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SUMMARIES OF RESEARCH ON THE HUMAN PERFORMANCE EFFECTS OF VIBRATION

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FOREWORD

This report was prepared in the Environmental Stress Branch of the Training Research Division, Behavioral Sciences Laboratory, Aerospace Medical Research Laboratories, under Project 1710, Task 171002, "Performance Effects of Environmental Stress." The reports described were compiled by Miss Carolyn Custer who also wrote the first draft summaries. The final draft summaries were prepared by Dr. W. Dean Chiles. 1/Lt. Robert Buckhout made a number of contributions during the time when the reports were being acquired.

These summaries were prepared with the primary end in view of providing a ready source of the salient information about the performance effects of whole-body vibration. This information was needed both in planning the research program of the Environmental Stress Branch and in assisting members of the Branch in arriving at best answers to questions posed about Air Force operational situations. With the exception of three reports that deal only with problems of vibration tolerance (subjective or medical) our attention was restricted to reports of investigations that dealt exclusively with the performance effects of vibration or in which performance was measured as a prominent variable.

The summary table on page 21 is included to facilitate cross comparisons among studies. For this reason, the studies were listed in that table under the two general headings that provided sufficient numbers of entries to make such comparisons meaningful.

ABSTRACT

This report is a compilation of summaries of published reports dealing with the human performance effects of low frequency, high-amplitude vibration. The research described in each report is covered as fully as possible as regards the information needed to evaluate the investigations with respect to their applicability to Air Force operational human performance problems and research efforts. However, the implications of the reports for Air Force problems are not discussed as such.

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1. Ashe, W. F., Physiological and Pathological Effects of Mechanical Vibration on Animals and Man, National Institutes of Health, Washington, D.C., RF Project 862, Progress Report No. 3, September, 1960.

Purpose. The physiological, pathological and psychophysical effects of vibration on groups of rats (Section I), of dogs (Section II), and of human subjects (Section III) were investigated.

Method. Section I describes research which included the testing of unrestrained rats for physiological response to varying periods of exposure (1/2 - 6 hrs. daily for up to 45 days) to horizontal sinusoidal vibrations of 5, 10, 15 and 20 cps and vertical of 5, 10 and 15 cps at a constant amplitude of 0.25-inch. Measures of food and water intake and of bodily excretions were made along with body weight. In Section II, a description is given of research on unrestrained dogs tested under similar conditions.

In Section III of this study, five unrestrained human subjects were subjected to various levels of vibratory acceleration to study the differential effects of frequency and amplitude of vibration on performance. The frequencies used were 2, 4, 6, 8, 11, and 15 cps, respectively, at both 0.065 and 0.13-inch D.A. The accelerations in g's at 0.065-inches D.A. were 0.03, 0.10, 0.23, 0.41, 0.77, and 1.44; peak accelerations at 0.13 inches D.A. were 0.05, 0.20, 0.46, 0.82, 1.55 and 2.88. An electrically driven mechanical shake-table provided the source of vibration, and subjects were seated on a non-damping chair with a backrest. The task, two-dimensional compensatory tracking on a light matrix (see ref 7), was performed during two five-minute intervals of a 20-minute vibration period and integrated absolute error scores were recorded. Oxygen consumption, respiratory frequency, tidal volume and minute volume measurements were obtained from 5 subjects tested under similar experimental conditions by means of a modified Air Force pressure breathing oxygen mask. GSR and body-surface response measurements were also taken.

Results. Food and water balance studies of unrestrained rats exposed to horizontal vibration showed no consistent differences between experimental and control groups. Similar studies in the vertical plane of vibration showed a decrease in food intake and fecal output on the first day of exposure but subsequent exposures produced less effect. Integration of the pulse pressure curves of dogs being exposed to whole-body vibration indicated that a small decrease in blood pressure occurred during vibration.

Each of the 5 human subjects successfully completed the 20-minute exposure to all of the 12 different vibratory accelerations, even though the severity of the vibration under some of the conditions was near the limits of tolerance reported by other investigators for firmly restrained subjects over shorter time periods. All 5 subjects were able to perform the tracking task; however, there were performance decrements at all frequencies at the higher (0.13-inch) amplitude level. Two subjects reported feeling exhilarated during the higher amplitude tests (0.13-inch), and all reported feeling exhilarated at the lower amplitudes.

At the 0.065-inch D.A. level there was a performance decrement at frequencies of 6 cps and above. The error scores of some subjects showed improvement at 2 and 4 cps; and comparisons of tracking error scores for the control, the low amplitude and the high amplitude conditions revealed a slight overall improvement under the low amplitude condition. Analysis of variance showed the effects of frequency, amplitude and their interactions to be highly significant.

Respiratory frequency increased significantly at 15 cps at the 0.065-inch amplitude level, and there was a consistent though not significant increase in respiratory rate during compensatory tracking. Tidal volume was not affected significantly at the 0.065-inch D.A. condition, under the higher amplitude condition, frequencies of 6, 11, and 15 cps did produce a significant increase (the volume at 11 cps was twice that of 6 and 15 cps).

Minute volume (respiratory frequency x tidal volume) increased slightly at 15 cps at the 0.065-inch D.A. level. At the 0.13-inch D.A. level, the increase was 20% at 6 and 8 cps and 50% at 11 and 15 cps. Correlation coefficients between minute volume and acceleration, minute volume and velocity, and minute volume and time-displacement were between .80 and .90.

Although changes in skin resistance were elicited, there appeared to be no relationship between the amplitude of the GSR and the vibratory intensity.

Measurements of the effect of vertical vibration on body surface responses of standing subjects suggested that -

(1) A vertical forcing vibration may produce three-dimensional skin vibration.

(2) At certain frequencies, the vibration may be almost normal to the line of vertical forcing vibration.

(3) The resonant frequency for the body is about 5 cps; the torso, shoulders, head, thighs, and legs resonate in this order with a range of approximately 4 to 7 cps.

(4) The ratio of the amplitude of movement of points over adipose tissue to table amplitude may, as a result of resonance, exceeded 4.

(5) Individual differences must be considered.

<u>Discussion</u>. It was concluded that minute volume is related to the intensity of vibration, irrespective of the value of any particular component. The increase in minute volume under vibration is said to result from an increased tidal volume, since respiratory frequency remains relatively constant. The authors propose that this increase in tidal volume is related to the mechanical forces of vibration and does not represent any significant physiological control over the ventilation.

With respect to tracking, the authors concluded that amplitude was a relatively more important performance determinant than frequency.

2. Besco, R. O., The Effects of Cockpit Vertical Accelerations on a Simple Piloted Tracking Task, Report No. NA-61-47, North American Aviation, Los Angeles, California, 13 April 1961, Presented at the Midwestern Psychological Association Meeting, Chicago, Illinois, 6 May 1961.

Purpose. Determination of the effects of cockpit vertical acceleration on pilot performance during a closed loop, one-dimensional (pitch) tracking task.

Method. The "Pilot Operated Dynamic Flight Simulator" was used with an analog computer which was programmed for control actions. At the maximum rate of movement (12 ft per sec. for 5 ft of excursion), the frequency response is li ear and produces an acceleration of 3.5 g's. A 5-inch CRT, a "g" meter, and a green light (illuminated when pitch errors were less than 1/2 degree) were mounted in the simulator. Auditory and visual cues outside of the simulator were maximally reduced.

A compensatory tracking task of aircraft pitch attitude was presented to four highly experienced test pilots after pre-test practice sessions under the following conditions:

(1) Four conditions of motion:

(a) No motion.

(b) Aircraft response motion only.

(c) Aircraft response motion plus low turbulence (RMS value of 2 ft per sec.).

(d) Aircraft motion plus high turbulence (RMS value of 4 ft per sec.).

(2) Command signals at low, medium and high frequencies (.008 - .159 cps).

(3) Command signals of low, medium and high amplitude (1.5 - 4.5°).

(4) Replication after one week.

Results. Analysis of variance of the log RMS errors in pitch attitude showed the effect of motion to be significant at the .01 level. The introduction of subject-controlled cockpit motion enhanced tracking ability. When turbulence (i.e., motion extraneous to control movement) was added, tracking performance deteriorated significantly.

3. Buckhout, R., C. I. Goldsmith, H. Sherman, and P. A. Vitale, Research on Motion Simulation in Ground-Based Mission Simulators. MRL Technical Report (in press), 6570th Aerospace Medical Research Laboratories, Wright-Patterson AFB, Ohio, August, 1962.

Purpose. An investigation of several possible motion simulation techniques to determine which, if any, would contribute to the effectiveness of ground-based trainers in promoting transfer of training.

Method. Three groups of 12 subjects were trained for 12 two-minute trials on a one-dimensional (pitch) tracking task on the Gruman Motion Simulator under three treatment conditions. This simulator is capable of vertical translation (36" DA) pitch motion (±15°), and roll motion (±30°). The three training conditions were as follows:

A - Static - No motion stimuli.

B - 33% random buffet motion - 1/3 of the amplitude level of condition C.

C - Random Buffet Motion - (Vertical) RMS gust velocity of 3 feet per second with peak power occurring at 1 cps. This treatment simulated high-speed, low-altitude flight in turbulence. The subject had closed-loop control over motion.

All subjects were securely restrained during the trials. Following training, all subjects were transferred to the criterion test condition (Condition C) for four trials.

Results. Tracking error scores were higher during training for the random buffet conditions. However, when tested under Condition C, subjects trained statically had significantly higher error scores than did subjects previously trained under random buffet conditions. It was concluded that simulated motion during training promotes transfer of training to the criterion condition (simulated low-altitude, high-speed flight through turbulence).

4. Buckhout, R., Effects of Whole-body Sinusoidal Vibration on Human Performance, (In preparation as an AMRL-TDR).

Purpose. To determine the effects of low frequency sinusoidal vibration in the tolerable range on the performance of tracking, pattern discrimination and reaction time tasks.

Method. Subjects were tested on an electromagnetically actuated shake table equipped with a standard aircraft seat; they were restrained with a lap belt and shoulder harness. The performance measures were integrated error on each dimension of a two-dimensional compensatory tracking task using a side-mounted control stick, percent correct judgements as to whether successive pairs of patterns presented on a 6x6 matrix of lights were the same or different, and response latencies to three randomly illuminated warning lights (one central and two peripheral). Vibration trials were 5-minutes long. Three trials were given on each test day with 1½ minutes between trials, and a 5-minute control trial was given at the beginning and at the end of each session.

The frequencies and amplitudes of vibration used were 5 cps at 0.20, 0.24, and 0.28 inches DA; 7 cps at 0.12, 0.14, and 0.16 inches DA; and 11 cps at 0.09, 0.11, and 0.12 inches DA. The amplitudes for each frequency represent 25, 30, and 35 percent of the one minute tolerances (using a linear interpolation) for these frequencies as given by Magid, Coermann, and Ziegenruecker (ref 14). The peak g forces at 5 cps were 0.26, 0.31, and 0.36; at 7 cps they were 0.29, 0.35 and 0.41 g's; and at 11 cps they were 0.55, 0.66, and 0.77 g's. Each subject experienced each of the 9 frequency-amplitude conditions. The 8 subjects who served in this experiment had also served in a preliminary investigation which was essentially identical to the presently described study.

Results. No significant effects were found for the pattern discrimination task. Although some vibration versus post-vibration reaction time comparisons showed significance, no clear cut trend was apparent in the pattern of results of the statistical tests. With the exception of the middle amplitude level (0.11 inches DA) at 11 cps for horizontal tracking, all vibration trials yielded significantly higher error scores than the corresponding post-vibration control trials. The minimum increase in tracking error under vibration in the vertical dimension was 34%, the maximum increase was 74%; the minimum increase in horizontal error was 10% and the maximum 48%. The greatest decrements were found in the vertical dimension at the 11 cps, highest amplitude condition.

Apparatus problems invalidated the measurement of integrated output g as recorded at the chest in this study. However, in the preliminary study, comparison of the integrated input g levels (recorded on a rigid support at chest level) and output g levels showed amplifications of 3.75, 2.32, and 1.47 at 5, 7, and 11 cps respectively. The highest absolute output g level was at 11 cps, the next highest at 5 cps, and the least at 7 cps. This was also the ranking of performance over frequencies from worst to best. Thus the author suggested that the direct mechanical effect of imposed vibration through the amplification factor may be important as a determiner of tracking performance. However, this relationship did not hold up over the three amplitudes within a given frequency. At both 5 and 11 cps, the tracking error scores for the middle amplitude condition were lower than the corresponding error scores for the lowest amplitude condition.

There was a definite indication that the tracking performance under vibration was superior in the second study as compared to the preliminary study, even though the subjects had reached an apparent asymptote during the training trials. This suggests that subjects learn something about coping with the vibration with experience.

5. Crook, M. N., A. C. Hoffman, N. Y. Wessell, J. W. Wulfeck, and J. L. Kennedy, Effect of Vibration on Legibility of Tabular Numerical Material: Experiments 1 - 4. AeroMed Laboratory of Wright Field, TSEAA-694-1F, Wright-Field, Dayton, Ohio, ATI 6672, June 1947.

Crook, M. N., G. S. Harker, A. C. Hoffman, and J. L. Kennedy, Effect of Vibration on Legibility of Tabular Numerical Material: Experiments 8 and 9, AeroMed Laboratory of Wright Field, WCREWD-694-1, Wright Field, Dayton, Ohio, ATI 139063, October 1948.

Crook, M. N., A. C. Hoffman, N. Y. Wessell, J. W. Wulfeck, and J. L. Kennedy, Amplitude Thresholds for Visual Perception of Vibration. Institute for Applied Experimental Psychology, Tufts College, Massachusetts, Memorandum Report No. 694-1R, February, 1949.

Crook, M. N., G. S. Harker, A. C. Hoffman, and J. L. Kennedy, Effect of Amplitude of Apparent Vibration, Brightness and Type Size on Numerical Reading: Experiments 10 to 14. Institute for Applied Experimental Psychology, Tufts College, Mass., AF Technical Report No. 6246, ATI 92222, September, 1950.

Purpose. Studies of the effects of apparent vibration of the visual field, illumination, type spacing and type size on visual acuity as indicated by the reading of numerical materials.

Method. Apparent vibration of the visual field was produced by the rotation of Risley prisms placed between the subjects' eyes and the stimulus materials. The stimulus sheets were 4½ inches square; they were located in a position normal to the subjects' line of sight at a distance of 14 inches from the eyes. The ap-
parent brightness of the stimulus materials was adjusted by the relative orienta-
tions of crossed polaroid filters positioned between the eyes and the stimulus
materials. Ambient room illumination was also controlled. The brightness
values were determined by Macbeth illuminometer readings made throughout the ex-
periments. Visual performance was assessed in some of the experiments by re-
quiring subjects to discriminate whether the members of a pair of digits were
the same or different. In others, subjects were required to add three digits
and specify whether the sum presented with them was right or wrong. A third kind
of experiment examined the thresholds for the perception of vibration.

Results. For the ranges of amplitudes of apparent vibration used in these ex-
periments, relatively little effect was produced on visual performance except
under relatively unfavorable conditions; i.e. small type sizes, low apparent
brightness and close type spacing. The thresholds for apparent vibration were
sensitive to frequency of the vibration, and the brightness; specifically, at
higher frequencies and at lower brightnesses thresholds were higher.

6. Dennis, J. P. The Effect of Whole Body Vibration on a Visual Performance Task, Report No. 104, Directorate of Physiological and Biological Research, C.E.P.R.E., (United Kingdom), AD 247 249, August, 1960.

Purpose. An investigation of the effects of a range of vibratory conditions upon speed and accuracy of reading digits.

Method. Twelve subjects were required to read a series of 2 digit numbers while
seated on a cam-driven vibration table. The numbers subtended a visual angle of
5 minutes at a distance of 10'10". Each subject was tested on six sessions:
each session consisted of a static trial followed by a "light" vibration (0.250 g)
trial, another static trial, a "heavy" vibration trial (0.500 g), and a final
static trial; durations of trials were not specified. Each S was exposed to 6
levels of "light" vibration (frequencies ranging from 5-27 cps; amplitude - 0.1
inch to 0.003-inch) and 6 levels of "heavy" vibration (frequencies of 7-90 cps;
amplitudes were 0.1 inch to 0.003 inch). A head mounted accelerometer was used
to measure g level at the head.

Results. A 6 x 6 Latin square analysis of errors, response times, and head movements was employed. Visual performance was significantly affected by all conditions under "heavy" vibration (0.50 peak g) and at all but one condition (19 cps) under "light" vibration (0.250 peak g) ($p < .05$). Heavy vibration increased errors over static conditions by 55%. Light vibration increased errors by 25%. Response times increased 3% under light and 10% under heavy vibration (not significant). Rate of change of acceleration of the head correlated with adjusted mean error scores, r = 0.61. This relationship was not consistent over the experimental conditions. The results indicate that subjects under vibration would have trouble reading an object of 5 minutes of arc under low illumination.

Discussion. It was concluded that the visual performance effects of vibration can be offset by reducing vibration at the head, and it was hypothesized that improved lighting conditions might improve visual performance.

7. Frazer, T. M., G. N. Hoover, and W. F. Ashe, "Tracking Performance During Low Frequency Vibration", Aerospace Med., Vol 32 (9), pp 829-835, September, 1961.

Purpose. An exploratory study of the effects of amplitude and plane of vibration on tracking performance with a vibrating versus a static display.

Method. Four subjects, two pilots and two non-pilots, were tested for two 60-second trials under all of the 48 different combinations of sinusoidal vibration yielded by four frequencies (2, 4, 7, and 12 cps), four double amplitudes (0.063, 0.125, 0.189, and 0.250 inches), and three planes of vibration (vertical, longitudinal (front-to-back), and transverse (side-to-side)). The subjects were seated on a minimum damping, wooden contour seat mounted on a three-degrees-of-freedom shake table. The maximum peak acceleration to which the subjects were exposed was 3.63 g. The subjects performed a two dimensional tracking task which consisted of a 9 x 9 matrix of lights and a floor-mounted control stick. The light at the center of the matrix was white and the concentric squares of lights were blue, green, yellow and red from the central to the peripheral portions of the display. For two of the subjects this display was attached directly to the shake table; for the other two subjects, the display was detached from the table so that it did not move with the motion of the table.

Results. The data of the two subjects who were tested with the moving display were subjected to an analysis of variance. The main effects in the analysis were vibration amplitude and frequency, vertical tracking error, horizontal tracking error and (based on the discussion) we assume that plane of vibration was also a main effect. The decrements in the vertical and transverse planes were large, whereas those in the longitudinal plane were small and not significant. The order of decrement as revealed by tracking error from least to greatest was the following: (1) vibration in the longitudinal plane had no significant effect on horizontal or vertical tracking; (2) there was some decrement in horizontal as well as vertical tracking when vibration was either vertical or transverse; and (3) control was poorest for vertical tracking with vertical vibration.

Frequency was found to be less important than amplitude in producing decrements in performance for any given plane of vibration.

Performance with the static display at the 0.25 inch D.A. was significantly poorer than the attached display in the majority of combinations of frequency and plane.

8. Gorrill, R. B. and F. W. Snyder, <u>Preliminary Study of Aircrew Tolerance to Low-Frequency Vertical Vibration</u>, Document No. D3-1189, Issue No. 36, Boeing Airplane Company, AD 155 642, 3 July 1957.

<u>Purpose</u>. A determination of the judgments by aircrewmen of short term vibration levels, and of the effects of vibration on visual-motor performance.

<u>Method</u>. The apparatus consisted of a B-47 seat, a control column and an oscilloscope. Two sets of cam-generated error signals were displayed as horizontally and vertically moving pips on the oscilloscope. Sinusoidal vibration in the frequency range of 3 - 30 cps with input accelerations up to approximately 2.5g, were used, with the intention of simulating the characteristics of those encountered in high-performance aircraft. Amplitude at each frequency level was increased while the subject performed the tracking task of nulling the pips; the vibration was stopped when he reported that the amplitude had reached each of the following subjective descriptions:

(1) Threshold of perception.
(2) Definitely or easily perceptible.
(3) Irritating or annoying.
(4) Maximum tolerable for continuous operations.
(5) Intolerable.

Each of the five subjects (pilots) were given static pre-test training on the tracking task to a criterion level, and the testing conditions were randomized.

<u>Results</u>. The subjective judgments indicated that the lowest tolerance levels were in the range from 8 to 15 cps. An efficiency score for the tracking task showed significant decrements to occur at 15 cps and at 1.5g. The more extreme judgments (vibration levels, 4 and 5) were accompanied by the poorest tracking performance. However, between subjects variability was quite large.

<u>Discussion</u>. The authors offer the following conclusions:

(1) Sinusoidal vibrations of 0.5g and greater, at frequencies in the 3-30 cps range and greater should normally be avoided (at 15 cps, acceleration should probably be less than 0.5g).

(2) At higher frequencies (15-30 cps), up to 2.0-2.5g can be tolerated safely by some individuals, indicating a short-period emergency maximum.

9. Hornick, R. J., <u>The Relative Effects of Noise and Vibration Upon Simple Reaction Time</u>, BRL Report No. 132, Bostrom Research Laboratories, Milwaukee, Wisconsin, January, 1961.

<u>Purpose</u>. A study of the relative effects of noise and vibration upon simple reaction time.

<u>Method</u>. Five male and three female subjects, aged 18 - 26 years, were each tested under four experimental conditions in counterbalanced order. The conditions were: (1) control (no noise or vibration); (2) noise alone (87 db.); (3) vertical vibration alone (3.5 cps at 0.30g); and (4) simultaneous noise and vibration (conditions 2 and 3 combined). The reaction time task required subjects to respond to the onset of a red signal light. During each twenty-minute session 40 signals were presented; the interval between signals ranged from 6-80 seconds.

<u>Results</u>. No significant difference was found in the effects of the four conditions which confirms the results of Schmitz <u>et al</u> (1960) that noise-vibration conditions have no effect on reaction time except immediately on cessation of vibration. It was also determined that there were no temporal trends in reaction time in any of the conditions.

10. Hornick, R. J., <u>The Effects of Tractor Vibration on Work Performance</u>, BRL Report No. 131, Bostrom Research Laboratories, Milwaukee, Wisconsin, June, 1961.

<u>Purpose</u>. Identification and specification of the types of vibration inherent in tractors in motion.

<u>Method</u>. Thirty male subjects were tested for one-dimensional (horizontal) compensatory tracking ability, RT, visual acuity, foot pressure constancy and body equilibrium. Ten subjects were tested under vertical vibration (0.9, 2.5, 3.5, 4.5, 5.5, and 6.5 cps, with intensity levels of 0.15, 0.25, and 0.35g for each). Twenty subjects were tested under transverse (side-to-side) vibration (1.5, 2.5, 3.5, 4.5, and 5.5 cps at the above intensity levels). Responses to light signals to the side of the subject and a Landolt ring directly in front of him served as measures of peripheral vision and visual acuity, respectively.

<u>Results</u>. Tracking ability was significantly impaired by vertical vibration with no apparent relationship to intensity or frequency. The subjects' reaction times were significantly slower (5% level of significance) after exposure to vertical vibration than before or during it. Visual acuity was not significantly affected. With respect to constancy of foot pressure, both intensity and frequency, as well as most of their interactions, were significant. There was no significant decrement in body equilibrium.

In transverse vibration, 1.5 cps was the most detrimental to tracking performance and decrements within frequencies were related to intensity increments. Tracking performance did not completely return to control levels during the

15-minute period following transverse vibration. RTs were not affected during vibration, but increased significantly following cessation of transverse vibration. Visual acuity was not impaired. The frequencies of 1.5 and 2.5 cps produced the greatest decrement in peripheral vision during the initial period of vibration, while peripheral vision following transverse vibration was better than that prior to it. Decrements in foot pressure constancy were related to increments of intensity, and frequencies of 1.5 and 2.5 cps produced the greatest effect, although recovery was complete on cessation of vibration. Errect postural position was not significantly affected by transverse vibration.

11. Hornick, R. J., C. A. Boettcher and A. K. Simons, <u>The Effect of Low Frequency, High Amplitude, Whole Body Vibration Upon Human Performance</u>, BRL Report No. E-123, Bostrom Research Laboratories, Milwaukee, Wisconsin, July, 1961.

<u>Purpose</u>. A study of the effects of transverse and longitudinal vibration on performance and on certain physiological functions.

<u>Method</u>. A multi-directional shake table with a mechanical drive mechanism was equipped with a straight-backed wooden chair. Two groups of 20 subjects each were exposed to five frequencies (1.5, 2.5, 3.5, 4.5 and 5.5 cps) and three levels of intensity (0.15, 0.25, and 0.35g) of vibration in four 15-minute time periods under both transverse (side-to-side) and longitudinal (direct front-to-back) vibration conditions. One-dimensional (horizontal) compensatory tracking, choice reaction time to peripheral stimuli, foot pressure constancy and peripheral vision were measured in a simulated driving situation. Subjects practiced for 1 hour prior to testing. Visual acuity was measured by means of a Landolt-ring target, and body sway was measured before and after each condition. Accelerometers monitored input at the table and motion at the head, chest and belt level of each subject to determine his individual "transmissibility." Respiration, oxygen consumption, metabolic rate, breathing frequency and ventilation were also recorded during the testing with periods of no vibration as reference points.

<u>Results</u>. For both transverse and longitudinal vibration, increments in amplitude produced decrements in performance within a frequency and there was a trend for tracking error to increase as time of exposure increased. The frequency level of 1.5 cps produced significantly greater tracking error with transverse vibration, but there was no significant difference between frequencies in the longitudinal direction. Compensatory tracking ability did not show complete recovery during the 15-minutes following exposure to vibration. Choice reaction time was not influenced by either transverse or longitudinal motion; however, reaction time did increase significantly following exposure to transverse vibration. Foot pressure constancy was most severely affected at 1.5 and 2.5 cps during transverse and at 3.5 cps during longitudinal vibration; error increased with intensity for both planes but there was no trend in error over time. Peripheral vision was impaired only during transverse vibration, and only during the first 15-minute exposure at 1.5 and 2.5 cps. During the post-vibration period peripheral vision was slightly better than before or during vibration. Neither visual acuity nor body sway were effected. Measures of transmissibility, particularly head movement, indicated that body disturbances occur near or below 1.5 cps in the transverse

condition. Respiratory measures of oxygen consumption, breathing rate, and total ventilation indicate that a state of hyperventilation probably occurs during horizontal vibration in both dimensions. Total ventilation during transverse vibration appears to increase with intensity of vibration.

12. Lewis, D., The Effect of Noise and Vibration on Certain Psychomotor Responses, Research conducted at the State University of Iowa by the Civil Aeronautics Administration, PB 50228 - CAA Division of Research Report No. 8, Washington, D.C., January, 1943.

Purpose. A determination of the effects of noise and vibration on performance on the Mashburn Apparatus, including supplementary studies of these effects on heart rate, breathing, tilt perception, brain waves, and hearing acuity.

Method. The Mashburn Automatic Serial Action Apparatus and a wooden seat were affixed to a shake-table which was mounted at its four corners on heavy coil springs. Forty-two non-pilots and thirty-eight pilot trainees were given 39 trials on this apparatus. Performance was measured under six conditions: (a) silence, (b) simulated aircraft noise at 85 dbs, (c) simulated aircraft noise at 110 dbs, (d) vibration at 0.008 and 0.012 inch D.A., (e) noise at 85 dbs combined with vibration at 0.008 and 0.012 inch D.A. vibration, (f) noise at 110 dbs with vibration at 0.008 and 0.012 inch D.A. The subject's adjustments of rudder, elevator and aileron were recorded on a polygraph.

The apparatus for measuring perception of tilt consisted of a 5-foot main platform which pivoted about a horizontal axis. Tilt angle was hydraulically controlled. A smaller platform mounted with a wooden seat, the vibrator housing and the control stick, provided for rotation of the subject either longitudinally, laterally or sagittally. The subject was blindfolded and then tilted at various angles up to 10° under the above six experimental conditions; he was required to return himself to the vertical position by means of the control stick. Pneumographic, ECG, and EEG records were made during the tests.

Results. Neither vibration nor noise produced performance decrements on the Mashburn apparatus. However, since the trainee group was superior (1% level of significance) to the non-pilot group the remaining analyses of variance were performed using trainee scores only. Neither noise nor vibration had any measurable effect on heart rate within a condition, but the difference between the first and last trials was significant at the 1% level. Regularity of breathing, breathing rate and heart rate were found to be unrelated to the experimental conditions. However, the subjects who appeared to be most highly motivated and gave the best performances tended to have the most irregular breathing patterns. Neither noise, vibration, nor a combination of these, affected estimates of tilt to a significant degree. Noise, the only variable analyzed for effect on the EEG, did not modify any feature of the EEGs significantly. When a test was made for hearing loss after a fifteen minute rest interval following an hour's exposure to noise at 110 dbs, significant losses in acuity were noted for frequencies between 1,000 and 6,000 cps.

13. Loeb, M. <u>Further* Investigation of the Influence of Whole Body Vibration and Noise on Tremor and Visual Acuity</u>, AMRL Report No. 165, Project 6-95 20-001, U.S. Army Medical Research Laboratory, Fort Knox, Kentucky, 22 October 1954.

<u>Purpose</u>. To determine the nature and extent of changes in visual acuity, manual tremor, and aiming tremor under the influence of intense noise and/or vibration.

<u>Method</u>. Eighteen subjects were divided into three equal groups which received 15, 25, and 35 cps vertical sinusoidal vibration respectively. "Light vibration" levels were achieved with platform double amplitudes of 0.068, 0.034, and 0.030 inches at 15, 25, and 35 cps respectively; "heavy vibration" double amplitudes were 0.112, 0.056, and 0.054 inches, also at 15, 25, and 35 cps respectively. Each subject was exposed to four conditions: (a) heavy vibration, (b) light vibration, (c) noise at 115 db (a recording of the platform in operation), and (d) neither vibration nor noise present (control). The subject performed 3 tasks: (a) a manual tremor task which required the subject to hold a stylus in the center of a 2 mm hole for one minute; (b) an aiming tremor task in which the subject aimed at a target with a rifle attached to an ataximeter which accumulated centimeters of vertical and lateral movement over a 30-second interval; and (c) a visual acuity task in which measurements were made of the subject's errors in judging the orientation of Ronchi rulings of varying degrees of coarseness. Each subject was tested at each amplitude for only one frequency to which he was randomly assigned. The vibration exposure times were 2½ hours per session. Performance was tested on six 20-minute trials for each session. The trials were distributed as follows: Trial 1 - pre-exposure; Trial 2 - beginning with exposure; Trials 3, 4, and 5 - after 40, 80, and 120 minutes of exposure respectively; and Trial 6 - immediately at the end of the exposure period.

<u>Results</u>. The variation in visual acuity as a function of trials and conditions was significant but not as a function of frequency. However, all 2-way interactions and the 3-way interaction of these three variables were also significant. Impairment in visual acuity at 15 cps was greater than at 25 and 35 cps. Manual tremor variations over trials, between conditions, their interaction and their interactions with frequency were highly significant; however, frequency was again not significant. The greatest effect on manual tremor was at 15 cps. Downward aiming tremor increased significantly during vibration; the greatest effect was produced by heavy vibration at 15 cps. Noise did not affect performance on any of the tasks.

*This report was preceded by Loeb, M., A preliminary investigation of the effects of whole-body vibration and noise. AMRL Report No. 145, 1954.

14. Magid, E. B., R. R. Coermann and G. H. Ziegenruecker, "Human tolerance to Whole Body Sinusoidal Vibration," Aerospace Medicine, 1960, 31, 915-924.

Purpose. The first experiment reported was designed to determine the maximum tolerable g forces for whole body sinusoidal vibration in the frequency range from 1 to 10 cps and 15 cps. The second study was designed to determine the ability of subjects to tolerate vibration for one minute at predetermined g values for frequencies from 1 to 20 cps; a second aspect of this study was aimed at determining the ability of subjects to tolerate three-minute exposures to slightly lower predetermined g values at frequencies from 1 to 10 cps.

Method. In the first experiment, a panel of 10 subjects was used; the same 10 subjects plus an additional 5 subjects served in the second experiment. A mechanical shake table was used to produce sinusoidal vibration at frequencies ranging of 3 cps and above; a vertical accelerator was used to produce the vibration at 1 and 2 cycles because the higher amplitudes could not be achieved with the mechanical shake table. In both experiments double amplitude was increased at a constant rate of .75 mm/sec for 3 cps and above and at 10 mm/second for 1 and 2 cps; in the first experiment, amplitude was increased until tolerance was reached and in the second until the predetermined double amplitude was reached.

The subjects were strapped into a modified T-33 aircraft seat equipped with a lap belt and shoulder harness. At the end of the arm rest was a button which the subject pushed to signal the operator to terminate the run. Prior to actual experimentation, each subject was given familiarization rides on the shake table and the vertical accelerator. The criterion of tolerance in the first study was based on the judgement of the subject, i.e., he was instructed not to stop the run until he thought continuation might result in personal injury. A similar instruction was used in the second study. The dependent variables in the first study were the verbal reports of bodily symptoms and tolerance by the g level reached when termination was requested. In the second study the dependent variable was the verbal report of symptoms; subjects were also asked to estimate the number of additional g's they could have sustained without injury. The independent variables in the first study were amplitude and frequency of vibration. In the second study the independent variable was amplitude-frequency combinations. Although direct comparisons were not made, exposure duration could also be considered to have been an independent variable across the two parts of the second experiment. The authors do not indicate the time intervals between successive trials but do mention that subjects were exposed to 4 to 6 frequencies in a given run in the second experiment.

Results. The results for the first experiment were expressed as the mean, standard deviation, and range of the g values for each frequency at which the subjects requested termination of the run. Tolerance was found to be lowest in the frequency range from 4 to 8 cps; at these frequencies vibration levels up to about 2.0 g's could be tolerated. Above and below this range of frequencies, tolerances increased markedly. The primary symptoms reported by subjects as their reason or reasons for halting the vibration were: (1) chest pain, (2) dyspnea, (3) abdominal pain, and (4) general discomfort. The authors felt that the spread of tolerance values was rather small in view of the differences in somatotype and the fact that a subjective response was involved.

In the second experiment, the vibration levels were selected so as to be "well within the range of tolerance." However, for the 1-minute study, 2 subjects could not complete the run at 7 cps and 2 could not complete the run at 9 cps; for the 3-minute study, 2 subjects could not complete 7 cps, one could not complete 8 cps and one could not complete 9 cps. The subjects estimated on the average that they could have tolerated 0.25 g more in the range from 4 to 8 cps and 0.5 g at the higher and lower frequencies. Only one subject in all of the runs showed abnormal electrocardiographic tracings; that was following the one-minute run at 8 cps and the subject recovered rapidly.

15. Mozell, M. M. and D. C. White, Behavioral Effects of Whole Body Vibration, NADC-MA-5802, Project NM 180112.4, Report No. 1, U.S. Naval Air Development Center, Johnsville, Pennsylvania, AD 156 470, 28 January 1958.

Purpose. Three studies on the effects of whole-body sinusoidal vertical vibration on the reading of digits (experiments 1 and 2) and on dual compensatory tracking (experiment 3).

Method. The vibration apparatus consisted of a cable-suspended platform driven by the rotary momentum of eccentrics. The frequency of the vibration was varied by changing the speed of the electric motor which actuated the eccentrics, and amplitude was varied by changing eccentrics. Amplitude was held constant for a given series of trials. The frequencies of vibration used in the first experiment (visual task) were 8, 13, 18 and 23 cps; four subjects were tested at a double amplitude of 0.05 inches and four were tested at a double amplitude of 0.10 inches. In the second experiment (visual task) five of the subjects from experiment 1 were tested at frequencies of 10, 20, 30, 40, and 50 cps and a double amplitude of 0.05 inches. In experiment three (tracking task) the frequencies used were 8, 13, 18, and 23 cps at double amplitudes of 0.05, 0.10 and 0.16 inches; four different subjects were tested at each amplitude.

In experiments 1 and 2, the subjects were seated in an aircraft seat mounted on the vibration platform; they were required to read off a series of 12 three-digit numbers presented at a distance of 7 feet. The digits, which were white on black, were 0.25 inches in height. They were presented on a mileage indicator which was not attached to the vibration platform. Each number was presented for five seconds with seven seconds between numbers. The duration of a given trial at a given frequency was two minutes 17 seconds. The duration of a session was about 30 minutes.

In experiment 3, subjects were required to perform a two dimensional compensatory tracking task displayed as a horizontal line on a two-inch oscilloscope. The subjects compensated for the motion of the line by manipulating an aircraft control stick. Both the display and the stick were mounted on the platform along with the aircraft seat. Trial durations were two minutes under each of the vibration conditions. Rest periods between trials were four minutes long. Subjects were given one hour of practice on the task before the experiment began.

Results. In the first experiment the visual task was not affected by increasing the double amplitude from 0.05 inches to 0.10 inches. However, significant increases in errors did occur as the frequency of the vibration increased from 8 cps (where performance equaled that under the control condition) through 23 cps. In the second experiment, with double amplitude held constant at 0.05 inches, errors increased as frequency increased from 10 through 40 cps with no difference between 40 and 50 cps.

The performance of the subjects in experiment 2 was somewhat better, presumably because of experience they gained from having served in experiment 1.

In experiment 3, tracking error in the horizontal dimension was not affected either by frequency or by amplitude; there was also no effect for the vertical dimension other than an interaction between amplitude and frequency.

16. Parks, D. L. A Comparison of Sinusoidal and Random Vibration Effects on Human Performance, Technical Report D3-3512-2, The Boeing Co., Wichita, Kansas, AD 261 331, 28 July 1961.

Purpose. An examination of the relation between certain physical descriptions of vertical vibration and data on human performance.

Method. The power spectral density (PSD) of vertical aircraft turbulence was simulated in order to compare performance under PSD (random) with that under sinusoidal vibration. The apparatus consisted of a human vibration platform on which was mounted a standard aircraft seat. Plywood was substituted for the cushion to insure the most complete transmission of vibration to the subject. A large aircraft control column, wheel, and special test display panel were mounted directly in front of the subject. A vertical compensatory tracking task was presented on an amber CRT; the subject was required to keep a horizontal light beam aligned with a fixed reference mark on the face of the CRT. He was also required to keep a vertical line at the center of a horizontal slot above the CRT. Four red reaction time lights were also located on the display panel.

Ten Boeing-Wichita employees with considerable experience on the task, though not under vibration, served as subjects. Each subject was tested under each of the ten following vibration conditions:

0.50 Amplitude Power Spectral Density*
Full Power Spectral Density*
0.75 cps Random Amplitude, 4.26 inches DA Maximum
0.75 cps Random Amplitude, 1.7 inches RMS
2.5 cps Random Amplitude, 2.16 inches Maximum
2.5 cps Random Amplitude, 0.09 inches RMS
0.75 cps, 1.57 inches DA
0.75 cps, 4.52 inches DA
2.5 cps, 0.26 inches DA
2.5 cps, 1.08 inches DA

*Based on an approximation of a recording of turbulence encountered in an actual aircraft flight.

Results. On a given day, a subject was tested under five of the ten vibration conditions and under the remaining five on a subsequent day. The specific tests and their sequence for a given subject were determined by a Latin Square matrix. Individual vibration trials were four minutes in duration; four minute non-vibration trials and two-minute rest periods were interspersed between vibration trials. Analysis of variance indicated that vibration conditions was a significant factor as regards the vertical dimension of the tracking task, but no changes were indicated for the horizontal dimension or for reaction time. Tukey's gap test revealed that performance under sinusoidal vibration at 2.5 cps, 1.08 inches DA was significantly poorer and, at 0.75 cps, 1.57 inches DA, was significantly better than performance under any of the other vibration conditions.

17. Parks, D. L., and F. W. Snyder, Human Reaction to Low Frequency Vibration, Technical Report D3-3512-1, The Boeing Co., Wichita, Kansas, AD 261 330, 24 July 1961.

Purpose. A study to obtain judgments of vibration intensities in the range of 1 - 27 cps. The first study of a series designed to determine the effects of vibration on human performance for a broad range of human skills.

Method. A hydraulically actuated shake table was used to provide vertical, sinusoidal vibration at frequencies of 1, 1.5, 2, 4, 6, 10, 14, 18 and 23 cps for seven subjects (Group A) and at 1.5, 3, 5, 8, 12, 16, 18, 20 and 27 cps for 9 subjects (Group B). The vibration platform was mounted with a standard aircraft seat having felt-covered plywood in place of the seat cushion and a heavy aircraft control wheel and column in the normal operating position. Four categories of subjective judgments were recorded along with ECGs. The subject was seated on the shake table and the amplitude of vibration (at one of the above-listed frequencies) was increased from zero. The subject was instructed to identify four subjective points of vibration severity: (1) definitely perceptible, (2) mildly annoying, (3) extremely annoying and (4) alarming Each subject was exposed for one trial at each of three frequencies on a given day. For the first two trials (frequencies) on a given day, when the vibration level became "alarming" the subject released a stop switch at which time the vibration ceased. On the third trial of a day, the subject reported verbally that the level was alarming but held the stop switch down and the vibration amplitude was gradually decreased. During the decreasing amplitude period, the subject again identified the three lower categories of severity.

Results. Curves obtained by integrating the data and plotting a smooth function were made for analysis of vibration judgments vs velocity, acceleration and double amplitude. Individual curves indicated that overlap between levels among the subjects' judgments occurred, but that distinct differences between levels do exist. The statistical analysis suggested that judgment of acceptability of vibration is affected by frequency. Subject differences were large, presumably at least partly as a result of differences in orientation and framework; the fact that the general curve trends were similar for all subjects was considered as evidence that these differences were of a semantic origin. According to a tabulation of reports of affected body area as a function of frequency, the effect shifted from the buttocks and lower thoracic abdominal areas at low frequencies to the upper body areas as frequency increased, and were concentrated in the head region at 27 cps. The reports of effects on extremities were less clear-cut, but a general trend was noticed i.e., from whole extremity effects to more localized effects as frequency increased.

18. Rulon, P. J., P. B. Sampson and B. Scholan, The Effects of "G" Forces on the Performance of Teletype Operators. Technical Report No. 6568, Educational Research Corporation, USAF, Wright-Patterson AFB, Ohio, October 1951.

Summary. Twelve "airsick-resistant", proficient, teletype operators were tested during flight under steady state accelerations between 1 and 3g with some turbulence also present. A comparison was made between the performances of six touch teletypists and six hunt-and-peck typists during six test flights. It was found that the speed and accuracy of hunt-and-peck typists improved under "g", while the converse was true for touch typists. The touch typists found that their hands became "disoriented" to the keyboard, leading to response errors (wrong finger) and displacement errors (hand on wrong keys). A large practice effect was noted for all subjects indicating a large amount of adaptation to "g". The operators became more aware of auditory, visual and kinesthetic cues in anticipating the aircraft maneuver and thus compensating for the forces. They found compensatory actions impossible in turbulent air, however, and the sudden "bumps" were very disturbing. Specification of errors as a function of magnitude and duration of "g" was not given in this report.

19. Schmitz, M. A., The Effect of Low Frequency, High Amplitude Vibration on Human Performance, Bostrom Research Laboratories Progress Report No. 2a, for Office of Surgeon General, Department of the Army, Washington 25, D.C., AD 218 201, January, 1959.

Purpose. To study the effects of frequency, amplitude and duration of whole body, vertical vibration on human psychomotor performance.

Method. Eighteen young male students, seated on a contour wooden chair which was mounted on a 3' x 5' mechanical shake table, were subjected to the following tests:

(1) Hand tremor - the subject was seated with his right forearm resting on a table with a small foam pad beneath his wrist; he was instructed to place his right index finger into a plastic finger cup at the end of a long flexible cantilever beam (restricted to vertical displacement) and to hold his hand as steadily as possible. Tremor was measured before and after vibration by means of a strain gauge bridge and recorded by an oscillograph.

(2) Before and after vibration measurements of body sway were made by means of a headpiece attached to a flexible, cantilever beam; two sets of strain gauges were used to give measures of fore-aft and side to side body sway.

(3) Visual acuity was tested by means of Landolt rings. A descending series of 8 measurements was made during the first and last 10 minutes of a 30-minute segment (not specified in detail) of each vibration session and the control session.

(4) A simulated driving task was used to test compensatory tracking (integrated error in the horizontal dimension) foot pressure constancy (integrated error) and foot RT.

(5) Accelerometers fastened to the subject's head and on his belt measured whole body-response to vibration with reference to readings given by an accelerometer attached to the top of the vibration table.

Intensity levels of vibration were 0.15 g and 0.30 g at 3.5 cps and 0.18 g and 0.35 g at 2.5 cps. However, the analyses of variance considered only the g levels.

The test procedure was as follows. The subjects performed the simulated driving task for a period of 15 minutes prior to the test run. At the end of this 15-minute pretrial, the vibration was turned on for the vibration sessions or a tape recording of the noise of the machine for control sessions. The sessions, which were 90-minutes in duration, were arbitrarily divided into 15-minute "trials." At the end of the session, a 15-minute post-vibration trial was given.

Results. The effects of intensity of vibration, trials, and the interaction of trials and intensity, were significant at the 1% level for both tracking performance and for foot pressure constancy. However, the significance of the trials effect was entirely a product of the difference between the pre- and post-trials as compared to the vibration trials. Although foot RT scores showed a significant between trials effect, no systematic trend is present; in fact the author appears not to accept the validity of this result. The post-vibration measures of frequency and magnitude of hand tremor and body equilibrium did not differ significantly from the control measures. There were significant differences in visual acuity among the intensity conditions. However, a breakout of the effects by frequency-intensity conditions, indicates that the significance of this effect is almost entirely attributable to the two vibration g levels at 3.5 cps. Expressed as a percent of the control measures, the acuity decrements were as follows: 11% and 23% at 0.15 and 0.30 g respectively for 3.5 cps; and 4% and 3% for 0.18 and 0.35 g respectively for 2.5 cps.

The vibration was amplified by the subjects as evidenced by a comparison of the output of an accelerometer placed on the subject's head and that of an accelerometer placed on the table. Specifically, the increases were 126% and 110% at 0.15 and 0.30 g respectively for 3.5 cps and 33% and 46% at 0.18 and 0.35 g respectively for 2.5 cps. The output of the accelerometer at the subject's belt was intermediate with respect to the outputs of the ones at his head and on the table.

Discussion. The author concludes that the frequency of vibration is a more important determiner of performance than is intensity. This is stated to be primarily a product of the resonance characteristics of the human body. The author does not discuss the fact that body sway was not significant in this study but was reported as significant in the study by Simons and Schmitz (January 1958).

20. Schmitz, M. A., A. K. Simons, and C. A. Boettcher, The Effect of Low Frequency, High Amplitude, Whole Body Vertical Vibration on Human Performance, Bostrom Research Laboratories and Department of the Army, Office of the Surgeon General, Final Report, 1 April 1957 to 31 January 1960.

Purpose. A study of the effects of low frequency, high amplitude, whole body vertical vibration on human psychomotor performance, and specification of the effects with respect to duration of exposure and type of task.

Method. The apparatus, tasks, and measures were the same as those in the previous study (Schmitz, 1959). Frequency levels of vibration were - 0.9, 2.5, 3.5, 4.5, 5.5 and 6.5 cps, each at intensities of 0.15, 0.25 and 0.35 g. Exposure periods were 30 minutes long.

Results. There was a significant decrement in tracking performance in the experimental conditions and this decrement appeared to be a function of increases in both frequency and intensity of vibration. The error for foot pressure constancy was similarly affected. The only difference in choice RT appeared in post-trials, just after cessation of vibration; specifically, longer reaction times were associated with the lower input intensities. In contrast to the results reported earlier by Schmitz (reference 19), visual acuity was not significantly affected under vibration. Accelerometer readings indicated that 4.5 cps was the point of whole-body resonance, and that the transmissibility values differed at various points over the body.

21. Simons, A. K. and M. A. Schmitz, The Effect of Low Frequency, High Amplitude Whole Body Vibration on Human Performance, Progress Report No. 1, Research and Development Division, Office of the Surgeon General, AD 157 778, January, 1958.

Purpose. An exploratory study of the effects of low frequency, high amplitude vibration on human psychomotor performance, and specification of the effects with respect to duration of exposure.

Method. The driving task, hand tremor, body sway, and visual acuity measures were the same as those described in Schmitz (reference 19), except that tests of tapping rate, mental addition, hand reaction time and depth perception (Howard-Dolman apparatus) were also given. Three treatments were presented to each of ten subjects in random order, viz, (1) 2.5 cps at 0.50-inch DA or 0.17g (2) 3.5 cps at 0.50-inch DA or 0.31g, and (3) a static run. Measurements were taken before and after each treatment and at 15-, 20-, or 30-minute intervals during the 120-minute experiment sessions.

Results. Neither the tapping rate nor mental addition tests were reported to show significant effects which could be attributed to different levels of acceleration. The results of the hand tremor test were uninterpretable because of artifacts produced by the equipment. Significant effects were reported for hand RT ($p < .05$), body sway, depth perception, visual acuity, tracking and constancy of foot pressure (all $p < .01$).

Discussion. The authors suggest that the increased decrements over time in visual acuity and foot pressure constancy under vibration (especially at 3.5 cps) may indicate possible fatigue effects. There is a serious question as to the appropriateness of the analysis applied to the data. Specifically, it appears that the trials effect is used as the error term to test the effects of intensity. If this is true, the statistics have, at best, a rather unusual meaning.

22. Tinker, M. A., "Effect of Vibration Upon Reading," Amer. J. Psychol., Vol 61, pp 386-390, 1948

Purpose. To study the effect of vibration upon speed of perception as measured by reading speed.

Method. Two groups of 69 students were presented with Forms I and II of Tinker's Speed of Reading Test in a well lighted (16 foot candles) laboratory. The control group was tested on the forms under the condition of constant noise, while the experimental group read during vibration of the reading stand at the rate of 5 cps and 0.063 inches D.A. in addition to constant noise. Reading periods were limited to ten minutes and scores were taken every five minutes.

Results. Vibration was found to have reduced reading speed by 5.19% in the first five minutes and by 5.47% in the second five minutes. The scores of the control group were superior to those of the experimental group ($p < .01$).

SUMMARY TABLE OF RESEARCH RESULTS

Tracking Tasks	N	Vibration Parameters	Results
a. Ashe (ref 1) 2-dimensional compensatory	5	2,4,6,8,11 & 15 cps; 0.065 & 0.13 inch DA (0.03-1.41g); 20 minute exposures.	Significant performance decrements at all frequencies at 0.13 inch DA.
b. Besco (ref 2) vertical compensatory	4	Simulated turbulence with "gusts" at 2 ft/sec RMS & at 4 ft/sec RMS; the simulator responded to the subject's control motions.	Significant performance decrements for both gust conditions.
c. Buckhout (ref 3) vertical compensatory	24	Random vertical buffeting at 3 ft/sec RMS & at 1/3 of this value. Involved use of a simulator that responded to the subject's control motions. 12 two-minute trials of training - 4 two-minute trials during testing.	Subjects trained with no buffeting had significantly poorer tracking scores when tested under high buffeting than those trained under high buffeting.
d. Buckhout (ref 4) 2-dimensional compensatory	8	5 cps - 0.20, 0.24 & 0.28 in. DA (0.26, 0.31 & 0.36 g's) 7 cps - 0.12, 0.14, 0.16 in. DA (0.29, 0.35 & 0.41 g's). 11 cps - 0.09, 0.11, 0.12 in. DA (0.55, 0.66 & 0.77 g's). Three 5-minute vibration trials per session, 1.5 minutes between trials.	Significant increases in integrated error, both dimensions, greatest for vertical. Vertical decrements 34 to 74%; horizontal - 10 to 48%. Evidence of improvement with experience with vibration.
e. Frazer (ref 7) 2-dimensional compensatory	4	Frequencies: 2,4,7 & 12 cps; Double Amplitudes: 0.063, 0.125, 0.189 & 0.250 inches; planes: vertical, longitudinal (front-to-back), & transverse (side-to-side). Maximum acceleration was 3.63 g. Two 60-second trials given under each of the 48 conditions.	Greatest decrements were noted with vertical vibration and the vertical tracking component.
f. Gorrill (ref 8) 2-dimensional compensatory	5	Frequencies of 3 to 30 cps up to 2.5 g in vertical dimension. Exposure durations were a function of the tolerance level.	Tracking decrements were pronounced at 15 cps at 1.5g.

Tracking Tasks	N	Vibration Parameters	Results
g. Hornick (ref 10) 1-dimensional (horiz) compensery	50	30 subjects at 0.9, 2.5, 3.5, 4.5, 5.5 & 6.5 cps vertical vibration at 0.15, 0.25 & 0.35g. 20 subjects at 1.5, 2.5, 3.5, 4.5 & 5.5 cps transverse (side-to-side), at above g's.	Significant decrements under all vertical conditions. 1.5 cps worst for transverse.
h. Hornick (ref 11) 1-dimensional (horiz) compensatory	40	Transverse and longitudinal (front-to-back) at 1.5, 2.5, 3.5, 4.5, & 5.5 cps each at 0.15, 0.25 & 0.35 g. Four 15-minute exposures at each condition.	Increasing g led to greater decrements. 1.5 cps worst for transverse. No frequency differences for longitudinal.
i. Mozell (ref 15) 2-dimentional compensatory	12	Experiment III - frequencies were 8, 13, 18, & 23 cps at 0.05, 0.10 & 0.16 in. DA; trial durations were 2-minutes with 4-minutes rest between trials.	No effects on tracking scores. Interaction between amplitude and frequency in vertical scores.
j. Parks (ref 16) 2-dimensional compensatory	10	Vertical vibration - simulated aircraft turbulence at 2 amplitudes, 0.75 cps random amplitude and sinusoidal and 2.5 cps random amplitude and sinusoidal. (See summary for exact figures). Exposures were 4 minutes, 5 trials per day.	Significant effects found for vertical dimension, none for horizontal. Sinusoidal, 2.5 cps, 1.8 in. DA best vibration condition.
k. Schmitz (ref 19) 1-dimensional (horiz) compensatory	18	Vertical vibration at 2.5 cps at 0.18 and 0.30g. Trials 90 minutes.	Significant effect of intensity on tracking.
l. Schmitz (ref 20)		Vertical vibration at 0.9, 2.5, 3.5, 4.5, 5.5 & 6.5 cps at 0.15, 0.25 & 0.35g. 30 minute exposures.	Significant tracking decrements with increases in frequency and amplitude.

Tracking Tasks	N	Vibration Parameters	Results
m. Simons (ref 21) 1-dimensional (horiz) compensatory	10	Vertical vibration: 2.5 cps at 0.17g and 3.5 cps a 31g. 120 minute exposures.	Significant tracking decrements under both conditions.
Vision & Reaction Time			
n. Buckhout (ref 4) Pattern discrimination	8	See entry d.	No effects.
o. Crook (ref 5)	-	Apparent vertical vibration was produced by rotating Risley prisms between the subjects eyes and the stimuli.	Decrements only under least favorable conditions, i.e., small type sizes, low brightness, and close spacing of numbers.
p. Dennis (ref 6) Reading numbers	12	Vertical sinusoidal, 0.25 g at frequencies from 5-27 cps (0.1 - 0.003 inches D.A.) and 0.50 g at frequencies from 7-90 cps (0.1 - 0.003 inches D.A. Trial durations not specified.	Decrements under both amplitude levels except at 0.25 g at 19 cps; errors increased 25% at 0.25 g and 55% at 0.50 g. Head motion in g's correlated 0.61 with errors.
q. Hornick (ref 9) Visual reaction time	8	Vertical sinusoidal 3.5 cps, 0.30 g. Trials were 20 minutes long. Also studied effects of noise. Responded to red signal light.	No effect of vibration or noise on task, but longer response times following vibration.
r. Hornick (ref 10) Reaction time and Visual Acuity	30	See entry g. Response to light signals and judgement of Landolt Rings.	Reaction times were significantly slower after than during vibration - visual acuity not affected.

Vision & Reaction Time	N	Vibration Parameters	Results
s. Hornick (ref 11) Reaction time, visual acuity, response to peripheral stimuli	40	See entry h. Response to light signals, judgement of - Landolt Rings, and response to peripheral stimuli. Trials were 15 minutes long.	Reaction time slower following vibration. Visual acuity not affected. Peripheral vision affected only by side-to-side vibration.
t. Loeb (ref 13) Visual acuity and aiming tremor (with a rifle)	18	Vertical sinusoidal; frequencies were - 15 cps at 0.068 and 0.112 inches D.A. 25 cps at 0.034 and 0.056 inches D.A. and 35 cps at 0.030 and 0.054 inches D.A. Exposure times were 2½ hours.	Visual acuity was decreased by vibration; frequencies did not differ. Aiming tremor increased significantly with vibration.
u. Mozell (ref 15) Reading digits	8.5	Exp. I - 8, 13, 18 and 23 cps vertical sinusoidal at 0.05 and 0.10 inches D.A.; Exp. II - 10, 20, 30, 40 and 50 cps at 0.05 inches D.A. Trials were 2 minutes 17 seconds.	Effect of amplitude not significant but increasing frequency was in Exp. I. Exp. II showed significant effect of frequency except at 50 cps vs 40 cps.
v. Parks (ref 16) Reaction time	10	See entry j. Response time to 4 red lights.	No effect of vibration.
w. Schmitz (ref 19) Visual acuity and foot reaction time	18	See entry k. Measured with Landolt Rings.	Major effect was found at 3.5 cps; decrements were 11 and 23% at 0.15 and 0.30 g respectively. Foot reaction time showed no effect.
x. Schmitz (ref 20) Reaction time Visual acuity		See entry l.	Reaction time was longer following vibration; visual acuity not affected.

Vision & Reaction Time	N	Vibration Parameters	Results
y. Simons (ref 21) Reaction Time Visual Acuity		See entry m.	Significant decrement in reaction time and visual acuity.
z. Tinker (ref 22) Reading	138	Apparent vibration - reading stand vibrated at 5 cps and 0.063 inches D.A.; trials were 10 minutes.	Significant decrease in speed of reading.

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13. ABSTRACT

This report is a compilation of summaries of published reports dealing with the human performance effects of low frequency, high-amplitude vibration. The research described in each report is covered as fully as possible as regards the information needed to evaluate the investigations with respect to their applicability to Air Force operational human performance problems and research efforts. However, the implications of the reports for Air Force problems are not discussed as such.

Security Classification

Security Classification

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Human Performance						
Vibration						

Security Classification