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EFFECTS OF LOW FREQUENCY VIBRATIONS

ON OPERATOR'S RESPONSE TIME

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EFFECTS OF LOW FREQUENCY VIBRATIONS
ON OPERATOR'S RESPONSE TIME

By

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ABSTRACT

EFFECTS OF LOW FREQUENCY VIBRATIONS
ON OPERATOR'S RESPONSE TIME

By

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A simulated vibrating platform was used to expose 15 male agricultural engineering students to vertical vibrations for 10 minutes for each frequency and amplitude combination. Ten participants were exposed to vibrations between 1 and 3.5 Hz., at 20.32 mm, amplitude and 5 particpants were exposed to vibrations between 1 and 8 Hz., at 9.52 mm amplitude.

Participants were involved in a tracking operation during the vibration period. They responded to random visual and audio warning signals by using foot pedals. Response time was measured and correlated to the vibration intensity and type of signal. The subjective verbal impressions of the test were also recorded and correlated to the vibration intensity.

In general, vibrations increased response time. As the vibration intensity increased, participants felt discomfort in the trunk region. The participants also felt that their performance was degraded.

The audio warning signal was superior to the visual one.

THIS THESIS IS DEDICATED TO

MY PARENTS,

CHISWAKHATA W. MKANDAWIRE

&

MLAWONA A. NYARUWANGA CHIRWA,

AND MY LATE SISTER,

SEKANAYO MKANDAWIRE

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Many individuals contributed to this study in many different ways. Although not all of them are mentioned by name, I extend my gratitude to all of them for their contributions.

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Friends, for the support.

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I. INTRODUCTION

1. The effects of Vibrations upon the Human Body

In almost every society today there is some form of mechanization that involves the use of tools, equipment, machinery, and transportation vehicles. Through the use of these aids, people are exposed to vibrations which may cause psychological and/or physiological discomfort and/or damage. Some vibrations have the potential to cause instantaneous discomfort while others have delayed effects.

Operators of farm machinery are exposed to vibrations as a result of operating equipment over uneven ground surface and reciprocating and rotational parts of machinery. These vibrations are transmitted through parts of the body in contact with the vehicle. The vibrations have the potential to cause physiological stresses on the body depending upon the magnitude and duration of exposure and also upon mechanical properties of various organ-tissue complexes of the human body. The organ-tissue complexes consist of masses suspended by elastic tissues with built-in dampers. When the forcing frequency approaches the natural frequency of any such sub-system, the sub-system goes into resonance. The human body, being made up of several of such sub-systems, has several frequencies at which different specific sub-systems will resonate.

Experience and investigations have revealed that many persons exposed to vibrations of sufficient intensity or duration may experience not only health problems such as back pain, digestive difficulty, and Raynaud's Disease but also may have a poorer performance level.

A number of studies have shown vibrations to have a detrimental effect on many of the physiological functions of the body.

Although vibration exposure standards are still not completely established, there is general agreement about the range of vibration and exposure that is considered to be hazardous to a worker's health.

In the area of performance, there is less documentation and agreement upon the effects of vibrations on performance and response time. As the speed of response and appropriateness of action taken is paramount in avoiding an accident in many agricultural situations, it is of considerable importance to investigate and understand how vibration exposure affects an operator's response time in various situations.

II. LITERATURE REVIEW

1. Problems in Vibrational Research

Several authors have written on the effects of vibrations on man. Hornick (1963) points out that problems have been encountered relating to procedural variations, terminology, performance evaluation, random verses sinusoidal vibrations, and single and multiple factors involved in experimentation.

Considerable work has been done on the effects of sinusoidal vertical vibrations on man,and the range that has been investigated rather extensively is that between 1 and 20 Hz. Cope (1960) states that vibrations in this range have been reported by operators of transport equipment. Magid and Coerman (1963) report the presence of this frequency range in high performance jet aircraft and space vehicles, trucks, tractors, motorcycles and other vehicles.

2. Physiological Responses to Vibrations

Several authors have reported physiological problems associated with this frequency range. Magid and Coerman (1963) report that man absorbs most of the vibration energy between 5 and 20 Hz. because his built-in vibration-isolation capacity is least effective in this range. And they attribute this phenomenon to the fact that several apparent resonances of body structures occur within this range. These authors report findings of increased blood pressure between 2 and 5 Hz.; reduced blood pressure between 6 and 20 Hz.; and increased respiration rate between 3 and 15 Hz., except between 5 and 7 Hz.

3. Physical Responses to Vibrations

Several studies have reported problems of visual acuity in humans as a result of exposure to vertical vibrations. Goldman and Henning (1960) report that resonance of the head (of a seated man) may contribute to reduced visual acuity. Cope (1960) and Guignard and Irving (1960) report that low frequency vibrations affect visual acuity in aviation. Lange and Coerman (1963) state that transmission of vibrations to eyeball is likely to produce a shift of image on the retina and may possibly deform the eyeball. These authors report that visual acuity is mostly affected between 25 and 40 Hz. and between 60 and 90 Hz. However, between 3 and 5 Hz. acuity is still affected, probably because the head (of a seated man) resonates at this range.

Physical affects of vertical sinusoidal vibrations on man and animals have been reported. Guignard and Irving (1960) report that 5 Hz. is the dominant resonance of a seated man. They further report that variations in resonance frequency may occur due to such variables as body size, posture and muscular tension, force of vibration, site and direction of application, clothing and sitting position.

Murrell (1965) reports that if a man is sitting in an uncusioned seat, his head resonates between 1½ and 3 times the amplitude of the seat if exposed to frequencies between 3 and 6 Hz. Cope (1960) reports similar results. Goldman (1957) and Cope (1960) report that effects of vibrations on man depend on structural complexity of the human body, i.e., the way in which the different dynamically suspended masses respond to vibrations of different frequencies. Damon, Stoudt and Farland (1966) say that the severity of damage depends on such physical properties as tissue elasticity, frequency of response, tensile and shearing strength and compressibility. Riopelle et al. (1958) report the detachment of the otolithic membrane of the vestibular apparatus in monkeys at vibrations of 10 Hz. and amplitudes between .00635 m and .0127 m. Roman (1958), Fowler (1955) observed extensive lung damage in mice and cats respectively. White and Mozell (1958) record chest pains in man at frequencies of 15 Hz. within 25 seconds of onset at an amplitude of .00381 m. Gierlee (1959) reports high incidents of osteoarthritis, traumatic fibrositis, herniated disks, coccygodynia, lumbosacral pain in drivers of trucks, tractors, motorcycles and other vehicles. Clark (1963) reports the following resonances in humans: mandible, 6 to 8 Hz.; facial skin, 13 Hz.; chest, 4 to 9 Hz.; substenal area 9 to 11 Hz.; pelvic region 9 to 20 Hz.; between 10 and 16 Hz. there is a definite urge to urinate and defecate; skeletal musculate

1 to 10 Hz.; and lumbosacral area 6.5 to 20 Hz. Coerman, Ziegenruecker, Wittmer an von Gierke (1960) report that the resonance frequency for thoraco-abdominal system lies at 3 Hz. This is where most damage occurs.

4. Subjective Responses to Vibrations

a) Perception and Tolerance

Studies have been conducted on perception and tolerance levels in humans. Lange and Coerman (1963) observe that vertical vibrations may affect the dioptric mechanism resulting in physiological and phychological difficulties. Parks (1963) derived the following judgment levels: threshold of perception, definitely perceptible, mildly annoying, extremely annoying and alarming. Goldman (1948) derived three levels of judgment: perception, unpleasant and intolerable. In any case Parks noted significant individual differences which he hypothesized to be due to semantic differences. Coerman (1962) observes that up to about 2 Hz. the human body responds as a pure mass, i.e., all parts move together. Resonance occurs at 4 to 6 Hz., 9 to 15 Hz. and when the body is in a sitting position and relaxed (as opposed to upright) resonant frequencies are reduced. Coerman further states that different individuals respond to the same subjective stresses in different ways. He goes on to say that this does not mean that physiological effects in some people are different from those in others, but rather, that only the secondary affects due to physiological stress may be different. Coerman also states that human performance would deteriorate under the influence of vibrations at resonant frequencies.

Many authors have noted differences in individual tolerance and performance during exposure to vibration. Magid and Coerman (1963) state that individual differences in tolerance are a manifestation of direct or indirect mechanical excitation of various organ-tissue complexes, and the resulting stimulation of associated sensory receptors. The organ-tissue complexes having lower resonance are affected at lower frequencies while those with higher resonance are affected at higher frequencies.

b) Performance

Several authors have indicated that there is no conclusive evidence on how vertical sinusoidal vibrations affect human performance. Murrell (1965) states that little is known about the effects of vibration on performance efficiency. Murrell points out that differences in individual attitudes towards vibrations is one of the reasons it is difficult to determine the effects of vibrations on performance. He goes on to say that while some people may accept vibrations, others may dislike them, and others yet may not even notice them.

5. Research Findings on Response Time

In physical education studies, work has been done on response time measurement. Sage (1971) states that reaction time and movement time are major components of response time and hence strongly affect response time. Colgate (1968), among others, states that reaction to auditory stimuli is faster than that to visual stimuli. Thus he states that response time to an auditory signal is lower than that to a visual signal. Sage (1971) and Munro (1951) among others report that forewarning cues improve reaction time. These authors also state that if a subject has to make a choice between signals, response time gets worse, i.e., a complex task increases response time. Several authors have stated that such factors as attention, motivation, anxiety, age, sex, and present state of the subject affect response time. Woodworth and Schlosberg (1958), Hodgkins (1963) and Henry (1952) found no evidence to show that reaction time is improved through practice. Tweit et al. (1963), on the other hand, states that movement time can be improved through practice. Smith (1961) and Henry both report no correlation between fast reaction time and movement time.

6. International Standard (ISO) for Vertical Whole Body Vibration

The International Organization for Standardization has put together an International Standard (ISO) which specifies exposure limits for vertical, whole body vibrations in the 2 to 8 Hz. range transmitted to the human body in normal health. The ISO defines people in normal health as, "people who are considered fit to carry out normal living routines, including travel, and to undergo the stress of a typical working day or shift."

The ISO has been compiled using data from many and different investigations with specific concerns. As a result of this diversity, the ISO is not absolute, but rather, it provides an accepted guideline for a wide range of situations that involve exposure of man to vertical, whole body vibrations.

The ISO for vertical, whole body vibration is generally broken down into three boundaries:

a) Fatigue-Decreased Proficiency Boundary (Efficiency Zone)

This boundary specifies a limit beyond which vertical, whole body vibrations have the potential to reduce working efficiency of man. The ISO indicates that the actual degree of reduction in efficiency varies with situational factors, however, man's efficiency is most affected between 4 and 8 Hz. for vertical, whole body vibrations.

b) Reduced Comfort Boundary (Comfort Zone)

This boundary specifies a limit beyond which vertical, whole body vibrations have the potential to reduce comfort of man. The values in this boundary are approximately one-third of the corresponding values in the fatigue-reduced proficiency boundary. The reduced comfort boundary is assumed to follow the same time and frequency dependence as the fatigue-decreased proficiency boundary.

c) Exposure Limit (Health or Safety)

This boundary specifies the maximum exposure limit for vertical, whole body vibration. Beyond the exposure limit vertical, whole body vibrations have the potential to be hazardous. The exposure limit values are double the corresponding values of the fatigue-decreased proficiency boundary.

The ISO recommends that exposure of man to vertical, whole body vibration beyond exposure limits should be restricted to "special justification or precautions."

III. THE VIBRATION RESPONSE PROBLEM

1. The Problem

The performance level of machine operators subjected to whole body vibrations, and their response to warning signals, is of interest as it may influence an operator's susceptibility to an accident situation.

As it is difficult to correlate body responses with random vibratory motion and its accompanying stresses, a practical approach is one that utilizes unidirectional forced sinusoidal vibrations of discrete frequency and amplitude. In this investigation selected human participants, in a seated position, were exposed to simple harmonic vertical vibrations typically associated with operating farm machinery and equipment (2 to 20 Hz.) This range is of particular interest as farmers are exposed to more vibrations in this range than any other. Research has shown that there is very little significant response below 2 Hz. and at frequencies above 20 Hz. it is relatively easy to isolate the human body from vibrations by protective means.

This investigation did not isolate the impact of psychological, physical, and physiological effects caused by vibrations upon response time. Rather, it was structured to see if such stresses did affect an operator's response time. This was accomplished by monitoring the response time of participants while they were exposed to various vibrational stresses. A statistical comparison was made of response times for the different vibrational exposures.

2. Objectives of the Study

a) To determine how vibrations in existing farm equipment affect an operator's response time.

b) To determine how audio and visual warning signals affect an operator's response time.

3. Hypothesis to be tested

a) Vibrations increase an operator's response time to both audio and visual signals.

b) If frequency of vibrations is increased, the operator's response time increases (i.e., the operator is slower).

c) Response time to an audio warning signal is faster than that to a visual warning signal.

4. Design of the Study

The effect of vibrations upon operator's response time was studied by subjecting volunteer participants to whole body sinusoidal vibrations using a simulated operator's platform. The operator and platform seat and steering wheel were oscillated vertically with varying amplitude and frequency. Participants were asked to perform a steering (tracking) task and respond to random signals by activating the brake and accelerator pedals. Their time of response was measured and correlated to the vibration intensity and type of stimulus.

5. Selection of Participants

Participants in the investigation were students at Michigan State University in the Agricultural Engineering Department. They ranged in age from 20 to 30 years old. Most of the students had an agricultural background. They frequently worked with farm equipment and machinery and had been exposed to vibrations in this range.

6. Exposure Limits

Frequency:	2 to 8 Hz.
Exposure time:	10 min. per frequency
Amplitude:	20.32 mm maximum

7. Experimental Limitations

a) As noted previously, this investigation did not attempt to isolate specific physiological and physical effects of vibrations on the participants. Such considerations were beyond the scope of the investigation from the standpoint of the required instrumentation and expertise of the investigator. However, it was assumed that the presence of such effects would interfere with the operator's performance.

b) The highest frequency that could be generated with the Agricultural Engineering equipment was 8 Hz. Although this does not cover the complete range of frequencies experienced in agriculture, it does cover the lower frequencies and frequencies that resonate the visceral area of the body. These frequencies are of primary interest.

c) In an effort to minimize variations in the study, only agricultural engineering students ranging in age from 20 to 30 years old were used. Although extreme differences in participants were avoided, no effort was made to evaluate the effects of such variables as clothing (loose or tight), body weight, sitting posture (relaxed or tense), and attitude toward the experiment.

d) The performance of the participants on the tracking task was not determined. This may have influenced the response time of some participants.

8. Definitions

a) Response Time: the time from the onset of a stimulus to the time the task is completed, i.e., it is the sum of reaction time and movement time.

b) Reaction Time: the time from the onset of a stimulus to the initiation of a response to the stimulus. Reaction Time includes:

1) perception of stimulus by receptor organ
2) transmission of impulse to the brain (afferent pathway)
3) central processing
4) transmission of message to the effector organ (efferent pathway)

c) Movement Time: the time from the start of movement to completion of task.

d) Stimulus: an agent or form which initiates an impulse producing an altered state of consciousness by arousing new or stronger sensations.

e) Response: specific type of behavior required by a given stimulus.

f) Reflex Time: the time from the perception of the stimulus to the start of the response. Reflex time is impossible to measure using equipment in this investigation. However, two things are known about reflex time:

1) reflex time is a part of reaction time
2) reflex time is involuntary

IV. EQUIPMENT AND PROCEDURES

1. Chair and Vibrating Generator

The chair and the vibrating generator, Figure 4a., were constructed by agricultural engineering students at Michigan State University.

Figure 4a. Simulated Operator's Platform showing Chair and Vibrating Generator.

A 230 v 3-phase motor drove the generator camshaft with a link chain. The shaft drove a piston (which was enclosed in a cylinder) in an up and down uniform fashion. The top end of the piston supported a wooden platform on which a rigid wooden chair was solidly mounted. Both the platform and the chair moved up and down with the piston as one unit. This arrangement prevented resonance of the chair and it facilitated complete transmission of vibrations to the participants.

The generator was set for a maximum amplitude of 20.32 mm and a minimum amplitude of 9.525 mm. The maximum obtainable frequency was approximately 8.1 Hz.

2. Task

A tracking operation was performed by the participants. The tracking mechanism, Figures 4b. and 4c., was constructed by agricultural engineering students at Michigan State University. The mechanism was constructed out of wood and had two pointers one above the other. A 120 v. 1-phase motor drove a cam wheel with a link chain. Riding on the cam wheel (by the use of a small wheel) was a lever to which a cable was connected (at the far end from the fulcrum) that made a loop over four pulleys, and back to the same end of the lever. A counterweight spring was connected to the end of the lever closest to the fulcrum. The function of the spring was to bring the riding end of the lever to the "home" position, i.e., to the valleys on the cam wheel.

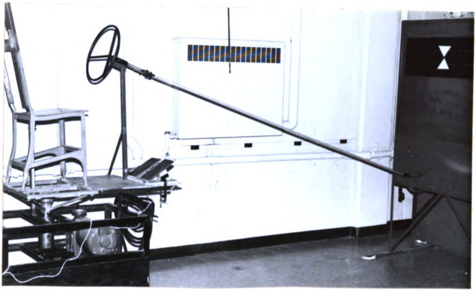

Figure 4b. Operator's Platform connected to the Tracking Mechanism by means of Steering Rod.

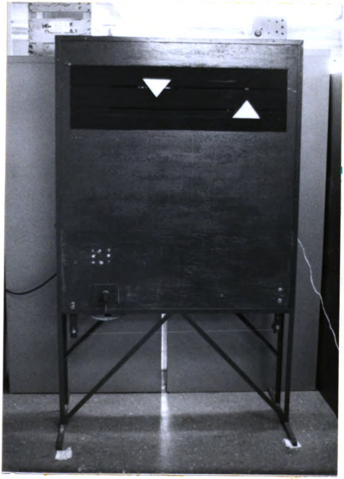

Figure 4c. Front view of the Tracking Mechanism showing Pointers.

As the cable looped around the pulley system, it was connected to the top pointer, so that the top pointer was a part of the riding lever.

The bottom pointer was operated by a steering wheel which was mounted on the generator platform and in front of the chair. A steering rod connected the steering wheel to a second pulley system in the tracking mechanism. This pulley system controlled the lower pointer (which was a part of this system).

3. <u>Recording Equipment</u>

Two industrial timers were used. An SC-100 industrial timer, Figure 4d., was used to measure reaction time. This timer had a compound dial with two pointers, the inside dial registered from 1 to 60 seconds in 1-second increments. The outside dial measured .01 to .99 seconds in .01-second calibrations. It was the outside dial that was used for reaction time measurement.

Figure 4d. Industrial Timer used to measure Reaction Time.

A Hewlett-Packard 512A industrial timer, Figure 4e., was used to measure response time. It displayed time in a digital fashion. The timer was manually gated, i.e., it was controlled by an external signal automatically. With a 60-cycles-per-second line and manual gating the percent error was ±2 using the 1 second automatic gate time.

The block and circuit diagrams of the arrangement appear in Appendix A.

Figure 4e. Hewlett-Packard 512A used to measure Response Time.

4. Stimuli

A light and a buzzer were used. The two stimuli were housed in a small compact metal box which was placed over the tracking mechanism directly in front of the participants' chair. The intensities of the stimuli were not varied.

Both stimuli were activated by the investigator using the appropriate switch on the relay interface (control) box, and they were deactivated by the participant as he responded to the administered stimulus.

5. Controls

Two foot pedals, Figure 4b., were solidly mounted on the foot platform by the right foot. The outer pedal was the "ready" pedal while the inner one was the "stop" pedal. In addition to indicating to the investigator that the participant was ready (when the participant's foot was on the outer pedal) this pedal stopped the reaction timer as soon as it (the pedal) was released.

Both the light and the buzzer signals were initiated by the investigator using the appropriate switch on the relay interface (control) box, Figure 4f. The relay interface box

Figure 4f. Control Box (Relay Interface).

also controlled the two timers.

A circuit diagram is included in Appendix A.

6. Procedures

Participants were involved in a tracking operation and were seated upright for maximum transmission of vibrations as shown in Figure 4a. The investigator was behind the participants to make sure that the participants' lines of vision were clear, and also to make sure that the participants were not aware of what the investigator was doing.

With participant's foot on the outer pedal the "ready" light came on the investigator's control panel. Meanwhile, the investigator had chosen the stimulus using the appropriate switch on the panel. After receiving the "ready" signal (this time was varied to prevent the participant from being "conditioned") the investigator administered the appropriate stimulus. At the application of the stimulus, both timers were set in motion. Upon receiving the stimulus, the participant stepped off the outer pedal and stepped on the inner pedal. Release of the outer pedal automatically stopped the reaction time clock, giving reaction time. Stepping on the inner pedal stopped the response time clock. The difference between response time and reaction time gave the movement time.

Frequencies from 1 to 8 Hz. were used. An amplitude of 20.32 mm was used on frequencies up to 3.5 Hz., and that of 9.525 mm was used on a 3 to 8 Hz. frequency range. The ISO exposure limits, Figure 4g., show the acceleration and frequency combinations that were used in the investigation.

The effects of such intrinsic variables as body size, body tension, age and sex are more complicated to determine and beyond the scope of this investigation. As such the assumption was made that these variables had relatively small variations between the participants whose ages did not vary considerably (20 to 30 years old), and neither did their physical build. The participants were familiar with farm machinery operation and, at one time or another, had been exposed to frequencies and accelerations of this level.

Participants were given enough time to familiarize themselves with the experimental arrangement and procedures. It was not explained to the participants what readings and why such readings were recorded until after the entire exercise was done. The reason for this was to avoid any attempts on the part of the participants to try and "beat" the timers. It was emphasized to the participants that they do the best possible job of matching the pointer (that was controlled by the steering wheel) with that of the tracking mechanism, and that they react as quickly as they possibly could (and yet naturally) to the stimulus given.

A total number of 15 participants was used and a maximum of ten pieces of data per person per frequency reading were collected.

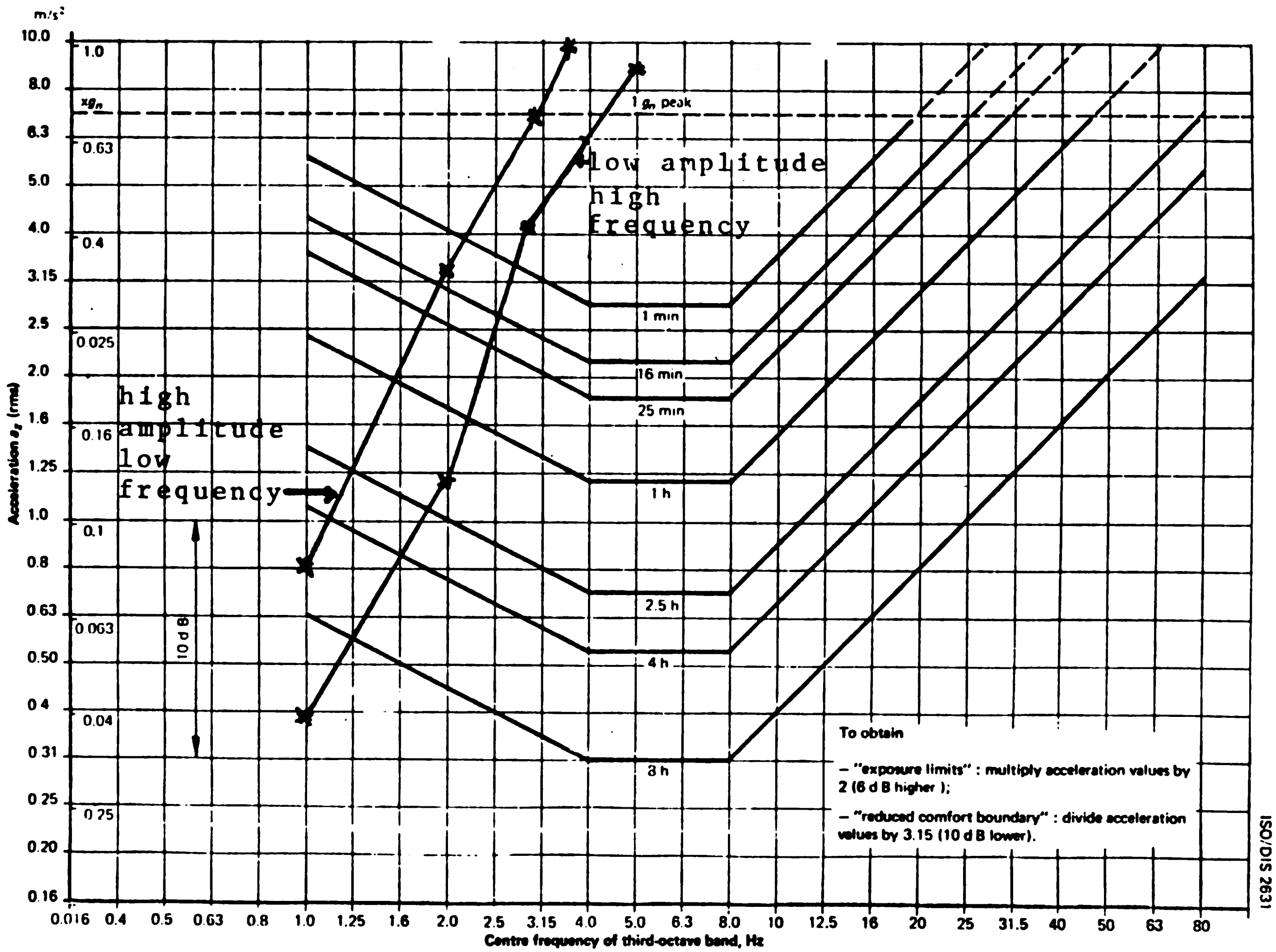

Figure 4g. Vertical vibration exposure limits as a function of frequency and exposure time; "fatigue-decreased proficiency boundary." Adapted from International Organization for Standardization, Guide for the Evaluation of Human Exposure to Whole-Body Vibration, ISO/TC 108, Geneva, Switzerland, 1972, p.14.

V. RESULTS AND DISCUSSION

1. Effects of Vibrations on Response Time

A total of 15 male students participated in this investigation. The results (Tables 5a. and 5b., and Figure 5a. and 5b.) showed that vibrations between 2 and 3.5 Hz., at 20.32 mm amplitude setting, and those between 1 and 8 Hz. at 9.525 mm amplitude, delayed response time. Both ranges of vibration had the same effect on reaction time (Figures 5c. and 5d.) and movement time (Figures 5e. and 5f.).

Table 5a. ANOVA Table for Response Time at 20.32 mm Amplitude.

Source	SS	df	MS	F
Participants	258807	9	28756	17.79**
Treatment	97039	9		
Warning Signal	50920	1	50920	31.51**
Frequency	44548	4	11137	6.89**
Interaction	1570	4	392.5	0.24
Residuals	130910	81	1616	
Total	486756	99		

**0.99 significance level.

Table 5b. ANOVA Table for Response Time at 9.525 mm Amplitude.

Source	SS	df	MS	F
Participants	336827	4	1258548	83.85**
Treatment	109939	11		
Warning Signal	44563	1	44563	29.07**
Frequency	57403	5	11481	7.49**
Interaction	7973	5	1595	1.04
Residuals	67426	44	1533	
Total	514192	59		

**0.99 significance level.

The response time for participants vibrated at 1 to 2 Hz., at 20.32 mm, was faster than it was with no vibrations and when the frequency was 2 to 3.5 Hz. (Figure 5a.) When the amplitude was reduced to 9.525 mm (Figure 5b.) the response time between 0 and 4 Hz. showed no significant change, while between 4 and 8 Hz. there was delayed response time. This pattern held true for both reaction time and movement time.

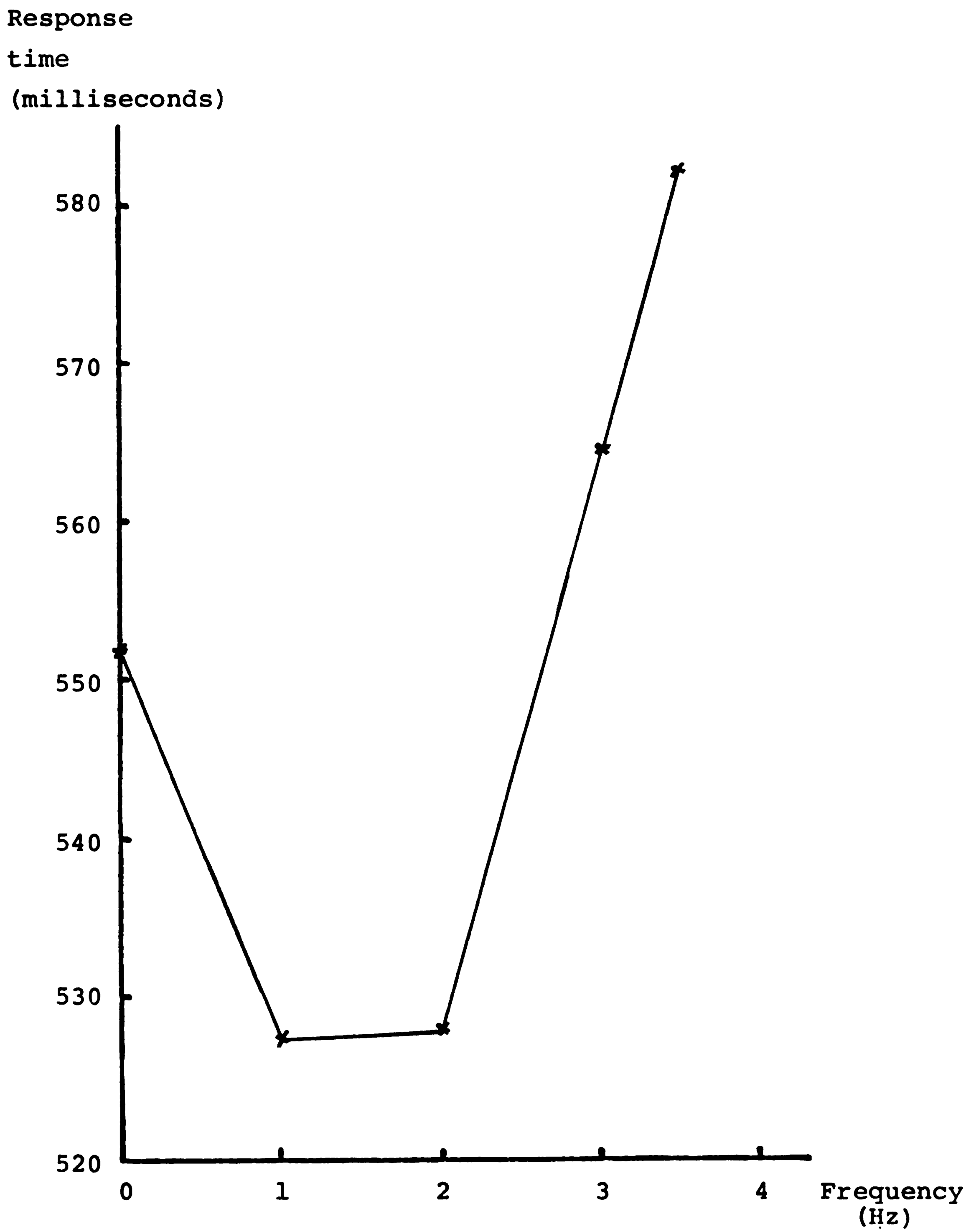

Figure 5a. Response Time versus Vibration Frequency at 20.32 mm Amplitude.

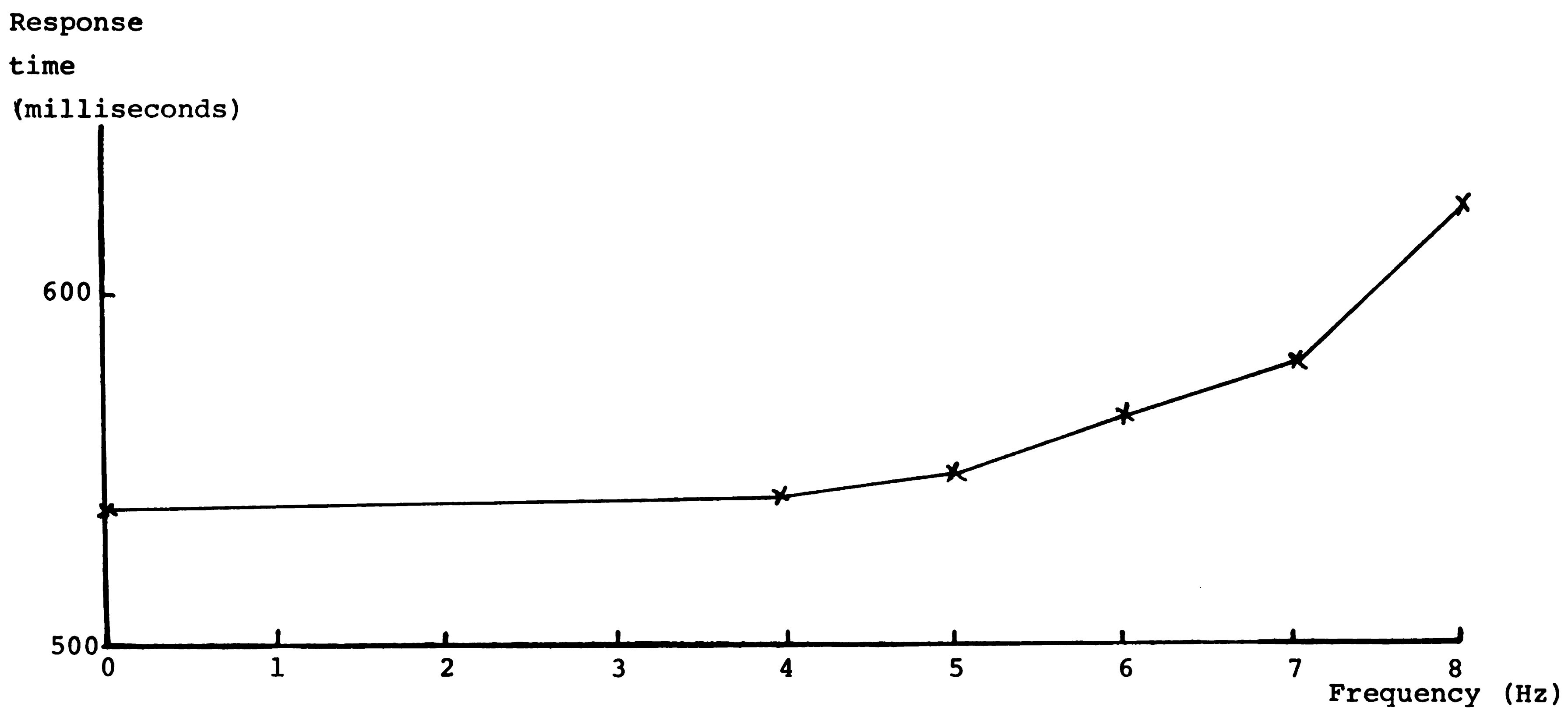

Figure 5b. Response Time versus Vibration Frequency at 9.525 mm Amplitude.

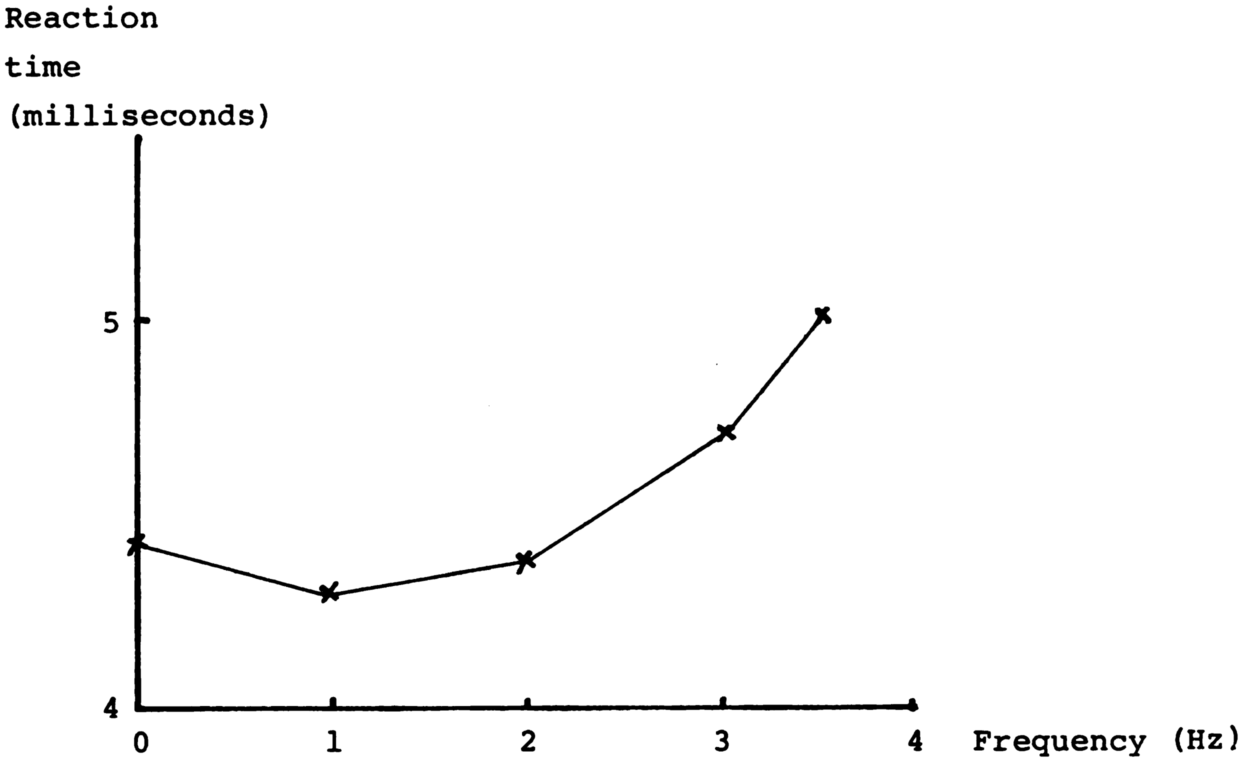

Figure 5c. Reaction Time versus Vibration Frequency at 20.32 mm Amplitude.

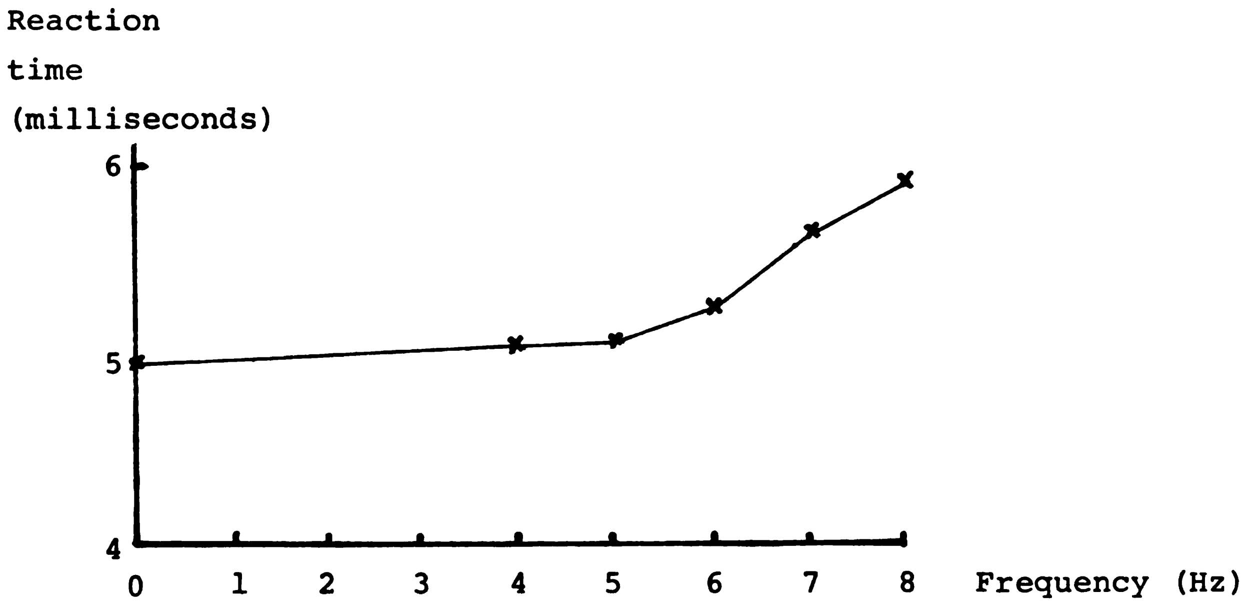

Figure 5d. Reaction Time versus Vibration Frequency at 9.525 mm Amplitude.

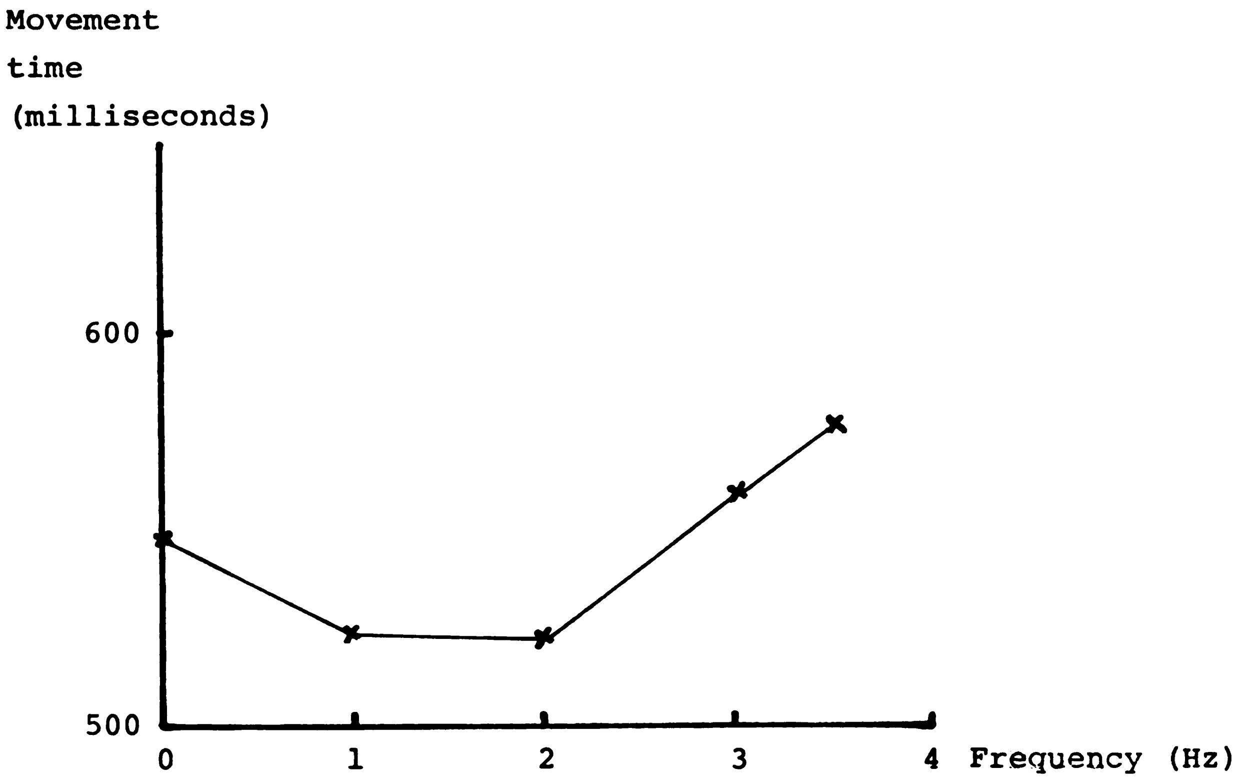

Figure 5e. Movement Time versus Vibration Frequency at 20.32 mm Amplitude.

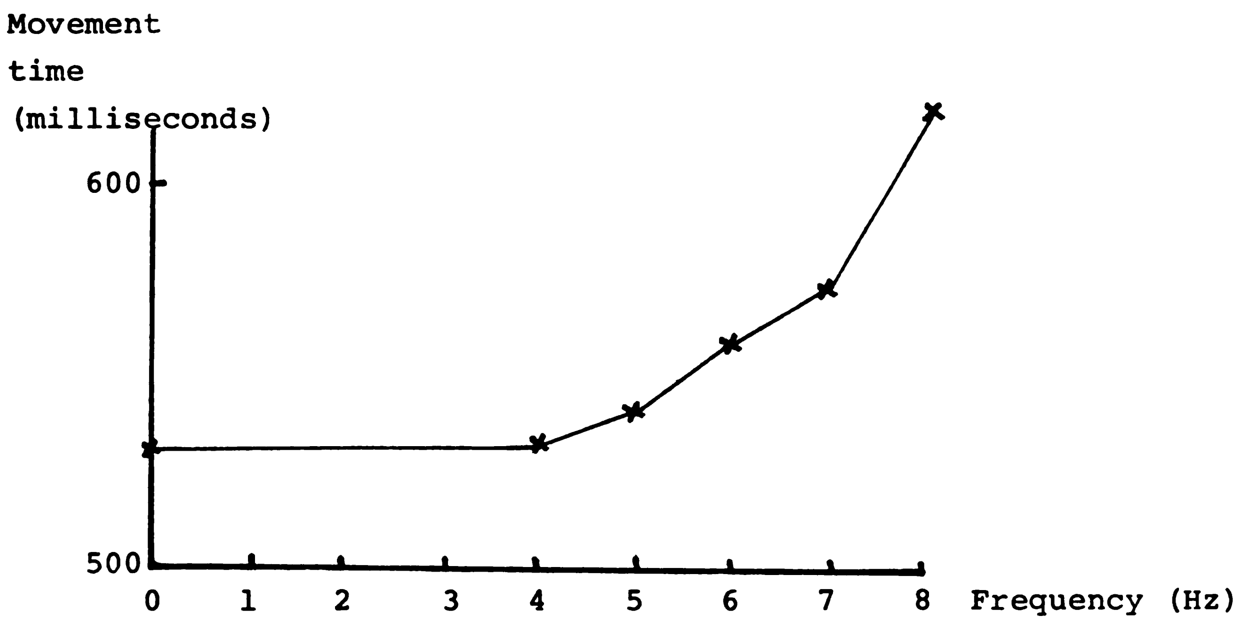

Figure 5f. Movement Time versus Vibration Frequency at 9.525 Amplitude.

2. Responses to Vibrations

a) Physiological Responses

No physiological measurements, such as blood pressure or heart rate, were taken during these tests. However, the participants were asked to subjectively evaluate and describe their reaction to the vibration exposure.

After an average exposure time of 4 to 5 minutes, at frequencies between 5 and 8 Hz. and amplitude of 9.525 mm, three of the five participants felt that they had faster heart beat. Six of the ten participants exposed to 20.32 mm amplitude, and all five participants exposed to 9.525 mm amplitude had beads of perspiration on their foreheads as a result of the stress situation.

No measurements were taken to determine the effects of vibrations on performance (tracking). However, at 20.32 mm amplitude, eight of the ten participants felt that their performance was affected by vibrations, and at 9.525 mm amplitude, the five participants exposed felt that their performance was affected when the frequencies reached 6 to 8 Hz.

b) Physical Responses

It should be noted, again, that the physical responses (Table 5c.) were not determined by direct measurement of the human body organs and tissues, but rather, they were subjective responses made by participants when asked to "describe exactly how they felt during exposure to vibrations".

Table 5c. Subjective Responses given by Participants after Exposure to Vibrations.

Frequency (Hz)	Amplitude (mm)	Exposure time (min)	Participants	Response
1-2	20.32	up to 10	3	comfortable
1-2	20.32	up to 10	3	nice
1-2	20.32	up to 10	2	not concerned
1-2	20.32	up to 10	2	not sure
3-3.5	20.32	from 4 on	6	thoracic, abdominal and buttock discomfort
3-3.5	20.32	from 4 on	3	buttock, back discomfort
3-3.5	20.32	from 4 on	1	all four forms of discomfort
1-4	9.53	from 4 on	5	generally concerned
6-8	9.53	from 4 on	3	whole/general body discomfort
7-8	9.53	from 4 on	2	breathing difficulties
7-8	9.53	up to 10	5	affected performance and concentration
7-8	9.53	from 4 on	1	tightening of chest muscles
7-8	9.53	from 4 on	1	rigidity of whole body

c) Variations in Responses

The participants exhibited a wide variation in their verbal responses. Exceptions were reported between 1 and 2 Hz., for 20.32 mm amplitude, and between 6 and 8 Hz. for

9.525 mm amplitude. The ten participants exposed to the 1 to 2 Hz. vibration range were either indifferent to, or not concerned about being exposed to this frequency range. It is of interest to note that the ten participants exposed to the 1 to 2 Hz. frequency range recorded the shortest response time within this range of vibrations.

On the other hand, between 6 and 8 Hz., the general feeling among the five participants exposed was that of concern for their well being. Within 4 to 5 minutes of exposure to the 7 to 8 Hz. range, three participants felt that this frequency was "unpleasant"; two felt that it was "very uncomfortable" and one felt that it was "alarming".

The 15 participants reported different perception and tolerance levels. This was particularly true between 3 and 3.5 Hz., at 20.32 mm amplitude setting, and between 1 and 5 Hz. at 9.525 mm amplitude setting. There was more uniformity among the participants in their perception for the 9.525 mm amplitude, and a lack of tolerance for vibrations beyond 5 Hz. The verbal responses made by participants varied so widely that no general performance pattern emerged. However, the general feeling expressed by participants was one that performance was degraded.

3. Effects of the Type of Stimulus on Response Time

The results showed that response time to audio stimulus was shorter than that to the visual stimulus (Figures 5g. and 5h.). This phenomenon held true at both 20.32 mm and 9.525 mm amplitude.

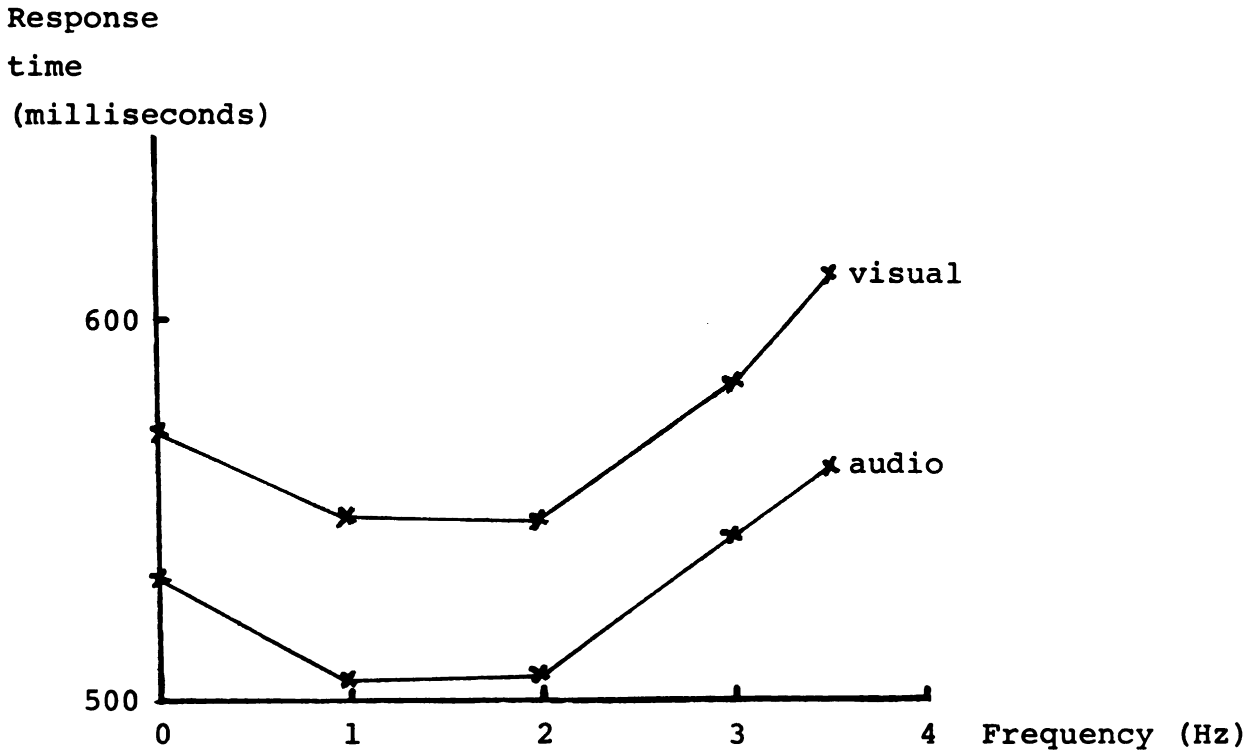

Figure 5g. Response Time for Audio and Visual Stimuli for Frequencies at 20.32 mm Amplitude.

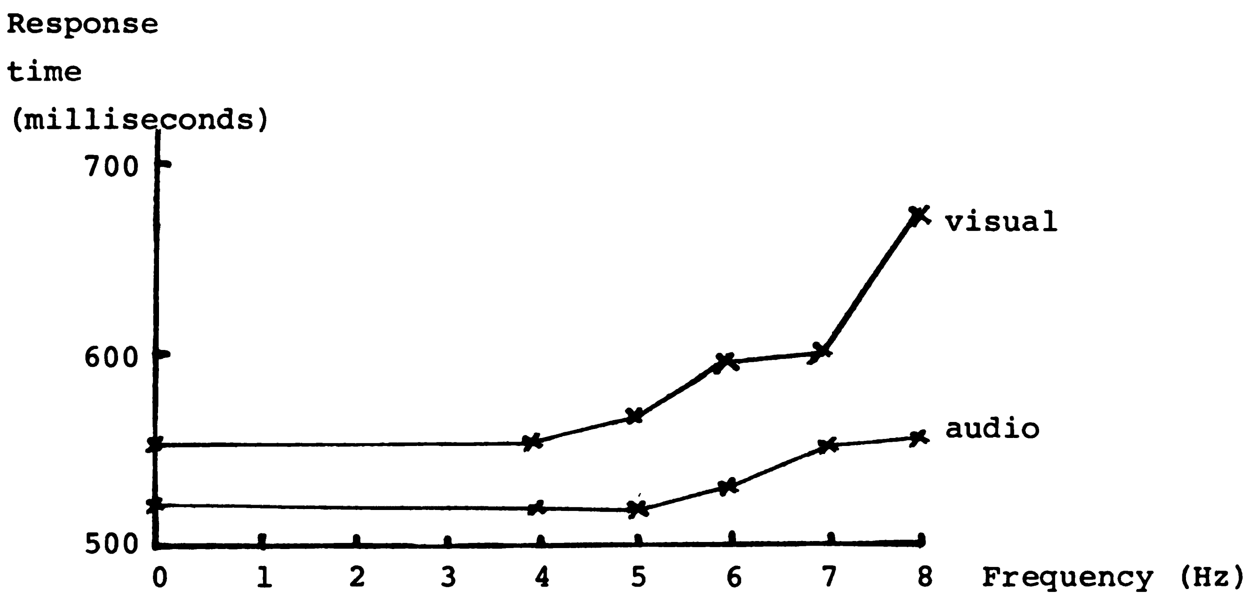

Figure 5h. Response Time for Audio and Visual Stimuli for Frequencies at 9.525 mm Amplitude.

4. The Implications of the Findings

The implications of these results can be categorized into: (1) those that reflect potential immediate danger to farm machinery operators and/or machinery and equipment by affecting response time, and (2) those that present potential health hazards to farm machinery operators over an extended period of time.

In the first category, the results indicate that response time is affected by vibrations. When vibration intensity is increased, response time is increased. The results of increased response time can be serious in emergency situations, which often occur in farm work. Some of these situations require short and proper response in order to avoid accidents, possible injury, equipment loss and/or property damage. Some of the emergency situations that require quick and proper response are:

a) A tractor (or any other machinery such as a harvester) suddenly hits a rock or stump. Quick and proper response could prevent possible machinery downtime.

b) Quick and proper response may prevent tip-overs or turn-overs in situations where an operator were suddenly faced with a ditch or a sharp incline.

c) In the event that a person's clothing were caught in a moving part of machinery or equipment, quick and proper response might prevent injury.

What should be noted is that not only is short response time necessary, but proper response is necessary also. In the case of moving machinery, or part thereof, quick response as well as the ability to choose the proper course of action is necessary.

In regard to the second category, health hazard, the results indicate that participants experienced one form of discomfort or another. The discomfort suggests potential health problems, particularly over extended periods of time.

5. Implications of Vibrational Effects on the Human Body Responses

a) Physiological Implications

Not all vibrations are dangerous to the human body. Vibrations at varying frequencies are increasingly used on humans for therapeutic and/or recreational purposes such as in the "vibrating easy chair" or hand massage device. In some kinds of machinery work, it is necessary and helpful to have the operator vibrating along with the machinery being operated. However, as vibration intensity increases, it can reach a level hazardous to humans.

This investigation focused on only some of the vibrations that approached the resonate frequencies of human body organs, and had the potential for physiological and physical damage.

Since no measurements were taken to detect physiological changes due to vibrations, and the verbal indications given by the participants are subjective impressions, the magnitude of physiological change is not clearly defined. For instance, the results do not indicate a doubling of blood pressure between 2 and 5 Hz., or a reduction of visual acuity of up to 35% between 3 and 7 Hz., or an increase in respiration rate between 3 and 5 Hz., as reported by Magid and Coerman (1963).

On the other hand, the 1 to 2 Hz. range of vibrations (Figure 5a.) suggests that this range "improved" the participants' ability to respond to warning signals. Two things support this argument. First, the ten participants exposed to between 1 and 2 Hz. recorded the shortest response time in this range of vibrations. Secondly, the 1 to 2 Hz. range posed no particular concern to the ten participants in contrast to results reported by Cope (1960), which indicated the presence of sea sickness in humans when exposed to this range of vibrations.

The results between 1 and 2 Hz. suggest that there might have been a "mastering" or "learning" process, or a stimulation of the "response phenomenon" in this range of vibrations. As a result, the response time in this range was shorter than it was with no vibrations. However, as the frequency increased from 2 to 3.5 Hz., vibrations affected the response process and the time was longer. On this basis, it suggests that physiological factors contributed to the delayed response time.

For the 9.525 mm amplitude setting, there was no significant change in response time for the five participants exposed to the 0 to 4 Hz. range. The participants recorded the shortest time between 0 and 4 Hz. There did not seem to be a "learning" or "mastering" process here as that between 1 and 2 Hz. at 20.32 mm amplitude. However, as the frequency increased from 4 to 8 Hz. the response time increased markedly (Figure 5b.). Again, this appreciable decrease in participants' ability to respond to warning signals suggests the possibility that physiological factors contributed to the delayed response.

When whole body vibration reached the 7 to 8 Hz. range at 9.525 mm, two of the five participants experienced breathing difficulty. This indicates that exposure of machinery operators to the 7 to 8 Hz. range at 9.525 mm amplitude setting can endanger the health of such operators.

Although no measurements were taken to determine the effect of vibrations on performance, verbal responses reflecting "general" or "whole" body discomfort indicate that performance was reduced by vibrations.

b) Physical Responses

It is emphasized again that in this investigation physical effects and physiological effects were interpreted from verbal responses made by the participants when asked to "describe exactly how they felt during exposure to vibrations."

In general, vibrations in the 1 to 2 Hz. range, at 20.32 mm amplitude, did not particularly concern the ten participants. However, as the frequency increased to 3 to 3.5 Hz. various forms of discomfort were experienced by the ten participants.

Some human body organs have their natural frequency in the 3 to 5 Hz. range. As the whole body vibration approaches this range, these organs begin to resonate and result in thoracic and abdominal discomfort. This indicates that machinery operators subjected to the 3 to 3.5 Hz. range, at 20.32 mm amplitude setting, for extended periods of time may experience damage. Riopelle et al. (1958), Roman (1958) and Flowers (1955) reported similar findings in their investigations with small animals.

As the frequency was increased to 6 to 8 Hz., at 9.525 mm amplitude, a similar "general" or "whole" body discomfort was experienced by the participants. This indicates a continued presence of resonances of body organs, and hence the potential danger to the health of machinery operators over extended periods of time. Parks (1963), Clark (1963) and Lange and Coerman (1963) reported similar findings in humans at frequencies between 3 and 9 Hz.

c) Variations in Responses

In this investigation verbal responses from the participants were taken as indications of physiological and physical excitation of the body organs. The participants reported discomfort in different body areas depending upon the frequency and the amplitude setting.

The problem with verbal responses is, however, that such responses are influenced by an individual's willingness to be vibrated at any given frequency. Willingness is a phenomenon that is not easy to measure and yet it affects one's level of perception and tolerance. Recognizing this fact, then, the findings of this investigation should be accepted as general guidelines rather than absolute standards.

With the intensity of vibrations going from low to high, there was a chance that some participants tried to "prepare" themselves for higher intensities. This introduced the possibility that participants did not perform as they ordinarily would, i.e., when they are not "expecting" interference and/or discomfort.

6. Implications of the Differences between Audio and Visual Warning Signals

The fact that the audio signal evoked shorter response time than did the visual signal indicates that under proper environment, audio signals are superior to visual signals. Colage (1968) reported similar findings. However, the situation would be different in a noisy environment or if the machinery operator were deaf.

Since the intensities of the light and the buzzer were easily perceived but not varied, this investigation varied from the real world operation of equipment and machinery on open land, where such factors as noise and/or inadequate light may be present and may affect the operator's ability to perceive such signals.

The implications and potential danger associated with delayed response time have been discussed above. For these reasons, it is very important that the right kind of stimulus be applied to achieve the optimum response time during emergencies.

VI. CONCLUSIONS

The following conclusions were drawn from the findings:

1. In general, vibrations increased participants' response time. This phenomenon was exhibited at high amplitude and low frequency combinations as well as at low amplitude and high frequency combinations.
2. Vibrations between 0 and 4 Hz., at 9.525 mm amplitude did not have a significant effect on response time.
3. Participants recorded the shortest response time when exposed to vibrations between 1 and 2 Hz. at 20.32 mm amplitude.
4. Vibrations between 3 and 3.5 Hz., at 20.32 mm amplitude, and vibrations between 6 and 8 Hz., at 9.525 mm amplitude, caused discomfort in the human trunk, and are a potential health hazard if exposure is prolonged.
5. Vibrations between 3 and 3.5 Hz. at 20.32 mm amplitude and those between 5 and 8 Hz., at 9.525 mm exceeded the ISO exposure limit and created discomfort in participants. Such frequency and amplitude combinations should be avoided in farm machinery work.
6. Under the test conditions, the audio warning signal had a shorter response time than the visual warning signal.
7. In an environment where they may be heard, audio warning signals are superior to visual.

VII. RECOMMENDATIONS FOR FUTURE STUDIES

1. Conduct field investigations to determine the effects of continuously changing frequency and amplitude of vibrations on machinery operator's response time, and his ability to perform as farm machinery travels over uneven terrain. Investigations should involve direct measurement of human body organ responses as well as verbal responses, in an effort to determine generally accepted standards for human body exposure to vibrations in farm work.

2. Consider the effects of a wider range of variables, such as weight, age, sex, clothing, time of investigation, weather conditions and mental tolerance to vibrations, on the operator's ability to respond and perform.

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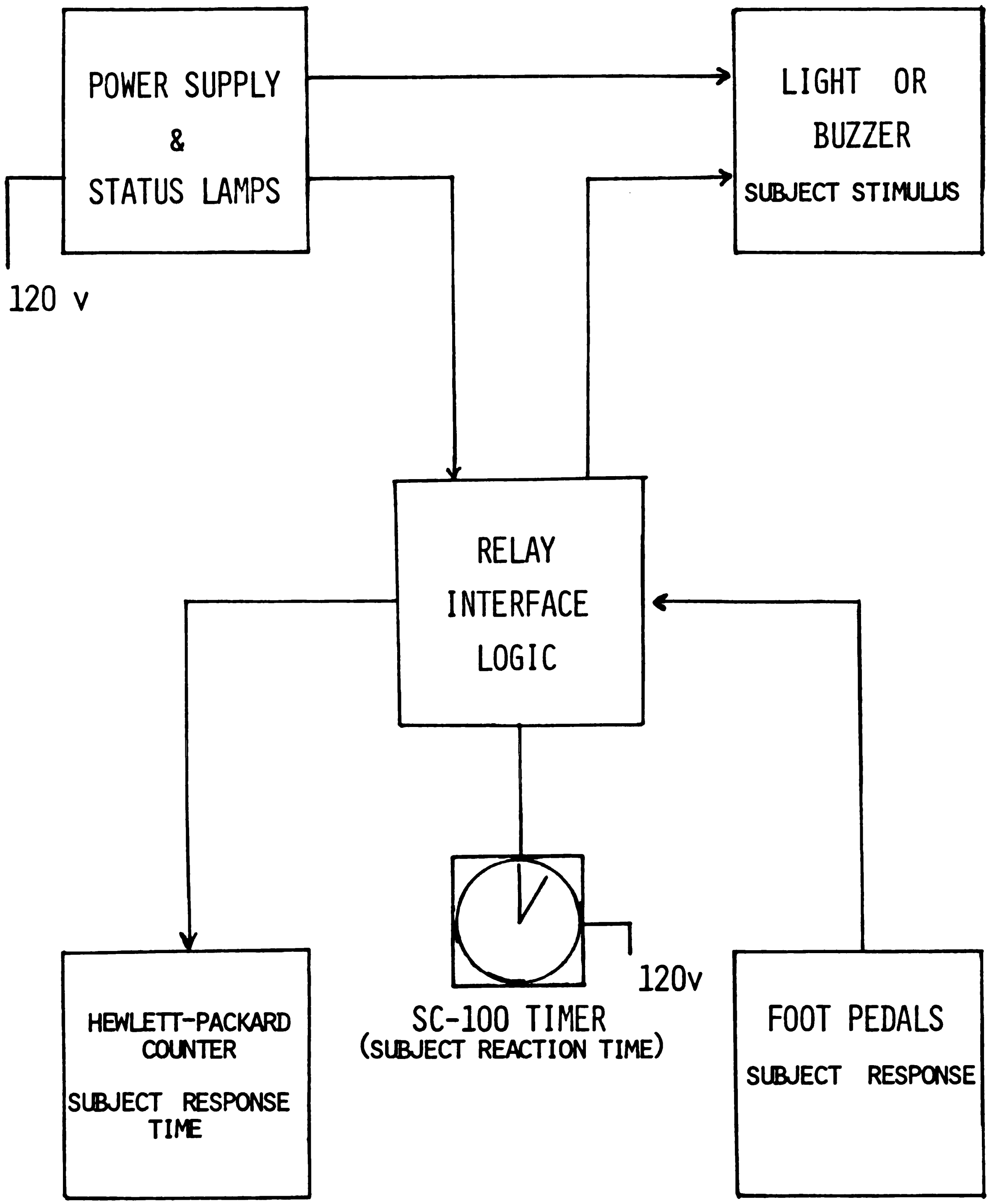
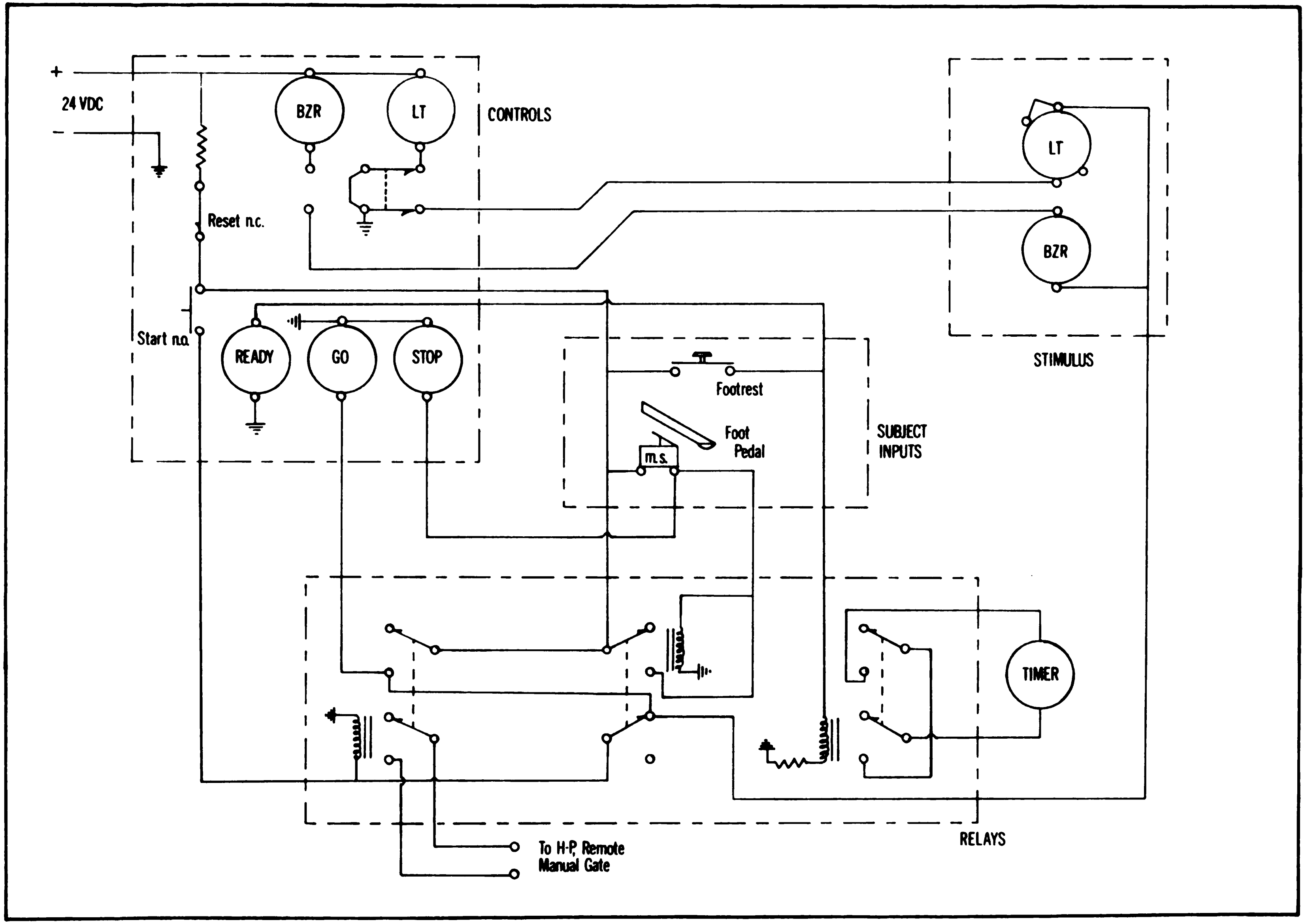
APPENDIX A



BLOCK DIAGRAM OF THE LAYOUT



CIRCUIT DIAGRAM OF THE LAYOUT

APPENDIX B

REACTION TIME (Milliseconds)
Amplitude: 9.525 mm

	Participant									
	K		L		M		N		O	
Frequency (Hz)	Light	Buzzer	Light	Buzzer	Light	Buzzer	Light	Buzzer	Light	Buzzer
0.0	4.65	3.86	4.57	3.93	7.03	6.33	4.72	4.46	4.86	5.33
4.0	4.81	4.99	4.84	4.24	6.27	5.88	4.72	4.59	5.20	5.02
5.0	4.90	4.15	5.24	4.88	6.16	5.22	4.70	4.30	5.64	5.28
6.0	5.40	4.51	5.78	5.05	6.59	5.97	4.64	4.45	5.23	4.57
7.0	5.33	4.15	6.34	6.14	6.89	6.21	5.50	4.81	5.51	5.13
8.0	5.76	4.48	5.88	5.37	7.43	6.48	6.11	5.34	6.30	5.12

MOVEMENT TIME (Milliseconds)
Amplitude: 9. 525 mm

	Participant									
	K		L		M		N		O	
Frequency (Hz)	Light	Buzzer	Light	Buzzer	Light	Buzzer	Light	Buzzer	Light	Buzzer
0.0	465.34	396.15	583.79	554.41	686.32	632.02	475.29	443.89	518.59	556.45
4.0	485.17	448.34	648.11	582.41	628.74	592.47	473.64	460.42	521.57	508.47
5.0	498.94	412.02	694.77	650.43	603.84	573.13	470.31	430.91	557.81	521.49
6.0	552.85	458.33	718.90	693.30	688.43	605.71	470.37	430.56	526.54	458.86
7.0	533.02	436.19	707.01	647.21	686.46	647.14	552.89	480.29	539.69	519.98
8.0	635.92	503.86	655.81	606.31	810.82	686.86	610.68	528.10	632.16	534.69

RESPONSE TIME (Milliseconds)

Amplitude: 9.525 mm

Participant

Frequency (Hz)	K Light	K Buzzer	L Light	L Buzzer	M Light	M Buzzer	N Light	N Buzzer	O Light	O Buzzer
0.0	470.01	400.01	588.34	558.35	693.35	640.21	480.89	448.35	523.44	571.78
4.0	490.01	453.35	653.35	586.68	635.01	598.35	478.36	465.01	526.77	513.44
5.0	503.34	416.67	700.01	655.01	610.01	578.35	475.01	435.21	563.45	526.77
6.0	558.35	463.34	724.68	698.35	695.02	611.68	475.01	435.01	531.77	463.43
7.0	538.34	443.35	713.35	653.35	693.35	653.35	558.45	485.09	545.10	525.11
8.0	641.68	508.34	661.72	611.68	818.25	693.34	616.79	533.44	638.46	540.11

REACTION TIME (Milliseconds)

Amplitude: 20.32 mm

Participant

Frequency (Hz)	A		B		C		D		E	
	Light	Buzzer	Light	Buzzer	Light	Buzzer	Light	Buzzer	Light	Buzzer
0.0	3.74	3.25	4.65	4.40	3.66	3.26	4.79	4.20	5.16	5.65
1.0	3.52	3.08	4.40	4.42	3.28	3.11	5.45	4.69	5.00	5.06
2.0	3.47	3.14	4.76	4.10	3.78	3.01	5.45	5.02	5.50	5.33
3.0	4.07	3.33	4.34	4.24	4.02	4.18	6.35	5.36	4.63	5.38
3.5	4.12	3.73	4.32	3.78	5.22	4.29	6.18	5.12	5.41	5.39

Participant

Frequency (Hz)	F		G		H		I		J	
	Light	Buzzer	Light	Buzzer	Light	Buzzer	Light	Buzzer	Light	Buzzer
0.0	7.24	5.61	3.63	3.58	4.79	4.69	3.77	3.17	5.03	4.49
1.0	5.00	5.06	3.45	3.13	4.75	4.75	3.37	3.09	5.14	4.92
2.0	5.50	5.33	3.23	3.06	4.49	3.93	3.81	3.09	5.12	5.39
3.0	6.67	5.65	3.80	3.61	4.17	4.27	4.63	3.90	6.15	5.34
3.5	8.18	6.57	4.41	3.68	4.45	3.72	4.71	4.04	6.75	6.02

MOVEMENT TIME (Milliseconds)
Amplitude: 20.32 mm

Participant

Frequency (Hz)	A Light	A Buzzer	B Light	B Buzzer	C Light	C Buzzer	D Light	D Buzzer	E Light	E Buzzer
0.0	573.04	503.44	635.49	605.73	499.44	445.16	560.32	545.89	514.94	561.13
1.0	528.25	500.35	600.72	595.70	441.81	435.31	566.33	463.74	578.43	540.05
2.0	608.69	551.01	492.98	472.09	561.32	515.08	537.94	518.01	595.69	556.07
3.0	599.38	501.77	595.78	562.54	483.24	484.25	680.29	618.01	462.13	538.62
3.5	606.00	566.38	607.47	542.99	513.22	430.79	642.28	553.32	529.69	533.05

Participant

Frequency (Hz)	F Light	F Buzzer	G Light	G Buzzer	H Light	H Buzzer	I Light	I Buzzer	J Light	J Buzzer
0.0		552.93	528.14	503.19	625.33	624.07	482.99	423.58	555.08	517.28
1.0	648.60	475.26	507.97	472.00	623.71	607.04	480.08	418.66	534.97	503.52
2.0	595.69	556.07	505.44	470.37	587.29	526.18	489.62	418.26	543.32	543.05
3.0	641.79	563.12	564.65	536.54	626.79	631.79	515.47	417.84	627.31	556.48
3.5	791.98	656.89	640.73	573.10	600.12	551.78	473.72	462.72	676.72	605.12

RESPONSE TIME (Milliseconds)
Amplitude: 20.32 mm

	Participant									
	A		B		C		D		E	
Frequency (Hz)	Light	Buzzer	Light	Buzzer	Light	Buzzer	Light	Buzzer	Light	Buzzer
0.0	576.78	506.77	640.12	610.12	503.43	488.42	560.32	550.11	520.10	566.78
1.0	541.77	503.43	606.12	600.12	445.09	438.42	561.78	468.43	523.44	545.11
2.0	518.44	473.43	613.46	551.01	496.77	475.09	566.78	521.10	543.44	523.44
3.0	603.45	505.10	600.12	562.54	486.76	488.54	685.14	623.46	466.76	543.44
3.5	610.12	570.10	611.79	551.79	519.44	435.09	648.47	558.45	525.11	538.45

	Participant									
	F		G		H		I		J	
Frequency (Hz)	Light	Buzzer	Light	Buzzer	Light	Buzzer	Light	Buzzer	Light	Buzzer
0.0	725.15	558.44	531.77	506.77	630.13	628.46	486.76	426.75	560.11	521.77
1.0	655.13	480.09	511.77	475.09	628.43	601.79	483.43	431.75	540.11	508.44
2.0	601.79	561.78	508.44	473.43	591.79	530.11	493.43	421.74	548.44	548.43
3.0	648.46	573.45	568.45	540.11	626.79	631.79	520.10	416.75	633.46	561.78
3.5	800.16	663.47	645.13	576.78	600.12	551.78	478.43	466.76	685.64	605.12

STATISTICAL ANALYSIS

p = kind of warning signal (a_i), where p = ( )

q = level of frequency (b_j), where q = ( )

n = number of subjects (s_m), where n = ( )

$$SSTO = \Sigma Y^2_{ijm} - \frac{Y^2_{...}}{nab}$$

$$SSBL = \frac{\Sigma Y^2_{..m}}{ab} - \frac{Y^2_{...}}{nab}$$

$$SSTR = \frac{\Sigma Y^2_{ij.}}{n} - \frac{Y^2_{...}}{nab}$$

$$SSA = \frac{\Sigma Y^2_{i..}}{nb} - \frac{Y^2_{...}}{nab}$$

$$SSB = \frac{\Sigma Y^2_{i.m}}{na} - \frac{Y^2_{...}}{nab}$$

$$SSAB = SSTR - SSA - SSB$$

$$SSRes = SSTO - SSBL - SSTR$$

Mean Squares

$$MSA = \frac{SSA}{a-1}$$

$$MSB = \frac{SSB}{b-1}$$

$$MSAB = \frac{SSAB}{(a-1)(b-1)}$$

$$MSE = \frac{SSRes}{(n-1)(pq-1)}$$

a) Test for Interaction

C_1: $\mu.j = \mu.. + \alpha_1 + \beta j$

C_2: $\mu.j \neq \mu.. + \alpha_1 + \beta j$

$$F^* = \frac{MSAB}{MSE}$$

If $F^* \leq F(1-\alpha;(a-1)(b-1),(n-1)ab)$, conclude C_1

If $F^* > F(1-\alpha;(a-1)(b-1),(n-1)ab)$, conclude C_2

b) Test for Factor A Effects

C_1: $\mu_1. = \mu._2$

C_2: $\mu_i. \neq \mu._2$

$$F^* = \frac{MSA}{MSE}$$

If $F^* \leq F(1-\alpha;a-1,(n-1)ab)$, conclude C_1

If $F^* > F(1-\alpha;a-1,(n-1)ab)$, conclude C_2

c) Test for Factor B Effects

C_1: $\mu._1 = \mu._2 = ... = \mu._n$

C_2: not all $\mu.j$ are equal

$$F^* = \frac{MSB}{MSE}$$

If $F^* \leq F(1-\alpha;b-1,(n-1)ab$, conclude C_1

If $F^* > F(1-\alpha;b-1,(n-1)ab$, conclude C_2