction levels to vertical, sinusoidal vibration. These levels: definitely perceptible; mildly annoying; extremely annoying; and alarming, were established as the first phase of the program (Ref. 2). In establishing curves for the levels, 16 discrete frequencies ranging from 1 through 27 cycles per second (cps) were used. Means of individual amplitude selections at each frequency used to derive the curves were selected for use for additional testing, making 64 vibration conditions available. However, only 40 were used in these experiments. Magid and Coermann (Ref. 7) indicated decreased physical tolerance for vibration in the 4 to 8 cps frequency range. With the time required at each vibration condition for this study, it was deemed advisable in light of these findings to eliminate those frequencies from the test sequence at the extremely annoying and alarming levels to avoid the possibility of subject tissue damage. In addition, because of suspected similarities in performance of the realitively simple tasks at level 1 and with no vibration, level 1 conditions were not used for testing except in that range where levels 3 & 4 could not be used.

Table I describes the vibration conditions of the experiment in terms of double amplitude (DA) and acceleration (G). Shaded portions of the table identify conditions not tested.

TABLE I
VIBRATION CONDITIONS USED IN VISUAL-MOTOR PERFORMANCE EXPERIMENT

FREQUENCY (CPS)	1	1.5	2	3	4	5	6	8	10	12	14	16	18	20	23	27
DA **				.057	.038	.026	.017	.040								
LEVEL 1 *** G				.026	.031	.034	.032	.130								
DA 3.600	2.574	1.477	.942	.370	.172	.148	.113	.055	.082	.056	.068	.053	.019	.012		
LEVEL 2 G	.184	.296	.302	.433	.303	.220	.273	.371	.281	.604	.565	.894	.871	.711	.515	.436
DA 4.877	3.974							.103	.116	.079	.096	.068	.055	.027		
LEVEL 3 G	.249	.457						.526	.871	.796	1.260	1.132	1.129	.737	.878	
DA 5.656								.145	.155	.110	.105	.085	.074	.034	.026	
LEVEL 4 G	.289							.740	1.141	1.097	1.368	1.408	1.518	.919	.987	

SUBJECTIVE REACTION LEVELS (REFERENCE 2 FIGURE 5)

LEVEL 1 "DEFINITELY PERCEPTIBLE"

LEVEL 2 "MILDLY ANNOYING"

LEVEL 3 "EXTREMELY ANNOYING"

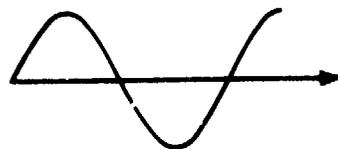
LEVEL 4 "ALARMING"

**Double Amplitude Displacement in inches

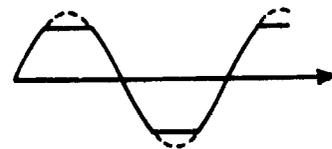
***Acceleration Force, G = .0511 F²DA

Vibration Fidelity

It had been evident that mechanical and hydraulic properties of the equipment system were introducing distortion into the sine wave output of the vibration table. An analysis of table input versus table output revealed that the distortion was due primarily to table friction. This friction was greatest at the peak of the sine waves and thus resulted in a clipping of the wave form output of the table. This is illustrated in the drawing below.



Wave Input Shape



Displacement Wave Output Shape

This distortion of the wave form resulted in significant third and fifth harmonics being generated in the output. Since the distortion source was essentially constant, it exerted a proportionately greater influence at lower amplitudes than at higher amplitudes.

Distortion also varied as a function of frequency (cps). The relationship with frequency is not a regular one since other factors, i.e. resonant frequency of the table itself and occurrence of odd and even harmonics, complicated the frequency picture.

The resulting distortion was analyzed with a describing function (see Boeing document D3-4937, reference 8) and empirically verified on the table. The functional relationship between distortion E_3 and fundamental amplitude (subjective reaction levels 1, 2, 3, and 4) is presented in Figure 4. It can be seen that in the three frequencies chosen (2 cps, 12 cps, and 27 cps) the greatest proportionate distortion occurs at subjective reaction level 1.

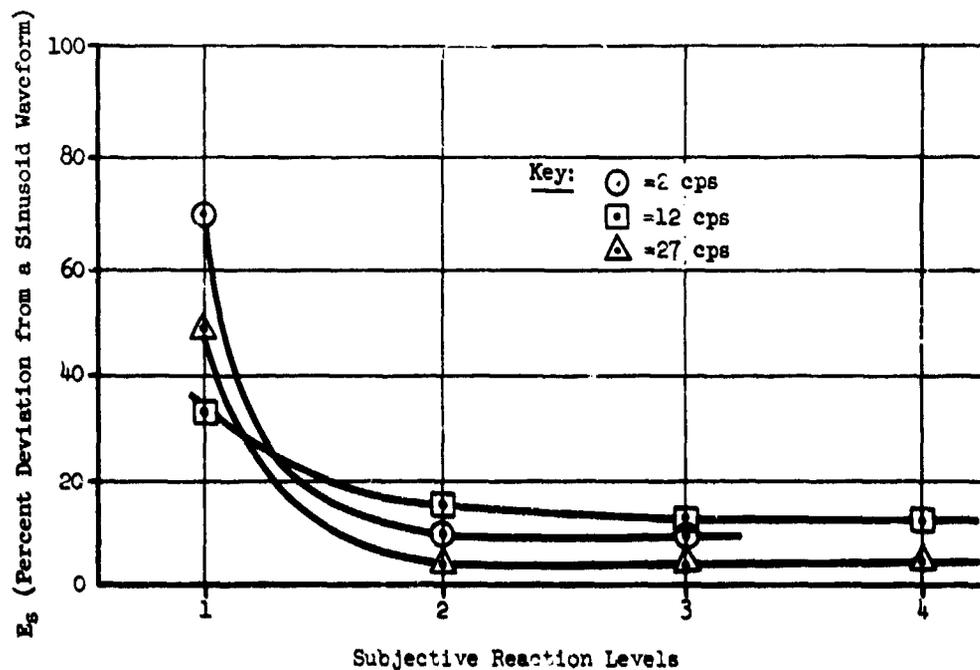


FIGURE 4. DISTORTION CURVES FOR SELECTED FREQUENCIES (AT FOUR REACTION LEVELS)

Experimental Sequence and Procedures

Test procedures for this phase of the program were very much as they had been throughout program testing. Two hours were scheduled for each test session, with individual subject sessions at least 72 hours apart. Subjects wore flight coveralls, street shoes and light gloves, and were fitted with ECG leads for medical monitoring during each test.

Prior to each session the subject was given a limited medical examination by the attending physician and a briefing on test procedures and instructions by the experimenter (Appendix A). After proceeding to the test area, the subject was situated in the test facility, ECG leads were connected to monitoring equipment and checked, and procedures were reviewed.

During initial sessions, practice runs were made until subjects had become familiar with the experiment, the apparatus and the tasks involved. If this was completed during the allotted 2 hour time period, vibration testing started. If not, the subject was released with practice continuing at the next session. Performance stabilization served as the criterion for practice completion.

At the start of each day's testing, performance data with no vibration were gathered for use as controls against which vibration data for that day could be compared. A test sequence lasted approximately eight and one half minutes with three minutes allowed between tests. Tasks for the tests were presented in random order according to one of eight pre-determined programs. An average of five test sequences were completed each session. A medical doctor monitored all vibration sessions.

SPEED, ACCURACY & CONTROL FORCE EXPERIMENT

Data Collection Procedures

The right hand manual task controls located on the right wing of the control-display panel were utilized in this portion of the program. Adjustment error to the nearest .1 degree and time requirements to the nearest .1 second were obtained for each control under the various control forces (2/3, 1-1/3, & 2 lbs.) and vibration conditions (Table 1).

Eight predetermined random programs were utilized to provide stimulus inputs to the subjects. Upon illumination of an indicator light adjacent to any of the controls, subjects, as previously instructed, utilized that control to adjust the right heading indicator to the 350° position. Deviations 10, 20 or 30° to either right or left of the command position were utilized in random order, with three time and error measurements taken for each control at each of the force and vibration conditions. Seven seconds were available in which to make each setting.

Data Analysis

The conditions of the experiment involved variations in the type of control being utilized, control force requirements, vibration severity (subjective reaction levels), and vibration frequency, all of which varied simultaneously in repeated observations of six subjects. Two dependent variables (error & time scores) were sampled under each condition.

Four dimensional analyses of variance (ANOV) were utilized in the analysis procedures. It will be recalled that certain frequencies were omitted from the experiment at the "extremely annoying" and "alarming" levels to avoid the possibility of bodily harm to subjects. Thus, two analyses of each type desired were required to cover the whole range of vibration conditions used. Analysis I of each type involved 9 frequencies (1, 10, 12, 14, 16, 18, 20, 23, & 27 cps) at 3 subjective reaction levels (2, 3, & 4). Analysis II, in each case, was concerned with 5 frequencies (3, 4, 5, 6, & 8 cps) at 2 levels (1 & 2). The vibration conditions used in each of the analyses are shown respectively in Tables II and III.

Initially, analyses utilizing time and error scores obtained under the median control force (1-1/3 lb.) were performed with subjective reaction levels (A), control type (B), vibration frequency (C) and subjects (D) making up the four dimensions. (Subjects emerge as a dimension because of repeated measurements on each of the other dimensions.) Thus a "3 x 6 x 9 x 6" and a "2 x 6 x 5 x 6" factorial each for time and error scores were required. Also, in order to ferret out differences in the results due to vibration from those inherent in the controls themselves,

TABLE II
THE 9 VIBRATION FREQUENCY AND 3 REACTION LEVEL CONDITIONS USED IN
ANALYSES OF VARIANCE I

	1	1.5	2	3	4	5	6	8	10	12	14	16	18	20	23	27
DA																
LEVEL 1																
G																
DA	3.600								.055	.082	.056	.068	.053	.035	.019	.012
LEVEL 2																
G	.184								.281	.604	.565	.894	.871	.711	.515	.436
DA	4.877								.103	.118	.079	.096	.068	.055	.027	.024
LEVEL 3																
G	.249								.526	.871	.796	1.260	1.132	1.129	.737	.878
DA	5.656								.145	.155	.110	.105	.085	.074	.034	.026
LEVEL 4																
G	.289								.740	1.141	1.097	1.368	1.408	1.518	.919	.987

TABLE III
THE 5 VIBRATION FREQUENCY AND 2 REACTION LEVEL CONDITIONS USED IN ANALYSES OF VARIANCE II

	1	1.5	2	3	4	5	6	8	10	12	14	16	18	20	23	27
LEVEL 1				.057	.038	.026	.017	.040								
DA																
G				.026	.031	.034	.032	.130								
LEVEL 2																
DA				.942	.370	.172	.148	.113								
G				.433	.303	.220	.273	.371								
LEVEL 3																
DA																
G																
LEVEL 4																
DA																
G																

and those due to normal day-to-day fluctuations, each of the analyses were performed using scores obtained under vibration, and difference scores between vibration and the no-vibration condition performances for a given test sequence.

To determine the effects of control forces on the accuracy and speed of the various assigned tasks, additional analyses with levels, required control forces, frequencies, and subjects serving as the dimensions were performed for each of the six controls. As before, two analyses ("3 x 3 x 9 x 6" and "2 x 3 x 5 x 6" factorials) were required to cover the vibration conditions used and both vibration and difference scores were analyzed. Again, time and error scores served as the dependent variables.

Results and Interpretation

Significance columns from each of the eight ANOV summary tables used in the speed and accuracy analyses are shown in Table IV. Since each of the analyses is intended to clarify an individual portion of the same problem, a composite approach to both data presentation and discussion is utilized in this report. Individual analysis summary tables are included in Appendix B, Pages 40 - 43.

As may be seen from Table 4, the only significant main effect in any of the analyses, other than the variations in scores between subjects, is that concerned with the differences in time required to adjust the various controls under the vibration condition. Also, because of the lack of a significant difference in the time to adjust the controls when analyzed using difference scores, an adjustment time difference under the non-vibration condition is a logical conclusion. Plots of the main effects of the analysis under both the vibrating and the non-vibrating conditions are shown in Figure 5. This also contains the most significant of the differences between subjects.

As is evident in the Figure, the small knob is adjusted most quickly under vibration, with the large knob and the horizontally mounted lever and thumbwheel approximately equal in second place and the vertically mounted controls requiring the most time. Also, as indicated by the analyses, this pattern remains much the same under the no-vibration condition, with a small increase in time produced on all controls except one with the addition of vibration.

It should be pointed out, that although the differences between adjustment times utilizing the various controls proved significant in this analysis, the real differences in terms of adjustment time are in all cases less than .3 second, or less than 10% of the total. With equal error production between controls, it is felt that this difference is of minor significance from a practical design standpoint, and should be given consideration only if and when other human factor considerations have been optimized.

TABLE IV
INDICES OF SIGNIFICANCE ON SPEED AND ACCURACY ANALYSES

ANALYSIS	ERROR SCORES				TIME SCORES			
	VIB. SCORES		DIFF. SCORES		VIB. SCORES		DIFF. SCORES	
	I	II	I	II	I	II	I	II
A (LEVELS)								
B (CONTROLS)					*			
C (FREQUENCIES)								
P (SUBJECTS)		*	**		***	*		
AB								
AC								**
AP				**		***		**
BC								
BP			**		***	*	**	
CP	***		***		***		**	*
ABC								
ABP		*						
ACP	***	***	***	***	***	***		
BCP								
ABCP								

ANALYSIS I 9 FREQUENCIES AT 3 LEVELS
 ANALYSIS II 5 FREQUENCIES AT 2 LEVELS
 * $p < .05$
 ** $p < .01$
 *** $p < .001$

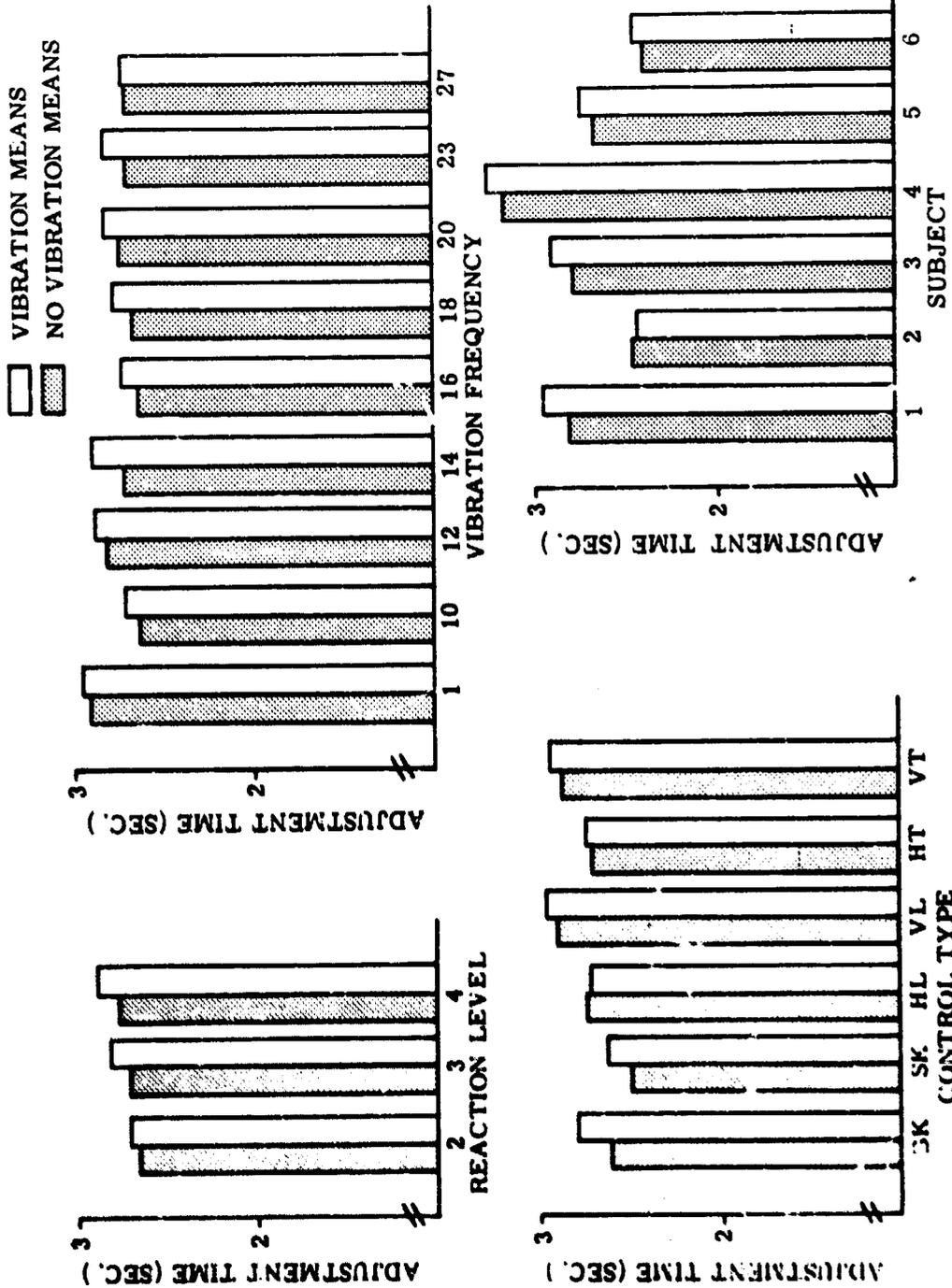


FIGURE 5
 TIME SCORE MAIN EFFECTS, ANALYSIS I
 (3 LEVELS X 6 CONTROLS X 9 FREQUENCIES X 6 SUBJECTS)

Also apparent from Figure 5, is evidence of the fact that subjects were the major source of variation in the experiment. With the degrees of freedom involved in the repeated design, little is to be gained by an attempt to interpret the numerous higher order interactions of subjects with the other variables, and no such attempt has been made.

Results of the control force analyses are shown in Tables V, VI, VII, and VIII. Tables V and VII respectively show the results of analyses performed on error and time scores obtained under vibration; VI and VIII show results of similar analyses performed on the differences between scores obtained under the vibration and no-vibration conditions. Individual ANOV summary sheets are included in Appendix B, pages 44 - 67.

As may be seen in Tables V and VI, differences in error scores due to variations in control force are significant only for the horizontal lever under vibration, and for the large knob when using vibration-no-vibration difference scores (significant main effects B). In addition, the difference scores for the large knob vary not only as a function of the control force required, but these differences vary significantly between subjects (BP interaction). Plots of the mean scores obtained under the two conditions using each control are shown in Figure 6.

Again, although there are two items of significance present, Figure 6 clearly shows that no control or control force is markedly different in its effect on control error than its counterparts, with only a slight overall decrease in error under the vibration condition when utilizing the median control force (1-1/3 lb). There is however, a consistent increase in error production in all cases when encountering vibration. Further, the significance tables indicate that these composite effects are generally independent of the frequency or level of vibration present in this experiment although apparently random differential effects occur between subjects.

Utilizing the median control force where errors are minimal, vibration produced an average error increase of 25% over all controls. In the experimental task employed to obtain these data, this difference means an error increase of slightly over .1 degree. From a design standpoint, the critical accuracies of the various tasks to be performed in a vibrating environment would need to be considered prior to a decision on the practical significance of such a difference. It is entirely feasible that situations could exist where a 25% error increase even in terms of .1 degree, could mean the difference between mission success or failure, and of course, situations also could occur where it would make no difference whatsoever. These are conditions which must be considered by the design engineer specific to a particular design situation.

TABLE V
 INDICES OF SIGNIFICANCE ON CONTROL FORCE ANALYSIS
 VIBRATION ERROR SCORES

	LARGE KNOB	SMALL KNOB	HORIZ. LEVER	VERT. LEVER	HORIZ. THUMBWHEEL	VERT. THUMBWHEEL	LARGE KNOB	SMALL KNOB	HORIZ. LEVER	VERT. LEVER	HORIZ. THUMBWHEEL	VERT. THUMBWHEEL
A (LEVELS)												
B (FORCES)			*									
C (FREQUENCIES)												
P (SUBJECTS)												
AB												
AC	*											
AP							**	*				
BC												
BP												
CP	***	***	***	***	***	***						
ABC												
ABP								*				
ACP	***	***	***	***	***	***	**	***	***	***	***	***
BCP								*		*		
ABCP												

9 FREQUENCIES, 3 LEVELS 5 FREQUENCIES, 2 LEVELS

* p < .05
 ** p < .01
 *** p < .001

TABLE VI
INDICES OF SIGNIFICANCE ON CONTROL FORCE ANALYSIS
ERROR DIFFERENCE SCORES

	LARGE KNOB	SMALL KNOB	HORIZ. LEVER	VERT. LEVER	HORIZ. THUMBWHEEL	VERT. THUMBWHEEL	LARGE KNOB	SMALL KNOB	HORIZ. LEVER	VERT. LEVER	HORIZ. THUMBWHEEL	VERT. THUMBWHEEL
A (LEVELS)												
B (FORCES)	*											
C (FREQUENCIES)						*				*		
P (SUBJECTS)	**	**	*	*		***	*					
AB												
AC												
AP								***	**	*	**	**
BC												
BP	*		*				**					
CP	***	***	***	***	**							
ABC												
ABP			*					*				
ACP	***	***	***	***	*	***	**	***	*	***	***	***
BCP								*		*		
ABCP												

9 FREQUENCIES, 3 LEVELS 5 FREQUENCIES, 2 LEVELS

* p < .05
** p < .01
*** p < .001

TABLE VII
INDICES OF SIGNIFICANCE ON CONTROL FORCE ANALYSIS
VIBRATION TIME SCORES

	LARGE KNOB	SMALL KNOB	HORIZ. LEVER	VERT. LEVER	HORIZ. THUMBWHEEL	VERT. THUMBWHEEL	LARGE KNOB	SMALL KNOB	HORIZ. LEVER	VERT. LEVER	HORIZ. THUMBWHEEL	VERT. THUMBWHEEL
A (LEVELS)												
B (FORCES)	**	**	*	***	**	**					**	
C (FREQUENCIES)						**						
P (SUBJECTS)	***	***	***	***	***	***	**		*		**	*
AB							*					
AC												**
AP							*		*			*
BC								**				
BP												
CP	**	***	***	***	***							
ABC	*	*			*							**
ABP		*										
ACP	***	***	***	***	***	***	***		*		*	**
BCP					*		*					
ABCP												

9 FREQUENCIES, 3 LEVELS * 5 FREQUENCIES, 2 LEVELS **

* p < .05
 ** p < .01
 *** p < .001

* p < .05
 ** p < .01

TABLE VIII
INDICES OF SIGNIFICANCE ON CONTROL FORCE ANALYSIS
TIME DIFFERENCE SCORES

	LARGE KNOB	SMALL KNOB	HORIZ. LEVER	VERT. LEVER	HORIZ. THUMBWHEEL	VERT. THUMBWHEEL	LARGE KNOB	SMALL KNOB	HORIZ. LEVER	VERT. LEVER	HORIZ. THUMBWHEEL	VERT. THUMBWHEEL
A (LEVELS)												
B (FORCES)		*				*						
C (FREQUENCIES)												
P (SUBJECTS)	*		*			*					*	
AB							**					
AC												*
AP				*				**		**		*
BC								**				
BP			*	***	**	**	**					
CP	*	**	*		***							
ABC		*			**							**
ABP												
ACP	*	*				*	*					
BCP							*					
ABCP												

9 FREQUENCIES, 3 LEVELS * 5 FREQUENCIES, 2 LEVELS **

* p < .05
** p < .01
*** p < .001

□ VIBRATION MEANS
▨ NO VIBRATION MEANS

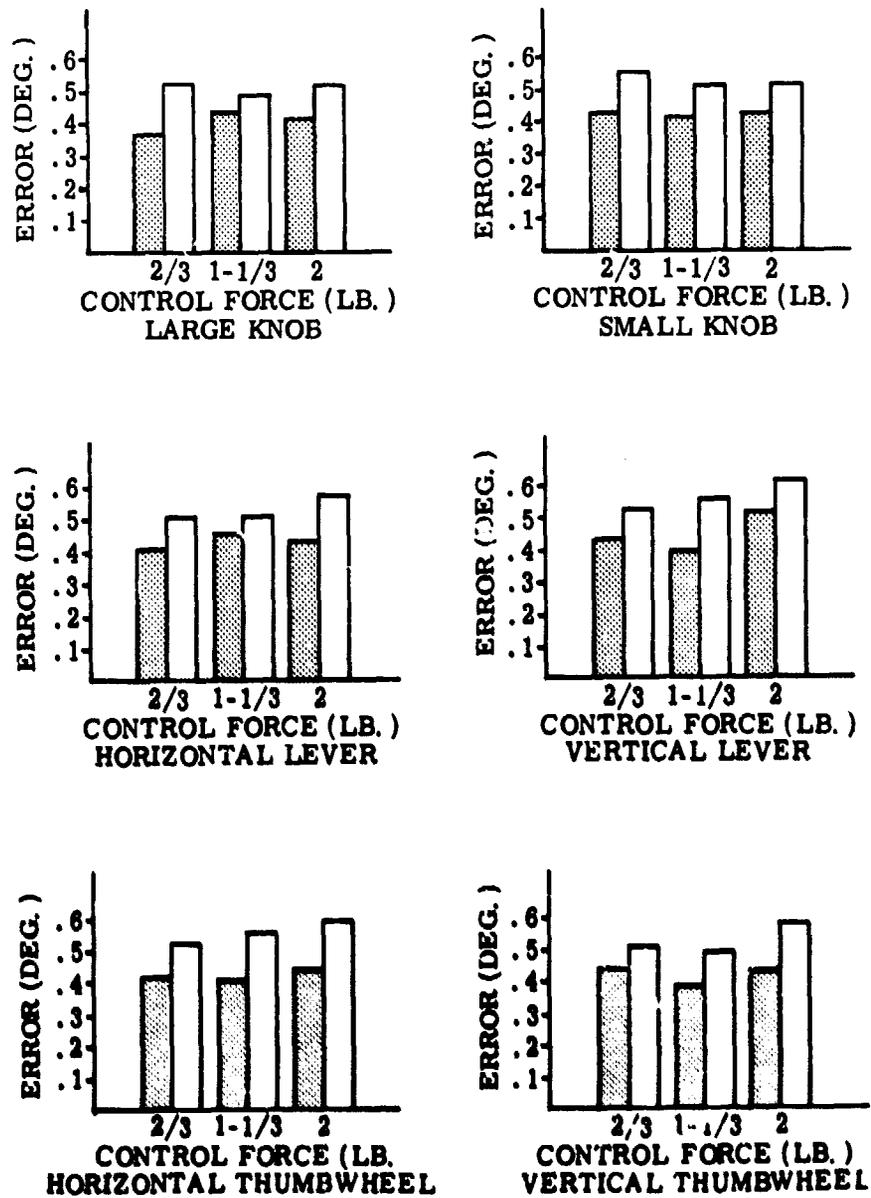


FIGURE 6
MEAN ERROR SCORES, CONTROL VERSUS REQUIRED FORCE

Tables VII and VIII show that the times necessary to adjust all controls vary as a function of the control force required, and that, in the case of the small knob and vertical thumbwheel, the differences in time between the vibration and no-vibration conditions also vary.

Times required for adjustment of each control with each of the required control forces under the vibration and no-vibration conditions are shown in Figure 7.

Several things are evident from an inspection of the figure. Initially it can be seen that little difference exists between adjustment times of the two knobs, while the lever and thumbwheel mounted in the plane of vibration take considerably longer to adjust than their counterparts mounted perpendicular to the vibration. Secondly, as would be predicted and as was noted in the previous analysis, adjustment time in nearly every case increases with the addition of vibration to the environment. And finally, adjustment times for each control are nearly equal between the first two required control force values ($2/3$ & $1-1/3$ lbs.) with a notable increase produced by the third. Thus, from a design standpoint, adjustment time can be expected to increase if vibration is to be encountered in the operational environment; controls should be mounted perpendicular to the expected plane of vibration; and less than 2 pounds control force at the point of application should be used if controls similar to those employed in this experiment are to be used.

□ VIBRATION MEANS
▨ NO VIBRATION MEANS

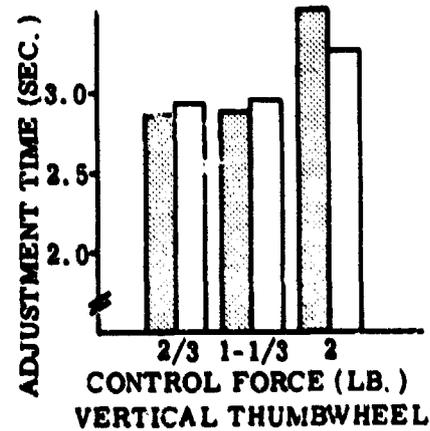
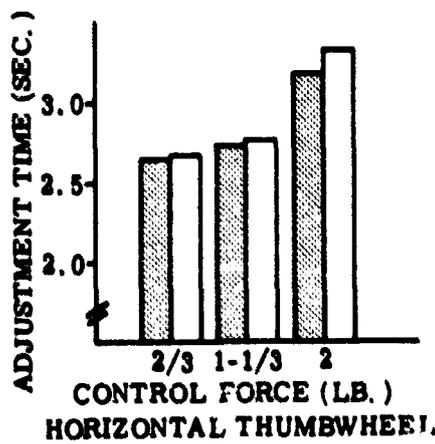
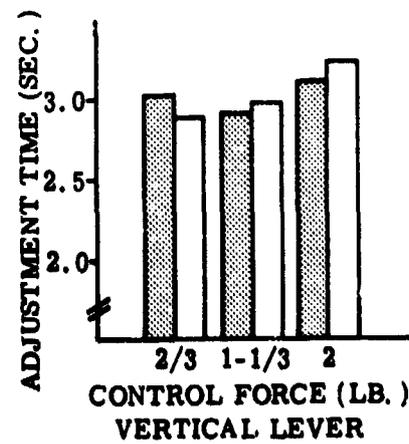
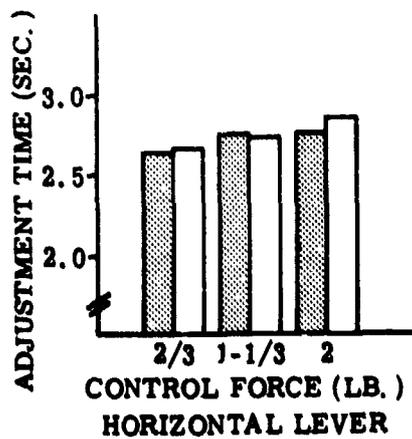
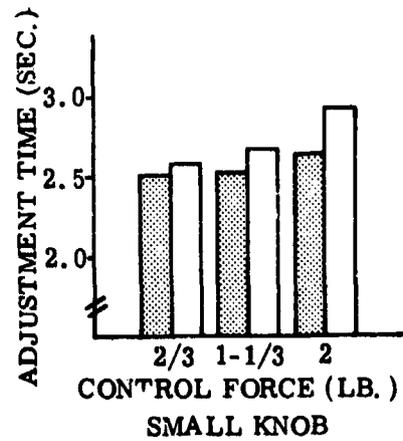
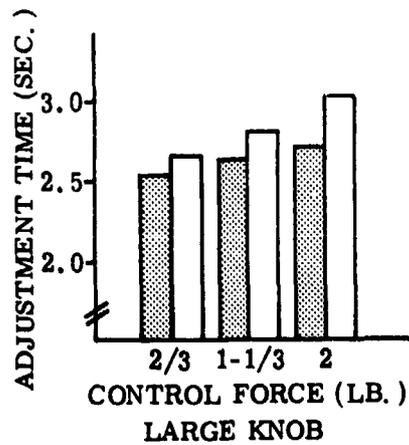


FIGURE 7
MEAN ADJUSTMENT TIMES, CONTROL VERSUS REQUIRED FORCE

INCREASED WORK LOAD EXPERIMENT

Data Collection Procedures

All controls and displays available to the subjects except the rudder pedals were utilized in this portion of the program. The right hand manual task controls again served as the controls from which the dependent variables (error and time) were recorded for analysis purposes. However, only the 1-1/3 pound control force requirement was used, with 4 readings of error and time on each control utilized for each test run.

In addition to the knob, lever, and thumbwheel settings, subjects were required to accomplish a number of increased work load tasks consisting of the following items:

- A. Continuous compensatory tracking of "pitch" and "heading" utilizing the wheel and column to center the heading indicator and the projected line on the panel CRT.
- B. Verbal reports of 4 readings each of the five five-digit counters.
- C. Four adjustments of "airspeed" utilizing the "throttle".
- D. Three actuations each of the two toggle switches.
- E. Four verbal reports of the clock indication to the nearest minute.

Although subjects were not notified of the fact, these additional tasks served only to increase operator work load, and data were not recorded.

As in the previous experiment, eight predetermined random programs were utilized to provide the stimulus inputs for the discrete tasks to the subjects. Illumination of an indicator light adjacent to the display or control cued the subject to the appropriate task, with time limitations the same as before.

Vibration conditions for this portion of the program were selected to representatively sample those used in the speed, accuracy, and control force experiment, and are shown in Table IX. With the lack of a consistent difference in results due to frequency in the previous experiment, deletion of approximately one-half the vibration conditions to achieve a comparable reduction in test time seemed appropriate.

Data Analysis

Error and time scores obtained under the increased work load situation were to be compared with similar scores obtained during the previous tests. Thus, repeated measurements for all subjects were obtained for each control

TABLE IX
THE 5 VIBRATION FREQUENCY AND 3 REACTION LEVEL CONDITIONS USED IN THE
INCREASED WORK LOAD ANALYSIS

	1	1.5	2	3	4	5	6	8	10	12	14	16	18	20	23	27
LEVEL 1	DA															
	G															
LEVEL 2	DA	3.600							.055	.056	.053					.012
	G	.184							.281	.569	.871					.436
LEVEL 3	DA	4.877							.103	.079	.068					.024
	G	.249							.526	.796	1.132					.878
LEVEL 4	DA	5.656							.145	.110	.085					.026
	G	.289							.740	1.097	1.408					.987

under conditions which varied simultaneously between operator work load, vibration frequency, and vibration severity. These data were again cast into four dimensional ANOV's for each control. Vibration scores and the difference between vibration and no vibration scores for both control accuracy and adjustment time served as the respective dependent variables.

Results and Interpretation

As in previous sections of the report, results of this experiment are treated and discussed as a unit. Significance columns from each of the analyses performed are shown in Tables X and XI. Table X shows results of tests on adjustment error. Table XI shows results of similar tests on adjustment times.

From Table X, the effect of different work loads on the accuracy of the operator are seen to be highly significant for all controls, (main effect B) and this is the only consistent effect present. However, these effects do vary on the knobs and horizontal thumbwheel as a function of the subject involved. Also, as a conclusion from the lack of significance values when utilizing difference scores, the differences are seen to exist in both the vibration and no vibration conditions. Figure 8 illustrates these relationships for each of the controls.

Table XI shows a similar variance in adjustment time between the two work load situations, both in the vibration and no vibration conditions. Also present, however, is a consistent difference in time requirements between subjects, as was the case in the previous experiment. Plots of mean adjustment times for each of the controls and work situations are shown in Figure 9.

Immediately apparent from inspection of the Figures is the degrading effect a work overload has on operator performance. Adjustment error is approximately tripled, and the time required for adjustment is approximately doubled between the two conditions of this experiment. Also evident is the fact that the effect is independent of the vibration conditions, on both variables.

A composite look at the results of this portion of the vibration program indicates that operator work load is singularly the most important item to which consideration should be given in the design of manned systems. Although under moderate work load conditions, the vibration and control force situations considered in the program are seen to affect operator performance to some degree, these effects are completely overbalanced by the degradation produced in a high work load condition. Thus, it appears that the operator, although a good environment and control design facilitate his performance, can within the limits of these experiments, adjust to less than optimum control conditions if alternate demands do not compromise his attention to the assigned task.

TABLE X
INDICES OF SIGNIFICANCE ON INCREASED WORK LOAD ANALYSIS
ERROR SCORES

	LARGE KNOB	SMALL KNOB	HORIZ. LEVER	VERT. LEVER	HORIZ. THUMBWHEEL	VERT. THUMBWHEEL	LARGE KNOB	SMALL KNOB	HORIZ. LEVER	VERT. LEVER	HORIZ. THUMBWHEEL	VERT. THUMBWHEEL
A (LEVELS)						*						
B (WORK LOAD)	**	**	***	**	**	**						
C (FREQUENCIES)							**					
P (SUBJECTS)												
AB												
AC												
AP												
BC												
BP	*	*			*		*	*		*		
CP												
ABC							*					
ABP												
ACP												
BCP												
ABCP												

* p < .05
 ** p < .01
 *** p < .001

VIBRATION SCORES

DIFFERENCE SCORES

TABLE XI
INDICES OF SIGNIFICANCE ON INCREASED WORK LOAD ANALYSIS
TIME SCORES

	LARGE KNOB	SMALL KNOB	HORIZ. LEVER	VERT. LEVER	HORIZ. THUMBWHEEL	VERT. THUMBWHEEL	LARGE KNOB	SMALL KNOB	HORIZ. LEVER	VERT. LEVER	HORIZ. THUMBWHEEL	VERT. THUMBWHEEL
A (LEVELS)												
B (WORK LOAD)	**	**	***	***	**	***						
C (FREQUENCIES)									*			
P (SUBJECTS)	***	***	***	***	***	***	*			*	**	
AB												
AC												
AP												
BC												
BP	***	***	*	*		*			*			**
CP			*									
ABC											**	
ABP												
ACP												
BCP											*	
ABCP												

VIBRATION SCORES

DIFFERENCE SCORES

* p < .05
 ** p < .01
 *** p < .001

□ VIBRATION MEANS
 ■ NO VIBRATION MEANS

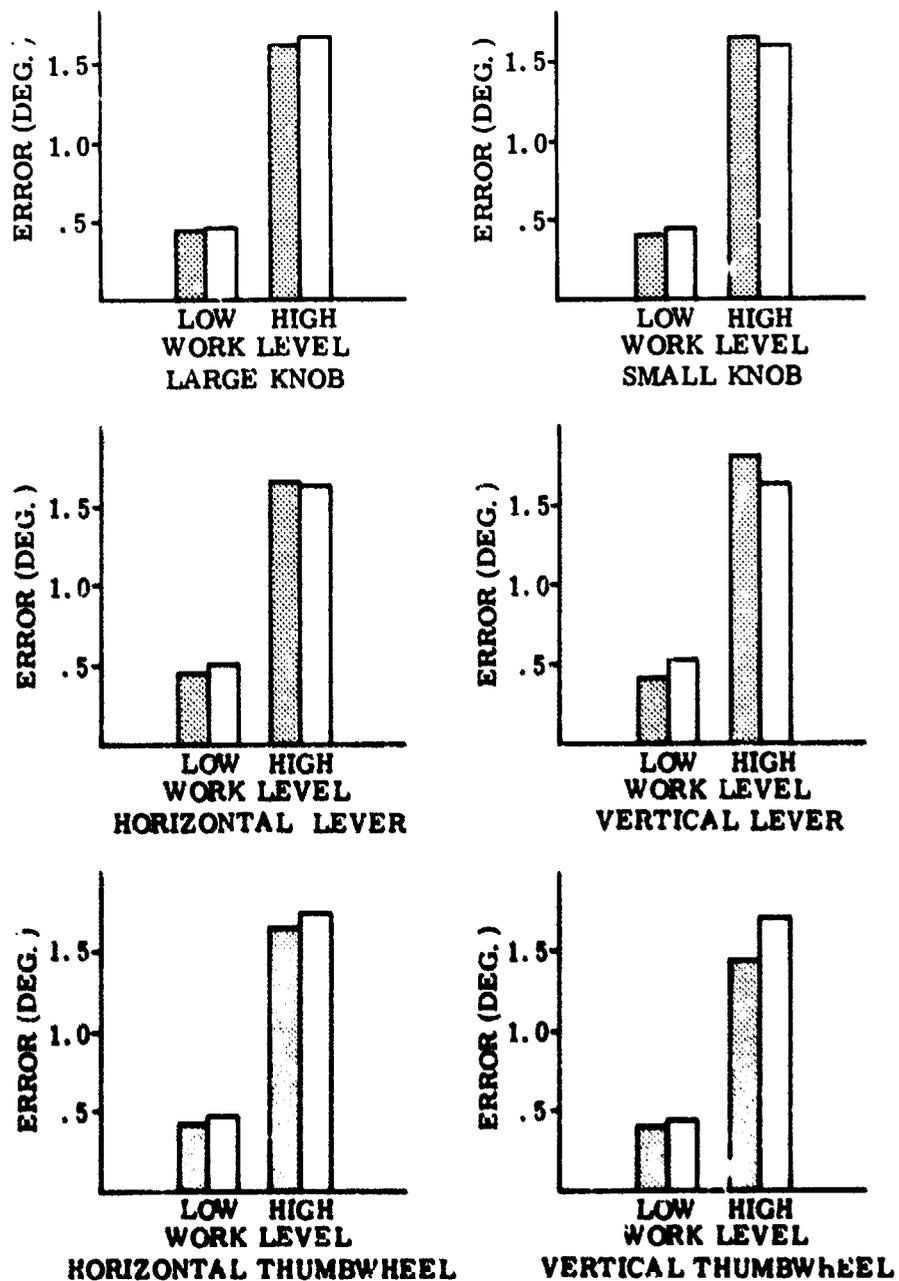


FIGURE 8
MEAN ERROR SCORES, CONTROL VERSUS OPERATOR WORK LEVEL

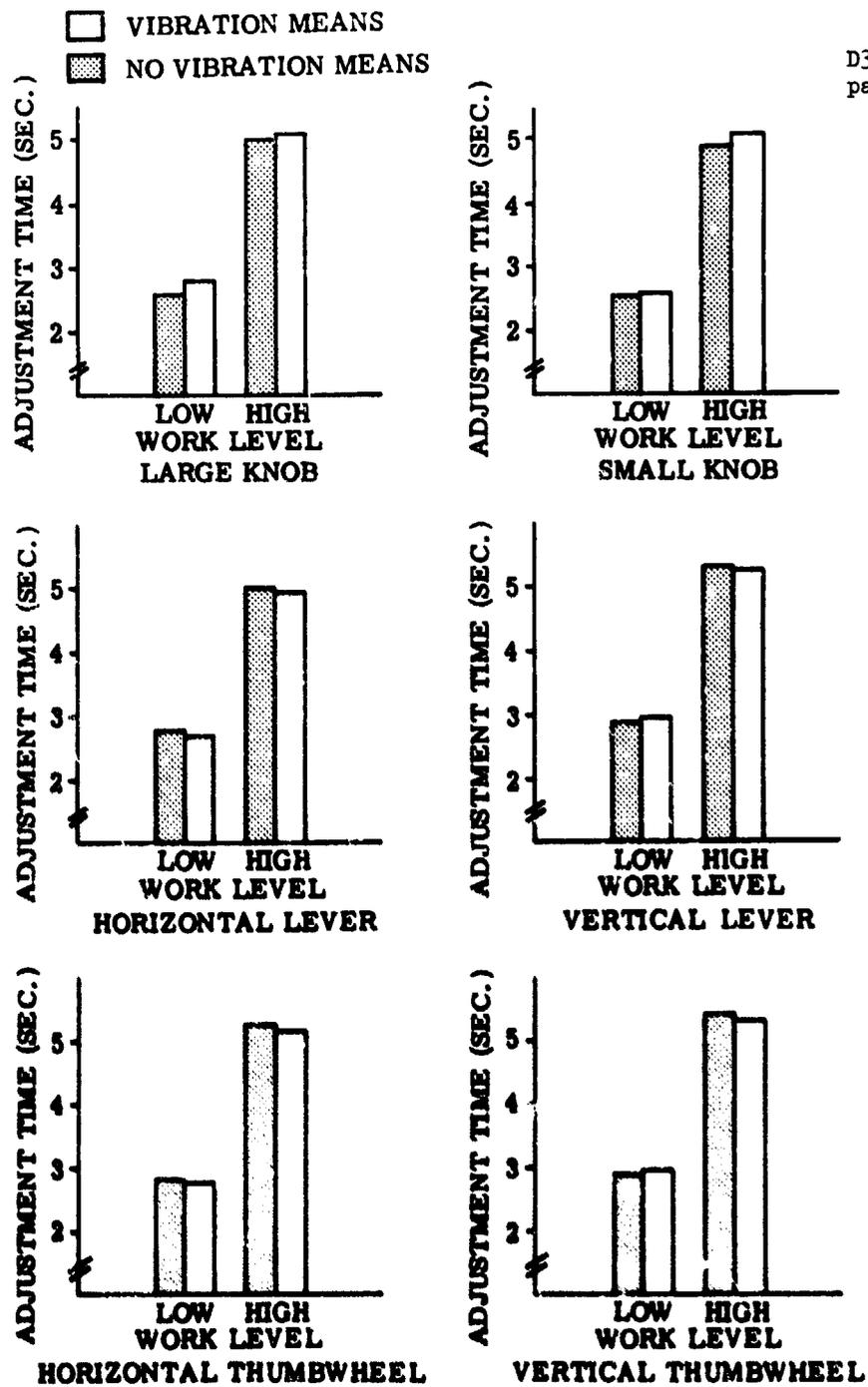


FIGURE 9
MEAN ADJUSTMENT TIMES, CONTROL VERSUS OPERATOR WORK LEVEL

SUMMARY AND CONCLUSIONS

Seven subjects participated in two experiments to determine the effects of vibration, control force, and work load on the speed and accuracy of visual-motor performance utilizing various types and sizes of controls. Several conclusions can be drawn from the results of these experiments.

1. Comparisons between controls used in the experiments show no significant differences in the accuracy of accomplishing the assigned task.
2. The times required to accomplish the assigned task vary significantly between controls, with the controls which moved vertically requiring the most time.
3. In a moderate work load condition, the addition of vibration to the operational environment produces increases in both adjustment error and time at all of the intensities and frequencies of vibration encountered in this study. However, the vibration environment decreases in relative significance as the operator work level approaches an overload condition.
4. Control forces of 2 pounds produce slight increases in error and significant increases in adjustment time over those produced by the lower control forces.
5. High work load conditions nearly double the time and triple the error of adjustments made by the operator with the controls used in these experiments.

Although the data generated in these experiments provide some insight into the effects of vibration on the accomplishment of visual-motor tasks, they are, as expected, quite limited in scope. Similar investigations are needed on other tasks typical of jobs commonly performed in a vibration environment such as tracking, and more detailed research with tighter control is required to completely cover the areas reported in this study. Based on these data, additional effort in the visual-motor area should first be directed toward a better understanding of the manner in which vibration interacts with varying degrees of operator work load. We have seen that with a moderate work load, vibration has a serious effect on performance, and that with a very high work assignment, vibration makes little difference. Knowledge of what happens between these conditions, and where within the range it happens, would greatly enhance our understanding of human capabilities in a vibration environment.

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APPENDIX A

Subject Descriptions and Instructions

Subject Descriptions

<u>Subject</u>	<u>Age</u>	<u>Height</u>	<u>Weight</u>
1.	41	72	225
2.	40	72	180
3.	34	71	190
4.	44	68	160
5.	41	67	175
6.	43	67	170
7.	45	67	160

SPEED, ACCURACY, AND CONTROL FORCE EXPERIMENT INSTRUCTIONS

This experiment is designed to study vibration effects on linear and rotary control adjustments. The test requirements are to set the pointer on the right panel indicator by adjusting a knob, lever, or thumbwheel control located on the right wing of the display-panel.

Use natural hand and arm movements to regulate the controls for an indicator setting of 350°. Rightward, clockwise or upward movement of all controls but one will move the needle clockwise. The vertically oriented thumbwheel reverses the order, a downward movement causes clockwise pointer movement. An amber caution light located by each will identify the control to be adjusted. The sequence of presentations will be random. Time and accuracy for each task will be recorded, with settings to be scored to 0.1° and 0.1 second.

Since vibration is expected to affect capability to perform some of these tasks and to have no effect on others, it is very important that any performance change be related to vibration only. For this reason, you are asked to avoid discussing details of tasks, procedures, and related details for any of the remaining tests with anyone but the experimenter. This is particularly important since even slight changes in your method of operation can be reflected in data changes. Since these would not be related to task or vibration changes and cannot be readily determined, the cause of change could become extremely difficult to analyze, at best.

INCREASED WORK LOAD EXPERIMENT INSTRUCTIONS

This test is designed to study effects of vibration on performance in a complex task. The additional tasks required involve readout of counters; time readout; operation of a throttle-type lever to control a dial pointer; depressing toggle switches, keeping a moving CRT displayed line aligned with a fixed line by control column fore and aft movement and keeping a moving pointer aligned with a fixed scale mark by control wheel rotary movement.

The procedures for operation will be the same as in prior tests. Verbal readouts are required for counter presentations and time indicated on the clock in response to the appropriate caution light. Toggles, knobs, levers and thumbwheels will be operated in response to caution light signals, and moving CRT and pointer alignment will be required as a continuous operation. The control display feedback for the vertically moving display and column arrangement is delayed. The moving pointer response to control wheel rotation will not feature any delay.

Release of both hands from the control wheel will immediately stop vibration and this is your prerogative if you feel the vibration levels unacceptable.

Are there any questions?

APPENDIX B

INDIVIDUAL ANALYSIS OF VARIANCE SUMMARY TABLES

TABLE XII SPEED AND ACCURACY
ANALYSES, VIBRATION ERROR SCORES

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	2.509	2	1.254	1.953
B (controls)	.696	5	.139	2.317
C (frequencies)	3.490	8	.436	< 1
P (subjects)	3.229	5	.646	< 1
AB	.124	10	.012	< 1
AC	9.368	16	.604	1.678
AP	3.975	10	.398	1.106
BC	1.423	40	.036	< 1
BP	1.735	25	.069	1.533
CP	26.544	40	.664	15.810***
ABC	3.379	80	.042	1.000
ABP	2.174	50	.043	1.024
ACP	28.790	80	.360	8.571***
BCP	9.022	200	.045	1.071
ABCP	16.981	400	.042	

ANALYSIS I

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.035	1	.035	< 1
B (controls)	.451	5	.090	90.00
C (frequencies)	.338	4	.084	2.049
F (subjects)	2.037	5	.407	6.075*
AB	.128	5	.026	< 1
AC	.090	4	.022	< 1
AP	.333	5	.067	1.970
BC	.885	20	.044	< 1
BP	.997	25	.040	< 1
CP	5.501	20	.275	1.074
ABC	.909	20	.045	1.324
ABP	1.618	25	.065	1.912*
ACP	5.122	20	.256	7.529***
BCP	4.075	100	.041	1.276
ABCP	3.442	100	.034	

ANALYSIS II

TABLE XIII SPEED AND ACCURACY
ANALYSES, ERROR DIFFERENCE SCORES

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.825	2	.412	1.648
B (controls)	1.510	5	.302	2.221
C (frequencies)	2.624	8	.328	< 1
P (subjects)	7.200	5	1.440	4.286**
AB	.555	10	.056	< 1
AC	5.453	16	.340	1.156
AP	2.037	10	.204	< 1
BC	2.185	40	.055	< 1
BP	3.589	25	.144	2.286**
CP	13.442	40	.336	5.333***
ABC	5.597	80	.070	1.111
ABP	3.998	50	.080	1.270
ACP	23.519	80	.294	4.667***
BCP	12.610	200	.063	1.000
ABCP	25.142	400	.063	

ANALYSIS I

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.256	1	.256	1.032
B (controls)	.791	5	.158	2.026
C (frequencies)	.296	4	.074	< 1
P (subjects)	4.137	5	.827	3.335
AB	.260	5	.052	< 1
AC	.788	4	.197	< 1
AP	1.239	5	.248	4.203**
BC	1.111	20	.056	< 1
BP	2.468	25	.099	1.356
CP	4.811	20	.241	< 1
ABC	1.818	20	.241	1.542
ABP	1.831	25	.073	1.237
ACP	5.564	20	.278	4.712***
BCP	5.472	100	.055	< 1
ABCP	5.923	100	.059	

ANALYSIS II

TABLE XIV SPEED AND ACCURACY
ANALYSES, VIBRATION TIME SCORES

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	4.719	2	2.360	3.367
B (controls)	12.136	5	2.427	3.492*
C (frequencies)	5.727	8	.716	1.095
P (subjects)	87.827	5	17.565	26.858***
AB	1.763	10	.176	< 1
AC	12.587	16	.787	1.019
AP	6.858	10	.686	< 1
BC	9.745	40	.244	1.099
BP	16.832	25	.673	3.032***
CP	26.148	40	.654	3.042***
ABC	22.522	80	.282	1.312
ABP	8.402	50	.168	< 1
ACP	61.789	80	.772	3.591***
BCP	44.481	200	.222	1.033
ABCP	86.158	400	.215	

ANALYSIS I

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.006	1	.006	< 1
B (controls)	3.533	5	.707	1.234
C (frequencies)	3.664	4	.916	< 1
P (subjects)	34.479	5	6.896	5.575*
AB	1.595	5	.319	1.271
AC	4.596	4	1.149	1.974
AP	6.183	5	1.237	7.069***
BC	4.986	20	.249	< 1
BP	12.636	25	.505	2.012*
CP	22.773	20	1.139	1.957
ABC	5.189	20	.259	1.480
ABP	6.272	25	.251	1.434
ACP	11.647	20	.582	3.326***
BCP	21.301	100	.213	1.217
ABCP	17.463	100	.175	

ANALYSIS II

TABLE XV SPEED AND ACCURACY
ANALYSES, TIME DIFFERENCE SCORES

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.897	2	.448	< 1
B (controls)	4.649	5	.930	1.553
C (frequencies)	1.802	8	.225	< 1
P (subjects)	3.511	5	.702	1.162
AB	2.486	10	.249	< 1
AC	9.008	16	.563	1.609
AP	5.241	10	.524	1.497
BC	10.387	40	.260	< 1
BP	15.852	25	.634	2.149**
CP	24.147	40	.604	1.961**
ABC	27.961	80	.350	1.136
ABP	10.496	50	.210	< 1
ACP	28.008	80	.350	1.136
BCP	58.947	200	.295	< 1
ABCP	123.016	400	.308	

ANALYSIS I

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.073	1	.073	< 1
B (controls)	1.280	5	.256	< 1
C (frequencies)	.512	4	.128	< 1
P (subjects)	1.094	5	.219	< 1
AB	1.730	5	.346	1.189
AC	5.557	4	1.389	6.910**
AP	5.888	5	1.178	3.764**
BC	7.913	20	.396	1.158
BP	11.549	25	.462	1.583
CP	9.435	20	.472	2.348*
ABC	6.413	20	.321	1.026
ABP	7.282	25	.291	< 1
ACP	4.027	20	.201	< 1
BCP	33.350	100	.334	1.067
ABCP	31.256	100	.313	

ANALYSIS II

TABLE XVI CONTROL FORCE ANALYSES
VIBRATION ERROR SCORES, LARGE KNOB

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.758	2	.379	< 1
B (forces)	.070	2	.035	< 1
C (frequencies)	2.169	8	.271	< 1
P (subjects)	1.630	5	.326	< 1
AB	.073	4	.018	< 1
AC	6.279	16	.392	1.815*
AP	2.169	10	.217	1.00
BC	.439	16	.027	< 1
BP	.561	10	.056	1.556
CP	15.493	40	.387	9.923***
ABC	1.591	32	.050	1.282
ABP	.838	20	.042	1.077
ACP	16.849	80	.216	5.538***
BCP	2.907	80	.036	< 1
ABCP	6.265	160	.039	

ANALYSIS I

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.057	1	.057	2.280
B (forces)	.066	2	.033	2.538
C (frequencies)	.262	4	.065	< 1
P (subjects)	.265	5	.053	2.120
AB	.015	2	.008	< 1
AC	.421	4	.105	< 1
AP	.123	5	.025	1.087
BC	.120	8	.015	< 1
BP	.228	10	.023	1.278
CP	2.916	20	.146	< 1
ABC	.234	8	.029	1.261
ABP	.185	10	.018	< 1
ACP	3.285	20	.164	1.130**
BCP	1.120	40	.028	1.217
ABCP	.920	40	.023	

ANALYSIS II

TABLE XVII CONTROL FORCE ANALYSES
VIBRATION ERROR SCORES, SMALL KNOB

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.773	2	.386	< 1
B (forces)	.235	2	.118	1.686
C (frequencies)	3.852	8	.482	1.470
P (subjects)	2.316	5	.463	1.412
AB	.036	4	.009	< 1
AC	6.028	16	.377	1.456
AP	2.760	10	.276	1.066
BC	1.225	16	.077	1.481
BP	.453	10	.045	< 1
CP	13.128	40	.328	5.964***
ABC	1.731	32	.054	< 1
ABP	1.165	20	.058	1.055
ACP	20.730	80	.259	4.709***
BCP	4.144	80	.052	< 1
ABCP	8.836	160	.055	

ANALYSIS I

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.173	1	.173	2.507
B (forces)	.203	2	.104	2.311
C (frequencies)	.196	4	.049	1.324
P (subjects)	.945	5	.189	2.739
AB	.128	2	.064	1.730
AC	.211	4	.053	< 1
AP	.344	5	.069	4.929**
BC	.222	8	.028	< 1
BP	.180	10	.018	< 1
CP	2.767	20	.138	< 1
ABC	.231	8	.029	2.071
ABP	.368	10	.037	2.643*
ACP	3.076	20	.154	11.000***
BCP	1.055	40	.026	1.857*
ABCP	.573	40	.014	

ANALYSIS II

TABLE XVIII CONTROL FORCE ANALYSES
VIBRATION ERROR SCORES, HORIZONTAL LEVER

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (Levels)	.488	2	.244	< 1
B (Forces)	.553	2	.276	6.732*
C (Frequencies)	1.090	8	.136	< 1
P (Subjects)	.918	5	.184	< 1
AB	.118	4	.030	< 1
AC	4.520	16	.282	1.752
AP	2.021	10	.202	1.255
BC	.475	16	.030	< 1
BP	.485	10	.048	1.297
CP	14.627	40	.366	9.632***
ABC	.892	32	.028	< 1
ABP	.887	20	.044	1.158
ACP	12.912	80	.161	4.231***
BCP	2.964	80	.037	< 1
ABCP	6.139	160	.038	

ANALYSIS I

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (Levels)	.008	1	.008	< 1
B (Forces)	.190	2	.095	< 1
C (Frequencies)	.128	4	.032	< 1
P (Subjects)	.789	5	.158	1.145
AB	.163	2	.081	1.125
AC	.182	4	.046	< 1
AP	.692	5	.138	3.450*
BC	.433	8	.054	1.227
BP	.891	10	.089	1.236
CP	3.030	20	.152	1.000
ABC	.320	8	.040	1.000
ABP	.723	10	.072	1.800
ACP	3.039	20	.152	3.800***
BCP	1.751	40	.044	1.100
ABCP	1.615	40	.040	

ANALYSIS II

TABLE XIX CONTROL FORCE ANALYSES
VIBRATION ERROR SCORES, VERTICAL LEVER

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (Levels)	1.237	2	.618	1.850
B (Forces)	.624	2	.312	2.737
C (Frequencies)	2.090	8	.261	< 1
P (Subjects)	2.251	5	.450	1.351
AB	.085	4	.021	< 1
AC	4.639	16	.290	1.349
AP	2.593	10	.259	1.205
BC	1.544	16	.096	1.655
BP	.757	10	.076	1.310
CP	13.314	40	.333	5.371***
ABC	1.983	32	.062	1.000
ABP	1.228	20	.061	< 1
ACP	17.201	80	.215	3.468***
BCP	4.669	80	.058	< 1
ABCP	9.843	160	.062	

ANALYSIS I

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (Levels)	.136	1	.136	3.886
B (Forces)	.054	2	.027	< 1
C (Frequencies)	.901	4	.225	4.167
P (Subjects)	.394	5	.079	2.257
AB	.067	2	.034	< 1
AC	.267	4	.067	< 1
AP	.175	5	.035	1.667
BC	.138	8	.017	< 1
BP	.364	10	.036	< 1
CP	1.688	20	.084	< 1
ABC	.141	8	.018	< 1
ABP	.383	10	.038	1.810
ACP	2.429	20	.121	5.762***
BCP	1.733	40	.043	2.048*
ABCP	.846	40	.021	

ANALYSIS II

TABLE XX CONTROL FORCE ANALYSES
VIBRATION ERROR SCORES, HORIZONTAL THUMBWHEEL

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (Levels)	1.252	2	.626	1.501
B (Forces)	.445	2	.223	1.088
C (Frequencies)	3.661	8	.458	1.101
P (Subjects)	2.677	5	.535	1.286
AB	.236	4	.059	< 1
AC	6.231	16	.389	1.581
AP	2.737	10	.274	1.114
BC	1.690	16	.106	< 1
BP	2.474	10	.247	1.669
CP	16.642	40	.416	3.176***
ABC	4.814	32	.150	1.145
ABP	1.970	20	.098	< 1
ACP	19.642	80	.246	1.878***
BCP	11.826	80	.148	1.130
ABCP	20.892	160	.131	

ANALYSIS I

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (Levels)	.172	1	.172	4.410
B (Forces)	.255	2	.128	1.196
C (Frequencies)	.443	4	.111	1.776
P (Subjects)	.792	5	.158	4.051
AE	.090	2	.045	< 1
AC	.146	4	.036	< 1
AP	.193	5	.039	< 1
BC	.204	8	.026	< 1
BP	1.144	10	.114	2.192
CP	2.675	20	.134	< 1
ABC	.512	8	.064	1.600
ABP	.521	10	.052	1.300
ACP	3.026	20	.151	4.775***
BCP	1.699	40	.042	1.050
ABCP	1.586	40	.040	

ANALYSIS II

TABLE XXI CONTROL FORCE ANALYSES
VIBRATION ERROR SCORES, VERTICAL THUMBWHEEL

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	1.073	2	.536	2.694
B (forces)	.631	2	.316	4.158
C (frequencies)	3.525	8	.441	1.142
P (subjects)	1.744	5	.349	< 1
AB	.027	4	.007	< 1
AC	3.093	16	.193	< 1
AP	2.145	10	.214	1.029
BC	.669	16	.042	< 1
BP	.913	10	.091	1.596
CP	15.448	40	.386	6.031***
ABC	1.158	32	.036	< 1
ABP	.967	20	.048	< 1
ACP	16.610	80	.208	3.250***
BCP	4.573	80	.057	< 1
ABCP	10.207	160	.064	

ANALYSIS I

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.184	1	.184	4.182
B (forces)	.036	2	.018	1.059
C (frequencies)	.104	4	.026	1.408
P (subjects)	.475	5	.095	2.159
AB	.007	2	.004	< 1
AC	.083	4	.021	< 1
AP	.219	5	.044	< 1
BC	.321	8	.040	2.000
BP	.444	10	.044	< 1
CP	2.179	20	.109	< 1
ABC	.296	8	.037	< 1
ABP	.312	10	.031	< 1
ACP	3.137	20	.157	3.413***
BCP	1.166	40	.029	< 1
ABCP	1.850	40	.046	

ANALYSIS II

TABLE XXII CONTROL FORCE ANALYSES
ERROR DIFFERENCE SCORES, LARGE KNOB

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.206	2	.103	< 1
B (forces)	.850	2	.425	4.620*
C (frequencies)	1.656	8	.207	1.020
P (subjects)	3.573	5	.713	3.512**
AP	.251	4	.063	< 1
A.	4.141	16	.259	1.506
AP	.737	10	.074	< 1
BC	.684	16	.043	< 1
BP	.966	10	.097	2.021*
CP	8.113	40	.203	3.691***
ABC	2.494	32	.078	1.418
ABP	1.439	20	.072	1.309
ACP	13.749	80	.172	3.127***
BCP	3.811	80	.048	< 1
ABCP	8.730	160	.055	

ANALYSIS I

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.116	1	.116	5.800
B (forces)	.605	2	.302	1.841
C (frequencies)	.399	4	.100	< 1
P (subjects)	.925	5	.185	9.250*
AB	.126	2	.063	2.864
AC	.811	4	.203	1.167
AP	.100	5	.020	< 1
BC	.170	8	.021	< 1
BP	1.233	10	.123	5.591**
CP	1.823	20	.091	< 1
ABC	.702	8	.085	1.466
ABP	.216	10	.022	< 1
ACP	3.478	20	.174	3.000**
BCP	1.212	40	.030	< 1
ABCP	2.326	40	.058	

ANALYSIS II

TABLE XXIII CONTROL FORCE ANALYSES
ERROR DIFFERENCE SCORES, SMALL KNOB

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.214	2	.107	< 1
B (forces)	.121	2	.060	< 1
C (frequencies)	2.108	8	.264	1.375
P (subjects)	3.456	5	.691	3.599**
AB	.127	4	.032	< 1
AC	4.441	16	.278	1.203
AP	1.522	10	.152	< 1
BC	1.144	16	.072	1.000
BP	1.138	10	.114	1.583
CP	7.675	40	.192	2.560***
ABC	1.518	32	.047	< 1
ABP	1.432	20	.072	< 1
ACP	18.449	80	.231	3.080***
BCP	5.776	80	.072	< 1
ABCP	11.971	160	.075	

ANALYSIS I

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.265	1	.265	2.054
B (forces)	.384	2	.192	4.085
C (frequencies)	.055	4	.014	1.214
P (subjects)	.982	5	.196	1.519
AB	.122	2	.061	1.271
AC	.141	4	.035	< 1
AP	.843	5	.129	5.609***
BC	.243	8	.030	< 1
BP	.335	10	.034	< 1
CP	2.656	20	.133	< 1
ABC	3.11	8	.038	1.652
ABP	.481	10	.048	2.087*
ACP	3.797	20	.190	8.261***
BCP	1.586	40	.040	1.739*
ABCP	.904	40	.023	

ANALYSIS II

TABLE XXIV CONTROL FORCE ANALYSES
ERROR DIFFERENCE SCORES, HORIZONTAL LEVER

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (Levels)	.054	2	.027	< 1
B (Forces)	.572	2	.286	1.810
C (Frequencies)	.924	8	.103	< 1
P (Subjects)	2.146	5	.429	2.480*
AB	.429	4	.107	1.081
AC	2.113	16	.132	1.048
AP	.849	10	.085	< 1
BC	1.016	16	.064	1.000
BP	1.579	10	.158	2.469*
CP	6.938	40	.173	2.932***
ABC	1.741	32	.054	< 1
ABP	2.090	20	.104	1.763*
ACP	10.104	80	.126	2.136***
BCP	5.105	80	.064	1.085
ABCP	9.442	160	.059	

ANALYSIS I

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (Levels)	.001	1	.001	< 1
B (Forces)	.070	2	.035	< 1
C (Frequencies)	.093	4	.023	< 1
P (Subjects)	1.889	5	.378	1.518
AB	.209	2	.104	1.518
AC	.810	4	.202	1.295
AP	1.247	5	.249	3.609**
BC	.677	8	.085	1.545
BP	1.470	10	.147	1.771
CP	2.759	20	.103	1.493
ABC	.476	8	.060	< 1
ABP	.931	10	.093	1.203
ACP	3.116	20	.156	2.261*
BCP	2.545	40	.064	< 1
ABCP	2.765	40	.069	

ANALYSIS II

TABLE XXV CONTROL FORCE ANALYSES
ERROR DIFFERENCE SCORES, VERTICAL LEVER

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (Levels)	.565	2	.282	1.709
B (Forces)	.421	2	.210	1.707
C (Frequencies)	2.007	8	.251	1.224
P (Subjects)	3.567	5	.713	3.478*
AB	.038	4	.010	<1
AC	4.153	16	.260	1.135
AP	1.337	10	.134	<1
BC	1.773	16	.111	1.542
BP	.835	10	.084	1.167
CP	8.184	40	.205	3.015***
ABC	1.561	32	.049	
ABP	1.571	20	.079	1.162
ACP	18.345	80	.229	3.368***
BCP	5.780	80	.072	1.059
ABCP	10.802	160	.068	

ANALYSIS I

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (Levels)	.319	1	.319	3.097
B (Forces)	.218	2	.109	<1
C (Frequencies)	.468	4	.117	2.395*
P (Subjects)	.615	5	.123	1.194
AB	.249	2	.124	2.818
AC	.199	4	.050	<1
AP	.517	5	.103	3.433*
BC	.126	8	.016	<1
BP	.594	10	.059	1.568
CP	1.395	20	.069	<1
ABC	.132	8	.016	<1
ABP	.448	10	.044	1.419
ACP	3.355	20	.168	5.419***
BCP	2.236	40	.056	1.806*
ABCP	1.235	40	.031	

ANALYSIS II

TABLE XXVI CONTROL FORCE ANALYSES
ERROR DIFFERENCE SCORES, HORIZONTAL THUMBWHEEL.

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (Levels)	.588	2	.294	<1
B (Forces)	.216	2	.108	<1
C (Frequencies)	2.568	8	.321	1.249
P (Subjects)	2.233	5	.447	1.739
AB	.451	4	.113	<1
AC	4.000	16	.250	1.269
AP	2.853	10	.285	1.447
BC	1.54	16	.096	<1
BP	2.265	10	.226	1.527
CP	10.299	40	.257	1.977**
ABC	5.535	32	.173	1.331
ABP	2.552	20	.128	<1
ACP	15.753	80	.197	1.515*
BCP	11.829	80	.148	1.138
ABCP	20.759	160	.130	

ANALYSIS I

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (Levels)	.355	1	.355	1.740
B (Forces)	.284	2	.142	1.060
C (Frequencies)	.677	4	.169	11.267
P (Subjects)	.715	5	.143	<1
AB	.167	2	.084	1.787
AC	.446	4	.111	<1
AP	1.022	5	.204	3.643**
BC	.207	8	.026	<1
BP	.969	10	.097	2.064
CP	1.774	20	.089	<1
ABC	.637	8	.080	1.429
ABP	.470	10	.047	<1
ACP	3.692	20	.185	3.304***
BCP	1.900	40	.048	<1
ABCP	2.258	40	.056	

ANALYSIS II

TABLE XXVII CONTROL FORCE ANALYSES
ERROR DIFFERENCE SCORES, VERTICAL THUMBWHEEL

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.389	2	.194	1.780
B (forces)	.552	2	.276	4.246
C (frequencies)	2.464	8	.308	2.990*
P (subjects)	3.187	5	.637	6.184***
AB	.029	4	.007	<1
AC	2.697	16	.169	<1
AP	1.554	10	.155	<1
BC	.792	16	.050	<1
BP	.848	10	.085	1.214
CP	6.110	40	.103	1.288
ABC	1.481	32	.046	<1
ABP	1.176	20	.059	<1
ACP	17.188	80	.215	2.687***
BCP	5.603	80	.070	<1
ABCP	12.844	160	.080	

ANALYSIS I

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.578	1	.578	2.429
B (forces)	.330	2	.165	2.426
C (frequencies)	.133	4	.033	1.727
P (subjects)	.947	5	.189	<1
AB	.058	2	.029	<1
AC	.187	4	.047	<1
AP	1.190	5	.238	4.491**
BC	.481	8	.060	<1
BP	.731	10	.073	2.147
CP	1.913	20	.096	<1
ABC	.573	8	.072	1.358
ABP	.335	10	.034	<1
ACP	4.271	20	.214	4.038***
BCP	1.696	40	.042	<1
ABCP	2.102	40	.053	

ANALYSIS II

TABLE XXVIII CONTROL FORCE ANALYSES
VIBRATION TIME SCORES, LARGE KNOB

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	2.676	2	1.338	13.653
B (forces)	10.186	2	5.093	15.361**
C (frequencies)	3.287	8	.411	<1
F (subjects)	78.115	5	15.623	30.875***
AB	1.136	4	.284	<1
AC	8.806	16	.550	<1
AP	1.910	10	.191	<1
BC	2.315	16	.145	<1
BP	2.040	10	.204	<1
CP	20.223	40	.506	1.902**
ABC	14.477	32	.452	1.699*
ABP	5.214	20	.261	<1
ACP	51.448	80	.643	2.417***
BCP	21.473	80	.268	1.008
ABCP	42.594	160	.266	

ANALYSIS I

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.319	1	.319	<1
B (forces)	3.299	2	1.649	2.529
C (frequencies)	.879	4	.220	<1
P (subjects)	39.253	5	7.851	17.966**
AB	1.090	2	.549	7.521*
AC	2.109	4	.527	<1
AP	2.185	5	.437	3.035*
BC	3.303	8	.413	1.000
BP	1.706	10	.170	2.411
CP	8.956	20	.448	<1
ABC	2.420	8	.302	2.097
ABP	.727	10	.073	<1
ACP	11.547	20	.577	4.007***
BCP	10.113	40	.253	1.757*
ABCP	5.742	40	.144	

ANALYSIS II

TABLE XXIX CONTROL FORCE ANALYSES
VIBRATION TIME SCORES, SMALL KNOB

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.551	2	.276	1.211
B (forces)	9.399	2	4.700	16.968**
C (frequencies)	4.139	8	.517	1.200
P (subjects)	46.398	5	9.280	21.531***
AB	.968	4	.217	<1
AC	8.124	16	.508	<1
AP	3.317	10	.332	<1
BC	3.478	16	.217	1.064
BP	2.644	10	.264	1.294
CP	17.233	40	.431	2.280***
ABC	9.310	32	.291	1.540*
ABP	6.554	20	.328	1.735*
ACP	48.998	80	.612	3.238***
BCP	16.317	80	.204	1.079
ABCP	30.193	160	.189	

ANALYSIS I

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	1.035	1	1.035	<1
B (forces)	.377	2	.188	<1
C (frequencies)	4.962	4	1.240	2.719
P (subjects)	18.48	5	3.697	2.873
AB	1.199	2	.600	1.626
AC	.555	4	.139	<1
AP	6.437	5	1.287	4.857**
BC	2.152	8	.269	6.405
BP	1.307	10	.131	<1
CP	12.662	20	.633	2.003
ABC	.738	8	.092	<1
ABP	3.691	10	.369	1.392
ACP	6.317	20	.316	1.192
BCP	8.605	40	.215	<1
ABCP	10.594	40	.265	

ANALYSIS II

TABLE XXX CONTROL FORCE ANALYSES
VIBRATION TIME SCORES, HORIZONTAL LEVER

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (Levels)	2.172	2	1.086	3.103
B (Forces)	3.678	2	1.839	9.782*
C (Frequencies)	6.742	8	.843	2.087
P (Subjects)	29.636	5	5.927	14.671***
AB	2.002	4	.500	3.247
AC	9.128	16	.508	1.114
AP	2.978	10	.298	< 1
BC	3.873	16	.242	1.169
BP	1.533	10	.153	< 1
CP	16.151	40	.404	2.061***
ABC	6.450	32	.202	1.031
ABP	2.970	20	.148	< 1
ACP	36.495	80	.456	2.327***
BCP	16.533	80	.207	1.056
ABCP	31.392	160	.196	

ANALYSIS I

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (Levels)	.325	1	.325	< 1
B (Forces)	.495	2	.248	< 1
C (Frequencies)	2.822	4	.706	< 1
P (Subjects)	12.074	5	2.415	7.166*
AB	.443	2	.222	1.247
AC	2.978	4	.744	1.746
AP	1.684	5	.337	1.546
BC	1.073	4	.268	< 1
BP	2.161	10	.216	1.213
CP	16.396	20	.820	1.925
APC	1.155	8	.144	< 1
ABP	1.778	10	.178	< 1
ACP	8.512	20	.426	1.954*
BCP	9.195	40	.230	1.055
ABCP	8.749	40	.219	

ANALYSIS II

TABLE XXXI CONTROL FORCE ANALYSES
VIBRATION TIME SCORES, VERTICAL LEVER

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (Levels)	2.388	2	1.194	4.131
B (Forces)	10.545	2	5.272	20.921***
C (Frequencies)	6.334	8	.792	1.760
P (Subjects)	33.586	5	6.717	14.927***
AB	.206	4	.052	< 1
AC	3.682	16	.230	< 1
AP	5.359	10	.537	1.123
BC	2.688	16	.168	< 1
BP	2.545	10	.254	1.494
CP	17.984	40	.450	2.133***
ABC	7.278	32	.227	1.076
ABP	3.851	20	.193	< 1
ACP	38.211	80	.478	2.265***
BCP	13.628	80	.170	< 1
ABCP	33.763	160	.211	

ANALYSIS I

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (Levels)	.798	1	.798	< 1
B (Forces)	5.370	2	2.685	6.334
C (Frequencies)	3.197	4	.799	1.278
P (Subjects)	20.843	5	4.169	4.622
AB	1.142	2	.571	1.627
AC	2.401	4	.600	1.396
AP	4.510	5	.902	3.774*
BC	.947	8	.118	< 1
BP	2.036	10	.204	< 1
CP	9.159	20	.458	1.058
ABC	3.261	9	.408	1.707
ABP	3.510	10	.351	1.469
ACP	8.658	20	.433	1.812
BCP	7.530	40	.188	< 1
ABCP	9.546	40	.239	

ANALYSIS II

TABLE XXXII CONTROL FORCE ANALYSES
VIBRATION TIME SCORES, HORIZONTAL THUMBWHEEL

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (Levels)	1.815	2	.908	1.327
B (Forces)	42.010	2	21.005	93.356**
C (Frequencies)	2.342	8	.293	< 1
P (Subjects)	34.243	5	6.849	10.222***
AB	.806	4	.202	< 1
AC	12.155	16	.760	1.484
AP	4.365	10	.436	< 1
BC	2.486	16	.155	< 1
BP	5.707	10	.371	1.233
CP	25.806	40	.670	3.059***
ABC	11.268	32	.352	1.607*
ABP	2.026	20	.101	< 1
ACP	40.995	80	.512	2.338***
BCP	24.102	80	.301	1.374*
ABCP	35.099	160	.219	

ANALYSIS I

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (Levels)	.596	1	.596	2.463
B (Forces)	20.740	2	10.370	25.170**
C (Frequencies)	2.657	4	.664	1.309
P (Subjects)	18.405	5	3.681	15.211**
AB	.322	2	.161	< 1
AC	.387	4	.097	< 1
AP	1.210	5	.242	1.061
BC	4.074	8	.509	1.631
BP	4.185	10	.418	2.523
CP	14.926	20	.746	1.567
ABC	2.796	8	.350	1.535
ABP	1.670	10	.167	< 1
ACP	9.514	20	.476	2.138*
BCP	7.611	40	.190	< 1
ABCP	9.139	40	.228	

ANALYSIS II

TABLE XXXIII CONTROL FORCE ANALYSES
VIBRATION TIME SCORES, VERTICAL THUMBWHEEL

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	4.477	2	2.238	2.270
B (forces)	12.057	2	6.028	22.409**
C (frequencies)	12.713	8	1.587	4.187**
P (subjects)	57.156	5	11.431	30.161***
AB	.382	4	.096	< 1
AC	14.154	16	.885	1.536
AP	6.772	10	.677	1.175
BC	3.662	16	.229	< 1
BP	3.222	10	.322	1.142
CP	15.146	40	.379	1.354
ABC	9.915	32	.310	1.107
ABP	5.788	20	.289	1.032
ACP	46.049	80	.576	2.057***
BCP	22.595	80	.282	1.007
ABCP	44.755	160	.280	

ANALYSIS I

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.061	1	.081	< 1
B (forces)	5.872	2	2.936	2.619
C (frequencies)	5.857	4	1.464	< 1
P (subjects)	20.921	5	4.184	9.776*
AB	1.932	2	.566	3.275
AC	7.431	4	1.858	4.466**
AP	2.139	5	.423	2.834*
BC	1.888	8	.236	< 1
BP	4.500	10	.450	1.525
CP	9.787	20	.489	1.175
ABC	4.477	8	.560	3.709**
ABP	2.951	10	.295	1.954
ACP	8.325	20	.416	2.755**
BCP	7.014	40	.175	1.159
ABCP	6.043	40	.151	

ANALYSIS II

TABLE XXXIV CONTROL FORCE ANALYSES
TIME DIFFERENCE SCORES, LARGE KNOB

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.442	2	.221	< 1
B (forces)	2.432	2	1.216	4.208
C (frequencies)	4.397	8	.550	1.036
P (subjects)	9.021	5	1.804	3.397*
AB	1.328	4	.332	< 1
AC	5.375	16	.336	< 1
AP	4.283	10	.428	< 1
BC	3.561	16	.223	< 1
BF	4.088	10	.409	1.192
CP	21.237	40	.531	1.654*
ABC	14.335	32	.448	1.396
ABP	6.105	20	.305	< 1
ACP	36.716	80	.459	1.430*
BCP	27.439	80	.343	1.069
ABCP	51.398	160	.321	

ANALYSIS I

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.800	1	.800	2.010
B (forces)	.944	2	.472	< 1
C (frequencies)	1.163	4	.291	< 1
P (subjects)	3.990	5	.798	2.005
AB	2.135	2	1.068	12.867**
AC	3.062	4	.766	1.733
AP	1.391	5	.278	1.733
BC	3.770	8	.472	< 1
BP	4.208	10	.421	5.072**
CP	6.675	20	.334	< 1
ABC	3.163	8	.395	1.725
ABP	.833	10	.083	< 1
ACP	8.838	20	.442	1.930*
BCP	17.770	40	.444	1.939*
ABCP	9.155	40	.229	

ANALYSIS II

TABLE XXXV CONTROL FORCE ANALYSES
TIME DIFFERENCE SCORES, SMALL KNOB

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.419	2	.210	< 1
B (forces)	3.223	2	1.611	4.942*
C (frequencies)	3.999	8	.500	1.126
P (subjects)	2.728	5	.546	1.230
AB	.714	4	.178	< 1
AC	5.456	16	.341	< 1
AP	2.554	10	.255	< 1
BC	4.556	16	.285	1.067
BP	3.085	10	.308	1.154
CP	17.745	40	.444	1.922**
ABC	11.328	32	.354	1.532*
ABP	6.900	20	.345	1.494
ACP	28.670	80	.358	1.550*
BCP	21.394	80	.267	1.156
ABCP	36.978	160	.231	

ANALYSIS I

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	1.823	1	1.823	1.475
B (forces)	.694	2	.347	1.770
C (frequencies)	2.997	4	.749	3.147
P (subjects)	.829	5	.166	< 1
AB	.783	2	.392	< 1
AC	1.700	4	.425	< 1
AP	6.180	5	1.236	3.700**
BC	3.981	8	.498	2.658**
BP	2.994	10	.299	< 1
CP	6.177	20	.309	< 1
ABC	.771	8	.096	< 1
ABP	4.947	10	.495	1.482
ACP	9.910	20	.496	1.485
BCP	8.672	40	.217	< 1
ABCP	13.345	40	.334	

ANALYSIS II

TABLE XXXVI CONTROL FORCE ANALYSES
TIME DIFFERENCE SCORES, HORIZONTAL LEVER

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (Levels)	.415	2	.208	< 1
B (Forces)	1.198	2	.599	1.060
C (Frequencies)	2.386	8	.298	< 1
P (Subjects)	5.520	5	1.104	2.928*
AB	2.0	4	.502	2.773
AC	6.965	16	.435	1.605
AP	1.577	10	.158	< 1
BC	4.405	16	.275	1.087
BP	5.427	10	.543	2.145*
CP	15.097	40	.377	1.484*
ABC	8.012	32	.250	< 1
ABP	3.699	20	.185	< 1
ACP	21.716	80	.271	1.067
BCP	20.264	80	.253	< 1
ABCP	40.588	160	.254	

ANALYSIS I

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (Levels)	.369	1	.369	1.425
B (Forces)	.382	2	.191	< 1
C (Frequencies)	1.061	4	.265	< 1
P (Subjects)	2.223	5	.445	1.718
AB	1.032	2	.516	2.335
AC	2.431	4	.608	1.865
AP	1.293	5	.259	< 1
BC	1.875	8	.234	1.225
BP	2.296	10	.230	1.041
CP	12.250	20	.612	1.877
ABC	1.521	8	.190	< 1
ABP	2.212	10	.221	< 1
ACP	6.524	20	.326	1.076
BCP	12.142	40	.304	1.003
ABCP	12.126	40	.303	

ANALYSIS II

TABLE XXXVII CONTROL FORCE ANALYSES
TIME DIFFERENCE SCORES, VERTICAL LEVER

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (Levels)	2.320	2	1.160	1.993
B (Forces)	6.531	2	3.266	3.413
C (Frequencies)	5.652	8	.706	1.677
P (Subjects)	2.598	5	.520	1.235
AB	.676	4	.169	< 1
AC	4.695	16	.293	1.003
AP	5.814	10	.581	1.990
BC	3.762	16	.235	1.103
BP	9.349	10	.935	4.390***
CP	16.825	40	.421	1.320
ABC	12.500	32	.391	1.226
ABP	5.297	20	.265	< 1
ACP	23.331	80	.292	< 1
BCP	17.048	80	.213	< 1
ABCP	51.089	160	.319	

ANALYSIS I

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (Levels)	.985	1	.985	< 1
B (Forces)	3.008	2	1.504	2.705
C (Frequencies)	2.134	8	.267	2.472
P (Subjects)	4.673	5	.935	< 1
AB	.743	2	.371	1.421
AC	.924	4	.231	< 1
AP	5.264	5	1.053	2.569***
BC	1.951	8	.244	< 1
BP	4.463	10	.446	1.709
CP	9.359	20	.468	< 1
ABC	4.887	8	.611	2.129
ABP	2.610	10	.261	< 1
ACP	9.666	20	.483	1.683
BCP	9.512	40	.238	< 1
ABCP	11.479	40	.287	

ANALYSIS II

TABLE XXXVIII CONTROL FORCE ANALYSIS
TIME DIFFERENCE SCORES, HORIZONTAL THUMBWHEEL

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (Levels)	.051	2	.026	< 1
B (Forces)	1.459	2	.730	< 1
C (Frequencies)	2.951	8	.369	< 1
P (Subjects)	5.155	5	1.031	1.305
AB	1.276	4	.319	1
AC	9.576	16	.598	1.541
AP	3.874	10	.387	< 1
BC	3.655	16	.228	< 1
BP	10.787	10	1.079	2.613**
CP	31.595	40	.790	2.416***
ABC	19.854	32	.620	1.896**
ABP	2.771	20	.139	< 1
ACP	31.004	80	.388	1.187
BCP	33.032	80	.413	1.263
ABCP	52.289	160	.327	

ANALYSIS I

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (Levels)	.462	1	.462	3.581
B (Forces)	1.250	2	.625	< 1
C (Frequencies)	.569	4	.142	< 1
P (Subjects)	5.358	5	1.071	8.302*
AB	1.247	2	.624	2.457
AC	2.351	4	.588	2.210
AP	.546	5	.129	< 1
BC	4.884	8	.610	1.456
BP	3.517	10	.352	1.386
CP	4.685	20	.234	< 1
ABC	3.264	8	.408	1.103
ABP	2.536	10	.254	< 1
ACP	5.322	20	.266	< 1
BCP	15.249	40	.381	1.030
ABCP	14.782	40	.370	

ANALYSIS II

TABLE XXXIX CONTROL FORCE ANALYSES
TIME DIFFERENCE SCORES, VERTICAL THUMBWHEEL

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	1.310	2	.655	< 1
B (forces)	9.038	2	4.519	4.649*
C (frequencies)	5.483	8	.685	2.095
P (subjects)	5.439	5	1.088	3.083*
AB	.234	4	.058	< 1
AC	12.258	16	.766	1.599
AP	7.613	10	.761	1.589
BC	5.008	16	.313	1.016
BP	9.670	10	.967	3.140**
CP	13.086	40	.327	< 1
ABC	12.423	32	.388	1.152
ABP	6.567	20	.328	< 1
ACP	39.358	80	.479	1.434*
BCP	24.633	80	.308	< 1
ABCP	53.472	160	.334	

ANALYSIS I

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.033	1	.033	< 1
B (forces)	1.469	2	.734	< 1
C (frequencies)	2.958	4	.740	< 1
P (subjects)	1.969	5	.394	< 1
AB	2.016	2	1.008	4.000
AC	5.397	4	1.099	3.392*
AP	2.700	5	.540	2.660*
BC	1.846	8	.231	< 1
BP	6.435	10	.644	2.556
CP	9.253	20	.463	1.429
ABC	5.024	8	.628	3.094**
ABP	2.523	10	.252	1.241
ACP	5.481	20	.274	1.596
BCP	8.297	40	.207	1.020
ABCP	8.126	40	.203	

ANALYSIS II

TABLE XL WORK LOAD ANALYSES
ERROR SCORES, LARGE KNOB

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	1.126	2	.563	< 1
B (conditions)	53.189	1	53.189	38.655**
C (frequencies)	1.617	4	.404	1.239
P (subjects)	3.465	4	.866	2.656
AB	.856	2	.428	< 1
AC	4.757	8	.595	1.621
AP	3.246	8	.406	1.100
BC	1.781	4	.445	1.279
BP	5.116	4	1.279	3.675*
CP	5.211	16	.326	< 1
ABC	5.515	8	.689	1.178
ABP	3.287	8	.411	< 1
ACP	11.746	32	.367	< 1
BCP	5.573	16	.348	< 1
ABCP	18.708	32	.585	

VIBRATION SCORES

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.545	2	.272	< 1
B (conditions)	.081	1	.081	< 1
C (frequencies)	5.327	4	1.332	6.110**
P (subjects)	2.047	4	.509	2.335
AP	1.678	2	.839	1.040
AC	5.245	8	.656	1.778
AP	2.200	8	.275	< 1
BC	3.543	4	.886	2.100
BP	6.426	4	1.606	3.806*
CP	3.487	16	.218	< 1
ABC	6.536	8	.817	2.468*
ABP	2.565	8	.321	< 1
ACP	11.806	32	.369	1.115
BCP	6.756	16	.422	1.275
ABCP	10.600	32	.331	

DIFFERENCE SCORES

TABLE XLI WORK LOAD ANALYSES
ERROR SCORES, SMALL KNOB

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	1.042	2	.521	2.499
B (conditions)	47.810	1	47.810	48.244**
C (frequencies)	.754	4	.188	< 1
P (subjects)	3.634	4	.908	2.447
AB	.792	2	.396	11.647
AC	1.791	3	.224	< 1
AP	1.301	5	.163	< 1
BC	.962	4	.240	< 1
BP	4.055	4	1.014	3.856*
CP	5.943	16	.371	< 1
ABC	3.882	8	.485	< 1
ABP	1.372	8	.172	< 1
ACP	14.282	32	.446	< 1
BCP	4.207	16	.263	< 1
ABCP	19.927	32	.623	

VIBRATION SCORES

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	1.634	2	.817	3.714
B (conditions)	.450	1	.450	< 1
C (frequencies)	.667	4	.142	< 1
P (subjects)	.754	4	.188	< 1
AB	1.576	2	.788	4.987
AC	2.856	8	.357	1.361
AP	.954	8	.124	< 1
BC	.782	4	.196	< 1
BP	3.173	4	.793	3.945*
CP	5.494	16	.343	< 1
ABC	3.188	8	.398	1.042
ABP	1.140	8	.142	< 1
ACP	8.514	32	.266	< 1
BCP	3.219	16	.201	< 1
ABCP	12.239	32	.382	

DIFFERENCE SCORES

TABLE XLII WORK LOAD ANALYSES
 ERROR SCORES, HORIZONTAL LEVER

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.327	2	.164	< 1
B (conditions)	47.581	1	47.581	131.279***
C (frequencies)	.784	4	.196	< 1
P (subjects)	1.421	4	.355	< 1
AB	1.065	2	.532	< 1
AC	4.582	8	.573	1.169
AP	5.217	8	.652	1.331
BC	.357	4	.089	< 1
BP	1.107	4	.277	< 1
CP	6.705	16	.419	< 1
ABC	4.426	8	.553	< 1
ABP	7.682	8	.960	1.693
ACP	15.688	32	.490	< 1
BCP	7.470	16	.467	< 1
ABCP	18.113	32	.567	

VIBRATION SCORES

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.331	2	.166	< 1
B (conditions)	.100	1	.100	< 1
C (frequencies)	2.011	4	.503	< 1
P (subjects)	3.493	4	.873	1.529
AB	.672	2	.336	< 1
AC	3.091	8	.386	1.300
AP	2.876	8	.359	1.380
BC	2.437	4	.609	1.321
BP	.670	4	.168	< 1
CP	9.140	16	.571	1.807
ABC	3.884	8	.486	1.538
ABP	5.580	8	.698	2.209
ACP	9.519	32	.297	< 1
BCP	7.374	16	.461	1.459
ABCP	10.101	32	.316	

DIFFERENCE SCORES

TABLE XLIII WORK LOAD ANALYSES
ERROR SCORES, VERTICAL LEVER

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.551	2	.276	< 1
B (conditions)	46.151	1	46.151	33.083**
C (frequencies)	1.964	4	.491	< 1
P (subjects)	5.125	4	1.281	2.459
AB	.731	2	.366	< 1
AC	3.778	8	.472	1.272
AP	2.934	8	.367	< 1
BC	2.466	4	.616	1.339
BP	4.955	4	1.239	2.693
CP	8.338	16	.521	1.143
ABC	4.959	8	.620	1.360
ABP	1.986	8	.248	< 1
ACP	11.870	32	.371	< 1
BCP	7.362	16	.460	1.009
ABCP	14.584	32	.456	

VIBRATION SCORES

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.101	2	.050	< 1
B (conditions)	3.015	1	3.015	1.938
C (frequencies)	3.117	4	.779	2.353
P (subjects)	3.537	4	.884	2.671
AB	.211	2	.106	1.963
AC	1.655	8	.207	< 1
AP	2.529	8	.316	< 1
BC	2.605	4	.651	1.543
BP	5.307	4	1.327	3.145*
CP	5.291	16	.331	< 1
APC	2.181	8	.273	< 1
ABP	2.060	8	.258	< 1
ACP	12.293	32	.384	< 1
BCP	6.757	16	.422	< 1
ABCP	15.267	32	.477	

DIFFERENCE SCORES

TABLE XLIV WORK LOAD ANALYSES
ERROR SCORES, HORIZONTAL THUMBWHEEL

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	1.716	2	.858	1.360
B (conditions)	59.804	1	59.804	39.139**
C (frequencies)	.437	4	.109	< 1
P (subjects)	4.721	4	1.180	2.516
AB	2.213	2	1.106	1.653
AC	3.566	8	.446	1.364
AP	4.099	8	.512	1.566
BC	1.263	4	.316	< 1
BP	6.518	4	1.630	3.900*
CP	7.507	16	.469	1.144
ABC	4.362	8	.545	1.329
ABP	4.269	8	.534	1.302
ACP	10.450	32	.327	< 1
BCP	6.688	16	.418	1.030
ABCP	13.122	32	.410	

VIBRATION SCORES

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.250	2	.125	< 1
B (conditions)	.007	1	.007	< 1
C (frequencies)	.928	4	.232	< 1
P (subjects)	2.158	4	.540	1.693
AB	1.244	2	.622	4.065
AC	2.150	8	.269	1.257
AP	2.253	8	.282	1.318
BC	1.506	4	.376	1.126
BP	2.233	4	.558	1.671
CP	5.097	16	.317	1.164
ABC	1.173	8	.147	< 1
ABP	2.239	8	.280	1.022
ACP	6.844	32	.214	< 1
BCP	5.344	16	.334	1.219
ABCP	8.783	32	.274	

DIFFERENCE SCORES

TABLE XLV WORK LOAD ANALYSES
ERROR SCORES, VERTICAL THUMBWHEEL

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	1.081	2	.540	3.344*
B (conditions)	60.566	1	60.566	43.169**
C (frequencies)	.963	4	.241	< 1
P (subjects)	4.063	4	1.016	1.773
AB	1.050	2	.525	1.617
AC	2.036	8	.254	< 1
AP	1.066	8	.133	< 1
BC	2.393	4	.597	1.012
BP	5.582	4	1.396	2.366
CP	9.161	16	.573	< 1
ABC	5.890	8	.736	< 1
ABP	.632	8	.079	< 1
ACP	24.129	32	.754	< 1
BCP	9.442	16	.590	< 1
ABCP	25.364	32	.793	

VIBRATION SCORES

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.137	2	.068	2.096
B (conditions)	1.577	1	1.577	6.089
C (frequencies)	1.490	4	.372	< 1
P (subjects)	.562	4	.140	< 1
AB	.027	2	.014	1.198
AC	.790	8	.099	< 1
AP	.701	8	.088	< 1
BC	1.782	4	.446	< 1
BP	1.073	4	.268	< 1
CP	7.603	16	.475	1.116
ABC	2.333	8	.292	< 1
ABP	.650	8	.082	< 1
ACP	10.363	32	.324	< 1
BCP	7.273	16	.455	1.48
ABCP	13.892	32	.434	

DIFFERENCE SCORES

TABLE XLVI WORK LOAD ANALYSES
TIME SCORES, LARGE KNOB

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.193	2	.096	<1
B (conditions)	187.627	1	187.627	51.902**
C (frequencies)	1.598	4	.400	1.117
P (subjects)	34.087	4	8.522	23.804***
AB	.096	2	.048	1.371
AC	2.592	8	.324	1.266
AP	1.204	3	.150	<1
BC	1.236	4	.309	<1
BP	14.518	4	3.629	11.235***
CP	5.721	16	.358	<1
ABC	3.062	8	.383	<1
ABP	.662	8	.083	<1
ACP	8.203	32	.256	<1
BCP	5.170	16	.323	<1
ABCP	13.800	32	.431	

VIBRATION SCORES

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.060	2	.030	<1
B (conditions)	1.166	1	1.166	1.151
C (frequencies)	1.772	4	.443	<1
P (subjects)	6.538	4	1.634	3.591*
AB	.206	2	.103	<1
AC	3.185	8	.373	2.144
AP	1.327	8	.166	<1
BC	2.568	4	.642	2.253
BP	2.623	4	.656	2.302
CP	7.281	16	.455	<1
ABC	4.213	8	.527	<1
ABP	1.733	8	.217	<1
ACP	5.575	32	.174	<1
BCP	4.553	16	.285	<1
ABCP	17.832	32	.557	

DIFFERENCE SCORES

TABLE XLVII WORK LOAD ANALYSES
TIME SCORES, SMALL KNOB

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.409	2	.204	< 1
B (conditions)	210.124	1	210.124	63.405**
C (frequencies)	.955	4	.239	1.096
P (subjects)	38.324	4	9.581	43.950***
AB	.202	2	.101	1.262
AC	2.168	8	.271	1.522
AP	1.308	8	.164	< 1
BC	1.282	4	.320	< 1
BP	13.475	4	3.369	8.984***
CP	3.489	16	.218	< 1
ABC	2.770	8	.346	1.116
ABP	.353	8	.044	< 1
ACP	15.681	32	.178	< 1
BCP	6.005	16	.375	1.210
ABCP	9.923	32	.310	

VIBRATION SCORES

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.076	2	.038	< 1
B (conditions)	.104	1	.104	< 1
C (frequencies)	.212	4	.053	< 1
P (subjects)	1.290	4	.322	1.293
AB	1.127	2	.564	9.097
AC	2.589	8	.324	< 1
AP	1.528	8	.191	< 1
BC	.152	4	.038	< 1
BP	1.685	4	.421	1.272
CP	3.977	16	.249	< 1
ABC	1.496	8	.187	< 1
ABP	1.451	8	.181	< 1
ACP	13.851	32	.433	1.415
BCP	5.292	16	.331	1.082
ABCP	9.776	32	.306	

DIFFERENCE SCORES

TABLE XLVIII WORK LOAD ANALYSES
TIME SCORES, HORIZONTAL LEVER

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.248	2	.124	< 1
B (conditions)	185.661	1	185.661	172.068***
C (frequencies)	4.545	4	1.136	2.123
P (subjects)	23.355	4	5.839	10.914***
AB	4.291	2	2.146	11.600
AC	2.319	8	.290	1.551
AP	.374	8	.047	< 1
BC	.503	4	.126	< 1
BP	5.013	4	1.253	4.177*
CP	8.559	16	.535	2.248*
ABC	2.162	8	.270	1.134
ABP	1.227	8	.153	< 1
ACP	5.975	32	.187	< 1
BCP	4.805	16	.300	1.260
ABCP	7.602	32	.238	

VIBRATION SCORES

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.247	2	.124	< 1
B (conditions)	.356	1	.356	< 1
C (frequencies)	6.190	4	1.548	3.550*
P (subjects)	1.526	4	.382	< 1
AB	4.249	2	2.124	6.417
AC	2.638	8	.330	1.294
AP	.481	8	.060	< 1
BC	.490	4	.122	< 1
BP	4.529	4	1.132	4.510*
CP	6.969	16	.436	1.633
ABC	2.321	8	.290	1.086
ABP	2.461	8	.308	1.154
ACP	8.147	32	.255	< 1
BCP	4.023	16	.251	< 1
ABCP	8.557	32	.267	

DIFFERENCE SCORES

TABLE XLIX WORK LOAD ANALYSES
TIME SCORES, VERTICAL LEVER

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.143	2	.071	< 1
B (conditions)	196.479	1	196.479	136.824***
C (frequencies)	2.697	4	.674	2.217
P (subjects)	24.055	4	5.014	19.783***
AB	.286	2	.143	1.021
AC	1.792	8	.224	< 1
AP	3.111	9	.378	1.400
BC	1.913	4	.478	1.282
BP	5.324	4	1.331	3.568*
CP	4.865	16	.304	1.236
ABC	1.380	8	.172	< 1
ABP	1.714	8	.214	< 1
ACP	8.645	32	.270	1.098
BCP	5.962	16	.373	1.516
ABCP	7.866	32	.246	

VIBRATION SCORES

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.321	2	.160	< 1
B (conditions)	.626	1	.626	1.605
C (frequencies)	1.631	4	.408	1.365
P (subjects)	5.152	4	1.288	4.308*
AB	.872	2	.436	2.236
AC	2.737	8	.342	1.396
AP	2.106	8	.263	1.073
BC	2.099	4	.525	1.141
BP	1.299	4	.325	< 1
CP	4.786	16	.299	1.020
ABC	1.502	8	.188	< 1
ABP	2.404	8	.300	1.024
ACP	7.828	32	.245	< 1
BCP	7.360	16	.460	1.570
ABCP	9.387	32	.293	

DIFFERENCE SCORES

TABLE L WORK LOAD ANALYSES
TIME SCORES, HORIZONTAL THUMBWHEEL

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.068	2	.034	1.109
B (conditions)	217.624	1	217.624	196.058**
C (frequencies)	1.368	4	.342	1.090
P (subjects)	31.127	4	7.782	24.783***
AB	.042	2	.021	< 1
AC	1.738	8	.217	< 1
AP	.760	8	.095	< 1
BC	.837	4	.209	< 1
BP	5.721	4	1.430	2.703
CP	5.025	16	.314	< 1
ABC	5.325	8	.666	1.897
ABP	2.307	8	.288	< 1
ACP	9.981	32	.312	< 1
BCP	8.466	16	.529	1.507
ABCP	11.228	32	.351	

VIBRATION SCORES

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.585	2	.292	2.026
B (conditions)	.105	1	.105	1.248
C (frequencies)	1.172	4	.293	< 1
P (subjects)	7.257	4	1.814	5.025**
AP	.661	2	.330	< 1
AC	1.077	8	.135	< 1
AP	1.709	8	.214	< 1
BC	1.305	4	.321	< 1
BP	1.036	4	.259	< 1
CP	5.777	16	.361	1.180
ABC	8.214	8	1.027	3.356**
ABP	3.007	8	.376	1.229
ACP	13.294	32	.415	1.356
BCP	9.910	16	.619	2.023*
ABCP	9.792	32	.306	

DIFFERENCE SCORES

TABLE LI WORK LOAD ANALYSES
TIME SCORES, VERTICAL THUMBWHEEL

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	2.034	2	1.017	2.296
B (conditions)	215.388	1	215.388	156.988***
C (frequencies)	1.704	4	.426	1.340
P (subjects)	36.706	4	9.176	28.855***
AB	2.173	2	1.086	7.490
AC	4.066	3	.508	1.881
AP	1.637	8	.205	<1
BC	2.269	4	.567	1.800
BP	4.480	4	1.120	3.556*
CP	5.095	16	.318	<1
ABC	2.057	8	.257	<1
ABP	2.548	8	.318	<1
ACP	8.606	32	.270	<1
BCP	5.034	16	.315	<1
ABCP	13.763	32	.430	

VIBRATION SCORES

<u>Source of Variability</u>	<u>Sum Squares</u>	<u>df</u>	<u>Mean Squares</u>	<u>F or F'</u>
A (levels)	.393	2	.196	2.390
B (conditions)	.736	1	.736	<1
C (frequencies)	1.646	4	.412	1.724
P (subjects)	.368	4	.092	<1
AB	1.023	2	.512	3.391
AC	1.487	8	.186	<1
AP	2.042	8	.255	<1
BC	.572	4	.143	<1
BP	4.971	4	1.243	5.404**
CP	3.824	16	.239	<1
ABC	1.762	8	.220	<1
ABP	2.399	8	.300	<1
ACP	11.498	32	.359	<1
BCP	3.686	16	.230	<1
ABCP	13.786	32	.431	

DIFFERENCE SCORES

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