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SOME INDIVIDUAL DIFFERENCES IN HUMAN RESPONSE TO INFRASOUND

by

D. S. Nussbaum and S. Reinis

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D. S. Nussbaum and S. Reinis

Department of Psychology
University of Waterloo

and

Institute for Aerospace Studies
University of Toronto

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Abstract

A review of literature describing the effects of very low-frequency sound on humans revealed a controversy between authors claiming that infrasound is very harmful to humans and those claiming that infrasound cannot engender any subjective or objective symptoms. This report shows that these discrepancies may be explained by individual variability in response to low-frequency sound.

An experiment was performed to determine whether some individuals are uniquely sensitive to infrasound. Three acousic conditions were employed. These consisted of a control (amplifier hum) condition and two 8 Hz infrasound conditions: a high distortion signal and a low distortion signal. Subjects were grouped by their subjective responses.

No control subjects exposed to amplifier hum reported any adverse responses. The distribution of symptoms (headache and fatigue vs dizziness and nausea) between the high and low distortion groups was significantly different. In persons reporting symptoms, the higher level of harmonics was primarily associated with headache and fatigue, while reduction of harmonics primarily resulted in dizziness and nausea.

Subjects reporting dizziness and nausea were subjected to up to four additional sessions — two control, one low distortion, and one with only some harmonics without infrasound. These sessions showed that these symptoms were replicable and related only to the infrasound.

Multivariate and univariate analyses showed that the subjects reporting adverse symptoms can be distinguished from the other groups on the basis of heart rate, respiratory rate, systolic and diastolic blood pressure changes, gaze nystagmus, time estimation, and mood scales but not EEG, plethysmography, TTS, a short-term memory task, Eysenck Personality Inventory, Cornell Medical Index or age.

The adverse responses of some individuals closely resemble motion sickness. Individual differences in the reaction to infrasound may then be explained by variability of inner-ear structure or central adaptive mechanisms.

Preface

Infrasound refers to very low frequency sound, falling below what is usually considered to be the range of human hearing. The literature contains reports of adverse subjective responses to infrasound and there is justifiable concern about potential effects of such exposure since our environment contains many sources of infrasound. Yet the literature abounds in contradictions: while some warn of infrasound dangers, others deny that infrasound has any ill effects on humans at all. This report is concerned with demonstrating whether or not infrasound has any clearly definable effects on humans and explores the possibility of individual variability in response to infrasound.

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1.0 REVIEW OF LITERATURE

1.1 Definition

Different authors assign infrasound's upper limit at some point between 16 and 40 Hz (Alford et al, 1966; Jerger et al, 1966; Anastassiadis et al, 1970; Pimonow, 1974; von Gierke, 1974; Leventhall, 1974; Nixon, 1974; Slarve and Johnson, 1975; Ashley, 1976; Broner, 1978; Busnel and Lehman, 1978). Since the issue of human response to infrasound focuses on whether stimuli below 30 Hz stimuli are biologically effective, 30 Hz will be considered as infrasound's upper frequency limit.

1.2 Prevalence of Infrasound in the Environment

Infrasound is found in natural and man-made environments and is related to thunder, tornadoes, rain, snow, ocean waves, etc. Because of their brief durations, low intensities and extremely low frequencies, naturally occurring infrasound has seldom been considered a problem. On the other hand, infrasound in working environments such as aircraft, automobiles, ships, subway, etc, may be considered potentially harmful, owing to longer exposures and greater intensities.

1.3 Subjective Human Responses to Infrasound

Two approaches are used by different authors to explain possible responses to infrasound. One avenue focuses on the immediate effects of energy transfer between the incident acoustical waves and the body. This "energetic" approach largely ignores individual differences. An alternate approach emphasizes the interactions occurring in the body after infrasound is transduced by a sensory system. Transduction initiates neural responses which convey information to various regions in the body. In this light, it is the sensory information provided by infrasound which initiates the response. These "informational" models are more amenable to individual differences.

Symptoms of vertigo, often accompanied by disorientation, nausea and vomiting were reported in response to infrasonic jet engine emissions by Edwards (1950) and Dickson and Chadwick (1951) (cited by Roth and Chambers, 1968). Gavreau et al (1966) reported symptoms of dizziness, nausea, headache and fatigue following accidental exposure to infrasound generated by a faulty ventilation system in a laboratory. Gavreau was able to reproduce these symptoms following a 2-hour exposure to the same sound. He also noted that when loud music accompanied the infrasound, the ill effects were prevented. Gavreau's report suggests that an informational mechanism may underlie these adverse responses, since loud music does not diminish the energy of the infrasound. Similar symptoms were observed in some workers during testing of the Concorde jet engines (Evans, 1976), and in other working environments (Andreeva-Galanina, 1971; Fecci, 1971).

Mohr et al (1965) did not find such adverse responses during 2-minute exposures of 5 subjects to infrasound and neither did Alford et al (1966) which employed 3-minute durations and 21 subjects.

Evans and Tempest (1972) reported the occurrence of "swaying", intoxication, lethargy and euphoria in some of their 25 subjects. Two individuals were particularly sensitive. One prematurely terminated the exposure to 2 Hz at 104 dB. The second sensitive subject had a long history of balance disturbance. Both complained of "such unpleasant sensations that the tests had to be terminated". This supports the contention that some individuals are sensitive to infrasound. This possibility was explicitly stated by Leventhall (1974).

Other authors who mention similar symptomatic responses include Leiber (1976); Revtov and Yerofeev (1976); Challis and Challis (1978); Yamada et al (1980); Landstrom (1980); and Okai et al (1980). Goldman (1978) has stated that symptoms of nausea, headache and fatigue develop in most persons at 135 dB if the exposures last longer than 20 minutes.

Johnson (1974) and Slarve and Johnson (1975) reported an experiment conducted on 4 military subjects exposed to various frequency-intensity combinations of infrasound for 8-minute durations. One of these subjects reported nausea, and 3 reported a lack of concentration or euphoria during or after at least one of the runs. Headache was also reported by one subject along with lack of concentration. Abdominal and chest vibrations were commonly encountered. From these results, Slarve and Johnson (1975) concluded that infrasound exposures as high as 144 dB are safe for "healthy" subjects for at least 8-minute periods. They also predicted that much longer exposures would be safe.

The same authors have attributed the adverse effects to harmonic distortion in the 30 to 100 Hz range generated by Evans and Tempest's equipment (von Gierke and Nixon, 1976). This is based on Harris and Sommer's (1968) findings of balance disturbance induced by 1500 Hz noise at 105 dB. But, distortion produced by Evans and Tempests's equipment in response to their fundamental signal of 130 dB did not exceed 60 dB in the 30 to 100 Hz band (Yeowart et al 1967; Yeowart, 1976). There is no evidence in the literature that sound at 60 dB could produce negative subjective responses.

The opinion of von Gierke and Parker (1976) and von Gierke and Nixon (1976) that infrasound is harmless is also based on their position that acoustical energy below 30 Hz is not transduced by the organism's sensory systems. This will be examined later.

Other authors who did not encounter sysmtomatic responses include Borredon and Nathie (1974) and Harris and Johnson (1978). Borredon and Nathie employed a relatively large subject sample (n = 42) and a long exposure duration (50 minutes), and they did note instances of somnolence reported by some of their subjects as well. However, their sample consisted of healthy, young military personnel only.

Harris and Johnson (1978) conducted 3 separate experiments in which their subjects were exposed to infrasound at various frequencies and intensities for 15 minutes. During half of the 15-minutes exposure to 7 Hz at 125 dB in their first 2 experiments, the infrasound was masked by a 110 dB masking noise. This masking noise was present during all infrasound exposures in their third experiment where intensities increased from 125 dB to 142 dB. Their subjects were also required to perform demanding mental tasks during most of their exposures.

Some of the described experiments have little bearing on the question of individual sensitivity. Small samples of subjects provides little power to detect sensitives. If an informational mechanism is involved in symptomatic responses to infrasound, the ongoing tasks would shift the subject's attention from the infrasound information. This could mitigate informational responses. Similarly, since potential 7 Hz throbbing would have been masked by the 110 Hz audible sound, the periodic information normally conveyed by infrasound was not delivered to the subjects in the majority of conditions in these experiments.

Thus, based on literature, it is reasonable to conclude that individual sensitivity in response to infrasound is a real possibility, though a convincing experimental demonstration is wanting. Energetic models do not offer insight into a mechanism for such sensitivity. Consequently, an examination of potential infrasound transducers is in order.

1.4 Infrasound and the Auditory System

Infrasound Auditory Thresholds

The most obvious sensory access of infrasound to the body is the auditory system. Numerous authors (Brecher, 1934; von Bekesy, 1936; Wever and Bray, 1936; Robinson and Dadson, 1956; Corso, 1958; Finck, 1961; Yeowart et al 1967: Whittle et al 1972; Yeowart, 1974; Yeowart and Evans, 1974) have established auditory thresholds of very low-frequency sounds which are in quite good agreement with each other.

Uncertainty exists in the literature as to whether these thresholds involve an auditory process and, if so, whether they reflect the fundamental infrasound frequencies or perceived distortion products.

Von Bekesy (1936) showed that these detection thresholds reflect auditory, not tactile sensations. Bekesy asked his subjects to localize the area of the body that was stimulated by the infrasound. Around the detection thresholds, the sensation was localized only in the ears. At higher intensities, a tactile sensation in the skin was also perceived.

Yamada et al (1980) and Okai et al (1980) suggest that the auditory system of some people is more easily stimulated by infrasound than that of others. Sensitive persons in their experiments had infrasound thresholds 15 - 30 dB below normal.

Von Gierke and Parker (1976) contend that frequencies below 30 Hz cannot be processed by the auditory system. Their contention is based on von Bekesy's (1948; 1960) observation that all frequencies below 30 Hz produce maximal basilar membrane deflection at one identical, most apical position of the basilar membrane. Von Gierke and Parker claim that reported auditory detection of infrasound is accomplished by harmonic distortion of the test signal either at the source, in the air, or in the middle ear. They also propose that subjects may distinguish the individual peaks of frequencies below 18 Hz on the basis of modulation of the audible harmonics.

But in spite of these objections which are related mainly to the interpretation of recorded thresholds, we may conclude that infrasound is perceived by the inner ear. Recent audiological data have confirmed that a "place" mechanism is not necessary to explain auditory perception below 400 Hz (Davis, 1960; Durrant and Lovrinic, 1977; Smith et al 1978).

One possible way of determining whether infrasound affects the auditory system is to determine whether infrasound exposure influences auditory thresholds at other frequencies. Exposure to intense sound in the conventional auditory range produces a temporary threshold shift (TTS), usually one-half to one octave above the eliciting frequency (Elliott and Fraser, 1970).

The literature contains numerous reports of TTS in response to infrasounds of varied frequency and intensity (Tonndorf, 1950, cited by von Gierke and Parker, 1976; Alford et al 1966; Jerger et al 1966; Nixon and Johnson 1973; Nixon, 1974). Like TTS resulting from higher frequency sounds (Elliott and Fraser, 1970), infrasound induced TTS in 33 to 50 per cent of the subjects in the papers cited above. However, unlike TTS at higher frequencies, infrasound-induced TTS is spotty, occurring at seemingly random frequencies throughout the audiofrequency spectrum. Also, the severity of this TTS is much less than that which occurs from similar intensities at much higher frequencies. The only study in the literature not reporting TTS in response to infrasound up to 154 dB (Mohr et al 1965) involved only 5 subjects whose ears were covered by protective acoustic ear-muffs. Furthermore, Mohr et al determined their post-exposure thresholds one hour after the infrasound exposure. Other investigators found recovery from infrasound induced TTS within 30 minutes.

1.5 Infrasound and the Vestibular System

The vestibular system represents an intriguing putative infrasound transducer. Systems similar to those reported by some individuals in response to infrasound (eg. dizziness, nausea, headache and fatigue) are well known consequences of intense, atypical or prolonged vestibular stimulation. It has been established that the vestibular system can be stimulated by intense acoustical energy (McLaughlin, 1979, 1978; Parker et al 1978; Reschke et al 1974). Different authors offer various mechanisms for acoustical vestibular stimulation (von Bekesy, 1935, 1948, 1960; Benson, 1965; Parker et al 1968; Reschke et al 1970, 1974; Evans, 1976; Parker, 1976; Parker et al 1978; Pryse-Phillips, 1979). The most direct conduit between the stapes and the vestibular apparatus runs from the inner ear vestibule, through the ductus reuniens, saccule, endolymphatic duct, utricle and finally semicircular canals.

Experimental evidence suggestive of vestibular response to infrasound in humans has also been provided. Mohr et al (1965) found visual field vibration in all of his subjects in response to a 22 Hz centered band at 148 dB. Visual field shifts are one possible indicator of vestibular stimulation (Parker et al 1978). Hood et al (1971) found a decrement in the time in which their subjects were able to maintain their balance on a 2.5 cm-wide rail when exposed to 110 dB infrasound.

Okai et al (1980) and Yamada et al (1980) found nystagmus in response to infrasound only in 1 and 2 subjects (respectively) in over 20 subjects. Significantly, these were the subjects who reported symptoms akin to motion sickness.

A more direct approach to the issue was provided by Evans and Tempest (1972) who exposed subjects to monaural, binaural in-phase, and binaural anti-phase infrasound. Higher intensities and longer durations of the infrasound elicited nystagmus. Only 28% of subjects exhibited clear nystagmus in response to monaural stimulation while 85% exposed to binaural antiphase stimulation showed clear vertical hystagmus. Subjects not exhibiting nystagmus tended to show random eye movements capable of masking nystagmus. Evans and Tempest's findings and their implications were disputed by Johnson (1974) who studied visual nystagmus in volunteers exposed to infrasound and did not observe it in any of his subjects.

Johnson (1974) and von Gierke and Parker (1976) attribute the nystagmus in Evans and Tempest's records either to machine noise switching transients or signal distortion. These interpretations are questionable. The machine noise hypothesis does not account for the different proportions of subjects reporting nystagmus in the monaural and anti-phase conditions. Switching transients would have elicited nystagmus bursts only during stimulus onset and offset. The signal distortion hypothesis requires minimum sound pressure levels for harmonics of 105 dB as it is based on Harris and Sommer's (1968) finding of vestibular activation to 1500 Hz at 105 dB, a level not approached in Evans and Tempest's experiments.

1.6 Respiratory System Response to Infrasound

Another possible infrasound conduit that requires consideration is the respiratory system which represents a potential energy gate as well as sensory transducer for infrasound. Due to the impedance mismatch between air and body tissues, approximately 99 per cent of incident acoustic energy is reflected from the surface of the body. A greatly reduced impedance is offered by air-enclosed organs such as the lungs or the middle ear (von Gierke and Parker, 1976). Von Gierke and Parker (1976) argue that although the resonant frequency of the lungs lies in the 5 Hz region, a loading factor introduced by the coupling of the lungs with the thorax should increase the resonant frequency of the respiratory system ten-fold to about 50 Hz. They, therefore, feel that the respiratory system is less responsive to infrasound than to frequencies around 50 - 60 Hz.

Recently, Fredberg (1978) has shown that lung resonance to acoustical energy occurs at 0.5 Hz. Consequently, if lung-thorax coupling increases the resonant frequency ten-fold, the resonant frequency should occur around 5 Hz. The variously noted subjective reports of chest-wall vibrations in the literature (Evans and Tempest, 1972; Slarve and Johnson, 1975) may be attributed to infrasound. Johnson (1980, pg. 8 of Panel Discussion) described a natural resonance of his own tracheal tube at 3.5 to 4.5 Hz at 143 dB.

The lungs may also act as a sensory transducer of infrasound via the stretch receptors located in the lung tissue. The information conveyed by these receptors to the central nervous system may bring about secondary changes in cardiovascular function. Respiratory activity could also be altered by infrasound affecting other sensory systems.

Respiratory alteration by infrasound has been reported in the literature. Alford et al (1966) found that the respiratory rates of some of their subjects increased by 4 or more respirations per minute. Difficulty in breathing, suggestive of infrasound interference with inspiration, was found by Andreeva-Galanina (1971). Slight increases in respiratory rate were also reported by Fecci (1971) and Pimonow (1971). No infrasound-induced changes in respiration were reported by Slarve and Johnson (1975) though von Gierke and Nixon (1976) state that "respiratory rhythm changes or modulation in humans begin around 130 dB". Similar findings were published by Landstrom (1980) and Okai et al (1980).

1.7 Central Nervous System Response to Infrasound

Other physiological systems probably respond secondarily to primary infrasound transducers. If infrasound energy is transduced by any sensory system, central nervous system activity may, consequently, be affected. Various authors (Gavreau, 1968; Andreeva-Galanina, 1971; Rao, cited in Ashley, 1976) suggest that the brain's alpha rhythm could be upset or driven by infrasound, possibly with harmful consequences (Gavreau, 1968; Johnston, 1971, cited by Broner, 1978). Work-place studies by Andreeva- Galanina (1971) and Fecci (1971) report CNS disturbances occurring due to infrasound exposure.

In laboratory studies, Revtov and Yerofeev (1976) showed that infrasound frequencies of 8 and 10 Hz at 135 dB are followed by an induced EEG rhythm. Individual differences in the extent of this activity and hemispheric magnitude were noted. A similar observation was published by Okai et al (1980). Only some individuals were effected. Landstrom (1980) contends that EEG responses confirmed subjective reports of tiredness and falling asleep.

These few studies suggest that infrasound information may be processed by the central nervous system.

1.8 Cardiovascular System Response to Infrasound

The cardiovascular system may also respond secondarily to infrasonic stimulation. Alford et al (1966) found individual differences in heart rate response to infrasound at 140 dB. Heart rate changes in response to infrasound in working environments were also reported by Andreeva-Galanina (1971) and Fecci (1971).

In a study conducted on French soldiers, Borredon and Nathie (1974) found that diastolic pressure increased significantly in response to 7.5 Hz at 130 dB, and this increase persisted over the 45-minute exposure. Borredon and Nathie suggest that the autonomic nervous system underlies these changes since diastolic pressure is more effected than systolic pressure.

Slarve and Johnson (1975) did not find significant changes in heart rate in their 4 college-age male subjects.

Landstom (1980) reported a reduction in systolic pressure and an increase in diastolic pressure during a 1 hour exposure to 16 Hz at 125 dB. Also, large rebound effects occurred shortly after termination of the infrasound signal.

Okai et al (1980) found an initial decrease in heart rate, followed by an increase which persisted for the subsequent 59 minutes of a 1-hour exposure. Okai et al partly attribute heart rate acceleration or deceleration to respiratory center activation since heart rate changes were associated with respiratory rate changes.

1.9 Biochemical Responses to Infrasound

Another reflection of infrasound's action on the body involves biochemical changes. Landstrom (1980) found that gastric hydrochloric acid production increased in 10 of 20 human subjects during a 1-hour exposure to 16 Hz at 125 dB. Blood cortisol levels were slightly reduced by the infrasonic exposure. Landstrom cites a study by Liszka et al (1978) (in Swedish) on 37 workers exposed to infrasound from a ventilation system. Exposed workers had approximately half the level of urinary adrenaline at the end of their working day. These studies suggest that there is a connection between infrasonic exposure, reduced production of stress-related hormones, and wakefulness (Landstrom, 1980).

1.10 Alterations in Mental Performance in Response to Infrasound

Mental performance reflects highly coordinated activity of the CNS. If infrasound generated input is processed by the brain, it is possible that demanding mental performance will be altered due to either general processes, like arousal, or more specific informational interference. Since infrasound exists within many modern transportation environments, performance alterations in response to infrasound may have practical importance.

Gavreau (1968) claimed that infrasound rendered "... the most simple intellectual task impossible" (pg. 36) though no supporting evidence was offered. Green and Dunn (1968) attempt to explain the higher incidence of school absenteeism and highway accidents during thunderstorms on the basis of the infrasonic components of thunder. Their correlative analysis did not include any environmental moisture factor which probably correlated highly with thunder, school absenteeism and traffic accidents.

In laboratory studies, Hood et al (1971) and Leventhall (1974) reported performance decrements in between 14 and 86 per cent of their subjects on a battery of cognitive and motor tasks. It is not clear whether a general or specific mechanism is involved from these results.

Benignus et al (1975) found that more numeric signals were missed on a monitoring task under infrasound than under control conditions. Individual differences in these deficits were also noted. Slarve and Johnson (1975) reported no performance alterations in response to infrasound. One of 6 individuals reported time contraction at 20 Hz and 135 dB.

Kyriakides and Leventhall (1977) exposed subjects to a variety of conditions one of which was infrasound exposure at 115 dB and they measured performance on a complex task. Infrasound produced an increase in the primary task error rate. The peripheral task showed improvement with infrasound.

Similarly, in Harris and Johnson's (1978) study, no performance deficit was associated with infrasound, though the authors allow that this may have been due to ongoing learning. Alternatively, Harris and Johnson contend that infrasound might initiate some arousal process which enhances task performance.

Ising (1980) reported absence of performance deficits in subjects exposed to 5 - 20 Hz infrasound for up to 4 hours. Moller (1980) however, did find performance deficits due to infrasound on tests such as arithmetic addition, complex reaction time and a cue utilization test. Silent control and traffic noise did not produce such deficits.

Lastly, Landstrom (1980) showed that occasions of falling asleep during a 2-hour infrasound exposure (16 or 12 Hz, 125 dB) were double that of control (50 Hz) conditions. Sleep occurrence was confirmed by EEG, though procedures and EEG results were not described.

From the preceding view of the literature, it is clear that no consensus exists on whether infrasound represents a danger to humans, what physiological systems are responsive to infrasound stimulation, how such stimulation might cause the symptoms that were reported by some authors and how some possibly sensitive individuals might be differentiated from the majority of non-sensistive individuals.

2.0 RATIONALE FOR THE PRESENT STUDY

This research originated in 1974 when knowledge concerning human response to infrasound was even more sketchy and fragmented than appears in the foregoing review. Actually, no systematic literature review had been written until von Gierke and Parker's effort in 1976. This project was initiated with three complementary purposes in mind. They were:

1) To assess whether infrasound, at levels commonly encountered, might prove deleterious;

2) to attempt development of a theoretical framework in which responses to infrasound might be understood;

3) to resolve the widely controversial conclusions concerning human response to infrasound.

In the pilot study, 16 subjects were exposed to infrasound at 8 Hz and 100 dB for 30 minutes. Each subject acted as his own control with 8 subjects receiving the infrasound session first and the other 8 subjects receiving the silent control session first. Sessions were identical, except for the stimulus.

In this pilot study, 2 of the 16 subjects reported episodes of dizziness, nausea, headache and fatigue a few hours after the end of their experimental sessions. None of the subjects reported any symptoms in response to the control session. Mean heart rate was significantly lower during infrasound exposure than during the control exposure, regardless of order and across all measured time periods. But, the two affected subjects uniquely showed heart rate increases occurring during the first 10 minutes of the experimental exposure.

The conclusion reached from the initial study was that individual differences may exist in human response to infrasound. Since at 8 Hz, 100 dB is below the auditory threshold, it is reasonable to suggest that if the noted symptoms were a consequence of the infrasound, some extra-auditory mechanism was responsible. The heart rate results also suggested that sensitivies might be characterized by an altered physiological response to infrasound.

Design Considerations

To determine whether infrasound produces symptoms of dizziness, nausea, headache, and fatigue in a fraction of the population, it was necessary to examine a large and varied subject pool. To clarify the roles of the general features of the experiment and the higher harmonics which some authors regard as crucial, it was necessary to vary the acoustical environment and observe whether statistically dissimilar numbers of subjects report these symptoms in response to the altered acoustical conditions. A between-groups design was chosen to avoid difficulties involved in repeated participation of a large number of subjects. Following their first session, subjects were partitioned by their subjective responses and their responses on measured dependent variables were then analysed for group differences. To further demonstrate that subjects reporting the noted symptoms were reacting to the experimental stimulus and not to the general features of the experiment, available sensitive subjects were rerun in up to 4 additional sessions which were identical except for the acoustical stimulus.

2.1 Selection of Independent Variables

Acoustical Parameters

Aside from acoustical environments, control and experimental sessions were identical. The control acoustical condition consisted of an approximately 60 dB amplifier hum which was distinctly audible. The experimental infrasound parameters were 8 Hz at 130 dB. 8 Hz was chosen since in the initial study, 2 individuals had reported symptoms of dizziness, nausea, headache and fatigue at this frequency. Furthermore, 8 Hz represents a frequency most often found troublesome in the literature. 130 dB was employed since this level was considered by the other authors (von Gierke and Parker, 1976) to be safe.

Two 8 Hz variants were used; an unfiltered high distortion signal and a filtered low distortion signal (see Figure 1). The total energetic content of the two signals was very similar - about 130 dB. Results from the initial study (using sub-threshold intensities), along with the foregoing analysis of the literature (eg. Evans and Tempest, 1972, whose harmonics were themselves inaudible) predicted that the fundamental and not the harmonics would be associated with symptoms.

2.2 Selection of Dependent Variables

The rationale for the selection of dependent variables is outlined in Figure 2. Figure 2 indicates that at least four potential infrasound transducers exist in the body. They are the vestibular, auditory and somatosensory systems plus the stretch receptors of the lungs. The somatosensory receptor's responses were not measured since there is no simple method for accomplishing this in intact humans, and there is little to implicate somatosensory receptors in the response of the organism to infrasound. To monitor these systems the following measures were taken:

1) Gaze Nystagmus as an indicator of Vestibular System activation;

2) Temporary Threshold Shift of the Auditory System;

3) Respiratory Rate as an indicator of possible reflex changes induced by the stimulation of pulmonary stretch receptors.

Gaze Nystagmus

Possible vestibular system response to infrasound was directly measured by checking for gaze nystagmus in the lateral position prior to the end of each session. The lateral position affords observation of small nystagmic beats which could be missed in the frontal position (Willis and Grossman, 1973).

Temporary Threshold Shift

The most obvious transducer of infrasound energy is the auditory system. Since 130 dB is well above the hearing threshold, detection was not an issue in this study. As an index of infrasound's effect on the auditory system, temporary threshold shift, ie. the difference in threshold levels before and after the infrasound exposure, at frequencies up to 8 kHz was measured. It has been suggested that TTS ought to be a major damage risk criterion for infrasound exposure (Nixon, 1974). The literature offers documentation that only some individuals experience TTS following brief infrasound exposure. It is then of interest to determine whether TTS might occur primarily in sensitive individuals.

Respiratory Rate

Infrasound may affect respiratory function directly, through expansion of the lungs by a pressure wave and by activation of the Hering-Breuer inflation and deflation reflexes. Respiratory system changes might also be associated with cardiovascular system alterations.

Respiratory rate might also be altered by hyperventilation, by motion sickness (Reason, 1976), or anxiety on the part of the sensitives. In the latter case, increased blood pressure would accompany the hyperventilation, whereas a drop in blood pressure usually accompanies vestibular stimulation (Moller, 1978). Hyperventilation is a well known associate of dizziness, nausea, headache and fatigue (Adams and Braunwald, 1974). Thus, it is of interest to see whether sensitives can be distinguished from non-sensitives by respiratory rate.

Other Selected Variables

EGG Analysis

If any or all of the above noted systems transduce infrasonic energy, the information may be conveyed to the central nervous system. One prime index of CNS activity is the electroencephalogram (EEG).

The literature suggests that infrasound may affect the EEG in one of two ways; by inducing an EEG rhythm at the infrasound frequency or by changing EEG frequencies to reflect anxiety (13-30 Hz activity) or fatigue (4-11 Hz).

Wessman-Ricks Mood Scale

Altered CNS activity might also be reflected in subjective mood states. A numerical scale for subjective responses was included to corroborate the subjects' verbal responses.

A subset of the Wessman-Ricks Mood Scale (1966) was selected in accordance with the following considerations:

1) Questions concerning dizziness,nausea, and headache should not appear to avoid suggesting these responses to the subjects.

2) A fatigue scale should be included, since it is difficult to assess verbal reports of fatigue.

3) A variety of other items should be included for two reasons. First, if only a fatigue scale were included, fatigue would be suggested. Second, it would be of interest to learn about other mood fluctuations which might accompany the symptoms. Specifically, anxiety and overall well-being were of interest to learn whether the physical symptoms could be explained by anxiety.

4) The scales should first present positive states rather than negative states to avoid a negative bias.

5) Each scale should cover a wide range of subjective states.

6) The scales should reflect acute rather than chronic states.

The Wessman-Ricks Mood Scale (1966) was selected for the above reasons. Nine of the 16 items were deleted as they were judged to be irrelevant.

Performance Variables

CNS activation might also be manifested by alterations in concurrent mental task performance. Part of the confusion in the literature regarding the effects of infrasound on performance revolves around the choice of task. Arousal is beneficial to some monotonous tasks (eg. vigilance, Broadbent, 1957) while very high levels of arousal may disorganize higher mental processes (Gellhorn, 1967). Consequently, it was decided to have a task which would reflect arousal levels early in the experiment. A second task, near the end of the session, was sought that would be sensitive to possible disorganization due to excessive arousal.

The early task was the time estimation. Time estimation as a cognitive task is supported by the findings that a depression of nervous-system activity leads to over-estimation of time intervals (Jones and Stone, 1970; Hollister and Gillespie, 1970), while an increased arousal facilitates under-estimation of time intervals (Ague, 1974).

The second test was digit span, which measures an individual's ability to recall a series of numbers. According to Gavreau et al (1966), even the most simple intellectual tasks were rendered impossible by infrasound. If so, at least the sensitives might show an inability to perform the digit span after 27 minutes of infrasound. Neither time estimation nor digit span is subject to ongoing learning, a fact which has rendered interpretation of earlier studies difficult.

Cardiovascular System Variables

Infrasound information impinging on the CNS might initiate cardiovascular responses. Cardiovascular system activity is adjusted in response to novel, alarming, familiar, intense or barely detectable stimulation in any modality (Hebb, 1948). The literature (eg. Alford et al 1966) suggests that different individuals change cardiovascular activity in different directionsin response to infrasound. Perhaps such differences might distinguish between sensitive and non-sensitive individuals.

Three related circulatory parameters are heart rate, blood pressure, and peripheral resistance. Additionally, heart rate may vary with changes in respiratory system activity. Moller (1978) suggested that infrasound may initiate cardiovascular alterations through a reduction in blood pressure via the vestibular depressor reflex. If infrasound initiates an alarm (defense) reaction in sensitive individuals, their blood pressure would be expected to rise (Rosen, 1970). Sensitive individuals might also possess unusually responsive baroreceptors in their blood vessels which could be triggered by intense acoustical energy or chest region resonance, and thereby influence blood pressure. Consequently, systolic and diastolic blood pressures were measured before and after the exposures.

Peripheral resistance is usually measured by recording pulse amplitude in the finger (Moller, 1978). Through finger plethysmography, changes in peripheral resistance were examined to help distinguish sensitives from non-sensitives.

Possible Predictors of Sensitivity

Medical History

Medical History was assessed by means of the Cornell Medical Index (CMI), a 177-item medical questionnaire.

Eysenck Personality Inventory

The Eysenck Personality Inventory (EPI) has been used in the past to predict severity of symptoms in Meniere's disease patients (Brightwell and Abrahamson, 1975), which are similar to those observed in the preliminary study. This inventory is built around arousal and inhibition.

Neurotics, lacking inhibition, respond more strongly to external stimuli. Extroverts, being oriented to external events, might be more attentive to infrasound. Perhaps neurotic extroverts might be more affected by infrasound than stable introverts.

3.0 METHODS

3.1 Subject Pool

Eighty male subjects from various walks of life were recruited. Twenty subjects served as controls. Twenty-seven subjects received the high distortion stimulus and thirty-three subjects the low distortion stimulus. All subjects underwent an otoscopic and audiometric examination prior to being accepted.

3.2 Equipment

The infrasound was administered in the loudspeaker-driven booth at the University of Toronto Institute for Aerospace Studies (UTIAS). The booth itself consisted of an almost airtight chamber with 12 loudspeakers located on one wall with inside wall surfaces lined with sound-absorbing fibre glass material. Free air volume was approximately 1.3 m^3. The booth was equipped with a seat, intercom and radio (Glass et al 1972).

The experimental stimuli were produced by function generator (IES model B34). Function generator output was led to two 100-Watt amplifiers with response that went down to direct current. The amplifiers' output activated six low-frequency loudspeakers (Altec-Lansing woofers, Model 515B, 38 cm diameter). The acoustical stimulus was calibrated by means of a Bruel and Kjaer pistonphone (model 4220, 124 dB, 250 Hz) mounted on a Bruel and Kjaer condenser microphone (1.25 cm diam. diaphragm) passed by a Bruel and Kjaer carrier system (model 2631) to a storage oscilloscope (Tektronix 5103 N/p13). The condenser microphone was used for all acoustical measurements.

Filtering was accomplished by passing the function generator output through dual Krohnhite filters at their lowest low-pass setting (10 Hz). This filtering reduced the second harmonic (ie. 16 Hz) by an additional 12 dB. The resulting spectrum of the high and low distortion signals is shown in Figure 1. In control sessions, the amplifiers produced ambient noise of roughly 60 dB.

Physiological Monitoring Equipment

EEG, respiratory rate and plethysmography were recorded by Narco-Bio Systems transducers whose output was fed to Narco-Bio type 7070 channel amplifier and continuously recorded by a four-channel Bruel and Kjaer 70034 FM tape recorder.

Heart rate was monitored by a telemetric Biolink 358 transmitter - receiving system (Biocom Inc.).

The auscultatory method was used for blood pressure measurements.

A Beltone II audiometer was used for pre- and postsessional audiograms.

The mean of the four 4.5-minute periods during which no task was performed was utilized for evaluating the four continuously monitored physiological variables (EEG, respiratory rate, heart rate, plethysmography). The other periods during which the performance tasks occurred contained altered values which could not be associated with responses to the acoustical conditions. Only low-distortion condition data were analyzed for these variables due to missing observations in the control (7/20) and high-distortion (13/27) conditions. Thirty-one of thirty-three observations were available for response pattern analysis of the low-distrotion condition.

The heart rate was counted from the electrocardiogram by a peak detector constructed according to the design of Shimizu (1978) and Hewlett Packard Universal 5325B counter. The respiratory rate was counted directly by the Hewlett Packard 5325B counter after filtration of the signal by an Ithaco 4213 electronic filter.

The plethysmography was evaluated in the following way:

> The analog FM tape was filtered by an Ithaco 4213 electronic filter and played at 10 times the recorded speed into a Bruel and Kjaer Type 2417 random noise voltmeter. Readings were taken every 27 seconds (4.5 minutes real time) to represent the average root mean squared (RMS) voltage of the plethysmography channel for that time period. Since the Narco-Bio 323 photoelectric pulse transducer is not a volumetric plethysmograph, these measurements represent relative pulse amplitudes rather than absolute pulse volumes. The RMS voltage for the first time period was taken as a standard (ie. 1.0) and the remaining readings converted to a value relative to the standard.

Spectral analysis of the EEG signal was performed by a digital signal processor (Spectral Dynamics, Digital Signal Processor (DSP) 360). The dominant feature of many of the spectra was a pronounced peak at 8 Hz. Since 8 Hz was the acoustic signal frequency, it was felt that perhaps a relationship existed between the signal to background noise ratio of the peak and subjective response. This has been suggested in earlier work on auditory driving of brain rhythms (Plutchick, 1966, 1959; Neher, 1961) as well photic driving (Walter and Grey Walter, 1949; Ulett et al 1953).

3.3 Description of the Experimental Session

After signing the Informed Consent Form, a tape describing the procedures and tasks was played, the audiograms were administered and the blood pressure taken. The EEG and EKG electrodes were placed, the plethysmographic respirometer fastened around the subject's right hand. The sound signal was turned on within 90 seconds of the subject entering the booth after all monitoring equipment was turned on. Five minutes later the time estimation task was administered.

The subject listened to taped bell sounds of 10, 20, 30, 40, and 50 second durations in that order. Following each sound, the subject gave his time duration estimate over the intercom. Then the next period was played and so on. No feedback was given as to how well a subject performed.

The next task, digit span, was given at the 20-minute mark. The taped WAIS digit span instructions were played for the subject over the intercom. The second chance sequence was read by the experimenter since attempting to skip tape was neither feasible nor uniform.

At the 28th minute mark gaze nystagmus was tested through the glass window of the experimental booth whose covering was removed during this procedure only. Thirty minutes after the monitoring equipment had been turned, the sound was turned off, the door was opened and the subject filled out the Wessman-Ricks Mood Scale questionnaire. Afterwards, the subject was asked: "Have you any additional comments on the experience?" The question was put this way to avoid drawing attention to the sound. The reply was written down by the experimenter. The subject remained seated for another minute and his blood pressure was taken. Then the post-exposure audiogram was administered as described earlier. Before the subject left, he was given copies of the Eysenck Personality Inventory and the Cornell Medical Index to complete and return. The following day the subject was contacted and asked: "Now that a day has passed, have you any further comments on the experience?" Again, comments were written down by the experimenter. This completed the session.

3.4 Experimental Design

The data were analyzed to answer two specific questions. First, to determine whether any reported symptoms could be associated with the acoustical conditions. Second, to determine whether responses on dependent variables (heart rate, mood scales, etc.) could discriminate between the various groups spontaneously reporting different subjective responses to the acoustical conditions. Subsequent analyses were employed to pinpoint the locus of differentiation on the relevant variables. Since the design was inherently unbalanced, Type III Sum of Squares in SAS (GLM) was used for multivariate and univariate analyses of variance. All functions were retained in the discriminant analyses because subjects were not randomly assigned to their response pattern groups (Eisenbeis and Avery, 1972). SPSS (Klecka, 1975) was used for the stepwise discriminant analyses.

3.5 Dependent Variable Analyses

The measured dependent variables were analyzed statistically in the following manner:

First, the control group data were deleted, since the control group did not contain response patterns to distinguish sensitives from non-sensitives.

Second, due to technical difficulties, heart rate, respiratory rate, EEG and plethysmography could not be analyzed for the high-distortion acoustical condition. These variables were analyzed for response pattern effects in the low-distortion condition only. Similar considerations hold for the paper and pencil tests which were not consistently returned by the subjects.

Two variables (temporary threshold shifts and eye movements) were dichotomized (scored either 0 or 1) with respect to absence or presence of TTS or eye movements. These were not analyzed by analysis of variance and were consequently not included in the MANOVA.

Subsequent Sessions

Since it was possible that the symptoms described by the subjects may have been associated with external factors unrelated to the experiment, the intent was to establish whether symptoms were replicable in those subjects. Therefore, it was decided to rerun the putatively sensitive individuals in three additional sessions. These subsequent sessions were as similar as possible to the initial session. The second and third sessions were control sessions (the infrasound would not be administered) and the fourth session contained the low distortion infrasound signal. In Campbell and Stanley's (1970) terminology, this sequence is referred to as an ABBA quasi-experimental design. This was undertaken to ascertain whether the experimentally generated infrasound (to the exclusion of all other unrelated factors associated with the experimental set-up) was related to the reported symptoms in those subjects. In addition, a fifth such session was run for available subjects utilizing an approximation to the distortion of the filtered signal (without infrasound) as a further control treatment.

4.0 RESULTS

4.1 Subjective Responses: Classification Results

From the outset, the thrust of the experiment was to distinguish subjective responses between the various acoustical conditions. Initially, only subjective responses of dizziness, nausea, headache and fatigue, and no others were anticipated. While initially perusing the verbal responses, five distinct response patterns emerged. These are described in Table 1B along with an arbitrary code number that reflects the relative adversity of the response pattern. The overall distribution of subjective response pattern by acoustic condition is shown in Table 1A.

To evaluate whether the different information or energy contained in the different acoustical environments could be associated with the different distribution of symptoms, the first analysis undertaken compared the type and number of symptoms reported in the two experimental conditions. This is illustrated in Table 2A. The probability of obtaining this exact distribution as obtained by the conservative Fisher Exact Test (Siegel, 1956, pp. 96-101) is 0.04895. The probability of a more extreme distribution is only 0.0023. Consequently, the probability of obtaining this distortion plus more extreme distributions by chance is only 0.051. This is not predicted by an energetic model but is consistent with informational models based on the initial study and literature reports such as Evans and Tempest (1972).

Discussion

These data demonstrate that the symptoms of headache and fatigue alone are primarily associated with the high-distortion stimulus, while dizziness and nausea are primarily associated with the purer (low distortion) 8 Hz stimulus. Further, the one subject reporting dizziness and nausea in the high-distortion condition asked that the session be terminated by the 10-minute mark. With one exception, subjects reporting dizziness and nausea in the low distortion condition experienced the symptoms hours later, after the experiment ended. Both subjects who experienced the symptoms during the session (one in each acoustical condition) reported recurrences a few hours later. The symptoms occurred and ceased suddenly and lasted between 15 minutes and two hours. Conversely, all subjects reporting only headache and fatigue noted these symptoms during the exposure, with the headaches lasting up to 5 hours beyond the exposure and the fatigue, 15 hours.

The fact that negative responses did not result from general features of the experiment is further attested to by the distribution of symptoms between experimental and control conditions. No control subject reported any symptoms at all. This is illustrated in Table 2B. The probability of this distribution occurring by chance is 7.6×10^{-27}.

During the subsequent sessions, all participating Response Pattern 4 subjects reported the same symptoms in response to the infrasound, but not to the two amplifier hum sessions nor to the harmonic distortion session. This shows that these sensitives were not responding to general features of the experiment nor to the energy contained in the harmonic distortion of the signal. More strikingly, the subject who reported dizziness and nausea in response to the high-distortion signal found the low-distortion signal much worse and he asked for termination of the low-distortion session in only 1.5 minutes. The presence of the harmonics seems to mitigate infrasound effects as suggested by Gavreau (1966) and Bryan (1976).

Since the energy levels of the fundamental 8 Hz in both low- and high-distortion signals were virtually identical, it appears that an informational model is required to explain the observed individual sensitivity to infrasound. If this model is applicable, it must also explain the delay in response encountered by Response Pattern 4 subjects. To guide the discussion of potential mechanisms, results from the selected dependent variables are now presented.

4.2 Univariate Results

Variables not evidencing significant response pattern effects include: initial systolic blood pressure, initial diastolic blood pressure, age, digit span, electroencephalogram, finger plethysmography, the Eysenck Personality Inventory, and the Cornell Medical Index.

Variables demonstrating significant response pattern effects include: the Wessman-Ricks Mood Scale, gaze nystagmus, respiratory rate, time estimation, heart rate, change in systolic blood pressure and change in diastolic blood pressure. Temporary Threshold Shift will also be discussed since infrasound affected the auditory system, though without regard to subjective response.

Wessman-Ricks Mood Scale

All three Wessman-Ricks Mood Scale items distinguished between groups reporting symptoms and those not reporting symptoms. The mean scores indicated that the groups reporting symptoms (Response Patterns 3 and 4) were less tranquil, more fatigued and less elated than the others not reporting symptoms. These are shown in Figures 3, 4, and 5. For Tranquility vs. Anxiety, the ANOVA F value was 3.16 with 4, and 47 dF for a 0.02 significance level. The Scheffe F, testing for differences between Response Patterns 0, 1, 2 and 3 plus 4, was 8.80, significant at the 0.10 level. (See Scheffe, 1953 for a discussion of this criterion.) Correspondingly, for Energy vs. Fatigue, the Response Pattern F was 3.84 (dF = 4.47) with a significance level of 0.0089. A Scheffe F of 14.23 declared the Response Pattern 0, 1, 2 vs. 3 and 4 comparison significant at the 0.025 level. For the Elation vs. Depression item, the Response Pattern F was 6.74 (dF = 4.47) with a significance level of 0.0002. The Scheffe value for comparing Response Patterns not reporting symptoms (0, 1, 2) against those reporting symptoms (3 and 4) was 28.29, significant beyond the 0.01 level.

Discussion of the Wessman-Ricks Mood Scale Results

These data provide corroborating numerical evidence for the subjective verbal reports. On the anxiety item no Response Pattern had a mean score below 5 (Figure 3). Therefore, anxiety per se was not evident even in the groups reporting symptoms. This also indicates that these groups were not scoring low universally in accordance with experimental demand. This demonstrates the importance of the Energy vs. Fatigue item where Response Pattern 3 had a mean score below 4 - indicative of substantial tiredness.

While these quantitative subjective data support the Response Pattern classification and the notion of legitimate individual fatigue and mood differences in response to infrasound, they tell us nothing about the underlying mechanism(s) associated with symptoms. For this one must turn to the physiological data.

4.3 Potential Infrasound Transducer Systems

Gaze Nystagmus

The observed eye movements suggest that sensitives have a proclivity for accoustical vestibular stimulation. From Table 3 it is evident that eye movements occurred in all subjects reporting dizziness and nausea, and occasionally in Response Pattern 1.

Discussion of Gaze Nystagmus Results

These data are consistent with the recent report by Okai et al (1980) who found nystagmus only in an individual sensitive to infrasound. This is also capable of resolving the conflict regarding nystagmus. A minority of subjects (presumably sensitives) experience nystagmus (Evans and Tempest, 1972) while the majority don't. Consequently, in studies involving few subjects (Johnson, 1974: von Gierke and Parker, 1976) nystagmus could not be found.

Temporary Threshold Shift

A physiological variable that is of interest, yet does not differentiate between groups is TTS. TTS was entirely absent in controls, it was independent of subjective response to infrasound, it was observed virtually equally following high- and low-distortion conditions, and it was spotty-that is, it was distributed throughout the whole range of studied frequencies, but no particular frequency was preferred. These results, summarized in Table 4, are consistent with other literature reports of TTS resulting from infrasound and low-frequency noise.

Discussion

From these data, an auditory impairment theory of infrasound sensitivity can be discounted. The prime acoustical instigator of infrasound-induced TTS cannot be the higher harmonics as Nixon (1974) tried to argue. If it were, greater and more common TTS should have resulted from the high distortion signal, particularly the harmonic frequencies.

The fact that infrasound-induced TTS is spotty might be explained by postulating that some areas along the basilar membrane (or supporting structure) are predisposed to auditory impairment. This may be due to anatomical irregularities or previous functional history. Since low-frequency waves traverse the whole basilar membrane, pre-existing damage-prone loci would be selectively impaired. However, as these loci differ between individuals, the resulting TTS appears spotty and without pattern when looking at a group of subjects. Of course, this has little to do with symptomatic responses. This mechanism is distinct from TTS resulting from intense higher-frequency sounds which are generally localized

1/2 to 1 octave above the frequency of the eliciting stimulus (Elliott and Fraser, 1970).

Respiratory Rate

The mean respiratory rate for Response Pattern 4 was higher than that for all other groups as shown in Figure 6 ($F = 7.39$; $dF = 1, 29$; $P > F = 0.01$). Furthermore, only this group (reporting dizziness and nausea) had an elevated respiratory rate (>16/min.) suggestive of hyperventilation (Willis and Grossman, 1973). Hyperventilation was also evident in this group in all subsequent experimental sessions and in some subsequent control sessions.

Discussion

These data suggest that a high respiratory rate may be one of the necessary conditions for infrasound-induced dizziness and nausea (Adams and Braunwald, 1974). Elevated respiratory rate is consistent with a mechanism involving vestibular activation (Monday, 1979) and motion sickness (Reason, 1976). The bidirectional respiratory rate changes found in different subjects in the infrasound literature (Alford et al 1966; Andreeva-Galanina, 1971; etc.) are explicable in light of these findings. Perhaps those showing respiratory rate increases are sensitives and the others are not. Furthermore, higher respiratory rate was independent of reports of chest-wall vibration. Since reports of chest-wall vibration were independent of reports of symptoms, it is also reasonable to suggest that the link between higher respiratory rates and symptoms was not due to energetic considerations involving the lungs or thorax. Rather, it appears that the hyperpnea associated with dizziness and nausea may characterize sensitive individuals and be indirectly associated with the symptoms.

Summary of Findings from Potential Transducer Systems

Two potential transducers, the vestibular and respiratory systems, differentiated between response pattern 4 and all others. Though the observed eye movements probably resulted directly from the infrasound exposure and may be related to a mechanism for inducing these symptoms, the hyperpnea seems to be an accompanying and not causative event. The third potential transducer, the auditory system, showed a TTS response that was independent of subjective responses to infrasound. These date suggest two avenues for infrasound information access.

4.4 Potential Secondarily Effected Systems

EEG Results

In many EEG records of infrasound-exposed subjects, very pronounced 8 Hz activity was evident. This was not found exclusively in sensitives nor was it absent in all non-sensitives. Analysis of the 8 Hz signal-to-noise ratio (Regan, 1979; Plutchik, 1966; Neher, 1961; Ulett et al 1953; Walter and Grey Walter, 1949) revealed no response pattern effect. Consequently, though 8 Hz EEG activity appeared in some subjects in this experiment as in other studies in the literature, this did not distinguish between sensitives and non-sensitives. Perhaps skull thickness, anatomical representation and/or electrode placement determined the extent to which 8 Hz activity was reflected in the EEG records.

Heart Rate

Heart rate and blood-pressure changes were also able to distinguish sensitives from non-sensitives, albeit in different ways. As shown in Figure 7, groups reporting symptoms had significantly higher heart rates than those not reporting symptoms (F = 2.80;p dF = 4, 26; P>F = 0.0468; Scheffe F = 10.31, F>F = 0.10). An alternate analysis, comparing Response Pattern 4 against all others combined was even more striking (F = 7.03 dF = 1, 29; P>F = 0.0128).

The magnitude of the difference separating groups reporting symptoms from those not reporting symptoms was approximately 10 beats per minute. Unlike respiratory rate, Response Patterns 3 and 4 were similar on heart rate. Control values were intermediate between sensitives and non-sensitives.

The difference in heart rate between the sensitive and non-sensitive groups may be explained in many ways. One possibility involves the defense reaction to intense sound (Borg, 1981). However, an increase of 6 beats per minute from control values does not readily furnish any clear-cut explanation. The difference in heart rate does not distinguish between dizziness and nausea on one hand and headache and fatigue on the other. And, even higher mean heart rates were observed in some of the sensitives during some of the control sessions with no concurrent reports of symptomatology. Consequently, it is safer to view the higher heart rates of the groups reporting symptomatology as a related, but not intrinsic part of the mechanism. In any case, these data may explain why some individuals described in the literature responded with cardiac acceleration, while others decelerated.

Blood Pressure

The other significant cardiovascular parameter, blood pressure change, served only to distinguish Response Pattern 3 from all others, as shown in Figures 8 and 9. This group, reporting headache and fatigue, uniquely showed increases of 10 and 12 mm Hg on systolic and diastolic pressure levels over the duration of the experiment. Changes found on all other groups were within limits of measurement error. For Systolic Pressure change, the F value of 3.28 (dF = 4, 47) is significant at the 0.0187 level and the Scheffe F (composing Response Pattern 3 and all others) of 12.74 is significant at the 0.025 level. For diastolic pressure change, the overall F value of 3.84 (dF = 4, 47) is significant at the 0.0089 level and the corresponding Scheffe F of 17.95 is significant at the 0.01 level. Pre-session values for all groups are in the normal physiological range.

Finger Plethysmography

No Response Pattern effect was manifested on the plethysmography variable. This may be due to the relatively imprecise (non-volumetric) technique employed.

Discussion and Summary of Plethysmological Variables

The increase in blood pressure is consistent with a general vasomotor, perhaps stress-related reaction present in Response Pattern 3. The marginally greater responsiveness in diastolic (vis-a-vis systolic) pressure is consistent with Borredon and Nathie (1974) and suggestive of a vegetative system response in this group. By themselves, however, these data do not offer an explanation for dizziness and nausea since Response Pattern 4 evidence no change at all.

Secondary physiological responses (including heart rate and both systolic and diastolic blood pressure changes) were able to distinguish Response Patterns 4 and 3 respectively from the non-sensitive groups. Plethysmography by itself did not identify any group. The 8 Hz activity found in some EEG records is too fragmentary to draw firm conclusions from.

Performance Variables

Time Estimation

Time estimation served to distinguish between groups reporting symptoms and those not reporting symptoms (see Figure 10). Only Response Patterns 3 and 4 over-estimated the durations of the bells by approximately 25%. Non-sensitive groups and controls either underestimated the durations slightly or were relatively accurate in their estimations. Response Pattern 1 furnished the lowest time estimations. The Response Pattern main effect was significant ($F = 4.25$, $dF = 4, 47$, $P>F = 0.0051$, Scheffe $F = 0.0495$), subsequent t-tests did not locate any individual Response Pattern that contained significant differences between Acoustical Conditions. This breakdown of the data is presented in Figure 11. The greatest such difference (though based on only 1 and 5 subjects) occurred in Response Pattern 4.

Discussion

The arousal hypothesis described by Leigh and Tong (1976), if real, would predict shorter time estimates for the groups reporting symptoms. The results were contrary. But one must note that Leigh and Tong did not differentiate positive (pleasurable) arousal from negative (aversive) arousal. It is reasonable to draw such a distinction. Consequently, though the groups reporting symptoms had higher physiological arousal levels as manifested by higher heart and respiratory rates, they may still over-estimate time. The greater time estimates for Response Pattern 3 vis-a-vis Response Pattern 4 are consistent with this notion since the symptoms affected Response Pattern 3 during the session while the symptoms affected most Response Pattern 4 subjects only after the session.

The difference in time estimates between the high- and low-distortion segments of Response Pattern 4 is explicable in terms of negative subjective states since the lone high-distortion condition subject to experience dizziness and nausea did so during the session while 4 of the 5 Response Pattern 4 subjects in the low-distortion condition experienced the symptoms only after the exposure.

4.5 Potential Predictor Variables

None of the potential predictor variables (Age, Personality, Medical History) proved effective in distinguishing sensitives from non-sensitives. On the Cornell Medical Index, none of the 6 Response Pattern 4 subjects shared any negative aspect of their medical histories, ie., no common complaints among the 177 items were noted. Analyses of the other predictor variables are presented in Nussbaum (1983).

4.6 Manova Results

A Manova was performed to insure that significant univariate results were not actually due to chance, given the large number of variables studied. Factors in the multivariate analyses of variance and the univariate ANOVAS were acoustic condition, response pattern and the acoustic condition by response pattern interaction. The 2 levels of the acoustic condition factor are high distortion and low distortion.

The MANOVA results are shown in Table 5. This demonstrates at the 0.002 level, that the different Response Pattern groups responded differently on the multivariate set of dependent variables. Thus, these inter-group differences are manifested in more than verbal responses alone. The interaction effect is in a region approaching significance, (0.11 in the Hotelling-Lawley trace) though no inference is permitted. This lack of significance is not surprising since relatively few subjects were manifestly affected by infrasound and they were probably too few to invoke significance for the overall Acoustic Condition by Response Pattern interaction effect. No Acoustical Condition main effect differences are apparent. With these considerations in mind, the univariate results can be accepted, and additional attention can be paid to the Response Pattern effect.

4.7 Discriminant Function Analyses Results

Though the selected predictor variables were of little help, the following multivariate analyses were successful in discriminating responses of sensitives from those of non-sensitives.

Separate discriminant analyses were performed for the high- and low-distortion conditions because the low-distortion condition data included four additional variables as explained earlier. Only the response pattern effect was analyzed as this was the only effect found significant by the MANOVA. A pooled covariance matrix generated the discriminant functions since no heterogeneity within covariance matrices existed ($x^2 = 23.41$, $dF = 234$, $P>x^2 = 0.99$ for the high-distortion variables; $x^2 = 96.16$, $dF = 544$, $P>x^2 = 0.99$ for the low-distortion variables).

The classification results for the high-distortion condition showed that 75% of all subjects were correctly classified by the derived function, as documented in Table 6A. This demonstrates that the verbal classification was in accord with the multivariate responses on the dependent variables. Response Patterns 1 and 3 were best defined in terms of Eye Movements and Diastolic Pressure Change respectively. The other groups were less well defined. Of note is the physiological nature of the dimension that best describes the symptomatic group in this condition. Consequently, there is no evidence that the affected group is psychologically different from the non-sensitive majority. The eye movements associated with Response Pattern 1 will be explored when a mechanism for the symptoms is discussed.

Additional details concerning the discriminant functions (Stepwise Summary, Eigenvalues, Canonical Correlations, Standardized Functions, Evaluations at Group Centroids, etc.) are included in Nussbaum, 1983.

The Low-Distortion Classification resulted in correct groupings for 96.67% of the observations, as shown in Table 6B. In this analysis, Response Pattern 4 was by far the best distinguished group (with a Canonical Correlation at Group Centroid of 7.06 vs. -2.78 for the next best defined group, Response Pattern 1). The four most important variables for defining this group reporting dizziness and nausea were physiological (change in diastolic pressure, change in systolic pressure, eye movements and plethysmography). This is further evidence that this group primarily differs from non-sensitives in the physiological domain. These results also show that the individuals originally classified by subjective responses are accurately distinguished by their multivariate scores as well. This strongly suggests that the noted subjective responses were grounded in physiological events unique to these sensitives. Additional details concerning these discriminant functions are included in Nussbaum, 1983.

The greater efficiency of the low-distortion classification (96.67%) relative to the high-distortion classification (75.0%) is probably due to two factors. First, the low-distortion analysis contained the Response Pattern 4 group which was best distinguished from all others. This group was not included in the high-distortion analysis since it contained only one subject, and discriminant procedures require a minimum of two observations per group (Klecka, 1975). Second, the low-distortion analysis included the four additional physiological variables.

5.0 Discussion: Potential Mechanisms for Sensitivity to Infrasound

Several factors must be considered prior to the presentation of a working hypothesis explaining these data.

First, the differences in frequencies of response pattern 3 and 4 in the high- and low-distortion condition eliminate the possibility of a pure energetic model.

Second, in any experiment with humans the posibility exists that responses may be suggested by the experimenter or the context of the experimental situation itself. But, specific cues increase the likelihood of specific responses (Loftus and Fries, 1979) while non-specific cues increase the likelihood of widely discrepant responses (Orne and Sheibe, 1964).

In this experiment, no information concerning symptom specifics was given beforehand. Also suggestion does not explain the differences in physiological findings and subjective complaints expressed by subjects exposed to the high- or low-distored infrasound.

Third, the presence of symptoms such as dizziness, nausea, and/or headache and fatigue may indicate the presence of the stress reaction. During exposure to arousing or stressful stimuli, a massive sympathetic discharge may occur leading to increased activity of numerous bodily functions (Victor and Adams, 1974; Adams and Braunwald, 1974; Lacey, 1967). But, if the experimental situation acted as a stressor, the symptoms should have occurred during the exposure. Further, headache and drowsiness do not follow such attacks (Adams and Braunwald, 1974). The contention that the dizziness and nausea resulted from anxiety and its attendant hyperventilation must be similarly rejected. In persons prone to hyperventilation dizziness, at least part of the attack can be reproduced by a short (2-3 min.) period of hyperventilation (Adams and Braunwald, 1974). But, higher respiratory rates in the control sessions of sensitive subjects did not elicit any adverse subjective feelings.

Fourth, it is possible to explain the subjective complaints of some experimental subjects as a consequence of intermittent rhythmic stimulation. Some individuals experience adverse effects from repetitive intermittent rhythmic sensory stimulation between about 5 and 25 Hz in any sensory modality (Walter and Grey Walter, 1949; Lovett Doust et al 1952, 1953; Plutchik, 1959). Generally, symptoms of fatigue and headache prevail though a small minority of subjects complain of dizziness. The 5-10 Hz range is most effective in eliciting these responses.

The physiological basis for the symptoms is believed to involve lowered blood oxygen (Lovett Doust et al 1953) or sugar levels in the brain (Walter and Grey Walter, 1949), which are well known associates of fatigue, headache, and dizziness (Adams and Braunwald, 1974).

However, a number of our findings are not readily accounted for by the general effect of intermittent stimulation. It does not account for dizziness and nausea being primarily associated with the low-distortion condition. Nausea is not listed as a symptom by Walter and Grey Walter

(1949) or Lovett Doust et al (1952, 1953). Nausea is mentioned only in passing by Plutchik (1959). Thus, the prevalence of nausea is not readily explained by the intermittent stimulation hypothesis. And, in the intermittent stimulation literature, the symptoms occurred during the exposure. There was no delayed onset of dizziness and nausea whether accompanied by headache and fatigue or not.

5.1 Acoustically induced Motion Sickness Hypothesis

For all these reasons, an alternative hypothesis was formulated which could explain our experimental data. The symptoms of dizziness and nausea which often occur a number of hours after the exposure resemble, most of all, motion sickness. Motion sickness consists of primary symptoms of dizziness, nausea and in severe cases vomiting often accompanied by headache and fatigue. Motion sickness results from sensory conflict following abnormal or prolonged vestibular stimulation in sensitive individuals. Detailed reviews of the topic are provided by Reason (1976) and Money (1975).

In the introduction, we described an anatomical connection between the auditory and vestibular systems. The ability of intense acoustical stimulation (above 100 dB) to stimulate the vestibular system was also documented (McLaughlin, 1978; Reschke et al 1974; Parker, 1976). Since lower frequencies are less liable to physical attenuation (Kinsler and Frey, 1972) and the vestibular system is tuned to low frequencies (Mayne, 1967; Deutsch and Deutsch, 1966; Howard and Templeton, 1966), the vestibular receptors should be more receptive to stimulation by infrasound than to higher frequencies. This could explain the specific symptoms reported in these experiments and in the literature.

The association of headache plus fatigue with the high distortion signal and dizziness plus nausea with the low distortion signal was detected in this study. There is one possible explanation for this relationship. Reschke et al (1974) have shown that induction of the acoustic reflex prevents acoustical vestibular stimulation by intense acoustical energy up to at least 130 dB. Further, the greater the number of peaks and the broader the bandwidth (Silman, 1979, Popelka et al 1976) of the acoustic stimulus, the stronger is the reflex and the greater the protection. Since the high-distortion signal contains more peaks which extend the upper-band limit to a region of greater acoustic reflex responsiveness, it is apparent that vestibular stimulation and the attendant probability of causing motion sickness is greater with a low-distortion stimulus.

The current findings of a more adverse response to the low- rather than high-distortion stimulus in one subject, and the lack of dizziness and nausea in all tested sensitives in response to the signal distortion is also consistent with this consideration. These results and this hypothesis are consistent with Okai et al (1980) and Evans and Tempest (1972) whose subjects reported such symptoms in response to very pure infrasound signals. Bryan (1976) also reported purer signals to be more troublesome in a field study. Perhaps most important, the experiment by Harris et al (1978) which contained a 110 dB background masking noise actually demonstrated nothing at all about human response to infrasound. The high frequency masker merely served as an acoustic-reflex eliciting protector.

This alone does not explain why only some individuals experience dizziness and nausea in response to a relatively pure infrasound signal. However, individual differences in strength and threshold of the acoustic reflex might favour protection in some individuals to a lesser degree than in others (Johnson and Sherman, 1979; Loeb and Fletcher, 1963). Another potentially differentiating factor surfaces if we consider the fluid path joining the oval window and the vestibular apparatus. Yuen and Schuknecht (1972) found that in 10 normal ears, the diameters of vestibular aqueducts ranged between 0.165 and 0.352 mm and endolymphatic duct diameters between 0.090 and 0.262 mm. Similar results were obtained in vivo using tomography by Clemis and Valvassori (1968, cited by Valvassori, 1975). Since fluid flow through a duct is governed by Poiseuille damping (Willis and Grossman, 1973), the rate of flow increases with the fourth power of the duct's diameter. Consequently, a doubling of the diameter (as measured by Yuen and Schuknecht, 1972) would result not in a doubling, but in a 16-fold difference in fluid flow to the vestibular end organs. Thus there exists an anatomical factor which might regulate the extent of physical stimulation of the vestibular system. Consequently, in different individuals, identical physical energy would lead to different levels of vestibular stimulation.

In the otological literature, cases are described of a fistula (opening or extreme thinness) in the bony wall of the vestibular apparatus (Pryse-Phillips, 1979). In persons with fistulae, vertigo occurs when movement of the soft tissues covering the fistula displaces endolymphatic fluid and the cupula following such common activities as sneezing, straining, quick head movements or manipulation of the auricle. Pryse-Phillips (1979) suggests that a labyrinthine fistula greatly enhances the probability of acoustical vestibular stimulation. A similar explanation was advanced by Benson (1965) to explain individual instances of pressure vertigo. Approximately 10% of pilots report experiencing vertigo upon landing or takeoff - always in the same orientation. Extreme thinness of the labyrinthine wall adjacent to the affected canal could explain these vertiginous responses to the pressure fluctuations.

To this point, factors affecting the transmission of energy to the vestibular system have been considered as possible differentiators between sensitive and non-sensitive individuals. However, even when vestibular stimulation is clear and unequivocal, as with whole body movement, some individuals are especially prone to motion sickness while others are not (Reason, 1976; Money, 1970). Though no definitive theory currently exists to explain this basic fact of motion-sickness, such sensitivity is believed to involve individual characteristics of the central nervous system (Reason, 1976). Considered characteristics include motion pattern learning ability (Groen, 1959), perceptual receptivity (Reason, 1968) and central adaptability (Reason and Graybiel, 1972). While the issue of the central component of motion-sickness susceptibililty has not been resolved, the underlying central tendencies might also distinguish our sensitive subjects from non-sensitives.

The motion-sickness hypothesis is also able to explain why most subjects reporting dizziness and nausea in this experiment did so a number of hours following the exposure. Reason (1976) notes that motion-sickness symptoms may occur suddenly many hours after the offending stimulus has ceased. One interesting example of this is disembarkment sickness, in which symptoms strike a victim a number of hours after he has left a ship. Presumably, though an adaptation or habituation has occurred during some stage of the experienced motion, the motion pattern itself has been learned and stored. A conflict between this pattern and the stationarity of dry land triggers the syndrome somewhat later. Our experiment was conducted with subjects in the dark. Consequently, no visual-vestibular conflict should have occurred during the infrasound exposure. Adaptation could have occurred during this period, with the conflict triggering the symptoms later, as in disembarkment sickness. Perhaps an inter-vestibular conflict (due to assymetry between left and right fluid duct diameters, or a single labyrinthine fistula) occurred in those sensitives who experienced dizziness and nausea during the exposure. A summary of this acoustically induced motion-sickness hypothesis (organized sequentially) is outlined in Figure 12.

This explanation is consistent with the data showing that Response Pattern 4 could be differentiated from the other groups on the basis of eye movements (indicative of vestibular involvement) and hyperventilation (indicative of vestibular involvement [Monday, 1979] and motion sickness as well [Reason, 1976]). Similar findings are reported in the literature (eg., Okai et al, 1980).

Since the use of mental imagery can alleviate motion sickness (Reason, 1976; Fukuda, 1976; Barr et al 1976), the finding that Response Pattern 1 (reporting the similarity of infrasound to a previous experience) did not experience symptoms is appreciable despite eye-movement responses of the subjects. Other findings consistent with the motion sickness hypothesis are the independence of TTS from infrasound sensitivity, symptomatic responses to sub-auditory threshold stimuli, and the ineffectiveness of personality or medical history evaluations to predict sensitivity.

5.2 Implications for Infrasound in Real-Life Situations

Caution is usually advisable in generalizing from laboratory experiments to extra-laboratory situations. This caveat is also true in the field of infrasound. But, there are some situations where infrasound may induce in sensitive individuals, adverse subjective reactions which cannot be explained in any other way.

Two comon propagating sources of infrasound are malfunctioning ventilation systems (where the infrasound is generated by the fan and is transmitted through the ducts to distant points) and transformer stations (Challis and Challis, 1978). Complaints tend to be voiced by persons living about two miles from the stations, and not by persons living nearer (John Manual, Noise Pollution Section, Ontario Ministry of the Environment, personal communication, 1978). Similarly, otherwise unexplained occurrences of dizziness and nausea in 10% of school children at Sir Adam Beck Public School, Etobicoke, Ontario (December, 1978) coincided with an adhesion of a vent covering while the fan-furnace system was operating.

One problem in such situations lies in symptoms occurring without an apparent cause. If these events were actually caused by infrasound as hypothesized, it is comforting to know that nothing more serious than insidious motion sickness was involved.

However, one must again exercise caution in generalizing. First, duration of exposure in our experiments was relatively brief. One does not know what time-intensity tradeoffs exist. Second, the evidence shows that two different distortion spectra led to different distributions of symptoms. Thus, it may be premature to generalize beyond our generated signals, theory notwithstanding.

5.3 Conclusions

1) Most individuals tolerate 8 Hz at 130 dB for 30 minutes without ill effects regardless of distortion level employed.

2) A minority of individuals were annoyed and physically affected by our experimental stimuli.

3) In sensitive individuals, the infrasound with high admixture of higher harmonics was primarily associated with headache and fatigue. The purer, low-distortion stimulus was primarily associated with dizziness and nausea, often beginning a number of hours after the exposure.

4) Sensitives were readily distinguishable from non-sensitives on the basis of their objectively detected characteristics of physiolocial and phychological responses to infrasound.

5) Presence or absence of TTS was independent of subjective response to the stimulus.

6) Considering infrasound as an intermittent rhythmic stimulus and/or an effective vestibular stimulus leads to hypotheses which possible account for our results.

7) These 'informational' hypotheses may resolve apparent discrepancies in the infrasound literature.

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2. Classification Data and Analyses

3. Eye Movement Results

4. Summary of Occurrence of TTS by Acoustic Condition and Response Pattern

5. Multivariate Analysis of Variance (MANOVA) Results

6. Discriminant Analysis Classification Results

Table 1 A. Distribution of Subjective Response Patterns By Acoustic Condition

Acoustic Condition	Subjective Response Pattern 0	1	2	3	4
Control n = 20	20	0	0	0	0
High Distortion n = 27	11	5	4	6	1
Low Distortion n = 33	10	8	8	2	5

B. Response Pattern Code

C : Control group (All Response Pattern 0)

0 : Reporting no negative subjective response

1 : Reporting no negative subjective response and spontaneously comparing the acoustic signal to a previously encountered environment

2 : Reporting negative subjective response to the acoustic signal, but no physical symptoms

3 : Reporting the symptoms of headache and fatigue, but not dizziness and nausea

4: Reporting the symptoms of dizziness and nausea

Table 2 A. Distribution of the Type of Physical Symlptoms Reported in Response to the High and Low Distortion Infrasound Conditions

	Reporting Headache and Tiredness	Reporting Dizziness and Nausea
High Distortion	6	1
Low Distortion	2	5

The probability of obtaining this exact symptomatic frequency distribution between the high and low distortion conditions by chance alone (as obtained by the Fisher Exact Test) is 0.04895.

B. Distribution of Symptoms between Control and Experimental Conditions

	Not Reporting Symptoms	Reporting Symptoms	
Control	20	0	20
Experimental	46	14	60
	66	14	80

The probability of obtaining this exact symptomatic frequency distribution between Control and Experimental conditions by chance along (as obtained by the conservative Fisher Exact Test) is 7.6×10^{-27}.

Table 3 Number of Observations of Verified Eye Movements/ Number of Subjects Per Acoustic Condition by Response Pattern Cell

RESPONSE PATTERN

ACOUSTIC CONDITION	0	1	2	3	4
1 Control	0/20	—	—	—	—
2 High Distortion	0/10	3/5	0/4	0/6	1/1
3 Low Distortion	2/10	1/8	0/8	0/2	5/5

The number above the line represents the number of subjects presenting eye movements in each cell. The number below the line represents the number of subjects in the cell.

Legend: Response Patterns are coded as follows:

C : Control group (All Response Pattern 0)

0 : Reporting no negative subjective response

1 : Reporting no negative subjective response and spontaneously comparing the acoustic signal to a previously encountered environment

2 : Reporting negative subjective response to the acoustic signal, but no physical symptoms

3 : Reporting the symptoms of headache and fatigue, but not dizziness and nausea

4 : Reporting the symptoms of dizziness and nausea

Table 4 Summary of Occurrence of TTS by Acoustic Condition and Response Pattern

I. TTS by Acoustcal Condition

Acoustical Condition	Number of Subjects	Number of Subjects with Measured TTS Reaching Criterion (See Text)
1	20	0
2	27	14
*3	32	15

II. TTS by Response Pattern for Acoustical Conditions 2 & 3

Response Pattern	Number of Subjects	Number of Subjects with Measured TTS Reaching Criterion
0	21	10
1	13	7
*2	11	6
3	8	3
4	6	3

III. TTS by Response Pattern for Acoustical Condition 2

Response Pattern	Number of Subjects	Number of Subjects with Measured TTSD Reaching Criterion
0	11	5
1	5	3
2	4	3
3	6	3
4	1	0

IV. TTS Response Pattern for Acoustical Condition 3

Response Pattern	Number of Subjects	Number of Subjects with Measured TTS Reaching Criterion
0	10	5
1	8	4
*2	7	3
3	2	0
4	5	3

* One subject terminated his session prior to administration of the post-exposure audiogram.

Table 5 Multivariate Analysis of Variance (MANOVA) Summary Table of Single Score Variables

	MANOVA STATISTIC					
	Wilk's Criterion			Hotelling-Lawley Trace		
Test for Hypothesis of No Overall:	dF	F Ratio	Probability F	dF	F Ratio	Probability F
Acoustic Condition Effect	10, 38	1.60	0.1452	10, 38	1.60	0.1452
Response Pattern Effect	40, 145	1.94	0.0024	40, 146	2.10	0.0008
Acoustic Condition X Response Pattern Effect	40, 145	1.28	0.1467	40, 146	1.34	0.1058

Included Variables: Tranquility vs Anxiety; Energy vs. Fatigue; Elation vs. Depression; (Mood Scale Items); Average Time Estimation; Initial Systolic Pressure; Initial Diastolic Pressure; Change in Systolic Pressure; Change in Diastolic Pressure; Digit Span; Age.

Data Set: 57/60 subjects

Wilk's criterion is sensitive to central tendencied in the data.
Hotelling-Lawley Trace is sensitive to extreme deviations in the data.

Table 6 Discriminant Analysis Classification Results:

A. High Distortion Condition

Actual Pattern Response Group	Number of Cases	Predicted Group Membership Response Pattern 0	1	2	3
0	10	9 90.0%	0 0.0%	0 0.0%	1 10.0%
1	5	2 40.0%	3 60.0%	0 0.0%	0 0.0%
2	3	1 33.3%	0 0.0%	2 67.7%	0 0.0%
3	6	1 16.7%	0 0.0%	1 16.7%	4 66.7%

Percent of Grouped cases correctly classified: 75.00%

B. Low Distortion Condition

Actual Response Response Group	Number of Cases	Predicted Group Membership Response Pattern 0	1	2	3	4
0	9	9 100.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%
1	7	0 0.0%	7 100.0%	0 0.0%	0 0.0%	0 0.0%
2	7	1 14.3%	0 0.0%	6 85.7%	0 0.0%	0 0.0%
3	2	0 0.0%	0 0.0%	0 0.0%	2 100.0%	0 0.0%
4	5	0 0.0%	0 0.0%	0 0.0%	0 0.0%	5 100.0%

Percent of Grouped cases correctly classified: 96.67%

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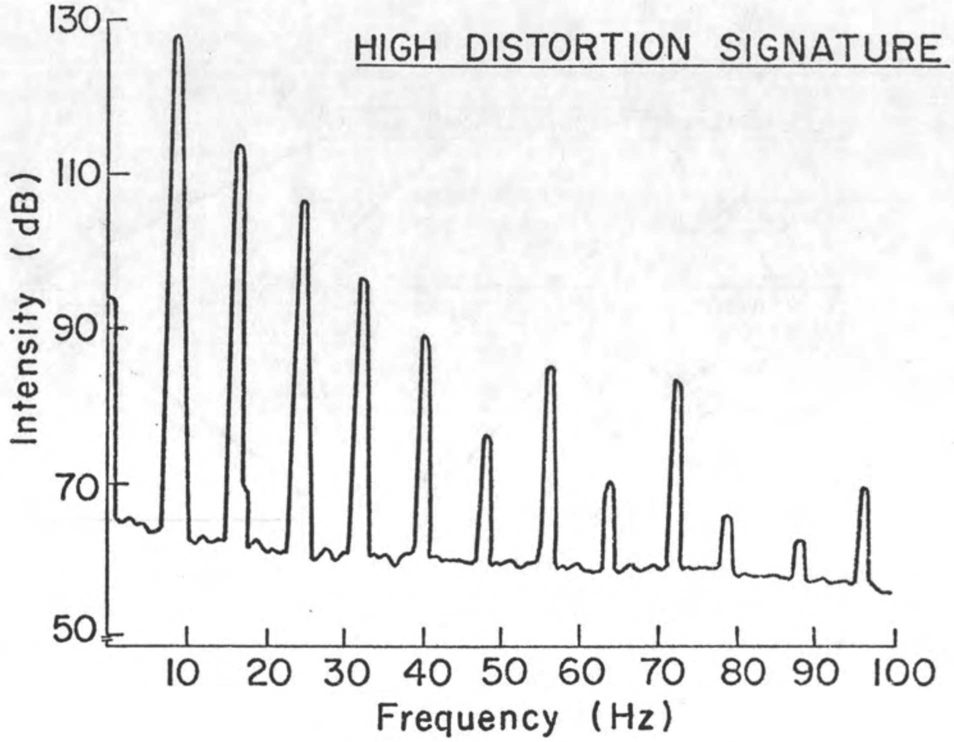
11. Time Estimation Data: Showing Response Pattern and Acoustic Condition Interactions
12. Summary of Acoustically Induced Motion Sickness Hypothesis

A



B

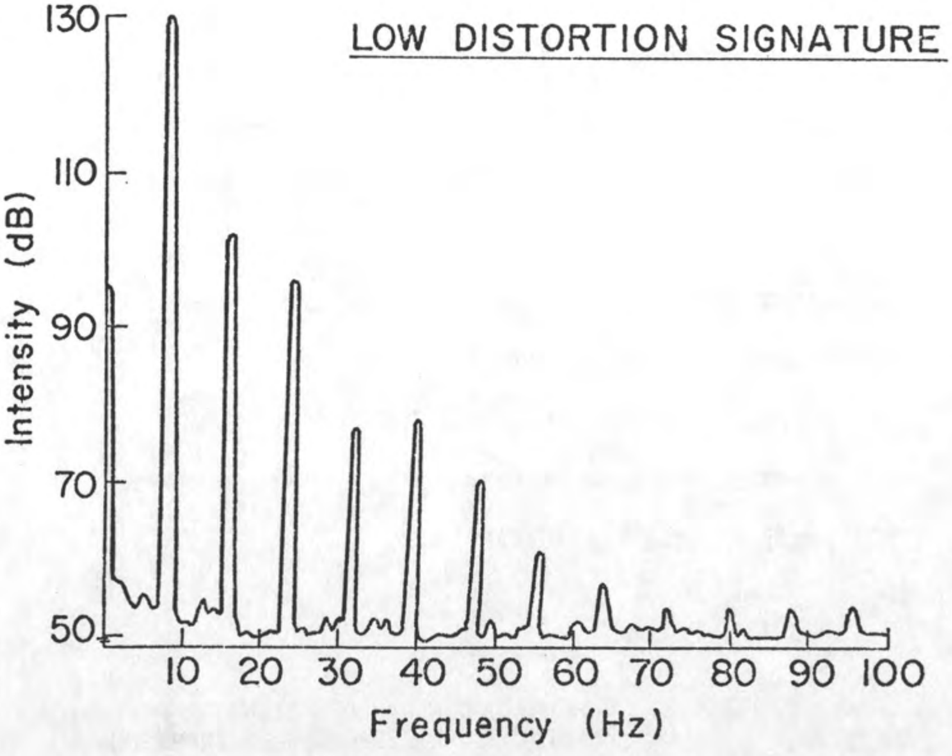


FIGURE 1 HIGH AND LOW DISTORTION INFRASOUND SIGNATURES

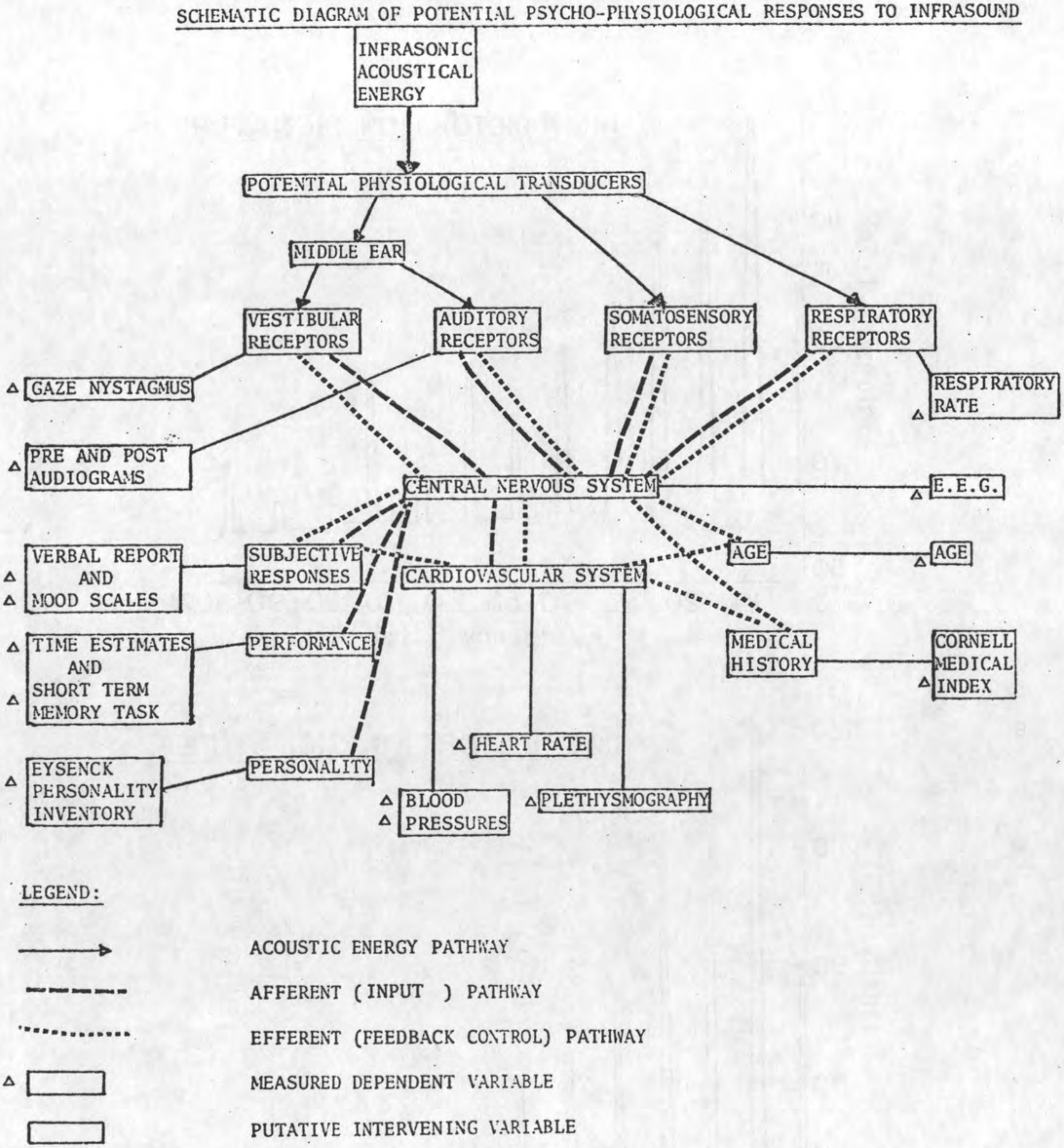
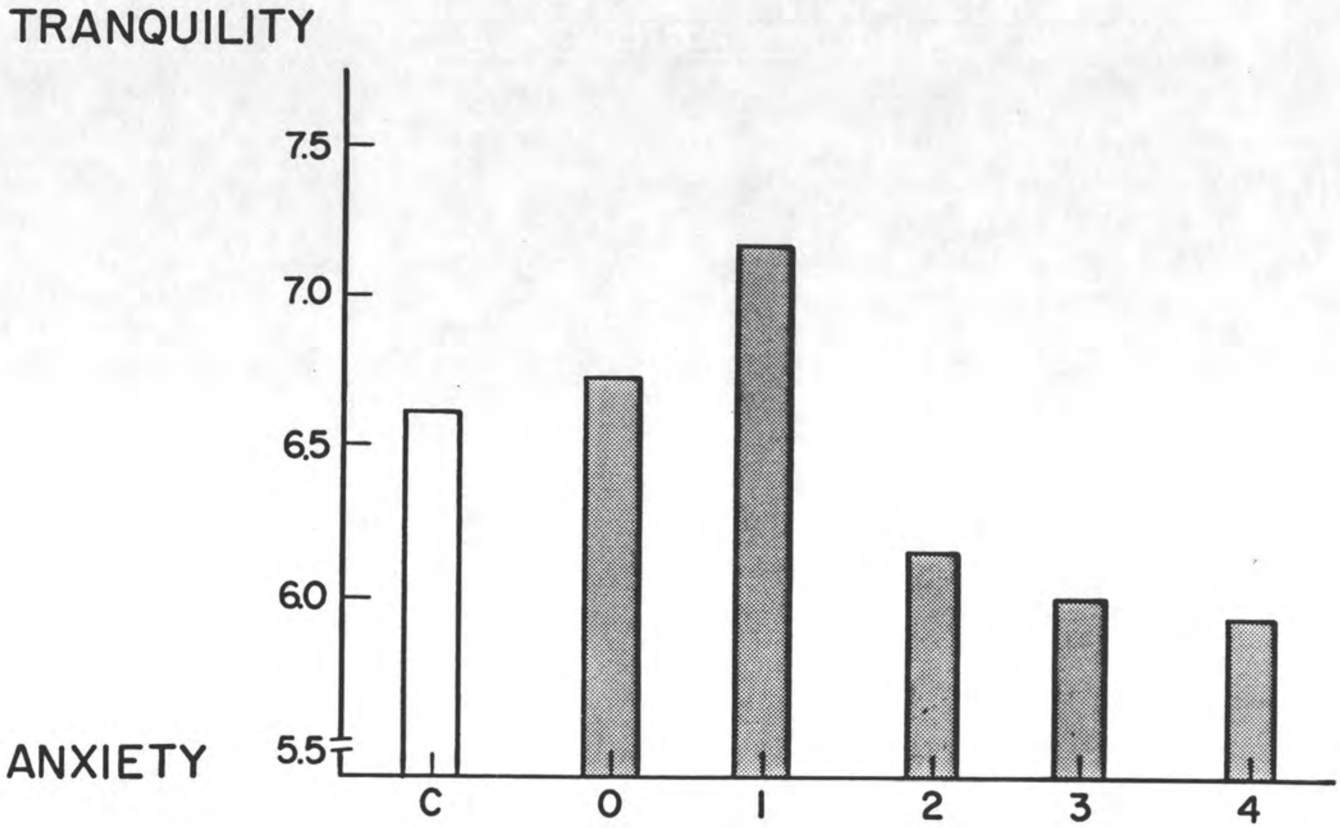


FIGURE 2. SCHEMATIC DIAGRAM OF POTENTIAL PSYCHO-PHYSIOLOGICAL RESPONSES TO INFRASOUND

MEAN WESSMAN AND RICKS TRANQUILITY vs. ANXIETY MOOD ITEM SCORES



RESPONSE PATTERN

LEGEND Response Patterns are coded as follows:

C : Control group (All Response Pattern 0) .
0 : Reporting no negative subjective response.
1 : Reporting no negative subjective response and spontaneously comparing the acoustic signal to a previously encountered environment.
2 : Reporting negative subjective response to the acousitcal signal, but no physical symptoms.
3 : Reporting the physical symptoms of headache and fatigue, but not dizziness and nausea .
4 : Reporting the physical symptoms of dizziness and nausea .

FIGURE 3. MEAN WESSMAN AND RICKS TRANQUILITY VS. ANXIETY MOOD ITEM SCORES

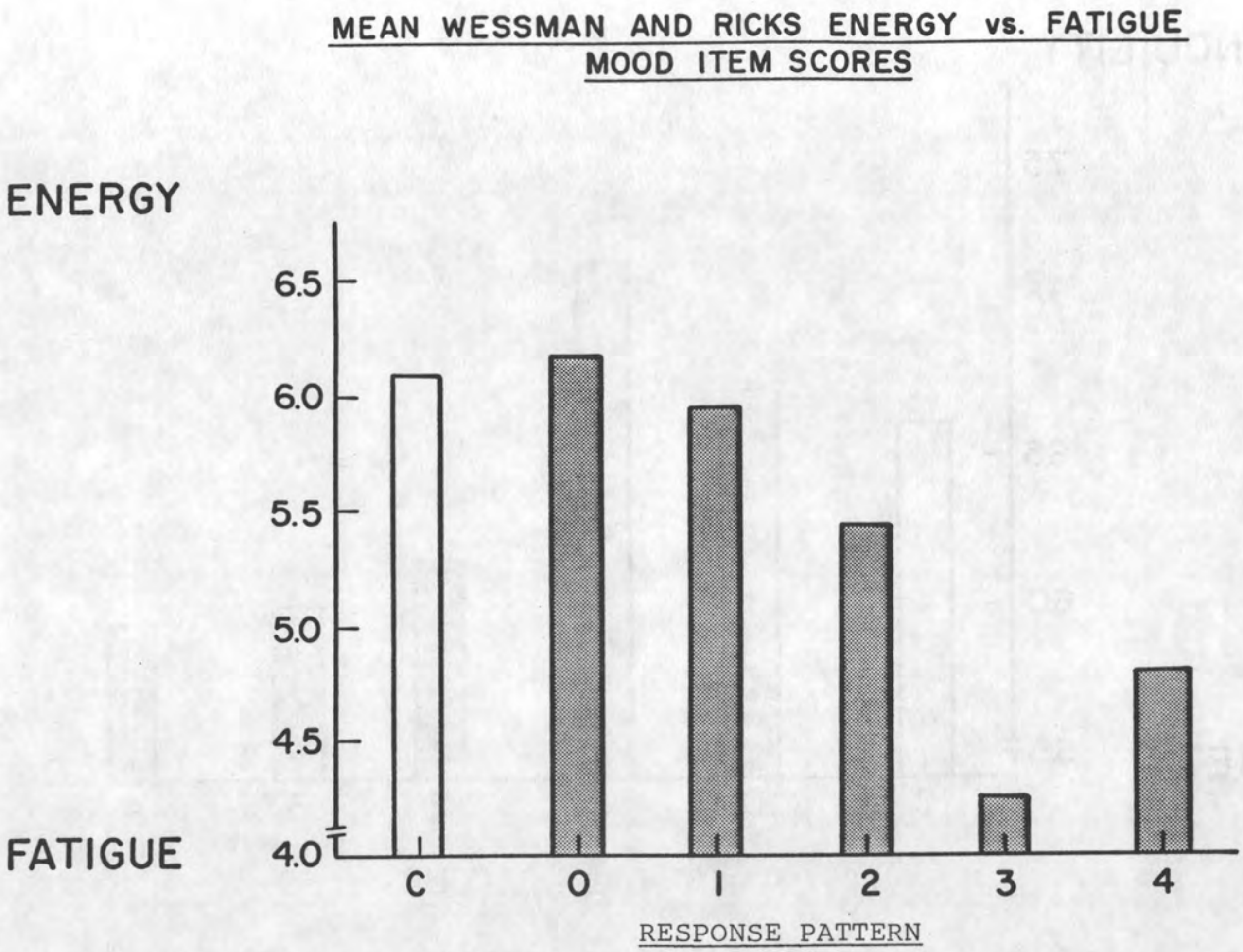


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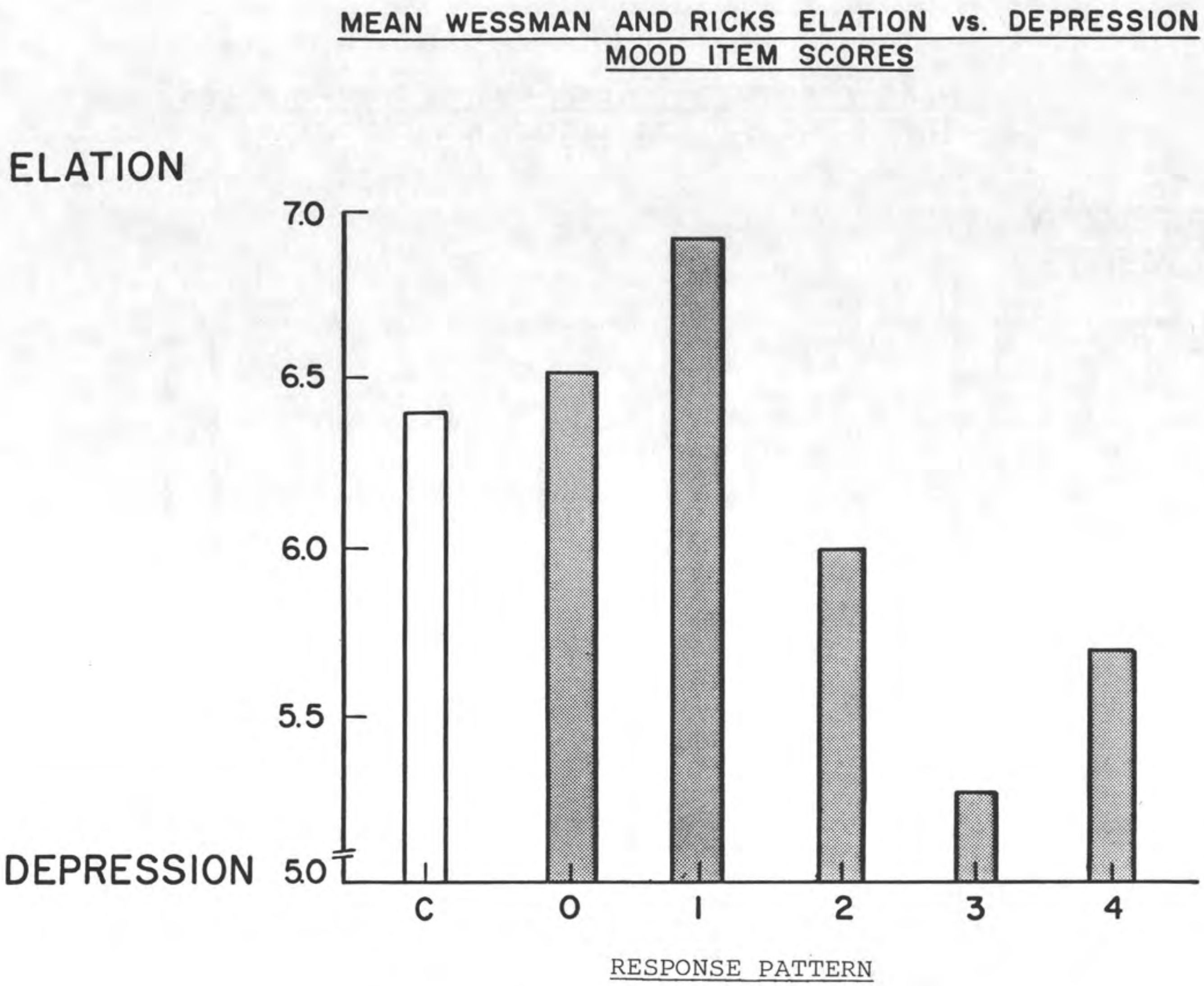
FIGURE 4. MEAN WESSMAN AND RICKS ENERGY VS. FATIGUE MOOD ITEM SCORES



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3 : Reporting the physical symptoms of headache and fatigue, but no dizziness and nausea .
4 : Reporting the physical symptoms of dizziness and nausea .

FIGURE 5. MEAN WESSMAN AND RICKS ELATION VS. DEPRESSION MOOD ITEM SCORES

MEAN RESPIRATORY RATE DURING THE FOUR NON-TASK TIME PERIODS (LOW DISTORTION CONDITION)

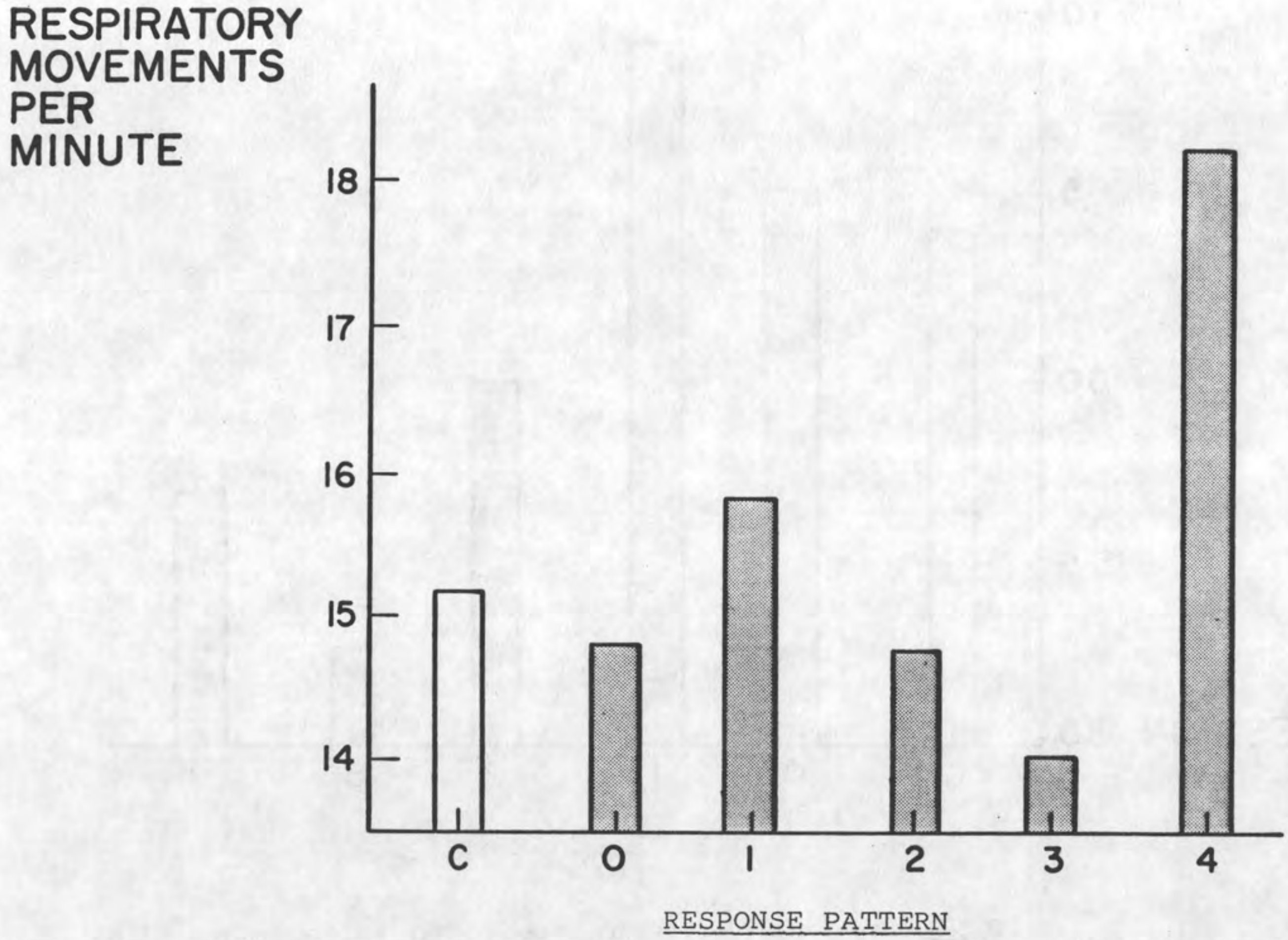

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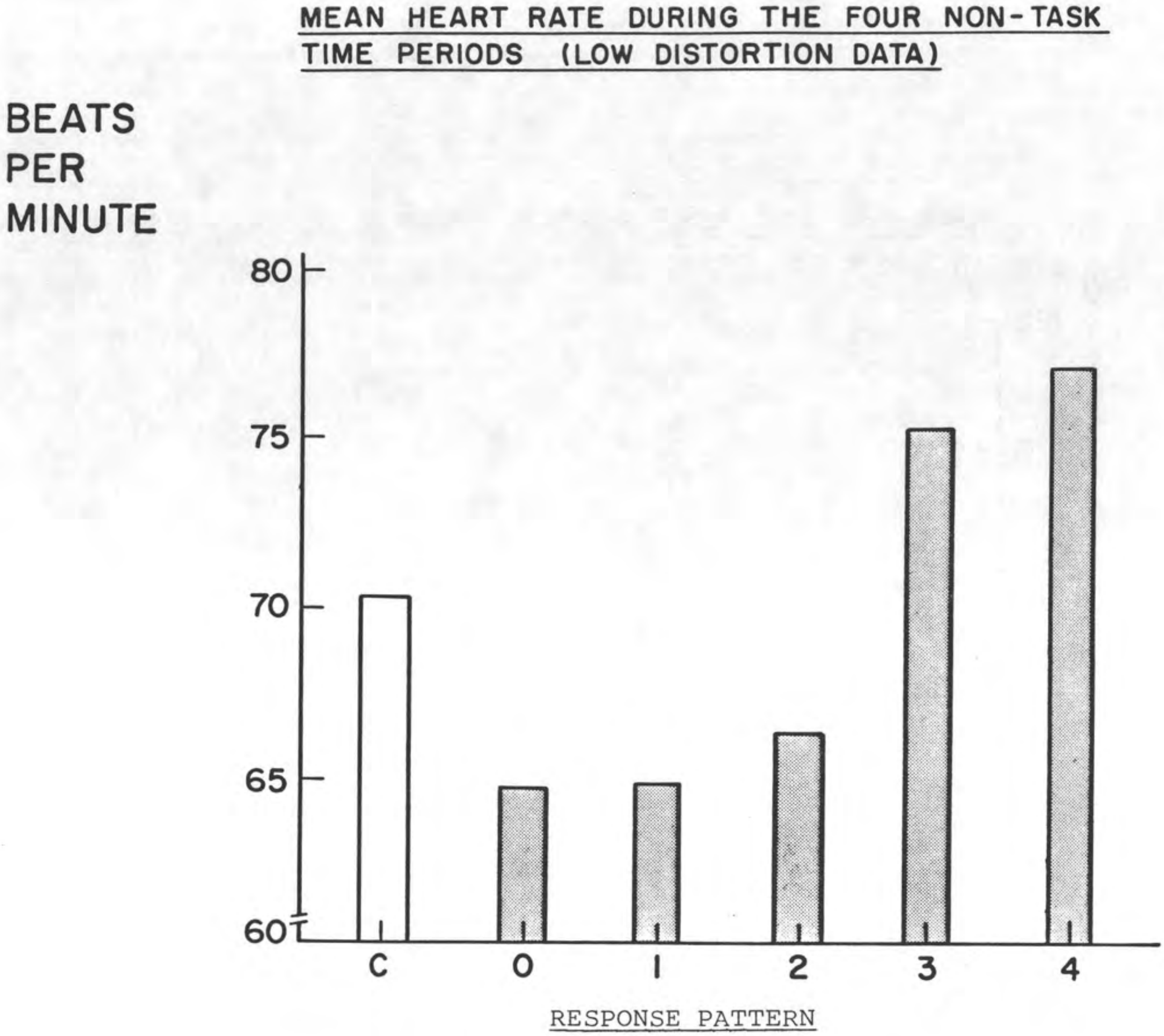
FIGURE 6. MEAN RESPIRATORY RATE DURING THE FOUR NON-TASK TIME PERIODS (LOW DISTORTION CONDITION)



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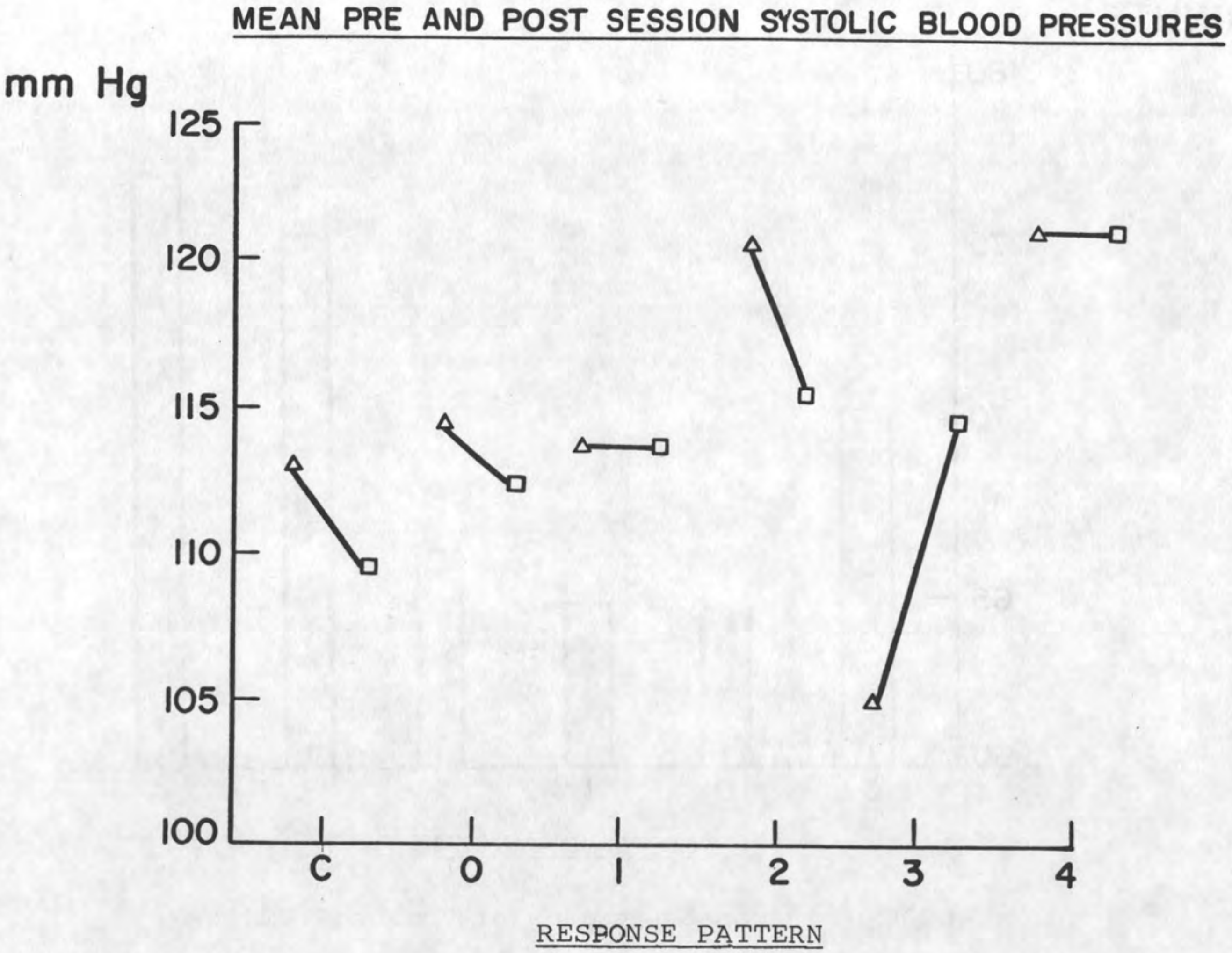
4 : Reporting the physical symptoms of dizziness and nausea .

FIGURE 7. MEAN HEART RATE DURING THE FOUR NON-TASK TIME PERIODS (LOW DISTORTION DATA)



LEGEND Response Patterns are coded as follows:

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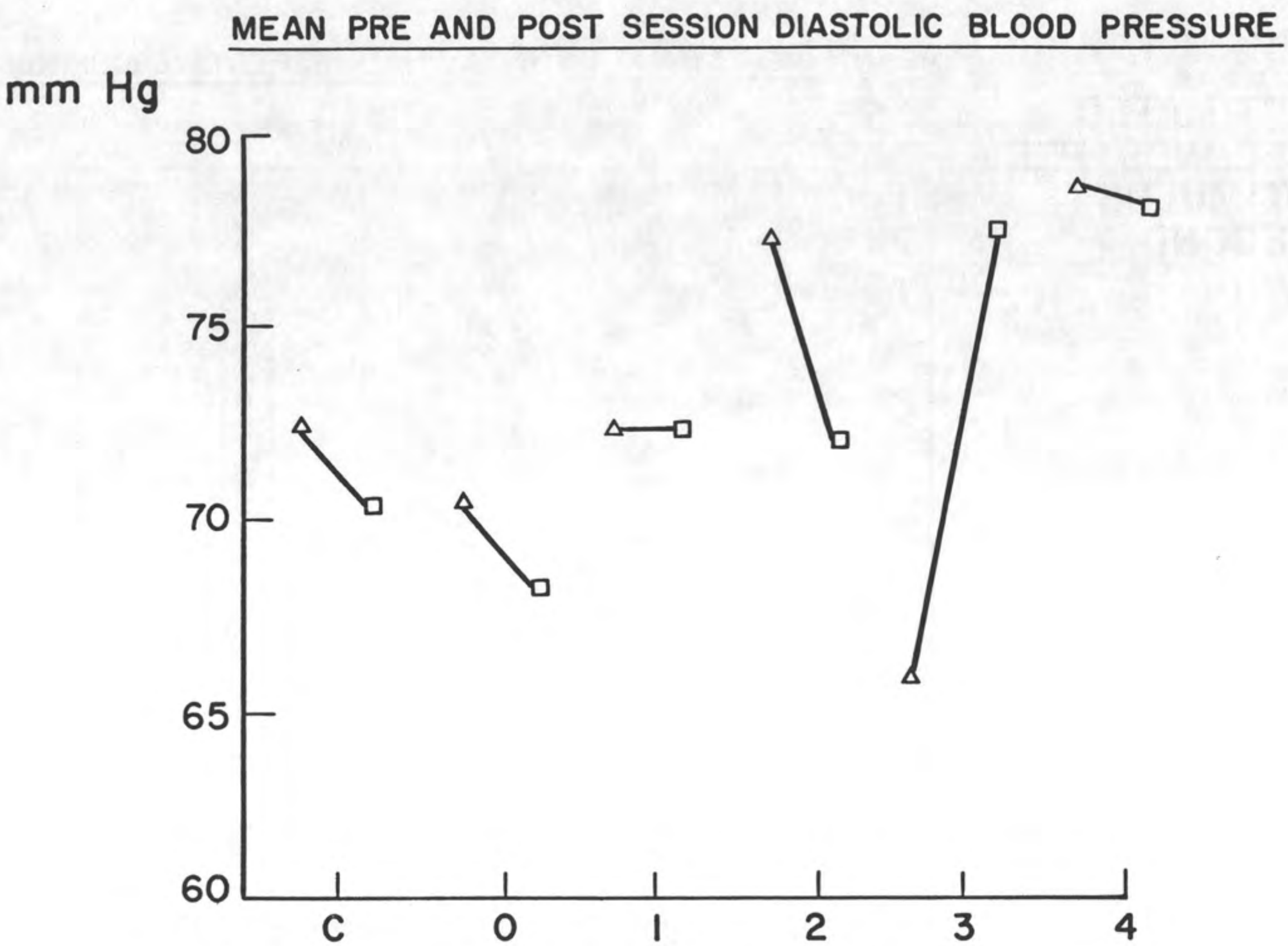
4 : Reporting the physical symptoms of dizziness and nausea .
△ : Pre-session value.
□ : Post-session value.

FIGURE 8. MEAN PRE- AND POST-SESSION SYSTOLIC BLOOD PRESSURES



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△ : Pre-session value.
□ : Post-session value.

FIGURE 9. MEAN PRE- AND POST-SESSION DIASTOLIC BLOOD PRESSURE

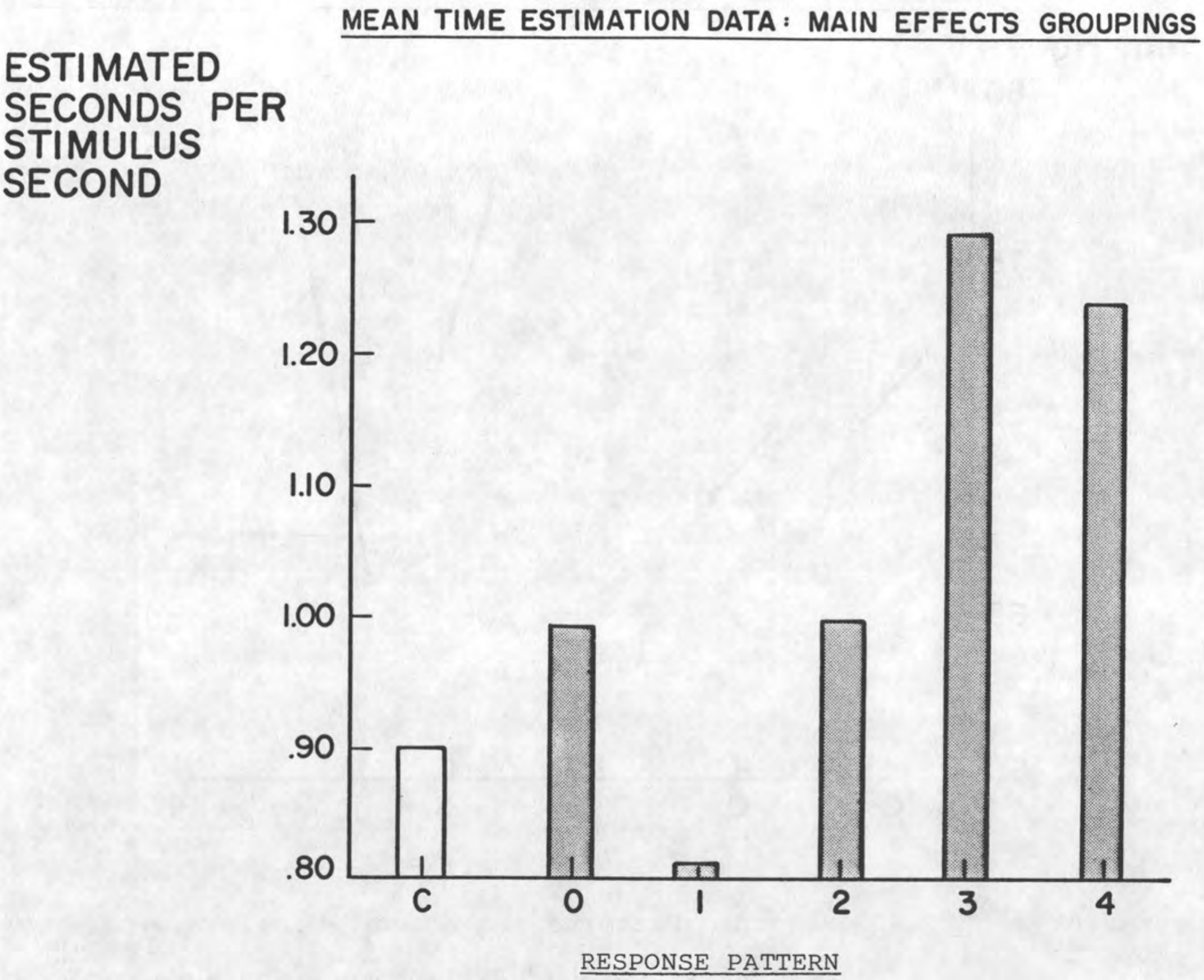

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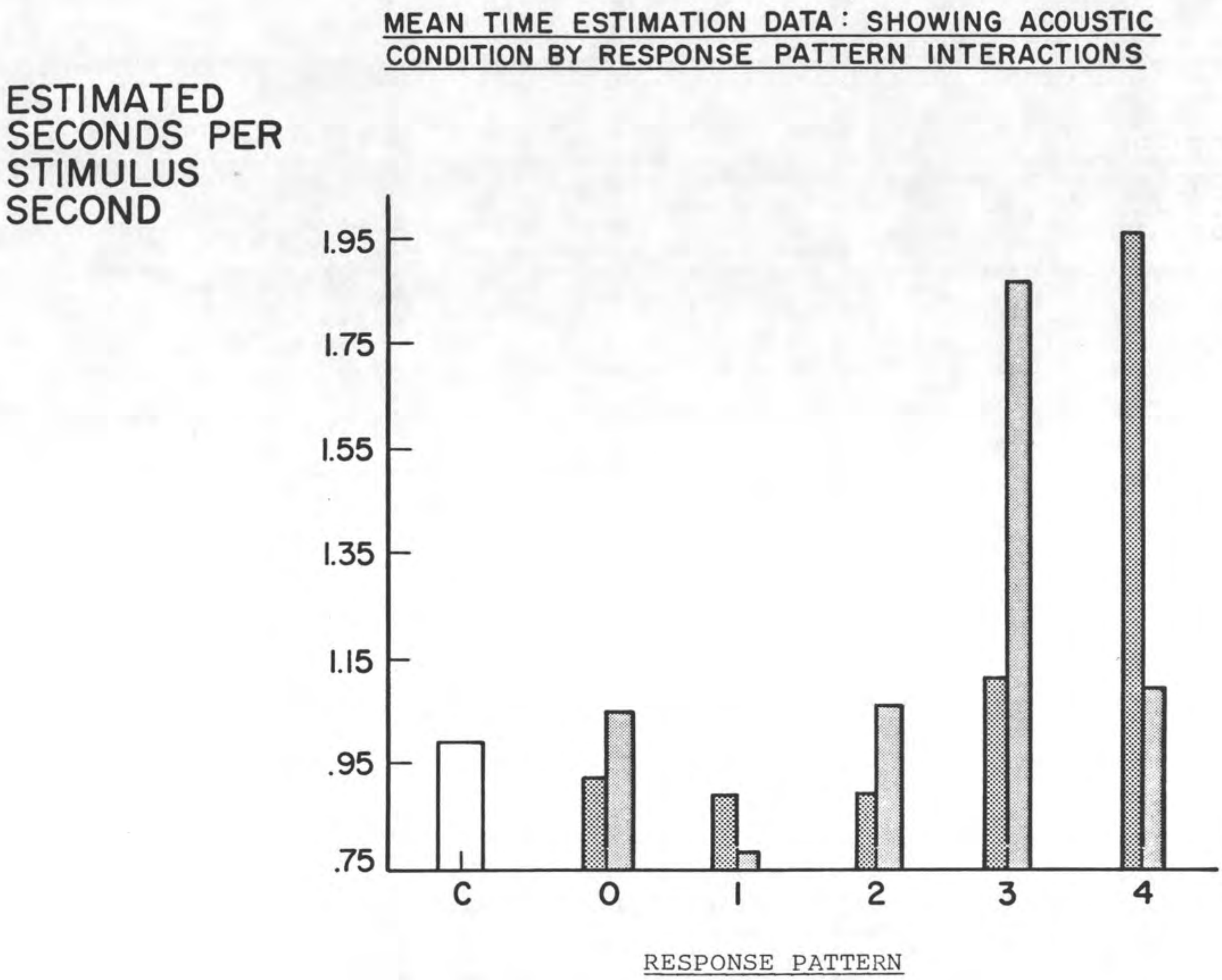
FIGURE 10. MEAN TIME ESTIMATION DATA: MAIN EFFECTS GROUPINGS.



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High Distortion data is on left. Low Distortion data is on right .

FIGURE 11. MEAN TIME ESTIMATION DATA: SHOWING ACOUSTIC CONDITION BY RESPONSE PATTERN INTERACTIONS

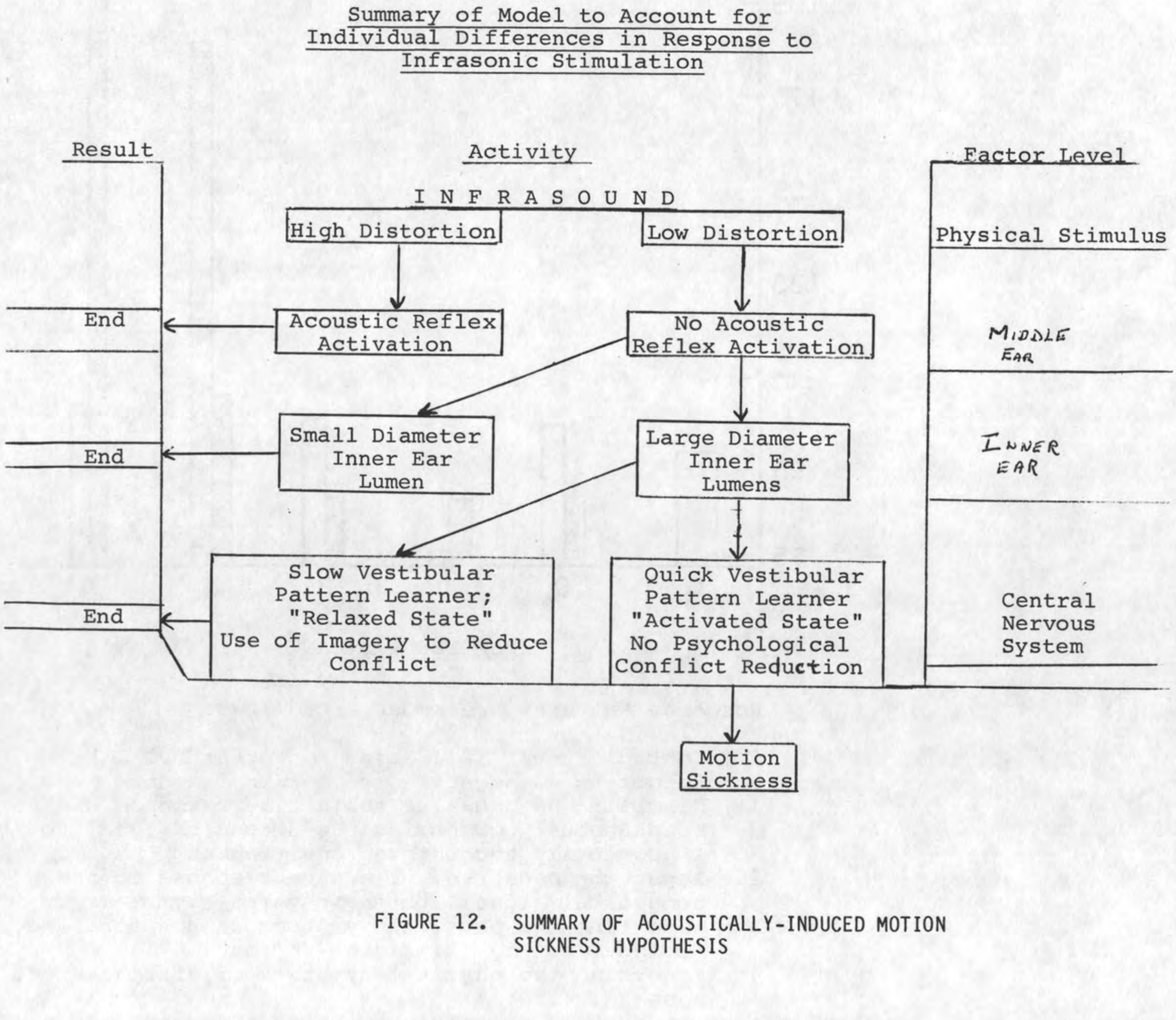

FIGURE 12. SUMMARY OF ACOUSTICALLY-INDUCED MOTION SICKNESS HYPOTHESIS

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SOME INDIVIDUAL DIFFERENCES IN HUMAN RESPONSE TO INFRASOUND

Nussbaum, D. and Reinis, S.

1. Infrasound 2. Individual differences 3. Discriminant responses 4. Subjective responses
5. Physiological responses 6. Performance responses 7. Hypothesized mechanisms of action

I. Nussbaum, D., Reinis, S. II. UTIAS Report No. 282

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5. Physiological responses 6. Performance responses 7. Hypothesized mechanisms of action

I. Nussbaum, D., Reinis, S. II. UTIAS Report No. 282

A review of literature describing the effects of very low-frequency sound on humans revealed a controversy between authors claiming that infrasound is very harmful to humans and those claiming that infrasound cannot engender any subjective or objective symptoms. This report shows that these discrepancies may be explained by individual variability in response to low-frequency sound. An experiment was performed to determine whether some individuals are uniquely sensitive to infrasound. Three acousic conditions were employed. These consisted of a control (amplifier hum) condition and two 8 Hz infrasound conditions: a high distortion signal and a low distortion signal. Subjects were grouped by their subjective responses. No control subjects exposed to amplifier hum reported any adverse responses. The distribution of symptoms (headache and fatigue vs dizziness and nausea) between the high and low distortion groups was significantly different. In persons reporting symptoms, the higher level of harmonics was primarily associated with headache and fatigue, while reduction of harmonics primarily resulted in dizziness and nausea. Subjects reporting dizziness and nausea were subjected to up to four additional sessions — two control, one low distortion, and one with only some harmonics without infrasound. These sessions showed that these symptoms were replicable and related only to the infrasound. Multivariate and univariate analyses showed that the subjects reporting adverse symptoms can be distinguished from the other groups on the basis of heart rate, respiratory rate, systolic and diastolic blood pressure changes, gaze nystagmus, time estimation, and mood scales but not EEG, plethysmography, TTS, a short-term memory task, Eysenck Personality Inventory, Cornell Medical Index or age. The adverse responses of some individuals closely resemble motion sickness. Individual differences in the reaction to infrasound may then be explained by variability of inner-ear structure or central adaptive mechanisms.

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Institute for Aerospace Studies, University of Toronto (UTIAS)
4925 Dufferin Street, Downsview, Ontario, Canada, M3H 5T6

SOME INDIVIDUAL DIFFERENCES IN HUMAN RESPONSE TO INFRASOUND

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