THE UNIVERSITY OF MANITOBA

ULTRASOUND AS A STIMULUS IN A FORCED CHOICE SIGNAL DETECTION TASK AND AS AN ACCESSORY STIMULUS IN A CRITICAL FLICKER FREQUENCY TASK

by

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ABSTRACT

Two experiments were carried out to investigate stimulus properties of ultrasound. A signal detection task was used in Experiment I to investigate whether human subjects receiving two different instructional sets could detect an acoustic stimulus in the ultrasonic range (25 kHz at 90 db). It was found that only one of twenty subjects was able to detect this stimulus. The results were viewed as supporting the conclusion, in studies carried out concurrently at the University of Manitoba, that ultrasound can affect behavior without the subject's awareness.

Experiment II followed up earlier reports that accessory stimulation with ultrasound improved performance on a visual acuity task. Subjects received fourteen minutes of stimulation with ultrasound (34.9 kHz at 108 db), audible sound (2kHz at 60 db) and an equivalent control period, and the critical flicker frequency (CFF) threshold was determined early and late in the stimulation period. Performance on the visual task was not significantly improved by audible sound or ultrasound at the early or late CFF threshold determination. There was a significant sound condition x time interaction, however, suggesting that CFF changed in different directions under the three sound conditions (ultrasound, audible sound, and control). Trends in the data were viewed as providing tentative support for the hypothesis that accessory stimulation with ultrasound or audible sound improves performance on visual CFF.

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ULTRASOUND AS A STIMULUS IN A FORCED-CHOICE SIGNAL DETECTION TASK AND AS AN ACCESSORY STIMULUS IN A CRITICAL FLICKER FREQUENCY TASK

Recent research at the University of Manitoba has investigated the properties of ultrasound as a stimulus in behavioral research. Kryter (1970) defined ultrasound as acoustic energy above the upper frequency limit of human hearing. Martin, Hawryluk and Guse (1974) have suggested that it may be possible to use ultrasound as a stimulus for investigating "unconscious" influences on behavior:

> A learning formulation defines consciousness along a continuum of the degree to which the subject can symbolize (usually in verbal symbols) the relevant contingencies.... The present series of studies was designed to explore a potentially more powerful method for studying unconscious influences that might have implications for both experimental work and clinical application. In essence, ultrasound (airborne vibrations of frequencies above the limit of human hearing) was used as a stimulus to affect behavior without accurate awareness (Martin, Hawryluk and Guse, 1974, pp.589-590).

Martin et al. suggested that ultrasound might be useful in the study of "subliminal perception" or "learning without awareness" (Dixon, 1971) or, if it produced sensations which were unusual or difficult to identify, it might be useful as a stimulus which could be misattributed to other factors in the environment as was done by Schachter and his co-workers with other stimuli (Schachter, 1964; Schachter & Singer, 1962; Schachter & Wheeler, 1962).

The experiments reported here were carried out in order to investigate specific stimulus properties of ultrasound. Experiment I was designed to investigate whether subjects in the age range used by Martin, Hawryluk and Guse (1974) could detect acoustic stimulation at the high frequencies used by Martin et al. when informed of sensations which might be produced and of the probability and timing of stimulation. Experiment 2 was performed to follow up on earlier reports of sensory interaction effects of ultrasound. These studies reported that ultrasound stimulation improved the performance of human subjects on visual acuity tasks.

Historical Background

In recent years the use of ultrasonic[1] devices has become widespread. These devices are used in industry for drilling, washing, welding plastics, and mixing liquids; in medicine (Gordon, 1964) for diagnostic purposes and for producing lesions; and in attempts at rodent control (Sprock, Howard, & Jacob, 1967). Ultrasound has been used in studies of animal learning (Belluzzi & Grossman, 1960; Kent & Grossman, 1968) and in many other research applications, although most applications have been outside the area of psychology.

Considerable concern over the possibility of deleterious effects of ultrasound on humans has accompanied the increased use of equipment which produces airborne ultrasound. Parrack (1952) described a complex of symptoms which had become popularized in the media as "ultrasonic sickness". Personnel working around jet-power plants complained of excessive fatigue, headache, nausea, vomiting, loss of neuro-muscular co-ordination, extreme irritability and other symptoms. According to Parrack, jet engine noise includes a wide spectrum of sonic and ultrasonic frequencies. The level of the ultrasonic components is less than 100 decibels (db)[2] while some of the sonic components are at a higher intensity level. Allen, Frings and Rudnick (1948), using a high frequency siren which produced 160-165 db of acoustical energy in the region of 20 kilohertz (kHz), demonstrated that mice and various insects were rapidly killed in high intensity acoustical fields. They also reported rapid heating of the experimenter's hands as the animals were placed in the sound field, the loss of equilibrium or slight dizziness when an observer was exposed to intense audible sound (even when wearing earplugs), and a tickling of the mouth and nasal passages at both audible and inaudible frequencies when the mouth was open. Von Gierke, Parrack and Eldredge (1950) repeated and extended this study using rats and guinea pigs and found that animals were killed by sonic and ultrasonic fields when sound pressure levels exceeded 152 db. It was concluded that the animals were killed by heating effects of acoustical energy. The absorption coefficients of various surfaces were determined experimentally and it was concluded that for the surface of the human body the absorption of acoustic energy is low compared to furred animals and decreases as the frequency increases. When a human subject's forearm was placed in the same field that killed small animals (greater than 152 db at 10 kHz), no ill effects were observed.

Parrack (1952) calculated that the practical airborne sound levels required to kill a human through heating effects would be very high, in the order of 180 db or greater of continuous energy.

The lethal level would be even higher in the ultrasonic range since with humans absorption decreases as frequency increases. Parrack concluded that the most probable hazard encountered in present settings would be audible frequencies which are high enough in intensity to injure the ears and perhaps cause other disturbances in physiological functions.

Skillern (1965) attempted to correlate subjective effects, including headaches, nausea, fatigue, and even auditory pain, with the acoustical levels found in the vicinity of industrial ultrasonic machines and concluded that the ear is sensitive to a narrow band of frequencies centered on 25 kHz. Upon further examination of his data, however, it was found that although much of the equipment examined had operating frequencies of 25 kHz, sound was produced at very high levels in a wide range of frequencies down to 10 kHz and below. Although Skillern arbitrarily defined anything above 10 kHz as being in the ultrasonic range, acoustic stimuli above this frequency have been found to be audible, especially at the sound pressure levels of 85-120 db that he reported in the 10-16 kHz range. Skillern measured sound pressure levels in a broad spectrum of frequencies and there was no way of separating the effects of sonic and ultrasonic stimuli in his study.

Parrack (1966) presented data from research carried out by the U.S. Air Force in the early 1950's on the effects of high frequency acoustic energy on humans. He reported that exposure to the audio frequency of 17 kHz or to the ultrasonic frequencies of

21, 24, 26, and 37 kHz using sound pressure levels in the region of 148-154 db resulted in loss of hearing sensitivity only for subharmonics of the test frequencies (at 8.5, 11, 12, 13, and 18.5 kHz). After an exposure of approximately five minutes to the high frequency sound, recovery from these losses was rapid and complete. Parrack concluded that industrial and environmental sound fields in the ultrasonic region are harmless for the human ear until the octave or one-third octave band levels approach 140 db and that acceptable intensity levels for single frequencies would be even higher. Parrack also discussed non-auditory effects of high intensity airborne ultrasound encountered in these studies. He described such effects as: vibration of hairs, particularly in the ear canals and nasal openings; local warming at these sites and at areas of contact between skin and clothing; and finally, as a result of standing wave patterns, pressure felt in the nasal passage or inside the oral cavity when the mouth is held open. These effects were not reported to be harmful. Unfortunately, no information was given about the number of subjects who reported these effects or the intensity levels at which they occurred. It seems likely from the data presented on threshold shifts at subharmonics, however, that the intensities used were probably quite high (in the 148-154 db region).

Acton and Carson (1967) investigated the possibility of hearing damage in workers in the vicinity of industrial ultrasonic equipment. Workers in the region of this equipment in a British factory complained of unpleasant subjective effects including fatigue, persistent headaches, nausea, and tinnitus (ringing in the ears). Measurement of sound pressure levels before the equipment was shielded revealed high levels in both audible and higher frequency ranges. Audiometric investigation led to the conclusion that hearing damage due to noise from industrial ultrasonic equipment was unlikely in this situation. Acton and Carson also carried out a laboratory investigation in which three subjects of unspecified age were exposed to noise produced by a Galton whistle that was maximal in the 16-40 kHz range. The two subjects with normal hearing experienced the same subjective effects of "fullness" in the ears followed by a headache reported by the operators of the ultrasonic washers and drills in the factory. The third subject, who was unable to hear a 16 kHz pure tone, remained unaffected. Acton and Carson found that the only marked difference between acoustic frequency spectra which produced subjective effects in the two subjects and those spectra which did not, occurred at 16 kHz with the transition occurring between sound pressure levels of 76 and 78 db. The former level did not produce subjective effects, whereas the latter did. Since the spectra with an intensity of 78 db at 16 kHz produced subjective effects in the two subjects, while an intensity of 101 db at 20 kHz did not, Acton and Carson concluded that the high frequency audible noise was responsible for these subjective effects in the laboratory and in the factory.

In summary, many unpleasant subjective effects formerly attributed to ultrasound and sensationalized in the popular media as "ultrasonic sickness" were, in fact, produced by audible sound frequencies. Only extremely intense ultrasound (probably in the region of 148-152 db) has been shown to affect humans (Parrack, 1966).

The Upper Frequency Limit of Human Hearing

In many of the studies mentioned above the frequency range of ultrasound was not clearly defined. Kryter (1970) defined ultrasound as acoustic energy at frequencies above the range of human hearing (see also American Standards Association, 1951). He further stated that the ultrasonic range includes acoustic energy in the frequency region above 20 kHz. There is, however, little agreement in the literature about the upper frequency limit of human hearing. Wever (1949) asserted that the upper limit of hearing is in the region of 24 kHz for young persons of unimpaired hearing. Pumphrey (1950) in a study involving three subjects, including himself, found an upper limit of hearing below 16,500 Hz with a transducer held close to the external meatus. There was no mention of the sound pressure level or the age of the subjects, however, and the low limit may be a result of insufficient intensity. Pumphrey does mention that the threshold rises very steeply above 12 kHz.

Corso and Oda (1961), in a well-controlled study, determined the thresholds of seven male subjects between 18 and 24 years of age at various high frequencies with a speaker located 30 cm from the subject's ear. Thresholds were obtained for all subjects at 18 kHz with a mean intensity of 72.1 db. These thresholds were determined by the minimum audible pressure (MAP) technique in which the sound pressure required for hearing was measured at the eardrum by a probe-tube microphone. The MAP curve has the same general form as the minimum audible field (MAF) curve (where the sound pressure level is measured in an acoustic free field at the position which is later to be occupied by the observer's head) but lies approximately 20 db below the MAF curve (Sivian and White, 1933). Thus, it would be necessary to add a factor of about 20 db to the values reported by Corso and Oda (1961) in order to compare them to the other values reported in this paper. At 20 kHz only five of the subjects could detect the tone and the mean threshold obtained was 84.9 db MAP. The individual thresholds at 20 kHz were 93.0, 96.0, 82.0, 92.0, and 61.5 db MAP, showing a wide range between individuals even in this small, homogeneous sample. These thresholds were obtained using a modified method of limits. Crude estimations of the upper frequency limit were then obtained by having the subject hold the tweeter near his ear and operate controls to increase the frequency and the intensity until he no longer had an auditory sensation. The highest sound pressure level used in these trials was approximately 120 db MAP. In these preliminary observations one subject responded to a signal of 46 kHz, several subjects responded to 31 kHz, and all but one subject responded up to 25 kHz.

In evaluating studies using high frequency acoustical energy, it is important to consider the intensity of acoustical energy used, whether pure tones or acoustical energy over a range of frequencies are used, the frequency or range of frequencies, and the number of subjects and their ages. Any statement made about the upper frequency limit of human hearing should be qualified by stating the maximum intensity of acoustical energy to which this limit applies. Studies using pure tones offer greater ease of interpretation, although acoustical energy covering a range of frequencies is encountered more frequently outside the laboratory. The statement by Kryter (1970) that acoustical energy in the frequency region above 20 kHz is inaudible to man does not seem to be the case at high intensity levels although this may be a useful generalization at the lower intensity levels ususally encountered in the environment, especially for older subjects. The large range of individual differences in sensitivity to acoustical energy makes it difficult to make general statements about an upper frequency limit of human hearing. Overall, there seems to be a paucity of good research on the sensitivity of human observers to high frequency sound. The difficulty in obtaining equipment which can accurately produce high frequency sound at relatively high intensities without producing unacceptable levels of distortion may in part account for this lack of research.

Research with Ultrasound Carried Out at the University of Manitoba

Following the suggestion in earlier literature that ultrasound may act as an aversive stimulus (Allen, Frings and Rudnick, 1948; Parrack, 1952), Brickman (1972) carried out an analogue study of "repression" using ultrasound as an aversive stimulus. Thirty-six male subjects learned a paired-associate list to criterion and then received ultrasound paired with half of the pairs in twelve overlearning trials (each word pair was presented for 4 seconds on each trial). Three groups of subjects were presented with different levels of acoustic stimulation at 20 kHz: 95-97 db, 86-88 db, and 0 db (control group). Subjects were tested for differential recall on relearning trials one week later. Although it had been hypothesized that there would be differences in recall between experimental words (words paired with ultrasound) and control words (words not paired with ultrasound) and that these differences would vary directly with the intensity of ultrasound, no such differences were found. It was found, however, that the acoustic stimulus disrupted performance on the overlearning trials for the group receiving the higher intensity level. This may have been due to auditory effects which were described by subjects in response to a post-experimental questionnaire. Both groups which received the stimulus referred to noise significantly more frequently than control subjects and seven of twelve subjects in the higher intensity group mentioned having heard noises or humming during parts of the experiment. Two subjects volunteered that these noises were associated with some of the word pairs. Brickman's findings seem to suggest that ultrasound at these levels is not an aversive stimulus and that the 20 kHz stimulus was audible to some proportion of the subjects (although equipment limitations made it possible that some of the auditory effects may have been due to sound distortion by the equipment, particularly at the 95 db level).

Griffin (1972) investigated the possibility of using ultrasound as a misattributed stimulus. He suggested that ultrasound may produce subjective effects which are not described by subjects as being auditory. Griffin presented blindfolded subjects with slides and asked them to distinguish which were black and white and which were color in what was ostensibly an ESP experiment. Subjects were told that some people had experienced feelings such as "a slight change in pressure on my skin (Griffin, p. 17)" which had enabled them to discriminate between black and white and color slides. They were instructed to attend to any feelings that they might have and to attempt to use these feelings to make the discrimination. The slides which were arbitrarily designated as color slides (after a pretraining period without the blindfold all of the slides were blank) were paired with an acoustic stimulus of 85 db at 21 kHz. For half of the subjects, "correct" responses were followed by feedback (the sounding of a doorbell chimes). Griffin found, in a post hoc analysis, that a significantly greater number of correct responses were given by males who received ultrasound paired with the "color" slides along with feedback as to the accuracy of their responses. The results were seen to be somewhat equivocal, however. Starkell (1972) replicated part of Griffin's study using 40 male subjects, all of whom received feedback with their correct responses. The level of background noise in the experimental chamber was also reduced for half of the subjects by reducing the noise from the slide projectors. Starkell found no differences between the experimental and control groups in the number of correct responses, suggesting that ultrasound was not used as a cue in this task. This finding was inconsistent with Griffin's finding of more correct responses in the ultrasound with feedback group.

On reviewing the summary data for individual subjects included in Starkell's report, it seems likely that one of the subjects who scored considerably higher than any of the other subjects (17 out of 20 correct responses, improving consistently over each block of five trials) was able to hear the 85 db, 21 kHz, stimulus, which he described as producing a "ringing in the ears for color slides".

Hawryluk (1972) attempted to produce a classically conditioned galvanic skin response (GSR) to ultrasound by pairing ultrasound as the conditioned stimulus (CS) with a loud noise as the unconditioned stimulus (UCS). A 22 kHz signal was presented for 4 seconds at an intensity of 83-85 db over seven conditioning trials and four extinction trials in which the magnitude of the GSR was recorded. Although results were in the predicted direction, no significant differences were found between experimental and control groups. It was suggested that possible factors that may have accounted for the lack of significant results were: the low number of conditioning trials, the low intensity of ultrasound used, the possible non-aversive nature of the UCS and the possibility that magnitude change in GSR was too gross a measure to demonstrate possible subtle effects on the GSR. The possibility that subtle or unusual effects produced by ultrasound might not be detected over a small number of trials was also a factor in the studies by Griffin (1972) and Starkell (1972). In addition, in both Griffin's and Hawryluk's studies, a small number of subjects were excluded from the data analysis when they reported auditory effects of the stimulus in a post-experimental questionnaire.

In a very interesting report, Martin, Hawryluk and Guse (1974) described a series of studies, the first of which examined secondary evoked responses at the vertex to high frequency acoustic signals in ten male and fourteen female subjects. The evoked response in the vertex area has been found to be sensitive to stimulation in a number of modalities including auditory and tactile. Each subject was tested at three audible frequency levels and three inaudible frequency levels with each member of the series of frequencies separated by 1 kHz. The thresholds were individually determined by a preliminary procedure in which each frequency from 15-22 kHz (at 1 kHz intervals) was randomly presented five times and the subject was asked to press a button whenever he heard a high frequency tone. For the purpose of this experiment, the threshold was defined as the point at which the subject responded two or fewer times (out of five presentations) to a given frequency, and not at all to higher frequencies. In addition, the subject was told to press the button whenever he heard a tone during the evoked potential testing period in order to ensure that he hadn't "dozed off". If the subject responded to the threshold frequency 15 times or more during the fifty averaged evoked response trials at each frequency, this frequency was considered audible and another inaudible frequency, 1 kHz higher than the previously highest frequency, was added to the series. Although some subjects were tested at more than six frequency levels, only six consecutive frequencies, 3 audible and 3 inaudible, were considered in the data analysis. The frequency levels tested were presented consecutively in blocks of 50 repetitions with an interstimulus time interval of 3 seconds, followed by a 30-60 second rest period. All tones had a duration of 200 msec and an intensity of 85 db.

Martin et al. found that 7 of the 24 subjects accounted for 13 positive evoked responses to 72 presentations (3 frequency levels for 24 subjects) which were not reported by the subjects to be audible. It was concluded that ultrasound can function as a stimulus (for evoked responses at least) even when subjects are not able to detect it. It was also found that there were more evoked responses to audible stimuli than to inaudible stimuli, although the hypothesis that there would be more evoked responses to inaudible frequencies nearer the threshold was not confirmed. One problem encountered in this study was excessive noise and drifting DC levels on the electroencephalograms of some of the subjects and it was suggested that this may have led to a somewhat lower number of positive evoked responses than might have otherwise been expected at both audible and inaudible levels. Martin et al. also presented some interesting data about individual differences in the thresholds obtained in this procedure. Thresholds ranged between 17 and 23 kHz at 85 db, with 13 of 24 subjects having a threshold of either 20 or

21 kHz. At the upper levels, three subjects had thresholds of 22 kHz and four subjects had thresholds of 23 kHz. These thresholds for young adults are higher than the traditionally accepted upper limits of human hearing (Kryter, 1970) and the limit may be even higher with tones of longer duration and at greater intensities than the 200 msec, 85 db tones used in this study. It was also noted that none of the subjects reported that ultrasound at this level produced even moderately unpleasant sensations, suggesting that ultrasound at these levels is not an aversive stimulus. Martin et al. concluded that their study lends support to the hypothesis that high frequency sound can function as a subliminal stimulus at inaudible levels.

EXPERIMENT I

The present study was carried out in order to examine the detectibility of high frequency acoustic stimuli at a frequency and intensity level (25 kHz at 90 db) used in two studies of "subliminal perception" and learning without awareness carried out concurrently with this study at the University of Manitoba (Martin, Hawryluck and Guse, 1974). One study involved an investigation of reaction time to a stimulus paired with ultrasound and the other involved GSR conditioning to ultrasound compounded with a light stimulus. Both studies will be described in detail later in this paper.

A frequent criticism of studies demonstrating subliminal perception or learning without awareness has been that the measures of thresholds or stimulus detectibility used in many of these studies are not sensitive enough and can overlook the possibility that some of the subjects can detect the stimulus or some aspect of it with some degree of reliability (Dixon, 1971; Eriksen, 1960, 1962). Price (1966) has criticized traditional methods of threshold determination on the grounds that they (a) yield results dependent on the psychophysical method used, (b) are arbitrary in the definition of the concept of threshold, (c) are unimproved by corrections for guessing, and (d) confound the observer's sensory capabilities with his criterion for reporting a given stimulus event. This last criticism is particularly serious when a stimulus which may produce low level or unusual sensations is considered. Signal detection theory methods make it possible to obtain an estimate of the observer's ability to detect the stimulus and an independent estimate of his criterion for responding (Swets, Tanner and Birdsall, 1961). Both of these estimates are independent of the particular signal detection method used. Because of these advantages it was decided to use a signal detection paradigm in this study.

A two-alternative forced-choice design (Green and Swets, 1966) was the method selected since it avoids the problem of determining the observer's criterion for responding. In each trial two observation intervals are provided with a signal occurring in either the first or the second interval. The observer is instructed to choose the interval most likely to have contained the signal and he is told that he must make a choice during each trial. If the experimenter determines in advance that the probability of the signal occurring in each of the two intervals will be 50%, then it is possible to provide a simple summary measure of the detectibility of a signal. This scale of detectibility ranges from 50% to 100%--the lower number representing chance performance or zero detectibility and the upper number representing perfect performance or perfect ability to detect the signal.

In a previous study using this signal detection paradigm, Walker (1972) investigated the ability of subjects to detect a 22 kHz signal at 85 db with a duration of either 1 second or 3 seconds. One block of control trials (during which no signal was presented) was given at the end of the series of experimental signal detection trials to assess the effect on the proportion of correct responses of any systematic pattern of responding or response bias that subjects may have developed over the course of the task. It was found that only the male one-second duration group scored significantly higher on experimental trials (signal presented in one of two intervals) than on control trials (no signal presented). A second group of male subjects was then run in the 1 second duration condition and once again subjects showed significantly better performance on experimental trials than on control trials. It was concluded that males could detect the 22 kHz signal of 1 second duration at a level higher than chance. When the data from individual subjects were examined, it was found that those subjects who could detect the stimulus most reliably (subjects scoring from 83-100% correct, considerably above the chance level of 50%) all reported that they could hear the high frequency sound, suggesting that the acoustic signal was not ultrasonic for these subjects. When the responses of the subjects to the post-experimental questionnaire were examined, it was found that the percentage of subjects in each group who reported non-auditory sensations similar to those described in the instructions as accompanying ultrasound (similar to those described by Griffin, 1972), varied from 57-89%, while 11-44% of the subjects in each group reported auditory sensations (this figure rose to 56% in the additional male 1 second duration group). These findings, even among subjects who were not responding at above the chance level, were taken as evidence that many subjects were responding to the suggestive nature of the instructions.

In the present study, it was decided to use a stimulus of 25 kHz which following the threshold data of Martin et al. probably would be inaudible to most subjects in the age range sampled (18-24 years). The subject instructions were also varied between groups to suggest either that subjects attend to auditory cues or to sensations described by Griffin (1972)--"tingling of the skin or a feeling of pressure in the head" which had been described by earlier workers. Varying the instructions used would allow an examination of whether subjects under different instructional sets differ in ability to detect the stimulus. Since it was necessary to have the subjects in the "sensations" group attend to certain cues without mentioning the possibility of auditory stimulation, a set of instructions was developed in which subjects were asked to attend to certain sensations which might be produced by an infrared light to which they would be exposed. Infrared light is not visible to the human eye and mention of its uses in scientific studies and military applications have been fairly frequent in the popular literature in recent years. A rather elaborate and unusual looking light apparatus was set up in front of the subject's chair for subjects in the "sensations" group and was described as the source of infrared light. It was hoped that this would provide a plausible source of these sensations for subjects in this group. Subjects in the "sound" group were told that the stimulus they would be required to detect would involve a change in the sound level of the room. The nature of the stimulus was not described more explicitly as a high frequency sound so that it would later be possible to examine the subjects' description of the signal for reports of high frequency sounds.

As was the case in the previous study (Walker, 1972), it was decided to estimate the detectibility of the acoustical signal by comparing the number of correct responses made on the last block of a series of detection trials with the number of correct responses made in a block of control trials in which no signal was presented in either interval. During each of these control trials, one of the two intervals was arbitrarily designated as being the correct one, giving the chance level of responding. In addition, a comparison was planned between the groups receiving the two instructional sets to examine whether there were differences in ability to detect the signal for subjects receiving the two different sets of instructions. Considering the degree of variability found among subjects in the ability to detect high frequency acoustic signals (Martin, Hawryluk and Guse, 1974, Walker, 1972) it was also planned to examine the data of individual subjects for an indication of the detectibility of the signal.

To provide an index of the subject's degree of confidence in his responses, four response alternatives were used. Not only was the subject required to report whether a signal took place in the first or the second interval of each trial, but he was also required to report whether he was "confident" of his response of if he was "not sure or guessing". It was planned to examine this data to investigate whether subjects would make more "confident" responses on experimental trials than on control trials or more "confident" responses under one instructional set than under the other.

METHOD

Subjects

Twenty-six male undergraduates served as subjects. Of these six subjects were eliminated from the data analysis: one because he did not speak English well enough to determine whether he understood the instructions, two because of construction in the building causing excessive noise and vibration and three because of failure in an electronic switch. The remaining 20 subjects ranged in age from 18-22 with a mean age of 19.5 years. Subjects participated in the experiment for laboratory credit in an introductory psychology course.

Apparatus

The high frequency acoustic signal was produced by a wide range oscillator (Hewlett Packard special model H20-200CD) with output amplified by a Crown D-150 power amplifier. The amplifier output was switched by a "click free" audio switch (Small, 1969) designed to fade the signal in and out without producing audible switching transients. This switch had an "on" switching time of approximately 30 msec. and an "off" switching time of approximately 150 msec. The speaker used to produce the high frequency signal consisted of a set of four electrostatic plates from a Janszen Model 150 speaker mounted in the open face of a 13½ x 10½ inch plywood box (outside dimensions) lined with fiberglass insulation (2 in.). The output from the audio switch was monitored by an oscilliscope (Heath Co. OM-3) and sound pressure level readings were taken with a Breul and Kjaer Precision Sound Level Meter (Type 2203) with a Type 4133-½ inch microphone placed in the position which was to be occupied by the subject's right ear. To mask any possible noise from the areas adjoining the sound attenuated room, a noise generator (Grason-Stadler Model 901B) was used to drive two 8 ohm speakers, one on either side of the subject's chair. Tape recorded audio static was also fed into the white noise generator input and mixed with the white noise to mask any static noises produced by the equipment. These speakers produced a steady sound pressure level in the room of 55 db at the position to be occupied by the subject's right ear.

The ultrasonic acoustical stimulus used during the experiment was a 25 kHz signal of 1-sec. duration at a sound pressure level of 90 db which is well within the safety limits for human hearing (Acton & Carson, 1967; Parrack, 1966).

Experimental Chamber

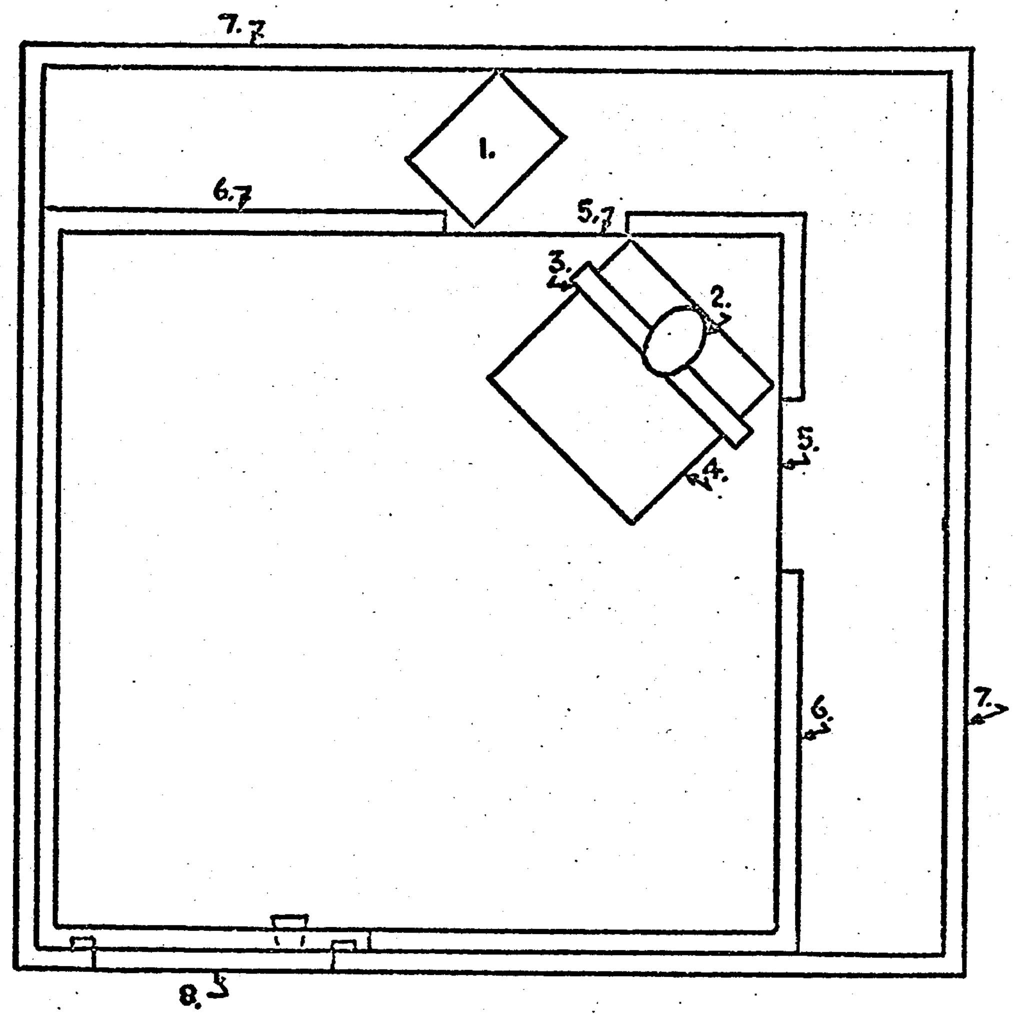
A sound attenuated chamber was constructed within a slightly larger room so that there were two false walls 17 in. from the regular walls as shown in Figure 1. The two false walls, the two regular walls, and the ceiling were covered by one-inch thick fiberglass insulation, covered in turn by black broadcloth. The floor was covered by blue carpet underpadding. The broadcloth was used in order to disguise the two false walls of the chamber by making all of the walls appear to be uniform. Subjects were told that the room had been sound attenuated in order to reduce outside distractions. The chamber was 74 in. x 71 in. x 93 in. high.

Insert Figure 1 about here

A modified aircraft radio operator's chair (which could be raised and lowered mechanically) was located in the corner where the two false walls met facing out into the room. During the experimental procedure a padded chin-rest was placed on two uprights such that the subject's chin was 42½ in. above the floor and in a constant

Figure 1

Schematic of experimental chamber.
The diagram illustrates: 1. speaker,
2. subject's head, 3. chinrest,
4. chair, 5. broadcloth wall with
fiberglass removed, 6. false wall of
chamber, 7. wall of experimental room,
and 8. door.



7.
1.
6.
5.
3.
2.
4.
5.
6.
7.
8.

position relative to the room and the speaker. The chair could be adjusted vertically for each subject until he was relatively comfortable and his head was in the required position. The chair was padded, tilted back at 12 degrees from the vertical and had armrests in order to make the subject as comfortable as possible during the experimental task. The left armrest was padded and the right armrest had four pushbuttons located at the end of it, where the subject's hand could rest comfortably. The purpose of these pushbuttons is described in the subject instructions.

A panel of lights was located on a stand in front of the chair at a distance of 37 in. from the subject's head. This panel, shown in Figure 2, consisted of six 4-watt lights (Spectro 1818) and various colored lenses (Jana DJ-4002) used to inform the subject of the various events during each trial. The speaker used to present the 25 kHz signal was located behind the false wall on the right side of the chair and directed perpendicularly towards the subject's right ear at a distance of 26 inches. The speaker was placed on a 37 in. high stand and the section of fiberglass directly in front of the speaker was removed so that only the cotton broadcloth remained between the subject and the speaker. The speaker was not visible from the experimental chamber and all four walls were similar in appearance. The chamber was illuminated by a pole lamp with three 60 watt bulbs directed towards the wall in one of the other corners to reduce glare. The stimulus programming and recording equipment was located in the adjacent room.

Insert Figure 2 about here

Subjects in one of the two experimental groups were told that they were to try and detect the occurrence of an infrared stimulus originating from the lamp in front of them. For this group a lamp was located at a height of 5 ft. a distance of 50 in. in from the subject and was described to the subject as an infrared lamp. In fact, the lamp used was a professional photographer's lamp (Smith and Victor A-10 reflector on a Smith and Victor 8 1/2 ft. stand with a Sylvania DVY quartz iodide peanut shaped lamp with a large spiral filament) which was rather exotic in appearance but was never actually switched on during the experiment. The purpose of this lamp was to provide a plausible source of infrared light. The lamp was placed in the retracted position in a corner of the room facing away from the subject for the subjects in the other group.

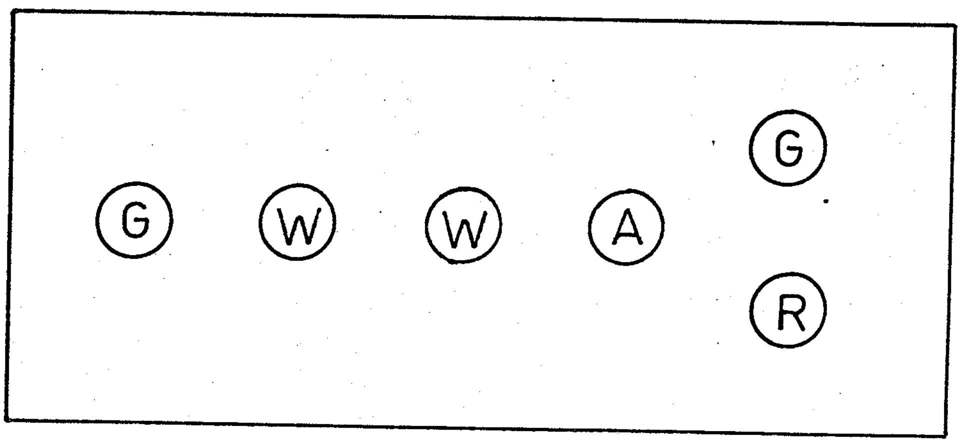
Procedure

Subjects were randomly assigned to one of the two experimental groups in order of their appearance for the experiment with the constraint that there be an equal number of subjects in each group. As the subject was being seated and the seat was being adjusted to a comfortable level, the experimenter gave the following introduction to the experimental situation:

> In this study we are investigating certain aspects of perception. As you have probably noticed, the walls and the ceiling of this room are covered with black cloth and in addition, the room has been partially soundproofed in order to reduce outside distractions. We have also installed speakers which are producing the

Figure 2

Subject's panel of lights



A - Amber
G - Green
R - Red
W - White

> background noise or white noise that you can hear to further reduce outside distraction. This white noise will be turned up to a slightly higher level once the experiment begins.

This part of the instructions was given in a casual manner. From this point on different sets of instructions were read for the subjects in each group. The instructions for Group I ("sound" group) asked subjects to attend to changes in sound level in the room. The instructions were as follows:

> This experiment involves a sound discrimination task. During the experiment we will be presenting a sound stimulus and your task will be to listen carefully and to decide when a change in sound level has occurred. This change may involve a noticeable sound or simply a change in the level of background noise. Once the experiment is completed I would like you to fill out a questionnaire in which you are asked to describe as well as you can any sounds or changes in sound level that you noticed which helped you decide when the stimulus was on.
>
> The experimental task is as follows: During each trial there is a sound stimulus which occurs in one of two time intervals. I would like you to indicate in which interval the stimulus occurred by pressing one of the buttons that are by your right hand. The two buttons on the left indicate the first time interval and the two buttons on the right indicate the second time interval. Press the outside buttons (pointing) which are labeled First Confident and Second Confident, when you are confident of your response and the buttons closer to the center, labeled First Interval and Second Interval when you are not sure of your response or when you are guessing. The panel of lights will show you when to expect the stimulus. First, (pointing) a green light will flash on to indicate that a trial is about to begin. Then the first white light will come on to indicate that the first interval has begun. The light stays on for the one second time interval and then switches off. Then, the second white light will come on to mark the second time interval. Shortly after the second time interval has been completed the amber light will come on. This is the signal to make your response. A stimulus will always occur in one of the two time intervals so be sure to make a choice every time the amber light comes on. If you are not sure in which interval the stimulus took place, guess. Be sure to make a choice while the amber light is on, otherwise your response will not be counted.
>
> When you do press one of the buttons a light will come on to

indicate whether or not your response was the correct one. The green light will come on for a correct response and the red light for an incorrect response. Press the button down firmly and only press once per trial. There is no particular pattern in how the stimulus switches from interval to interval so you would do best not to try and find a pattern, just concentrate on trying to detect the stimulus during each trial. The stimulus will occur an equal number of times in each interval. Remember, if you are not sure which interval the stimulus occurred in, guess.

Don't be discouraged if you do not seem to be getting a great many correct responses. This is quite a difficult task and there are large differences in perceptual abilities between individuals so just do your best all the way through. What we are interested in is the number of correct responses you make over a period of time, not just for one trial. There will be four blocks of 48 trials each with a short rest period between blocks. Each trial takes only about ten seconds.

If at any time you do not wish to continue with the experiment you can withdraw and still get credit for the experiment simply by getting up from the seat and coming to tell me in the next room or by telling me now. I will be in the next room throughout the experiment. Do you have any questions about the instructions?

Any questions the subject had were answered in as straightforward a way as possible without disclosing the exact nature of the stimulus actually being investigated.

The subjects assigned to Group II ("sensations" group) were given similar instructions except for the fact that the stimulus was described as being an infrared light. This description of the stimulus was used to provide a rationale for asking the subjects to attend to certain bodily sensations which have been described as possibly accompanying ultrasound stimulation (Allen, Frings and Rudnick, 1948; Acton & Carson, 1967; Griffin, 1972), without mentioning changes in sound level. Following the introduction the instructions continued as follows:

> The type of stimulus that we are studying in this experiment is infrared light which will be produced by this lamp. You may have heard of scientists using infrared photographs to study crop diseases and heat changes in the earth's surface. Infrared light is very common in the natural environment but it is at such a long wavelength that it is not visible to the human eye. Even though it is not visible, it may be possible to detect infrared light in other ways. There are some reports that it produces such sensations as a tingling or a pressure on the skin or a fullness in the head. You may or may not find that this sensation occurs while you are doing the task, but try and use any sensations that you do have to tell when the stimulus is on. Once the experiment is completed, I would like you to fill out a questionnaire in which you are asked to describe as well as you can any sensations that you had which helped you to decide when the stimulus was on. The experimental task is as follows:...

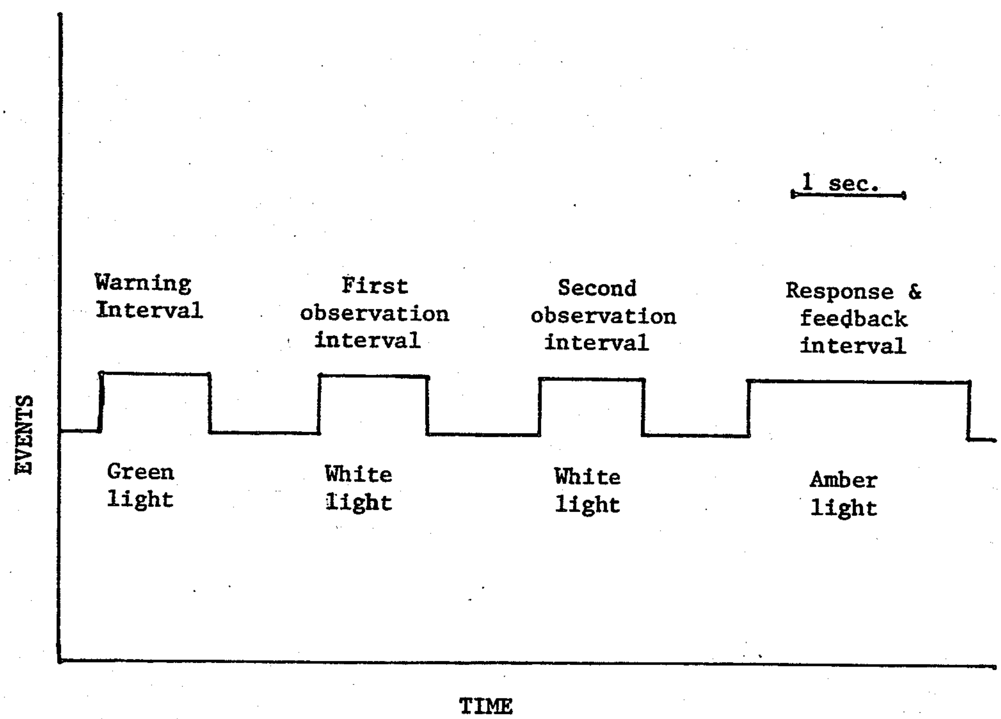
From this point on the instructions for Group II were the same as the the instructions for Group I except that references to "sound stimulus" were changed to refer to "infrared stimulus".

Once the instructions were completed and the experimenter had answered any questions that the subject had, he left the room and started the equipment. The events and time sequence for the events during each trial are shown in Figure 3. When the subject pressed one of the pushbuttons during the two second response interval, a feedback light (green for a correct response and red for an incorrect response) came on and remained on as long as the subject held the button down within the response period. Each subject received three blocks of 48 experimental trials followed by one block of 48 control trials with blocks separated by two minute rest periods.

Insert Figure 3 about here

Figure 3

Events during each trial of the two-alternative forced-choice task.


1 sec.
Warning Interval
First observation interval
Second observation interval
Response & feedback interval
EVENTS
Green light
White light
White light
Amber light
TIME

The time interval in which the signal was presented during each experimental trial or the interval which was arbitrarily scored as the correct choice for the control trials was from a sequence prepared in advance. This was derived from a list of chance sequences for two-alternative discrimination tasks designed by Fellows (1967) to ensure a chance level of performance for common response strategies and to minimize the reinforcing effects on these strategies. Purely random sequences would be unlikely to satisfy these requirements. Four different sequences of 48 trials were used. The same sequences were used for the first two blocks for all subjects, but since comparisons were to be made between the last block of experimental trials and the blocks of control trials, the particular sequence used for each of these blocks were counterbalanced within each group.

For each block of trials, the number of correct responses and the number of times each response alternative was used was recorded. On a few occasions a subject did not respond during the response interval on the first trial of a block, in which case a trial was added to the block in order to insure a constant number of recorded responses. When the trials were completed the subject was taken to another room and was asked to fill out a post-experimental questionnaire designed to investigate the kinds of stimuli and strategies that subjects would report having used in making their responses. The form of the questionnaire was varied slightly between the groups to conform to the nature of the instructions. Copies of the questionnaire are shown in Appendix A. Another purpose of the questionnaire was to ascertain whether the subject had normal vision and hearing.

RESULTS

The number of correct responses (out of a total of 48) for each experimental group on each block of trials is shown in Figure 4. An analysis of variance was carried out on the data from the last two blocks comparing experimental trials (Block 3, ultrasound signal presented) and control trials (Block 4, no signal presented) for the two groups. The results of this analysis are shown in Table 1. No significant effects were found due to blocks (experimental vs. control), instructional set (sound vs. sensations), or instruction x block interaction. The number of "confident" responses for each block of trials was recorded and is shown for each group in Figure 5. An analysis of

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Insert Figure 4 and Table 1 about here

---

variance was carried out to investigate whether there were differences in the number of "confident" responses between the groups on Blocks 3 and 4. The results of this analysis are shown in Table 2. Significant effects were found due to instructional set ($\underline{F}$ = 4.77; $\underline{df}$ = 1, 18; $\underline{p} <$ .05) with subjects in the "sound" group making more "confident" responses than subjects in the "sensations" group. No significant effects were found due to blocks (experimental vs. control) or instruction x block interaction.

Insert Figure 5 and Table 2 about here

Figure 4

Mean number of correct responses on each block of 48 trials for each group.

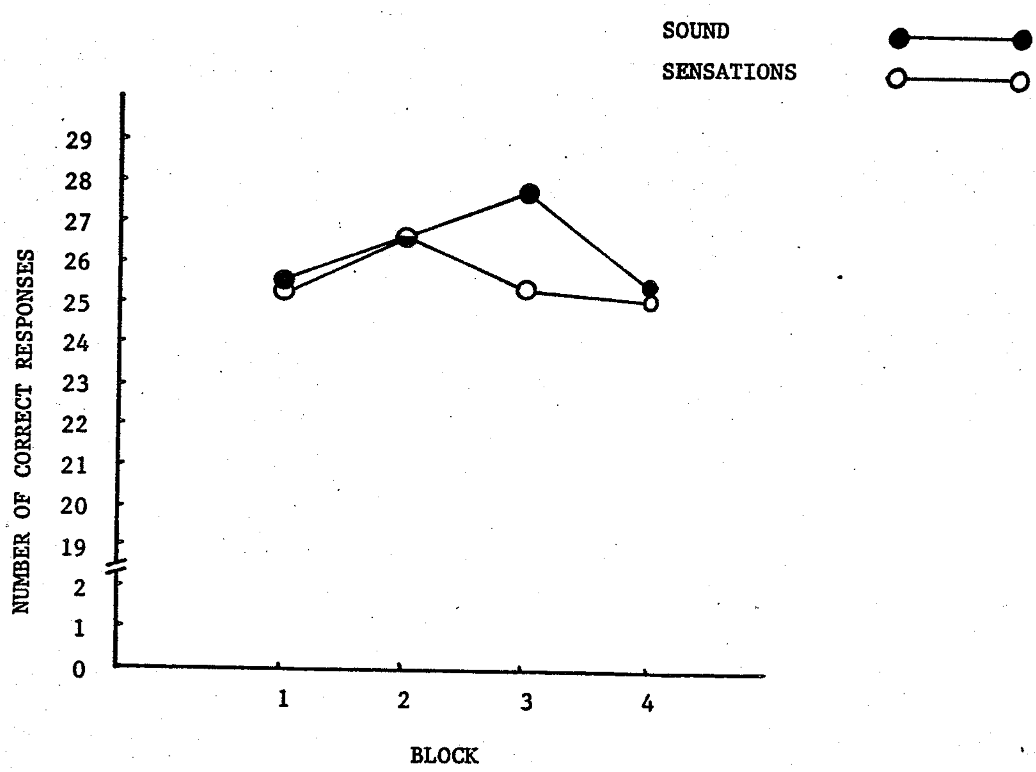

SOUND
SENSATIONS
NUMBER OF CORRECT RESPONSES
0
1
2
19
20
21
22
23
24
25
26
27
28
29
1
2
3
4
BLOCK

TABLE 1

Analysis of Variance: Correct Responses on Experimental and Control Trial Blocks

Source	df	SS	MS	F
Instruction	1	32.40	32.40	0.67
Error 1	18	868.10	48.23	
Block	1	36.10	36.10	1.19
Instruction X Block	1	1.60	1.60	0.05
Error 2	18	547.30	30.41	
Total	39	1485.50		

Figure 5

Mean number of "confident" responses on each block of 48 trials for each group.

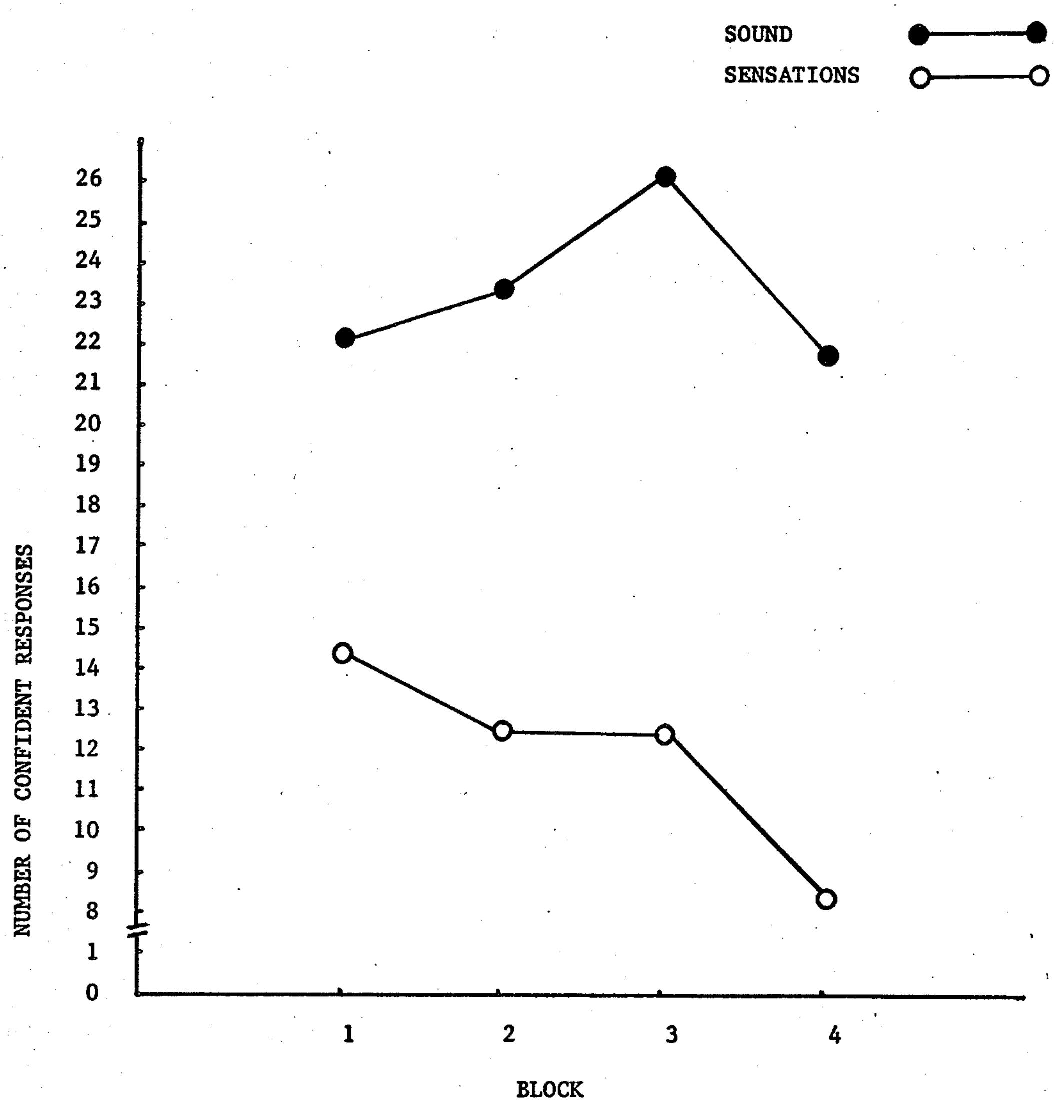

SOUND
SENSATIONS
NUMBER OF CONFIDENT RESPONSES
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
1
0
1
2
3
4
BLOCK

TABLE 2

Analysis of Variance: Confident Responses on Experimental and Control Trial Blocks

Source	df	SS	MS	F
Instruction	1	1795.60	1795.60	4.77*
Error 1	18	6776.80	376.49	
Block	1	176.40	176.40	2.27
Instruction X Block	1	0.00	0.00	0.00
Error 2	18	1399.60	77.76	
Total	39	10148.40		

*$p < .05$

The data on position preference (first vs. second interval responses) were examined in a supplementary analysis to investigate whether the sequence of alternatives for the assignment of correct responses in the two-alternative task had been successful in minimizing position preference. The number of times the first interval was chosen in each block (out of 48 responses) is shown in Figure 6. An analysis of variance was carried out on the data for the last two blocks to investigate whether there were any differences in position preference between experimental and control trials for either of the two groups. The results of this analysis are shown in Table 3. There were no significant differences due to block effects, instruction effects, or instruction x block interaction.

Insert Figure 6 and Table 3 about here

DISCUSSION

The finding of no difference in performance between experimental and control trials suggests that overall neither group of subjects was able to detect the stimulus at greater than the chance level. When the data for individual subjects (shown in Appendix B) were examined in both groups, it was found that the number of correct responses in the control trials (Block 4) ranged from 15-35 (out of 48 responses) while the number of correct responses in the final block of experimental trials (Block 3) ranged from 14-47. When the subject in the "sound" group who made 47 correct responses (out of 48 possible) on Block 3 is elimin-

Figure 6

Mean number of first interval responses
on each block of 48 trials for each group.

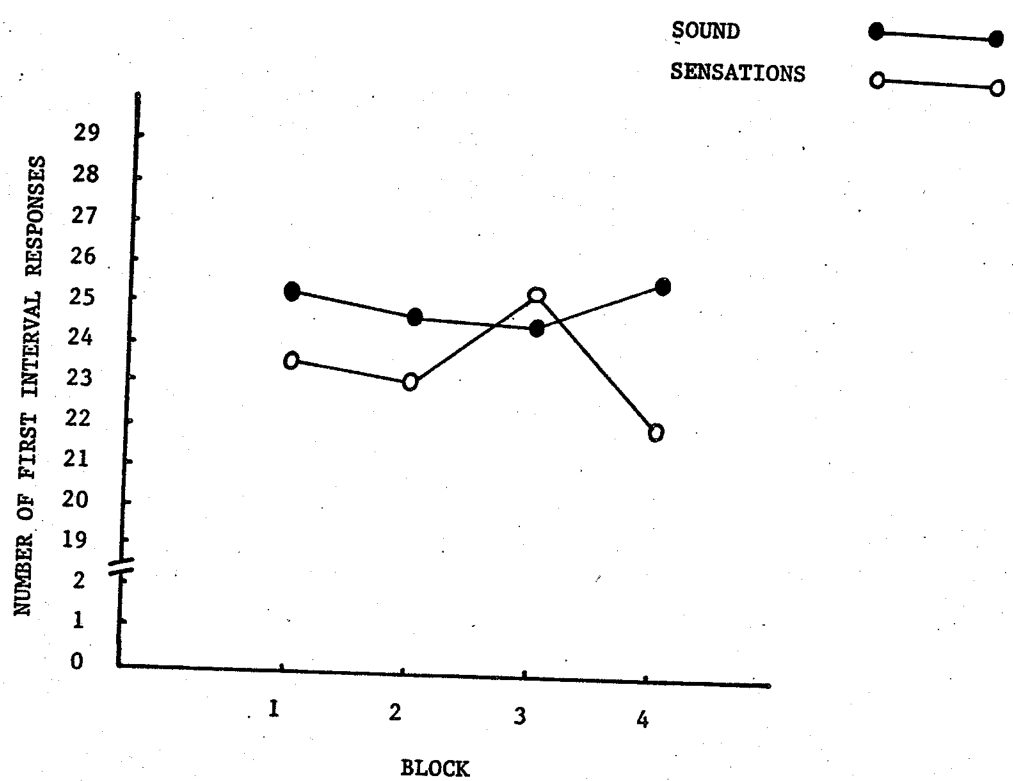

SOUND
SENSATIONS
NUMBER OF FIRST INTERVAL RESPONSES
29
28
27
26
25
24
23
22
21
20
19
2
1
0
1
2
3
4
BLOCK

TABLE 3

Analysis of Variance: First Interval Choices on Experimental and Control Trial Blocks

Source	df	SS	MS	F
Instruction	1	24.03	24.03	0.82
Error 1	18	525.45	29.19	
Block	1	13.23	13.23	1.03
Instruction X Block	1	46.23	46.23	3.60
Error 2	18	231.05	12.84	
Total	39	839.99		

ated from consideration, the range for Block 3 is more similar to the range for Block 4 at 14-38 correct responses, while the range over all four blocks was 13-38. This subject (with 47 correct responses on Block 3) seems to be the only subject who could reliably detect the stimulus. The pattern of his scores over the four blocks of trials was: 22, 38, 47, and 24, indicating an increasing level of success at detecting the signal over the three blocks of experimental trials until almost the 100% level was reached, dropping back to chance performance on the control trials. This subject's responses to questions on a post-experimental questionnaire about whether he found the task difficult and about any sounds that he used to make his choices were: "Sometimes I could hear the frequencies distinctly, but nearing the end I couldn't hear a thing and guessed at most of the answers" and "A sound like the ringing of the bell, at the end of my trials, however, I heard no ringing of a bell". It appears from these responses that the subject was attempting to describe a high frequency auditory sensation and that the subject noticed that this stimulus was no longer being presented towards the end of the task. When the responses of the other subjects to the post-experimental questionnaire were examined, it was found that once again many of the responses seem to have been suggested by the instructions. Three subjects in the "sound" group and one subject in the "sensations" group reported high pitched sounds in response to a question asking them to describe any sounds which helped them to make their choices at least some of the time. None of the subjects in the "sound" group reported any sensations similar to those described previously but a number of subjects in the "sensations" group reported various kinds of sensations such as: "A tingling on the nose" and "Tickling in my left fingers, sometimes a hissing in my ears". In addition, one of the subjects in the "sensations" group reported that he did not believe that there was any infrared light and another reported that there were no sensations and that he attempted various other response strategies. In summary, it appears that although a number of subjects reported sensations or sounds as suggested by the instructions, only one of the subjects could reliably detect the stimulus and this subject described the signal as a high frequency ringing sound. This is in agreement with the earlier study by Walker (1972) which also found that all subjects who could detect the signal reliably were those who described it as a high frequency sound.

In considering the difference in the number of "confident" responses between the "sound" and the "sensations" groups, it seems that the number of "confident" responses was influenced more by the instructions than by the number of correct responses a subject was making (since the number of correct responses was not significantly different between the two groups). The task of detecting the sensations described in the instructions to the "sensations" group would seem to be a more ambiguous, vague and unusual task than that of detecting changes in sound level, so this may have been the main factor in producing fewer "confident" responses in the "sensations" group. Since on visual examination (Appendix B) there did not seem to be much relation between the number of correct responses and the number of "confident" responses on the individual level and since there was great individual variation in how subjects used these categories, it seems that these ratings were not in most cases accomplishing the intended function. It may be possible, in future studies of this sort, to give the subjects pretraining on a less difficult task or on the experimental task to produce more stable use of the confidence categories.

The finding that subjects (with the exception of one subject in the "sound" group) were not able to detect the 25 kHz signal at an intensity level of 90 db and with a duration of 1 second is particularly interesting in relation to two other studies carried out concurrently with this one at the University of Manitoba. Martin, Hawryluk and Guse (1974), in their second study, used a 25 kHz tone at 85-89 db and with a 3 second duration as part of a compound stimulus in a classical conditioning paradigm. The ultrasound conditioned stimulus (CS_1) preceded the onset of a 2 second red light (CSs) by 1 second and the electric shock UCS (unconditioned stimulus) of .5 seconds duration was coincident with the offset of the compound conditioned stimulus(CS_1 and CSs). They found that GSR conditioning to the compound stimulus (over 17 trials) resulted in shorter GSR latencies to the compound stimulus than to the red light alone during extinction trials. To ensure that the high frequency tone was not audible to subjects included in the study, subjects who reported any use of sound cues to anticipate the shock in a post-experimental questionnaire were eliminated from the data analysis. Since the finding of shorter GSR latencies to the compound stimulus than to the light stimulus was not seen in the control group (who received random presentations of ultrasound, not paired with the red light during conditioning trials), Martin et al. concluded that ultrasound is capable of altering the temporal aspects of a well-established conditioned response without the subject's awareness. Magnitude measures of GSR conditioning were not affected and it was suggested that temporal characteristics of the response were more sensitive to these subtle stimulus manipulations carried out without the subject's reported awareness.

In their third study, Martin et al. attempted to modify a temporal aspect of a well defined instrumental behavior. In a reaction time task, the subject was required to move a lever as quickly as possible in one direction at the onset of one stimulus light and in the other direction at the onset of another stimulus light. In order to encourage rapid responding, subjects were told that the task would continue until there were 150 trials in which they had responded in 1/3 seconds or less, although this contingency was not actually enforced. Without informing the subject, one of the lights was preceded by an ultrasound signal which was expected to act as an anticipatory cue. The 25 kHz ultrasound stimulus was of 500 msec duration at an intensity of 89 db. To ensure that the high frequency tone was not audible to subjects included in the study, subjects were asked in a post-experimental interview about any cues which enabled them to anticipate the lights and about any distracting noises from the equipment. No subjects reported using sound cues and the reports of subjects who felt they could anticipate one or other of the lights did not coincide well with actual delivery of the ultrasound. It was predicted that reaction time to the light preceded by ultrasound would become faster over the 150 trials relative to reaction time to the other light, a difference which would not occur among control subjects who received no ultrasound. When the light with which the ultrasound was paired was switched later in the task for 16 trials, it was predicted that there would be a performance decrement among experimental subjects because of the arousal of conflicting response tendencies. Martin et al. found that although reaction times to the first light preceded by ultrasound did not increase, when the ultrasound stimulus was paired with the opposite stimulus light there was a decrement in reaction time performance. They concluded that although ultrasound as an anticipatory cue was not found to facilitate reaction time performance, it was established as a cue in some manner and can have an effect on instrumental behavior. Martin et al. discussed a number of possible explanations for the finding that ultrasound did not act as an anticipatory cue: visual inspection of the data suggested that ultrasound may have facilitated the performance of some subjects while disrupting the performance of other subjects, with these two effects cancelling out when averaged over subjects; another possibility was that reaction time performance was so close to ceiling levels already that it was difficult to further enhance speed but was easier to produce a response decrement.

Martin et al. have pointed out that it is difficult to determine, with a post-experimental assessment of "awareness", whether the subject is "unaware" of the stimulus simply because his attention has not been drawn to it or because he would be unable to detect it even if his attention were drawn to it. In addition, there are other problems with the post-experimental questionnaire as a method of assessing "awareness". Weinstein and Lawson (1963) found that subjects who were presumably fully aware, because of what they had been told during the learning period, did not uniformly reveal complete "awareness" with any of the methods of assessment used. Levy (1967) found that subjects were reluctant to tell the truth in a post-experimental interview if they thought that it might disappoint the experimenter. The use of a signal detection paradigm, particularly a forced choice paradigm, which should be sensitive to any information which the subject has available in making his response, can provide further information on whether or not it is possible for the subject to detect the occurrence of the stimulus. The present study seems to indicate that an ultrasonic stimulus at this intensity and frequency level (90 db at 25 kHz) is not detectible even when subjects are alerted as to possible sensations which it may produce and are informed of the precise time interval in which the signal will occur with a given probability. The only qualification to this conclusion seems to be that there is a small proportion of subjects in the age range sampled (one of the 20 subjects participating in this study, for example), for whom acoustic energy at this frequency and intensity level is not ultrasonic, who can detect it reliably and who describe it as a high frequency sound. The findings in this study support the conclusions by Martin, Hawryluk, and Guse (1974) that the phenomena which they demonstrated involve the operation of ultrasound as a "subliminal stimulus" (a stimulus which is registerable but not detectible) and that this finding supports the position that, under some circumstances, learning can take place without awareness.

It seems that ultrasound may be a particularly useful tool for investigating such phenomena as "subliminal perception" or "learning without awareness" because it is relatively easy to apply without the subject's knowledge that he is receiving stimulation. It is the subject's knowledge that he is receiving stimulation which creates difficulty in interpretation in other studies in the area (Dixon, 1971). It seems that at higher frequencies, which have not yet been investigated, that there will be even a lower probability of the stimulus being audible for any proportion of the subjects.

EXPERIMENT II

In a review of the literature on ultrasound, the only use of ultrasound as a stimulus in psychological experiments with human subjects (previous to the studies carried out at the University of Mantioba) appeared in connection with research on sensory interaction. Sensory interaction (London, 1954) involves the effect on the response to stimulation in one modality of stimulation presented in another modality (accessory stimulation). London (1954), in a review of studies of sensory interaction in the Soviet Union, noted that Soviet researchers (Kekcheev and Ostrovskii, 1941) had reported that accessory stimulation at ultrasonic frequencies (e.g., 32.8 kHz) increased peripheral visual sensitivity. This was in contrast to the finding in other Soviet studies reported by London that, as a rule, peripheral visual sensitivity declined on exposure to audible sounds of average or above average intensity (Dobriakova, 1947; Dubinskaia, 1947). On the other hand, with central vision, Soviet researchers reported that audible accessory stimulation of moderate intensity heightens central sensitivity to white light for the dark adapted eye, while when monochromatic light is employed, the effect varies with the wavelength utilized. No studies of the effects of ultrasound on color or central vision were mentioned by London (1954) and very little information was provided about the details of the Soviet studies.

Studies of the Effect of Accessory Auditory Stimulation on Visual Acuity

Although the original Soviet studies on sensory interaction have not been widely available, there have been a number of reports in the North American literature which have referred to and attempted to replicate some of the Soviet findings with audible sound. Hartmann (1933) carried out an experiment similar to one reported earlier by the eminent Soviet researcher Kravkov (1930). Hartmann used a visual acuity task in which subjects were asked to report when a space appeared between two black blocks on a white background or between two white blocks on a black background. Using 180 Hz and 2100 Hz tones he confirmed the Kravkov finding that auditory stimulation increased visual acuity in reporting the presence of a space between two black blocks on a white background. He also found that discrimination of the space between two white blocks on a black background was improved with accessory stimulation, a finding which disagreed with Kravkov's finding of a decrement in performance on this task. Hartmann reported similar increments in visual sensitivity with odor, touch, and pain stimulation. In a subsequent report, Kravkov (1934) suggested that the disagreement between his findings and those of Hartmann was a result of procedural differences. He reported in his studies that changes produced by accessory stimulation lasted for a period of about six or seven minutes after stimulation was terminated, while Hartmann allowed only a two minute pause between his stimulus conditions. Another study by Kravkov (1935) was cited by Maier, Bevan, and Behar (1961) in which it was reported that a continuous tone raised critical flicker fusion frequency (CFF) for foveal presentation and lowered CFF for peripheral presentation.

Allen and Schwartz (1940) studied the effect of accessory sound stimulation on CFF to light of various wavelengths. Auditory stimulation with tones of 150 and 1200 Hz was carried out for two minutes after which the CFF was determined immediately and at various intervals of time (1.5, 3, 5, and 7 minutes). They found both increases and decreases in the CFF depending upon the wavelength of light involved and they reported that these results were in agreement with Kravkov's

(1936) findings with color vision. It was also suggested that the CFF oscillated (showing both increased and decreased sensitivity) for a number of minutes after the accessory stimulus was removed. These early studies should be interpreted with caution, however, because standards of data evaluation and reporting were not always clear.

Maier, Bevan, and Behar (1961), in a more recent study, examined the effect of accessory auditory stimulation on the CFF for different regions of the visual spectrum. Three loudness levels (0, 40, and 80 phons[3]) and three frequencies (290, 1050, and 3900 Hz) of accessory stimulation were used. They found that when the test source was orange-red, the CFF decreased with an increase in loudness; when it was green, no change was affected; and when it was blue, CFF increased with an increase in loudness. Maier, Bevan, and Behar (1961) have noted that although sensory interaction effects were found, the results were not in agreement with earlier reports by Kravkov (1939) and Allen and Schwartz (1940). These differences were difficult to reconcile since the frequency range and loudness levels were similar, but Maier et al. suggested that they may be due to differences in the intensity of the visual stimuli. The levels used in the earlier studies were not reported but Kravkov (1939) had stated that sound added to a dim green test light resulted in a decrease in CFF while sound added to a bright green light increased CFF.

McCroskey (1958) studied the effect of white noise upon the visual CFF with white light and found a significant lowering of the CFF threshold (indicating lowered sensitivity) by white noise at 85, 95, 105, and 115 db. No significant differences were found among the four levels of noise. This study differs from others cited in that white noise was the accessory stimulus whereas in the other studies pure tones were used. The only other studies found using white noise as the accessory stimulus found no effect on CFF (Ogilvie, 1956; Walker and Sawyer, 1961).

Sensory Interaction with Ultrasound as the Accessory Stimulus

The only study, other than the Soviet studies reviewed by London (1954), in which ultrasound was used as an accessory stimulus in a sensory interaction study was reported by Van Eyl and Wildman (1973). In a visual discrimination task, each subject was asked to report which of four circles on a black and white slide had a slice missing (the missing slice was in the part of one of the circles which was closer to the upper or lower border of the slide--that is, in the peripheral portion of the slide). After a warmup task, a series of 96 slides was presented for 125 msec. each to each subject in a darkened room. For each series of 16 slides the auditory condition was changed to allow for periods of no sound; 2 kHz acoustic stimulation (audible); and 40 kHz acoustic stimulation (ultrasound) which were randomized for each subject. The intensity of acoustic stimulation was not specified in Van Eyl and Wildman's very brief report. They found that both auditory and ultrasonic acoustic stimulation facilitated visual discrimination and that there was no significant difference in effect between auditory and ultrasonic accessory stimulation.

The present study was carried out to determine whether the findings of Van Eyl and Wildman could be repeated with visual sensitivity measured by the CFF to white light presented foveally. Each subject in the experiment received 14 minutes of stimulation with an audible stimulus (2 kHz at 60 db); 14 minutes of stimulation with an aultrasound stimulus (34.9 kHz at 108 db) and an equal 14 minute period with no acoustic stimulation (except the ambient level of sound stimulation in the room--approximately 50 db). Although it would have been desirable to determine visual sensitivity with the use of a signal detection paradigm, such as the very reliable forced-choice method used by Clark, Rutschmann, Link and Brown (1963), this was difficult in the present situation because of the possibility that sensory interaction effects may vary over the period of stimulation. Signal detection and forced-choice techniques generally require a relatively large number of trials that can take up a considerable amount of time and which might allow for changes in visual sensitivity while the procedure was being carried out. Because of this difficulty, a descending method of limits threshold measure, which can be carried out rapidly, was relied upon as the major measure of visual sensitivity. Zubek and Bross (1973) found this to be a very reliable and stable measure in studies in which they found it to reflect changes in the sensitivity of one eye as a result of varying periods of light deprivation of the other eye. This measure was also found to be sensitive to changes in visual sensitivity over time.

During this experiment the threshold was measured twice during each 14 minutes stimulation period--after one minute of accessory stimulation and after twelve minutes of accessory stimulation. This was done to determine whether there were changes in the threshold over the period of accessory stimulation. In addition, 15 trials of a four-alternative forced-choice detection task (similar to that used by Clark et al., 1963) were presented in the period between the threshold determinations to investigate whether this might provide a useful and sensitive index of visual sensitivity. This procedure involved considerably fewer trials than the procedure used by Clark et al., who used 12 trials at each of five frequencies, the frequencies each being separated by 2 Hz (for a total of 60 trials). It was necessary to use fewer trials in this experiment because of the time involved (the 15 trials at a single flicker frequency took approximately eight minutes) and because of equipment limitations (in the Clark et al. study the flicker frequency could be switched automatically whereas in this study this had to be done manually by the experimenter, increasing the duration of each trial).

The hypotheses of this experiment were as follows:

1. The CFF threshold would be higher (indicating greater sensitivity) under conditions of accessory stimulation with ultrasound or audible sound than under the control condition. No difference was predicted between ultrasound and audible accessory stimulation.

2. Subjects would make more correct responses on the forced-choice signal detection task under conditions of accessory stimulation with ultrasound or audible sound than in the control condition.

3. No predictions were made as to differences in the CFF determined early and late in the accessory stimulation period under the three stimulation conditions.

Method

Subjects

Sixteen male undergraduate students served as subjects in this experiment. Of these, four subjects were eliminated from the data analysis: two because of failure in an electronic switch; one because of an inconsistent pattern of responding on the threshold task; and one because he did not wish to continue with the experiment. This last subject, who had some difficulty with English, reported that he did not feel he could make a choice on the forced-choice task when he wasn't sure of his response. The remaining twelve subjects ranged in age from 18 to 22 with a mean age of 19 years. Subjects participated in the experiment for laboratory credit in an introductory psychology course.

Apparatus

The 2000 Hz, 60 db acoustic stimulus was produced by a wide range oscillator (Hewlett Packard special model H 20-200 CD) with output amplified by a Brute 70 amplifier (Louis, 1967). This signal was recorded prior to the experiment on audio tape (Maxwell Ultradynamic "UD 50-7") and was played back during the experiment on a tape deck (Sony TC 366) through a Pioneer SA 500 amplifier and a Wharfedale Denton speaker. The signal was prerecorded in order to eliminate possible switching noises.

The 34.9 kHz ultrasound stimulus at an intensity of 108 db was produced by an electroacoustic horn (Boucher and Kreuter, 1969) driven by a signal generator/amplifier with a built-in switch for silent switching. This apparatus was constructed for the University of Manitoba ultrasound laboratory by the Ontario Research Foundation, Sheridan Park, Ontario. Sound pressure level readings were taken with a Breul and Kjaer Precision Sound Level Meter (Type 2203) with a Type 4133 1/2-inch microphone placed in the position which was to be occupied by the subject's left ear. The ultrasound level of 108 db used in this experiment was within the safety limits for human hearing (Acton and Carson, 1967; Parrack, 1966). The ambient sound pressure level in the experimental chamber was 50 db.

The visual stimuli used in the CFF task were produced by a Lafayette Instrument Co. Flicker Fusion Apparatus (Model 12025) with a Lafayette Viewing Chamber (Model 12027). The stimulus was a 5/8-inch diameter circle illuminated by a Sylvania R1166 "Glow Modulator" lamp. The flicker generating apparatus was set at a light-dark ratio of 0.50 and a lamp current reading of 22.6 milliamperes.

Experimental Chamber

The same chamber was used in this experiment as in Experiment I. The subject was seated on a padded chair at a 42 x 30 inch table in the corner of the room where the two false walls met. The speaker and the electroacoustic horn used to produce the acoustic stimuli were located behind the false wall on the subject's left side at a distance of approximately 12 inches from the subject's left ear. Both the speaker and the horn were aimed at the position occupied by the subject's ear when he looked into the viewing chamber. The viewing chamber was attached firmly to the table so as to hold the subject's head in a constant position while he was carrying out the experimental task. During the experiment, the experimenter sat at the other end of the table (facing the subject's right side) in order to operate the flicker generating apparatus and record the subject's responses. The subject and the experimenter were separated by a black cardboard shield to prevent any light from the flicker generating apparatus from reaching the subject. The remainder of the equipment was located in the adjacent room.

Procedure

Subjects were randomly assigned to one of the six possible orders of presentation of the three accessory stimulus conditions (audible sound, ultrasound, and control period) on their appearance for the experiment with the constraint that two subjects be assigned to each possible order. Each subject's preferred eye was determined by having the subject look through a small hole in a hand held plastic wand and read part of an eye chart. This procedure was repeated twice and in every case the subject used the same eye on both occasions. The experimenter used a black cardboard shield to cover half of the viewing slot so that the subject was able to see the stimulus with only his preferred eye. The subject was taken into the experimental chamber and the following tape recorded instructions were played:

> This experiment involves a test of visual sensitivity. During the experiment I will be asking you to make judgments of a visual stimulus at a number of different times. Once we start the experiment proper I will explain how I would like you to make these judgments. This will be the only task required of you during the experiment except that I would also like to ask you a few questions about the experiment once the procedure is completed. Most of the experiment will be done under conditions of dark adaptation in this sound attenuated room and it will last for about two hours.
>
> If at any time you do not wish to continue with the experiment you can withdraw and still get credit for the experiment simply by telling me that you wish to withdraw. Do you have any questions about the experiment so far?

> (Pause during which any questions were answered)
>
> I'd like you to sit in front of the viewing chamber now. It's very important that the viewing chamber and the desk are not moved so try to position yourself so that you are in as comfortable a position as possible without moving the chamber or the desk. To get comfortable at the viewing chamber, put your elbows on the desk and put your head up to the viewer with your hands on the side of the viewer. In this position try to get as comfortable as possible, without moving the chamber.
>
> I'll be putting a blindfold on you so that we can start with the dark adaptation period while I get the equipment ready. I'll be taking the blindfold off again in about 15 minutes.

At this point the experimenter placed a blindfold on the subject and extinguished the room light. During the 15 minute dark adaptation period the experimenter conversed casually with the subject although discussion of the experiment was avoided. Conversation was also permitted during three ten minute rest periods which separated the three stimulus conditions later in the experiment. Once the dark adaptation period was completed the instructions were resumed:

> We are going to be using this viewer for two different procedures and I'd like you to practice each a few times before we start the experiment. In the first task, which I'll call Procedure 1, when I say "READY" a light will appear in the viewer at a flickering frequency too high for the human eye to distinguish. The frequency will then be gradually decreased until at some point you will no longer see the light as a steady spot and it will start to flicker. Indicate when it starts to flicker by saying "NOW" <u>as soon as you first see the flicker appearing</u>. Do you have any questions about this?

After answering any questions that the subject had, the experimenter gave the subject five practice trials with the descending method of limits (Procedure 1). The instructions were then continued:

> In the second task, which I will call Procedure 2, I will be presenting a series of 15 trials. Each trial will consist of four short presentations of a light source or stimulus. One of these four stimuli will be flickering, the other three will be

> steady. Your job will be to report which of the four stimuli was flickering by saying "FIRST", "SECOND", "THIRD", or "FOURTH" after the trial. Now to get each of these stimuli to come on, you will have to press the pushbutton which is by your left hand when you hear me making this tapping sound (experimenter demonstrates). In order to keep track of which stimulus is which I would like you to call out which stimulus is due each time before you press the pushbutton. Be sure not to press the button before you hear this tapping sound (experimenter demonstrates). To summarize, then, in each trial you hear a tap, then you say "FIRST", press the button and observe the stimulus, then wait until you hear another tap, then you say "SECOND", press the button and observe the stimulus, and so on. As soon as the last stimulus is over you decide which of the four was flickering and say it out loud. Be sure to make a response each time--if you are not sure which one was flickering, guess. I will be marking down which responses are correct and I will also say "CORRECT" out loud when you make the correct response. Otherwise I will say nothing and you can listen for the next tap which starts the next trial. Although it takes a long time to explain, this procedure should go quite quickly. Do you have any questions about it? (PAUSE) Let's try a few practice trials with easy ones at first.

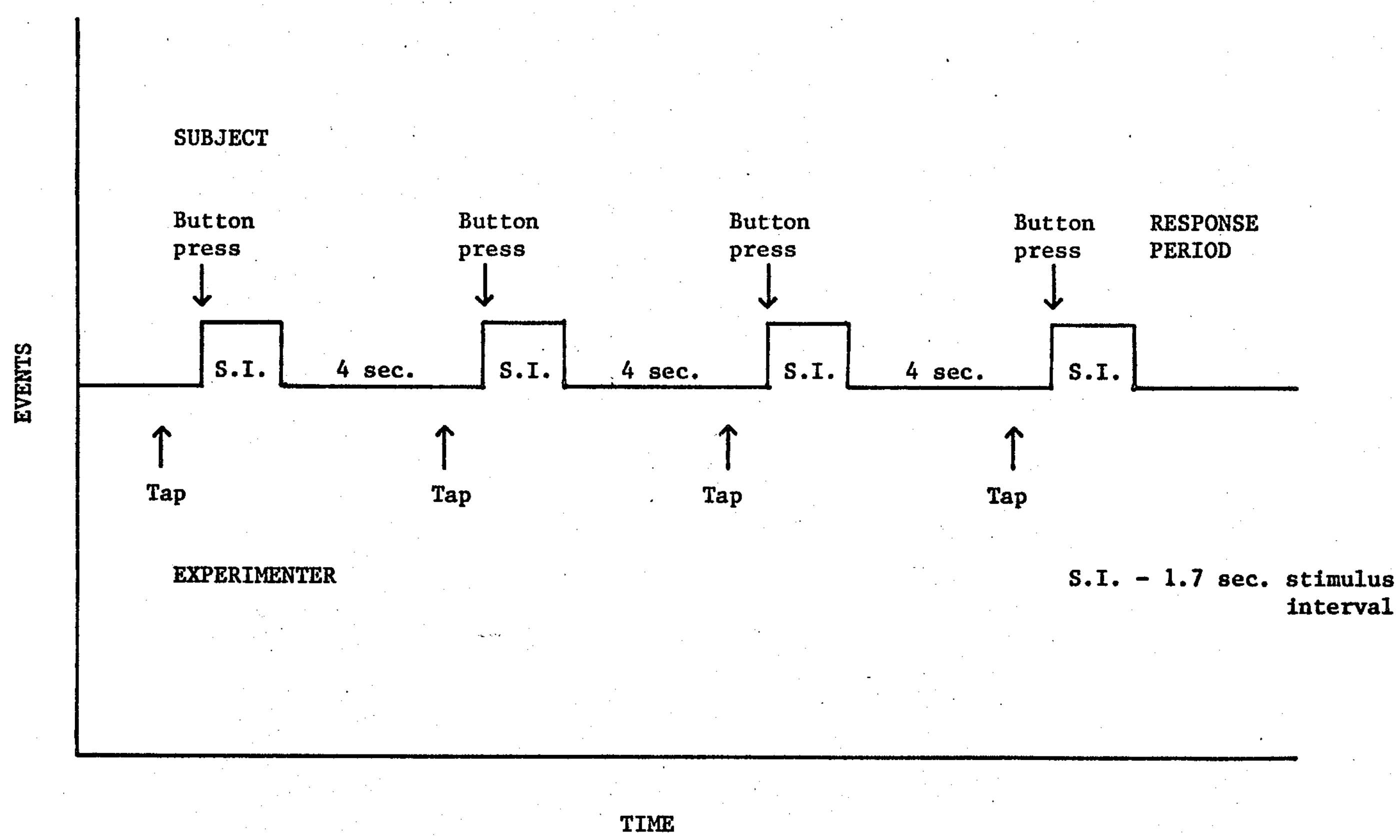
At this point the subject was given five practice trials of the four alternative forced-choice signal detection task (Procedure 2). The events during each trial are shown in Figure 7. The interval in which the flickering stimulus occurred was determined in advance and varied randomly over the 45 trials in the experiment proper with the same series being used for all of the subjects. The frequency level of the flickering stimulus was chosen so as to be quite easy to detect on all of the practice trials. The flicker frequency for the "steady" stimuli was 60.0 Hz.

Insert Figure 7 about here

Once the practice trials were completed the experimenter continued with the preliminary threshold determination using Procedure 1.

Figure 7

Events during each trial of the four-alternative forced-choice task.


SUBJECT
Button press
Button press
Button press
Button press
RESPONSE PERIOD
S.I.
4 sec.
S.I.
4 sec.
S.I.
4 sec.
S.I.
EVENTS
Tap
Tap
Tap
Tap
EXPERIMENTER
S.I. - 1.7 sec. stimulus interval
TIME

The mean of ten trials was taken as the descending CFF threshold. The level of the flickering stimulus to be used in Procedure 2 was then determined by adding 2.0 Hz to each subject's preliminary CFF threshold. It has been determined with pilot subjects that this level represented an intermediate level of stimulus difficulty under normal conditions (25% correct responses would represent the chance level of responding and 100% correct would represent perfect performance).

The taped instructions were continued as follows:

> Now we will start with the first threshold determination with Procedure 1. Look into the viewer and when I say "READY" a steady light will come on and I would like you to say "NOW" as soon as you first see the light flicker. Remember, this is a difficult task so concentrate hard on what you are doing and follow the instructions exactly. Are you ready?

When the preliminary threshold determination was completed, the last part of the taped instructions was given:

> One thing that I didn't mention earlier was that while you are doing Procedure 2 you will be earning five cents for each correct response you give. This applies only to Procedure 2 and I hope that by doing this it will make the task more interesting for you and make it more of a challenge. I will be recording as you make your responses and I will say "CORRECT" for each correct response and when the experiment is over I will add up all of the correct responses and give you five cents for each correct response that you have made. As we continue with the experiment there may be acoustic or sound stimulation presented from a speaker on your left. You don't have to do anything special when a sound stimulus comes on, just concentrate on the visual sensitivity task and follow the instructions carefully. Please let me know if you find the acoustic stimulation unpleasant or annoying. As I mentioned earlier, if at any time you do not wish to continue with the experiment you can withdraw and still get credit simply by telling me that you wish to withdraw.

Once the instructions were completed the experiment proper was carried out. The temporal order of the events occurring during a session are shown in Figure 8. As was mentioned earlier, the order of presentation of the three stimulus conditions (audible sound, ultrasound, and control) was counterbalanced over the six possible stimulus orders with two subjects receiving each order.

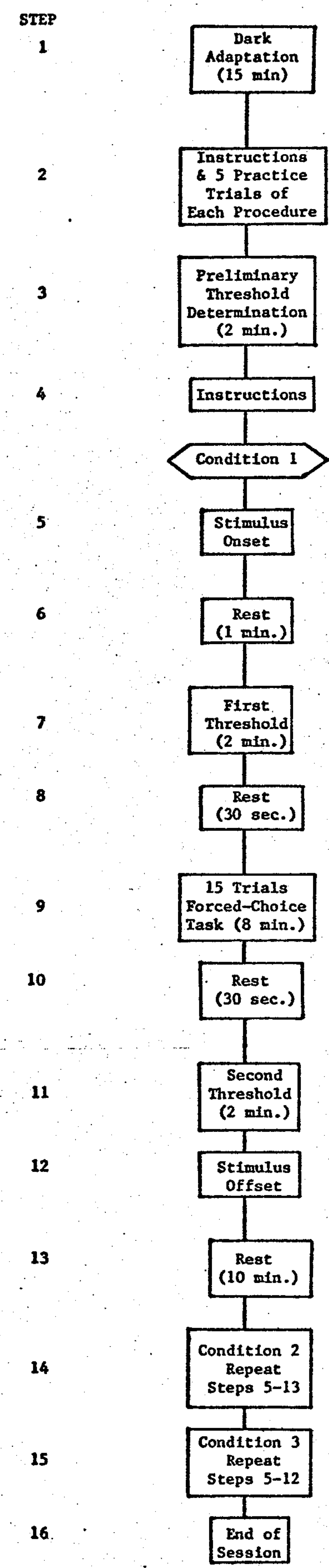
Insert Figure 8 about here

During each of the threshold determinations (Procedure 1), the mean of 10 trials was taken as the descending CFF threshold.

Once the session was completed each subject was given a short post-experimental questionnaire (a copy of which is shown in Appendix C) while the experimenter recorded his responses. Following this the subject was given five cents for each correct response that he made on Procedure 2, and was thanked for his participation in the experiment. None of the subjects reported hearing high frequency sounds during the ultrasound stimulation period on the post-experimental questionnaire.

Figure 8

Events for each subject during a single session.


STEP
1
Dark Adaptation (15 min)
2
Instructions & 5 Practice Trials of Each Procedure
3
Preliminary Threshold Determination (2 min.)
4
Instructions
Condition 1
5
Stimulus Onset
6
Rest (1 min.)
7
First Threshold (2 min.)
8
Rest (30 sec.)
9
15 Trials Forced-Choice Task (8 min.)
10
Rest (30 sec.)
11
Second Threshold (2 min.)
12
Stimulus Offset
13
Rest (10 min.)
14
Condition 2 Repeat Steps 5-13
15
Condition 3 Repeat Steps 5-12
16
End of Session

RESULTS

The mean CFF threshold determined after one minute of stimulation (Early) and after twelve minutes of stimulation (Late) in each of the three stimulus conditions is shown in Figure 9 as is the mean threshold on the preliminary determination. An analysis of variance was carried out comparing the CFF thresholds for the six possible orders of stimulus presentation (the only between-subjects variable) under the three sound conditions (control, audible, and ultrasound) at the two threshold determination times (early and late). The results of this analysis are shown in Table 4.

Insert Figure 9 and Table 4 about here

No significant effects were found due to order, sound condition or determination time, but there was a significant sound x time interaction ($\underline{F}$ = 7.31, $\underline{df}$ = 1, 6; p $<$.05). (Note that because this was a within-subjects variable, the conservative $\underline{F}$-test degrees of freedom suggested by Kirk (1968) and Geisser and Greenhouse (1958) were used in determining the significance level). This interaction suggests that thresholds under the three sound conditions changed in different directions over the time period involved.

In order to clarify this sound x time interaction, simple main effects analyses (Kirk, 1968) were carried out for the early and late threshold determinations. The results of the analysis on thresholds obtained after one minute are shown in Table 5 and the results for thresholds obtained after twelve minutes are shown in Table 6. There

Figure 9

Mean CFF thresholds: preliminary threshold and thresholds determined after one minute and after twelve minutes of stimulation in each of the three stimulus conditions.

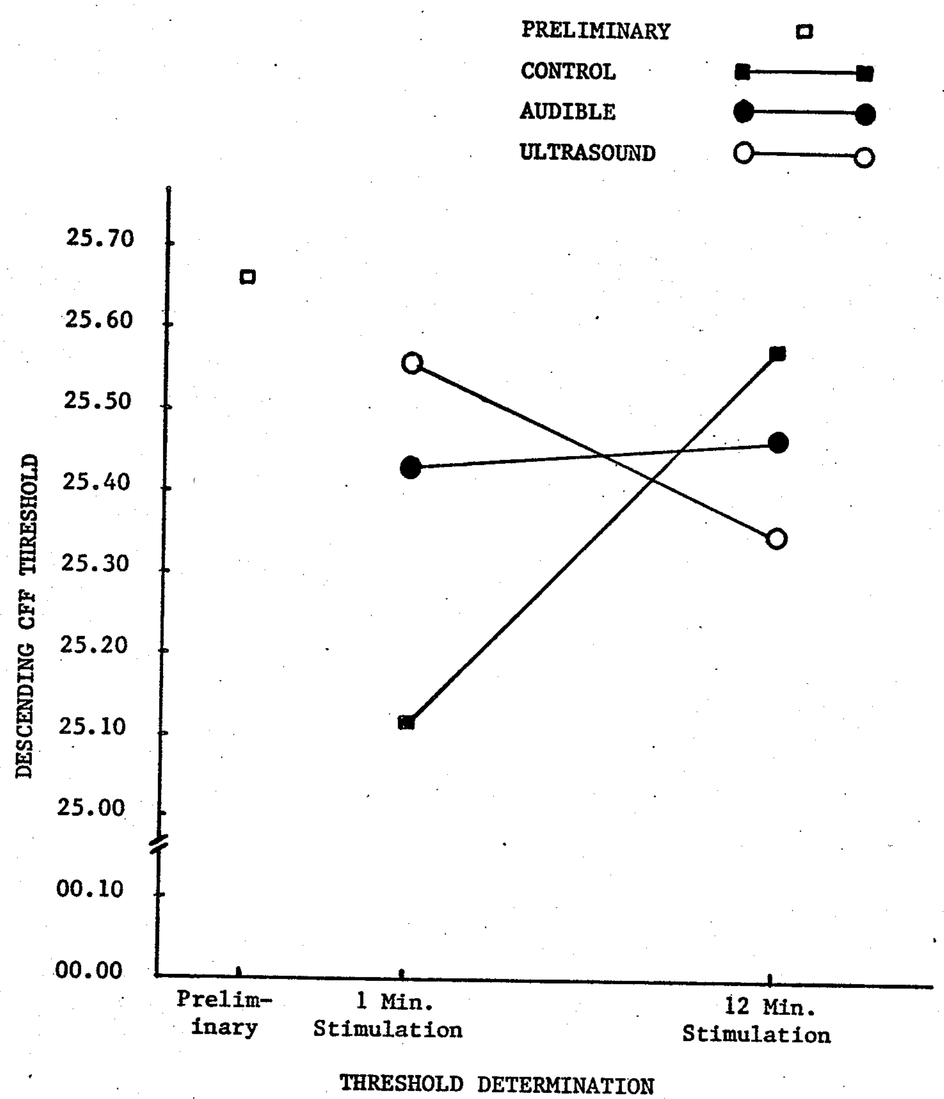

PRELIMINARY
CONTROL
AUDIBLE
ULTRASOUND
25.70
25.60
25.50
25.40
25.30
25.20
25.10
25.00
00.10
00.00
DESCENDING CFF THRESHOLD
Prelim-
inary
1 Min.
Stimulation
12 Min.
Stimulation
THRESHOLD DETERMINATION

TABLE 4

Analysis of Variance: CFF Threshold under Three Sound Conditions at Two Threshold Determination Times

Source	df	SS	MS	F
Order	5	58.27	11.65	0.37
Error 1	6	189.32	31.55	
Sound	2	0.16	0.08	0.27
Order X Sound	10	4.53	0.45	1.58
Error 2	12	3.45	0.29	
Time	1	0.17	0.17	1.00
Order X Time	5	0.35	0.07	0.41
Error 3	6	1.02	0.17	
Sound X Time	2	1.38	0.69	7.31*
Order X Sound X Time	10	1.88	0.19	2.00
Error 4	12	1.13	0.09	
Total	71	261.66		

*$p < .05$

were no significant effects at the 0.05 level, due to either order or

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Insert Tables 5 and 6 about here

---

sound condition found in either of these analyses. The possibility that there might be changes in the threshold between the two determination times was examined by comparing the "early" and "late" thresholds for each of the three sound conditions. In addition, a comparison was made between the preliminary threshold and the "early" threshold in the control condition because, as is shown in Figure 9, these means are the most widely separated. Bonferroni t-tests were used to make these comparisons and in order to control the error rate for this family of post hoc comparisons at the $p < .05$ level overall a significance level for each t-test of $p < .0125$ was selected (Keselman, 1974; Miller, 1966). The t-statistics calculated were as follows: control condition, early-late, $t = 2.35$, $df = 11$, $p < .0385$; audible sound, early-late, $t = .30$, df 11, $p < .230$; ultrasound, early-late, $t = 2.12$, $df = 11$, $p < .058$ and preliminary threshold - early control comparison, $t = 2.39$, $df = 11$, $p < .0359$. None of these tests were statistically significant at the $p < .0125$ level selected.

The data obtained on the four-alternative forced-choice task were examined in an analysis of variance considering the six possible orders of stimulus presentation and the three sound conditions. The results of this analysis are shown in Table 7. No significant effects at the $p < .05$ level were found due to order of stimulus presentation or sound condition. The mean number of correct responses (out of a pos-

TABLE 5

Simple Main Effects Analysis: CFF Threshold Under Three Sound Conditions After One Minute Stimulation

Source	df	SS	MS	F
Order	5	25.44	5.09	0.32
Error 1	6	95.42	15.90	
Sound	2	1.21	0.61	2.94
Order X Sound	10	3.68	0.37	1.79
Error 2	12	2.48	0.21	
Total	35	128.24		

TABLE 6

Simple Main Effects Analysis: CFF Threshold under Three Sound Conditions after Twelve Minutes Stimulation

Source	df	SS	MS	F
Order	5	33.17	6.63	0.42
Error 1	6	94.92	15.82	
Sound	2	0.32	0.16	0.91
Order X Sound	10	2.73	0.27	1.56
Error 2	12	2.10	0.18	
Total	35	133.24		

Insert Table 7 about here

---

possible 15) for each of the sound conditions was as follows: control 9.3, audible sound 9.9, and ultrasound 8.8.

TABLE 7

Analysis of Variance: Correct Responses on Forced-Choice Task for Three Sound Conditions

Source	df	SS	MS	F
Order	5	138.00	27.60	0.54
Error 1	6	307.33	51.22	
Sound	2	8.17	4.08	1.77
Order X Sound	10	22.83	2.28	0.99
Error 2	12	27.67	2.31	
Total	35	504.00		

DISCUSSION

The hypothesis that CFF threshold would be higher (indicating greater sensitivity) under conditions of accessory stimulation with either ultrasound or audible sound than in the control condition was not directly supported for either the one minute or the twelve minute threshold determination. The finding of a sound x time interaction was an interesting one, however. This interaction suggests that thresholds under the three sound conditions changed in different directions over the time period involved. Post hoc multiple comparisons did not clarify which of the conditions contributed to this interaction, however.

Although it is not possible to make any strong statements about which conditions contributed to the significant interaction, it might be interesting to speculate on which factors were involved in this interaction. For one thing, there seems to be an upward trend in threshold, indicating greater sensitivity, between the one minute and twelve minute threshold determinations during the control condition. Ten of twelve subjects showed a change in this direction. (Data for individual subjects are shown in Appendix D.) In the ultrasound condition, on the other hand, there seems to be a downward trend in threshold, indicating lower sensitivity, between the one minute and twelve minute determinations. (Ten of twelve subjects showed a change in this direction.) In addition, there seems to be a downward trend in threshold, indicating lower sensitivity, from the preliminary threshold determination to the first control condition determination, with a change in this direction being shown by ten of twelve subjects. (Note that only six subjects showed all three of these trends at once.) The upward trend during the control condition and the downward trend between the preliminary threshold and the early part of the control condition were unexpected and are rather difficult to explain. There seems to be two possible ways of interpreting these trends. One possible interpretation is that these were chance findings. The other possible interpretation is that the subjects did perform at a lower level in the initial part of the control period than at the other points (shown in Figure 9). The low performance levels in the initial part of the control condition may be attributed to experimental procedures intervening between the threshold determinations. One might speculate that subjects performed at a higher level before they received the last part of the instructions (indicating that they were to receive five cents for each correct response in the forced-choice task and that they would be repeating each of the procedures a number of times). It is also conceivable that performance in the control condition (which was initially relatively low) improved immediately after performing the forced-choice task in which the flickering stimulus was set at 2 Hz above the preliminary threshold. If one accepts the possibility that subjects performed at a lower level in the initial part of the control condition then it seems that there was a tendency for subjects to have higher thresholds, indicating greater sensitivity, in the early part of the accessory stimulation period. Clearly, this suggestion is only speculative at this point and the difference (if there was indeed a difference) was too small to be statistically significant. Considering the data from individual subjects, ten out of twelve showed a higher initial threshold (after one minute) in the audible sound condition than in the control condition and nine out of twelve showed a difference in this direction between the ultrasound and the control conditions. Thus, trends in the data support the hypothesis that accessory stimulation with ultrasound or audible sound improves performance, at least initially, on the CFF task. It would be necessary to replicate this finding, however, before one could be confident in it. In any case, the sound x time interaction does suggest that thresholds changed in different directions over the period between threshold determinations in the three sound conditions.

The second hypothesis, that subjects would make more correct responses on the forced-choice task under conditions of accessory stimulation, was not supported. Fifteen trials of the forced-choice task at just one flickering level may not have been sufficiently sensitive to detect possible sensory interaction effects. In addition, since it took approximately eight minutes to do this task any initial effect may have diminished over this time period.

Although a number of studies have demonstrated that audible sound can produce increases in performance on visual tasks, the present study provides only tentative evidence of sensory interaction with either audible sound or ultrasound. One possible factor contributing to this result is that sensory interaction effects are typically of small magnitude. Maier, Bevan and Behar (1961), for instance, found reliable changes in CFF to colored light sources under conditions of accessory stimulation, but the magnitude of these changes was small--only 2-4% of the base level. The measures used in this experiment may not have been sufficiently sensitive to detect a small sensory interaction effect at a statistically significant level. It may be possible to improve the sensitivity of the visual task in future experiments by having each subject do more trials of the task. Another factor contributing to this result is that accessory stimulation effects may be largest near the onset of the accessory stimulation and diminish as time goes on. The present study began the first threshold determination one minute after the onset of the accessory stimulus whereas Allen and Schwartz (1940) began at the offset of the stimulus after two minutes of accessory stimulation. In contrast, Maier, Bevan and Behar (1961) presented the accessory stimulus only while the visual stimulus was on--a case of discrete rather than continuous stimulation. Research has not yet clarified the time course of sensory interaction effects and this would be an interesting variable for future investigation. It would be particularly interesting to replicate the present study with some subjects performing the threshold task immediately after the onset of the accessory stimulus to investigate whether there would be clear differences between the three stimulus conditions. If it were found that sensory interaction effects diminish over time, the method of discrete or simultaneous presentation of the accessory stimulus used by Maier et al. would have the advantage of decreasing the likelihood that the effect was diminishing over the course of the experimental task. This method would allow for more trials of the visual task and might also allow for the use of signal detection methodology which has been shown to be more sensitive than traditional psychophysical methods.

It is not clear from the present study which factors were responsible for producing the sound x time interaction. This interaction may have been due to the specific forced-choice task intervening between the two threshold determinations. On the other hand, it may have been due to the subject's involvement in a task requiring concentration or even to the passage of time. A replication of this study varying the activity in this interval would be helpful in clarifying this finding.

In spite of the somewhat tentative findings in this experiment, the sensory interaction paradigm seems to be a promising one for investigating the phenomenon of subliminal perception, particularly with ultrasound as a stimulus. It may also be useful in future investigation of the range of intensities and frequencies over which ultrasound may act as a stimulus that can affect human behavior, an area which is, as of yet, unexplored.

Finally, it is interesting to note that this study differed from the previous studies in the series carried out at the University of Manitoba in that a more intense level of ultrasound stimulation (108 db at 34.9 kHz) was used with a longer duration than had been used previously (14 minutes). In response to the post-experimental questionnaire, none of the subjects described any high frequency sound or other sensations as accompanying the ultrasound stimulation. When asked about anything they found unpleasant or annoying about the experiment eight of the subjects mentioned factors such as the length of the experiment and the fact that their eyes tired from making so many visual judgments. None of the subjects, however, mentioned unpleasant feelings or sensations which might be attrub-utable to the ultrasound stimulation. This finding is in agreement with the suggestion in Experiment I that ultrasound is likely to produce non-auditory sensations such as heating or vibration only at very intense levels.

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Footnotes

[1]Kryter (1970) defines ultrasound as acoustical energy above the range of human hearing, although the term ultrasound is commonly applied to acoustical energy at frequencies greater than 20 kHz. The first definition will be the one used in this paper.

[2]All sound pressure levels (SPLs) mentioned in this report will be in db re: 0.0002 dyne/square cm. unless otherwise specified. In this study and most of those referred to the sound pressure level is measured in an acoustic free field at the position which is later to be occupied by the observer's head. This is referred to as the minumum audible field (MAF) technique and will be the technique which has been used unless otherwise specified.

[3]The phon is a unit of loudness. Equal loudness contours have been charted by having subjects compare the loudness of tones at different frequencies with standard tones at 1000 Hz. Thus, a tone judged to be equal in loudness to a 40 db tone at 1000 Hz is said to have a loudness of 40 phons and a tone judged to be equal in loudness to an 80 db tone at 1000 Hz is said to have a loudness of 80 phons. (See Thurlow, 1972, p. 246).

APPENDIX A

POST EXPERIMENTAL QUESTIONNAIRES

EXPERIMENT 1

I. Post Experimental Questionnaire for Group I (Sound)

Please answer the questions in order. Please do not go on to the next sheet until you have finished the previous one.

1. Did you find the task tiring? (circle response) Yes No

If YES, would it help to have:

a.) fewer trials Yes No

b.) the same number of trials presented faster Yes No

c.) more rest periods Yes No

d.) fewer rest periods Yes No

Any other comments or suggestions?

Did you find the task a difficult one? Yes No
If YES, please explain:

2. Was there anything in the situation which you found annoying, distracting, or unpleasant? Yes No
If YES, please explain:

N.B. If you find that you have already mentioned something that answers part of a question, just add what is necessary to answer the question completely.

3. Did you hear any sound which helped you decide what choice to make? Yes No

If YES, please describe the sound:

4. Did you notice any difference between the various blocks of trials? Yes No

If YES, please describe:

5. If you answered YES to question 3, what percentage of the time (excluding the last block of trials) did you use the sound in making your choice? (circle response)

0 10 20 30 40 50 60 70 80 90 100

6. Did you notice any other feelings or sensations? Yes No

If YES, please describe. Did you use these sensations to identify the correct interval and for what percentage of the trials (excluding the last block of trials)?

7. Did you use any other strategy or strategies in making your responses? Yes No

If YES, please describe this strategy (or strategies) including the approximate percentage of the time you used it (excluding the last block of trials).

8. Do you have normal vision and hearing? Yes No

If NO, please describe the problem:

9. Did you hear anything about this experiment before you participated in it?

Thank you for participating in this experiment. If you have any suggestions as to how the procedure could be improved please feel free to mention them below and on the reverse side.

II. Post Experimental Questionnaire for Group II (Sensations)

Please answer the questions in order. Please do not go on to the next sheet until you have finished the previous one.

1. Did you find the task tiring? (circle response) Yes No

   If YES, would it help to have:

   a.) fewer trials Yes No

   b.) the same number of trials presented faster Yes No

   c.) more rest periods Yes No

   d.) fewer rest periods Yes No

   Any other comments or suggestions?

   Did you find the task a difficult one? Yes No
   If YES, please explain:

2. Was there anything in the situation which you found annoying, distracting, or unpleasant? Yes No
   If YES, please explain:

N.B. If you find that you have already mentioned something that answers part of a question, just add what is necessary to answer the question completely.

3. Did you experience any sensations which helped you decide what choice to make? Yes No

If YES, please describe these sensations:

4. Did you notice any difference between the various blocks of trials? Yes No

If YES, please describe:

5. If you answered YES to question 3, what percentage of the time (excluding the last block of trials) did you use these sensations in making your choice? (circle response)

0 10 20 30 40 50 60 70 80 90 100

6. Did you notice any other feelings or sensations? Yes No

If YES, please describe. Did you use these sensations to identify the correct interval and for what percentage of the trials (excluding the last block of trials)?

7. Did you use any other strategy or strategies in making your responses? Yes No

If YES, please describe this strategy (or strategies) including the approximate percentage of the time you used it (excluding the last block of trials).

8. Do you have normal vision and hearing? Yes No

If NO, please describe the problem:

9. Did you hear anything about this experiment before you participated in it?

We have been having some trouble with our equipment producing noise (other than the white noise) during the trials. Did you notice any unusual noises or sounds during the experiment?

Yes No

If YES, please describe:

Thank you for participating in this experiment. If you have any suggestions as to how the procedure could be improved please feel free to mention them below and on the reverse side.

APPENDIX B

DATA FOR INDIVIDUAL SUBJECTS

EXPERIMENT 1

Group I (Sound)

Block	1		2		3		4	
Subject No.	Corr[a]	Conf[b]	Corr	Conf	Corr	Conf	Corr	Conf
1*	22	7	38	19	47	47	24	0
2	27	2	33	9	29	8	30	4
3	32	44	22	46	23	48	15	48
4	30	13	31	9	32	8	31	10
5	21	30	22	35	26	28	25	36
6	20	41	22	39	23	42	22	43
7	21	0	27	0	34	0	27	0
8	28	13	21	17	23	11	24	15
9	24	27	24	18	27	23	31	21
10	27	45	27	43	14	46	26	42

[a] correct responses

[b] confident responses

* This subject seems to have been detecting the stimulus with greater than chance accuracy.

Group II (Sensations)

Block	1		2		3		4	
Subject No.	Corr	Conf	Corr	Conf	Corr	Conf	Corr	Conf
1	24	15	22	16	17	7	25	7
2	28	1	28	0	24	0	20	0
3	23	4	30	5	29	12	35	8
4	24	22	26	21	28	23	19	9
5	35	16	32	20	38	24	26	7
6	24	4	26	0	24	0	23	0
7	21	0	32	0	29	0	28	0
8	26	33	22	20	22	8	24	16
9	23	30	28	20	23	17	23	18
10	26	21	21	25	22	36	18	20

APPENDIX C

POST EXPERIMENTAL QUESTIONNAIRE

EXPERIMENT 2

Post Experimental Questionnaire

1. What is your age?

2. Was there anything about the experiment which you found to be unpleasant or annoying?

3. How would you describe the acoustic or sound stimulation you received during the experiment?

4. Did you notice anything unusual about the experiment?

5. Did you use any response strategies in carrying out Procedure 2 - that is did you any other cues than the fact that the light was flickering or not flickering?

6. We have been having a little trouble with our equipment making noise during the experiment. Did you notice any unusual noises during the experiment?

7. Did you find the task tiring?

8. Could you suggest any ways to improve the experiment?

APPENDIX D

DATA FOR INDIVIDUAL SUBJECTS

EXPERIMENT 2

MEAN CFF SCORE

Condition		Control		Auditory		Ultrasound	
Subj. No.	Prelim.	1 Min.	12 Min.	1 Min.	12 Min.	1 Min.	12 Min.
1	27.27	26.93	27.68	27.71	27.76	27.44	27.01
2	28.58	27.08	27.07	27.48	26.97	26.18	25.71
3	28.80	27.68	28.66	27.85	27.82	28.10	27.91
4	25.00	24.54	25.07	25.08	25.56	25.59	25.04
5	27.54	27.02	27.43	26.95	27.56	27.23	27.35
6	25.05	24.75	24.05	24.52	24.10	24.05	23.91
7	23.76	25.14	25.58	25.16	24.91	25.58	25.38
8	22.98	22.04	22.78	22.56	22.24	21.49	22.14
9	24.04	23.37	23.40	23.38	23.92	24.08	24.06
10	26.11	26.35	28.44	27.99	27.76	27.79	27.31
11	24.18	23.38	23.49	23.02	22.71	24.74	24.23
12	24.61	23.20	23.36	23.40	24.28	24.49	24.19
	25.66	25.12	25.58	25.43	25.47	25.56	25.35

SCORE ON FORCED-CHOICE TASK

Condition	Control	Auditory	Ultrasound
Subject No.			
1	9	8	6
2	6	8	7
3	11	10	12
4	6	9	5
5	13	14	12
6	11	13	10
7	10	10	7
8	6	9	3
9	7	4	8
10	15	15	15
11	3	4	5
12	15	15	15
	9.33	9.92	8.75