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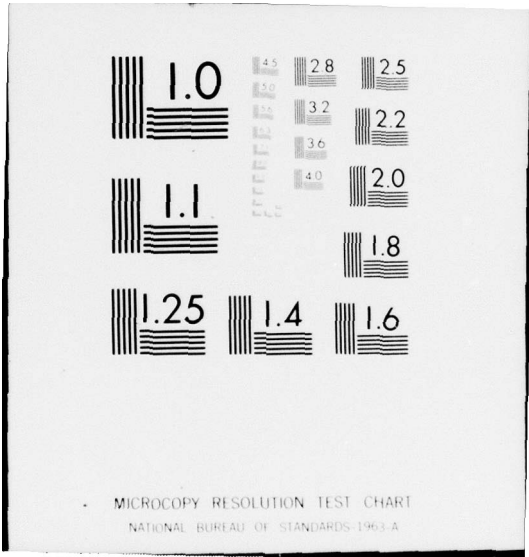
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Lynn C. Oatman
Jeffrey H. Lukas

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20. ABSTRACT (Continued)

potentials recorded from the lateral geniculate and visual cortex are suppressed in amplitude during attention to auditory stimulation. The results show that increased auditory attention had no significant arousal effects or changes in the amplitudes of the evoked responses recorded along the visual pathway.

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EXAMINATION OF AUDITORY ATTENTION AND VISUAL EVOKED POTENTIALS¹

INTRODUCTION

During the last few years, the U.S. Army Human Engineering Laboratory (6) has pointed out some of the problems related to the acquisition of auditory and visual information from auditory-visual displays. The project has led to explaining some of the sensory interactions that occur when auditory and visual information are presented simultaneously (8).

Oatman (9) proposed a model of auditory-visual interactions which describe the processes that might underlie *selective attention*. The model suggests that the central nervous system operates like a biological filter, attenuating information from one sensory system when it is necessary to pay attention to information coming in from another sensory system. It is necessary that an individual be able to filter out irrelevant information if he is to continue functioning in an integrated manner. When the central nervous system is overloaded, the human operator can become confused, disoriented and unable to perform efficiently. Therefore, it is important that one understand this filtering process, especially in the design of man-machine systems, where human operators must operate controls in response to information obtained through visual and auditory channels.

The present research continues the investigation of the physiological mechanisms responsible for the filtering process that controls sensory input to the central nervous system. Worden (14) discussed two neural physiological systems which could be responsible for filtering auditory information to the central nervous system. One system, a reticular feedback system, involves the regulation of auditory stimuli through middle-ear-muscle contractions. The other system, an extra-reticular feedback system, involves the regulation of auditory stimuli through the action of the olivo-cochlear bundle (OCB). It is believed that the OCB inhibits auditory stimuli to the central nervous system at the peripheral level (7). These two inhibitory systems are thought to be the physiological mechanisms responsible for the filtering process that controls auditory input to the central nervous system. Oatman (7, 10, 11) also showed that when an organism is attentive to meaningful visual information, non-meaningful (auditory) information is attenuated. Therefore, during attention to visual information, the central nervous system activates an inhibition system which attenuates auditory sensory inputs.

The question arises as to whether a selective central inhibitory mechanism operates to suppress afferent sensory impulses in the visual system. Does transmission through the visual pathways vary according to whether or not an organism is attentive to an auditory stimulus? Some evidence suggests that a selective central inhibitory mechanism might operate to suppress information in the visual pathways. Hernández-Peón, *et al.* (2) studied afferent transmission in the visual pathways of the cat during attentive behavior. These authors showed that flash-evoked potentials recorded from the visual cortex are depressed in amplitude during attentive behavior to either auditory, olfactory or somatic stimuli. Walley and Urschel (13) found similar results when they observed that photic-evoked potentials were reduced in amplitude following novel auditory stimulation. Kiyono (4) found a significant decrease in the lateral geniculate nucleus (t-wave)

¹In conducting the research described herein, the investigators adhered to the Guide for Laboratory Animal Facilities for Laboratory Animal Resources, National Academy of Sciences, National Research Council, Washington, DC.

responses to optic tract stimulation when the cat's vigilance level was shifted from a resting arousal to an attentive one by auditory "bow-wow" stimuli. More recently, Horn and Wiesenfeld (3) examined the lateral geniculate nucleus and visual cortex responsiveness to direct electrical stimulation of the optic tract in a vigilance task. They found that when the animals were vigilant to an auditory tone, the responsiveness of the lateral geniculate nucleus did not change; however, the responsiveness of the visual cortex to the thalamocortical input declined significantly as the length of the vigilance interval increased. Thus, transmission in the visual pathway does appear to be subject to central control and this control process is operative during arousal, novel stimulation and vigilance.

However, Walley and Urschel (13) presented conflicting evidence which showed that when responses were evoked by electrical stimulation of the optic tract, there was an increase in the amplitude of evoked responses in both the lateral geniculate and visual cortex during arousal induced by auditory stimulation. Similar results were obtained by Malcolm, *et al.* (5) who monitored transmission through the lateral geniculate nucleus of cats by measuring the response of the nucleus to electrical stimulation delivered to the optic tract. The shocks were delivered when the cat was relaxed and when it was alert. They found that the responsiveness of neurons in the lateral geniculate nucleus increased during arousal.

These discrepant findings and the consequent uncertainty concerning the occurrence of a central control inhibitory process that modifies the visual evoked potentials prompted the present investigation. The experiments reported here were designed to evaluate the amplitudes of the evoked potentials recorded from the lateral geniculate nucleus, visual cortex and auditory cortex as a function of increased electrical stimulation to the optic tract and attention to an auditory discrimination task.

METHODS

Subjects and Surgical Procedure

Five female cats, each weighing approximately 2.5 kg, had electrodes implanted in the optic tract (OT), lateral geniculate nucleus (LGN), visual cortex (VC) and auditory cortex (AC) under sodium pentobarbital anesthesia (.5 cc/kg at a concentration of 65 mg/cc). The OT and LGN electrodes were stereotaxically implanted through small holes bored in the skull according to coordinates in the stereotaxic atlas of Snider and Niemer (12). The OT electrodes were bipolar (David Koph, N.E. - 200 x 80 mm) with the poles 1 mm apart, each pole being 1 mm long and the insulation removed for 1/2 mm at the tip. The LGN electrodes were concentric and were made from .0254-cm Formvar-coated stainless steel wire which was inserted into 25-gauge hypodermic stock. These electrodes were insulated with vinyl coating (Stoner-Mudge) up to 1 mm from the tips, which were one 1 mm apart. Stainless-steel screw electrodes were implanted into the skull above the VC and AC as well as one over the frontal sinus to serve as an indifferent electrode and one at the posterior part of the skull as a ground for the animal. The electrodes were terminated in a 19-pin Amphenol connector attached to the skull with dental cement.

Visual and Acoustic Stimulation

The tests were made in a sound-attenuating chamber which had a response lever, a liquid food dipper mounted in the floor, and a speaker mounted in the top of the box.

The cat's task was to learn the auditory discrimination for food reinforcement. The cats, deprived of food until they were on a 24-hour deprivation schedule, learned the auditory discrimination task with Purina tuna mixed with water as food reinforcement. All cats received 75 trials or 50 food reinforcements each day. After testing, the cats were returned to their home cages and allowed 15 minutes free access to Purina cat chow.

The auditory stimuli, generated by conventional instrumentation (11), consisted of auditory tones presented successively for discrimination. The first tone was a 1.5 sec. 1,000 Hz at 80 dB SPL (re 0.0002 microbar) and the second tone was a 5 sec. 800 Hz at 80 dB SPL (re 0.0002 microbar). Sound pressure measurements were made in the sound-attenuating cubicle, where a calibrated 0.635-cm condenser microphone (Brüel and Kjaer type 4135) was placed perpendicular to and just in front of the speaker. Figure 1 shows a schematic diagram of the presentation of the stimuli. The 1,000 Hz tone was presented first, which served as a warning stimulus for the cat to attend to the stimuli. Then the 800 Hz tone was presented. The cat had to respond by pushing the response lever during the 800 Hz tone to receive food reward. If the cat responded between the onset of the 1,000 Hz tone and the onset of the 800 Hz tone, it received no reinforcement, and the onset of the next trial was delayed 15 seconds. In order to increase the cat's attentiveness and avoid temporal conditioning, the temporal interval (t_1) between the onset of the 1,000 Hz and the 800 Hz tones was varied randomly between 1 and 6 seconds. The intertrial interval was 15 seconds.

Visual stimuli consisted of 0.1 msec constant current pulses delivered directly to the optic tract by a Grass S44 Stimulator and associated photoelectric isolation unit (PSIU-6A). Visual stimuli were presented continuously at a rate of 1/sec during the presentation of the successive auditory discrimination task, but they were not synchronized with the onset of the visual stimuli. The intensity of the pulses were individually set for each animal to produce a threshold amplitude for the intracortical components of the visual evoked potential (peak 4-5). The remaining intensity values were determined by doubling the threshold values (X2), quadrupling the threshold values (X4), and maximum amplitude of the visual evoked potential (peak 4-5). The intensity of the direct electrical stimulation to the optic tract ranged from 16 microamps to 1,680 microamps.

Data Collection and Procedure

Simultaneous recordings were obtained from the lateral geniculate, visual cortex and auditory cortex to optic tract stimulation. Recordings were obtained from the unrestrained animals via a Microdot shielded cable connected to an electroencephalograph (Grass model 7) located outside the sound-attenuating cubicle. At the same time, the evoked potentials were recorded on a 14-channel FM tape recorder (Sangamo 4700). From the FM tape recorder, the evoked potentials were led into a signal averager (Nicolet, model NIC80) and written on an X-Y plotter (Hewlett-Packard 7035B).

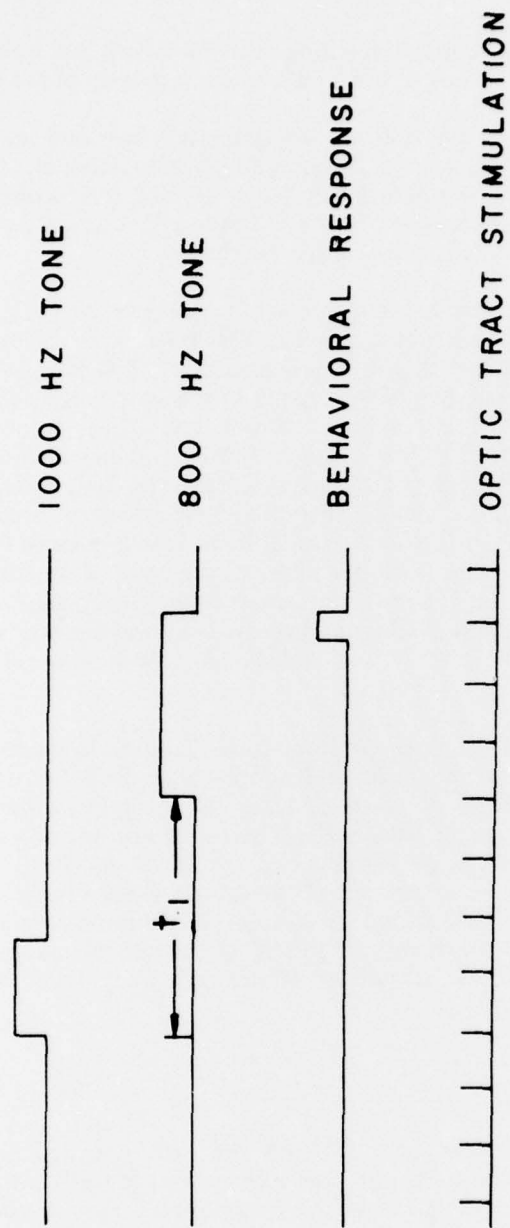


Figure 1. Schematic diagram of the presentation of the stimuli.

Four weeks after the operation, the cats were placed into the cubicle and the electrodes checked. Figure 2 shows an example of the evoked potentials from the LGN, VC and AC, and indicates how the peak-to-peak measurements were made for each electrode placement. Peak-to-peak measurements of the averaged data were measured by ruler to the nearest 5 microvolts in relation to a calibrated 1,000 Hz tone on the beginning of each tape.

After the electrodes were checked, the data were collected during recording sessions consisting of three different periods designed to effectively manipulate the attentive state of the subjects: (1) a pre-test control in which the cat was awake, relaxed, and non-attentive to any identifiable stimuli, (2) an experimental period during the presentation of the auditory discrimination stimuli when the cat was attentive, and (3) a post-test control similar to the pre-test control period. The evoked responses to optic tract stimuli were averaged for each of the three different attentive states; i.e., while the cat was relaxed, while attending the auditory discrimination, and when relaxed again. The evoked potentials, averaged while the cat was attentive to the auditory discrimination (Condition 2), included only those evoked responses presented during t_1 ; i.e., between the onset of the 1,000 Hz tone and the presentation of the 800 Hz tone (Figure 1). Evoked responses for each of the three attentive states were then collected at each of four different intensities (1 intensity per day) in an ascending order of presentation from threshold to maximum amplitude of the visual cortex evoked potential (peak 4-5).

RESULTS

The data consist of averages of 50 evoked potentials from three electrode locations: lateral geniculate (t-wave and r-wave), visual cortex and auditory cortex. The data plotted in Figures 3 through 6 are averages obtained from 300 measurements from each electrode placement recorded on each of four cats. One cat was discarded from the analysis since it stopped responding in the experimental condition. These figures show the average peak-to-peak amplitudes of the evoked responses plotted as a function of intensity for each of the three attentive states: pre-test-control group (cat non-attentive, relaxed but awake), experimental group (during auditory discrimination, cat very attentive), and post-test-control group (cat non-attentive, relaxed but awake).

Figure 3 shows that the mean peak-to-peak amplitudes of evoked potentials recorded from the visual cortex (peak 4-5) were of a smaller amplitude when the cats were very attentive to the auditory discrimination than when they were non-attentive. However, an analysis of variance (1) indicated no significant differences between the pre-test or post-test-control groups and the experimental group ($F = 1.04$, $df = 2/33$). The data (Figure 3) show large increases in the visual evoked potentials with increased optic tract stimulation and the analysis of variance showed that these increases were highly significant ($F = 195.49$, $df = 3/33$).

The mean peak-to-peak amplitudes of the t-wave (pre-synaptic) responses of the lateral geniculate as a function of the attentive state and increased intensity appear in Figure 4. Figure 4 shows that when the attention of the animals was focused on the visual discrimination, the mean peak-to-peak amplitude of the t-wave changed very little. An analysis of variance indicated no significant differences between the pre-test-control or the post-test-control groups and the experimental group ($F < 1$). However, the analysis of variance showed significant differences in the mean evoked potentials due to the increases in intensities ($F = 20.44$, $df = 3/22$).

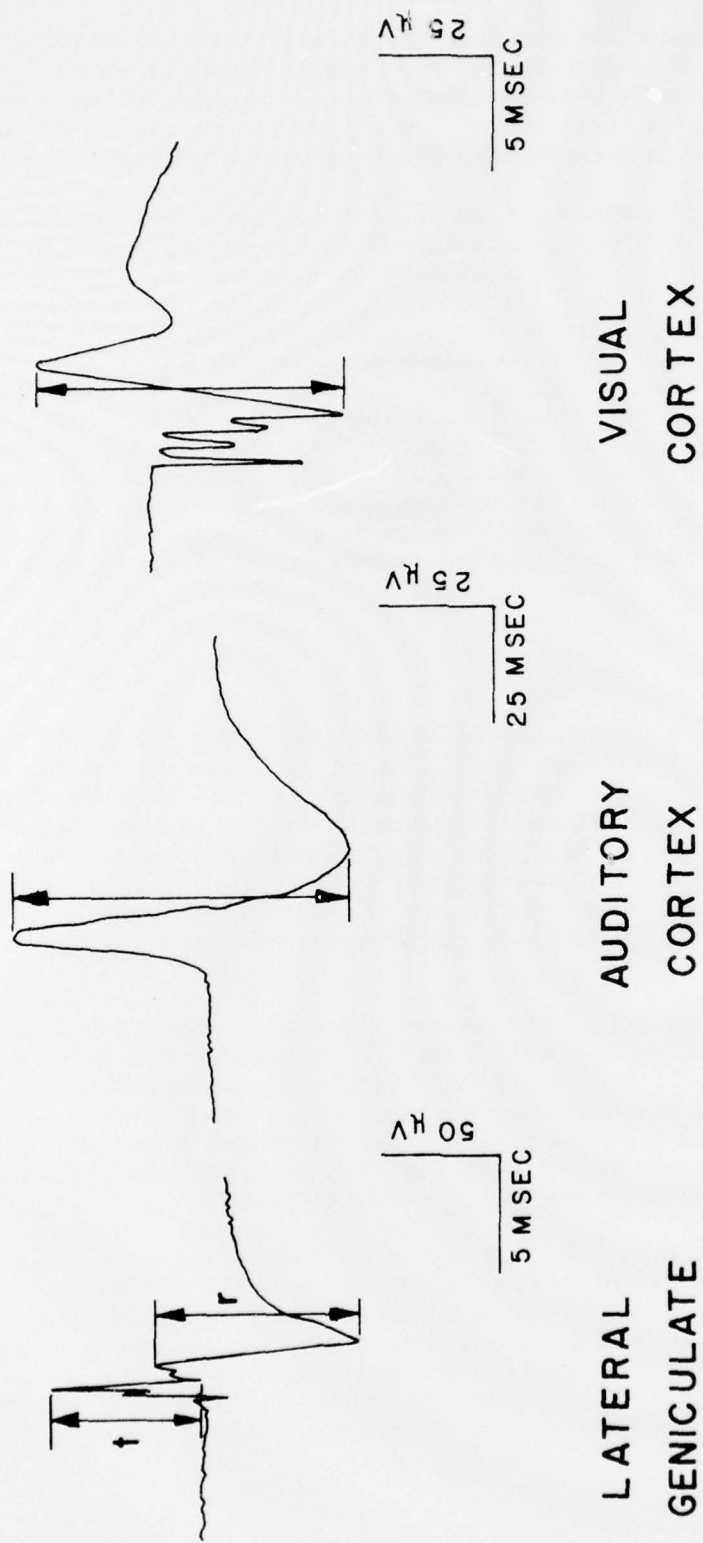
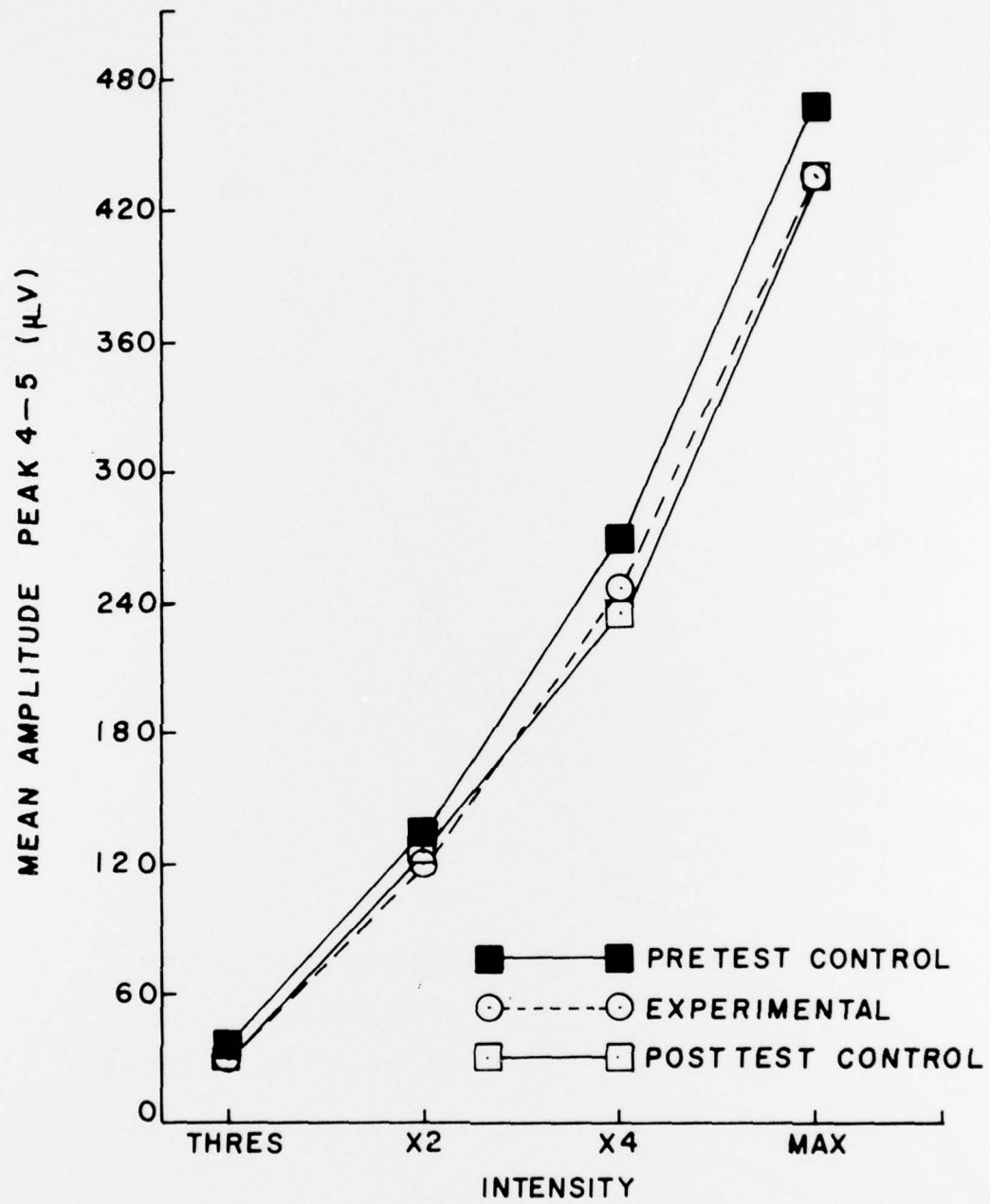
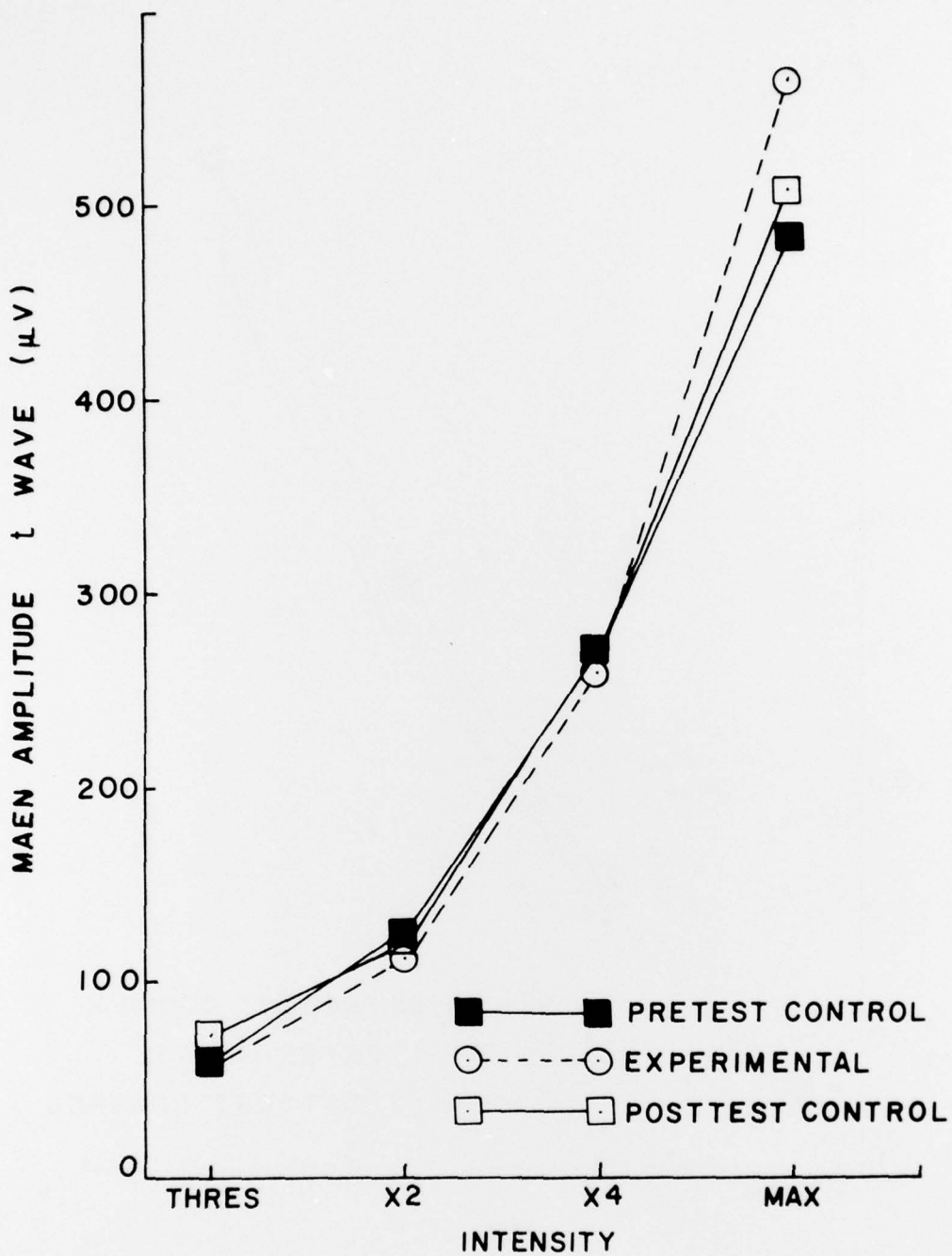


Figure 2. Averaged evoked responses recorded from the lateral geniculate nucleus, auditory cortex and visual cortex to direct stimulation of the optic tract. (The lateral geniculate wave form shows pre-synaptic responses [t-wave] and post-synaptic responses [r-wave]). The peak-to-peak conventions used to quantify the evoked potentials are noted.)



VISUAL CORTEX

Figure 3. The mean peak-to-peak amplitude of visual cortex evoked potentials in microvolts as a function of intensity and attentive state.



LATERAL GENICULATE NUCLEUS

Figure 4. The mean peak-to-peak amplitude of the t-wave (pre-synaptic) responses of the lateral geniculate nucleus in microvolts as a function of intensity and attentive state.

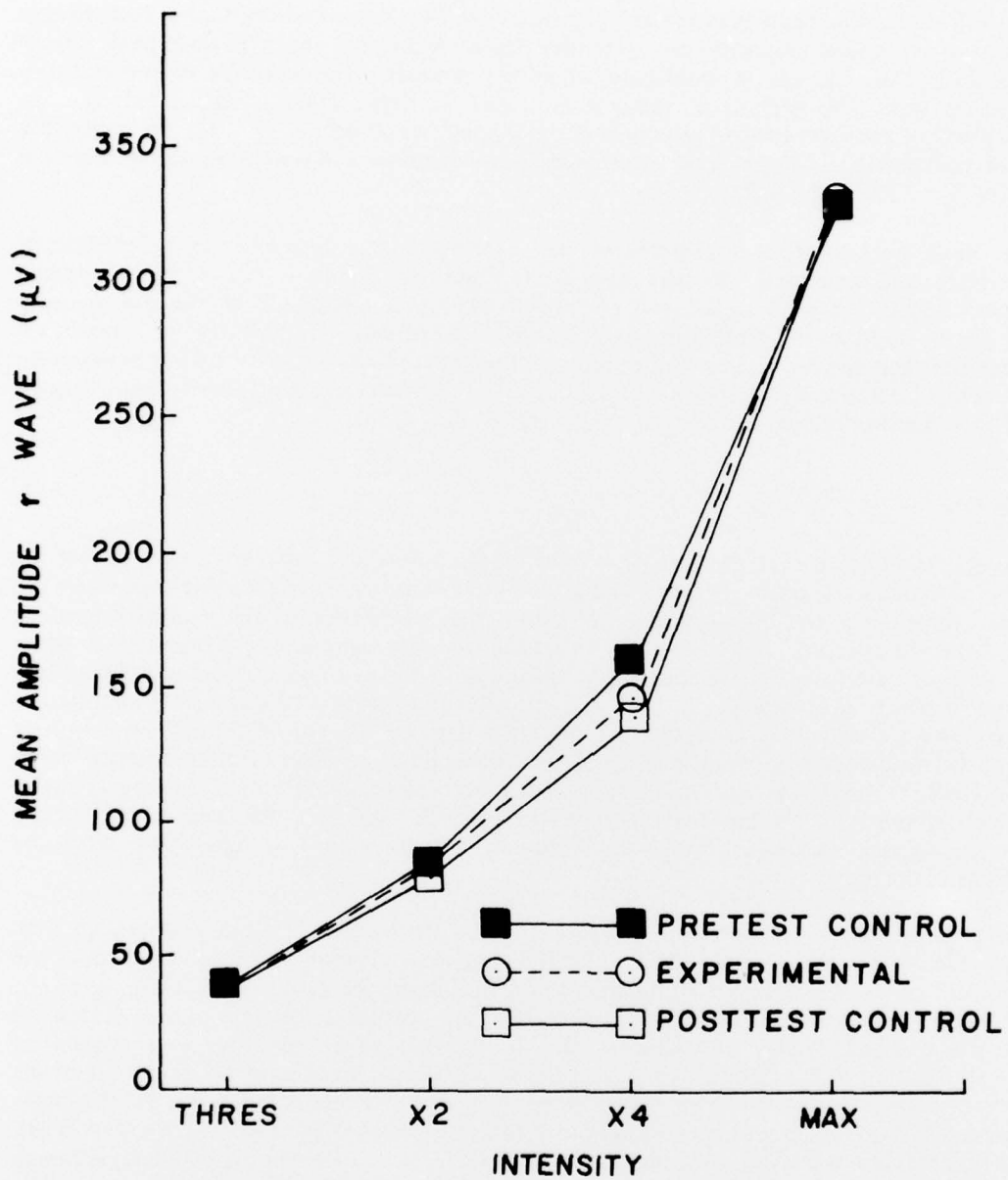
Figure 5 shows the mean peak-to-peak amplitudes of the r-wave (post-synaptic) responses as a function of increased intensity and attentive state. Again the mean peak-to-peak r-wave responses show little change in amplitude when the animals were attentive to the auditory discrimination task. The analysis of variance indicated no significant differences between the pre-test-control or post-test-control groups and the experimental group ($F < 1$). However, the analysis of variance showed significant differences in the mean evoked potentials due to increases in intensity ($F = 17.65$, $df = 3/22$).

The mean peak-to-peak amplitudes of the auditory cortex responses as a function of attentive state and increased intensity appear in Figure 6. Figure 6 shows that the mean peak-to-peak auditory cortex responses were not changed in amplitude when the animals were attentive to the auditory discrimination task. The analysis of variance indicated no significant differences between the pre-test-control group and the experimental group ($F < 1$) or between the post-test-control group and the experimental group ($F < 1$). However, significant differences were observed as a function of increased intensity ($F = 29.43$, $df = 3/33$).

DISCUSSION

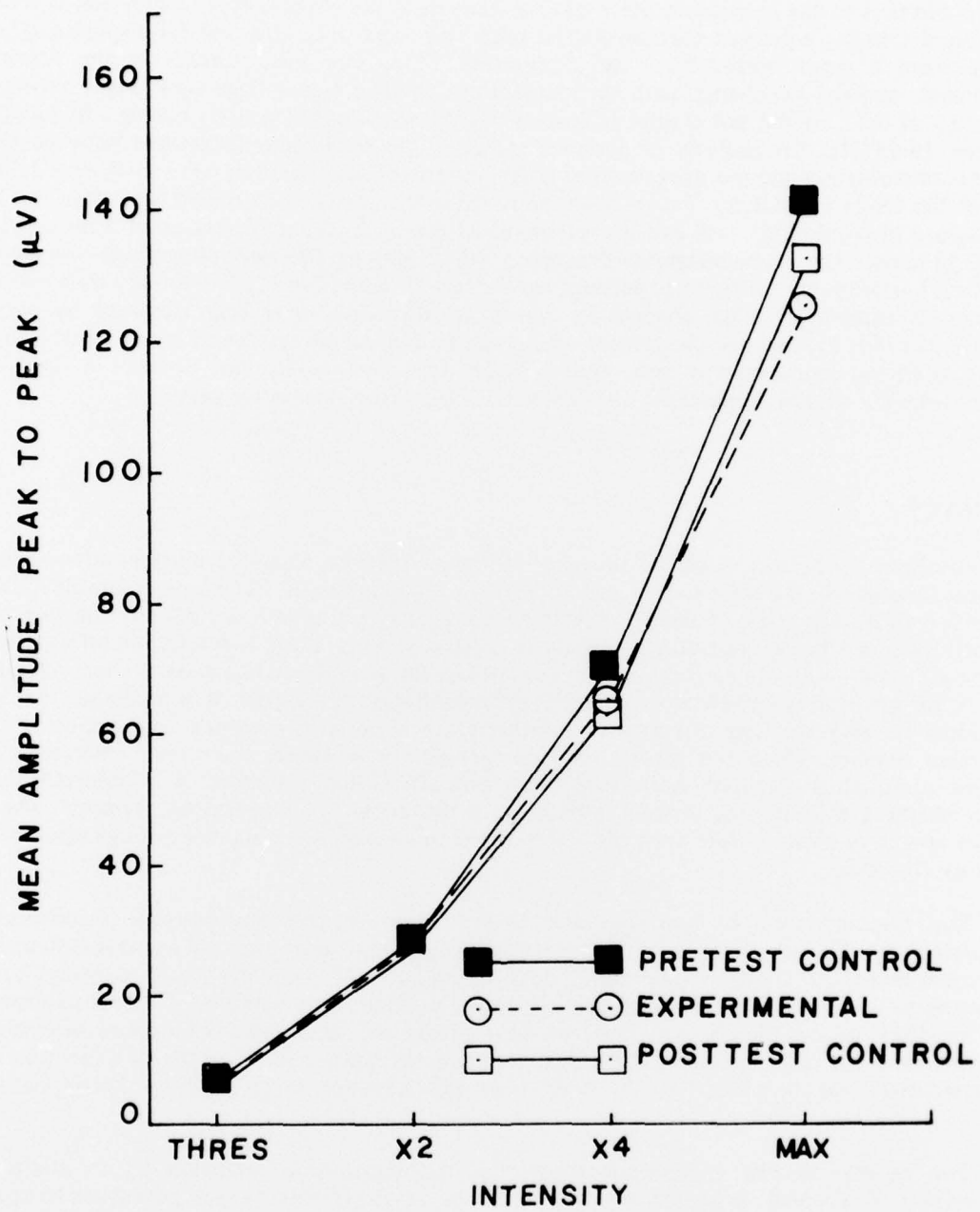
The results indicate that the attentive state of the animal did not significantly affect the amplitude of evoked responses recorded along the visual pathway. It is apparent that when the cats were attentive to the auditory discrimination, the amplitudes of the evoked potentials recorded from the AC, VC, and LGN (t- and r-waves) were not significantly different than when the cats were non-attentive. These data are consistent with the findings of Horn and Wiesenfeld (3), who also observed no changes in LGN responses (t- and r-waves) to optic tract stimulation when the cats were vigilant to an auditory tone. These data are also consistent with observations of Kiyono (4) who found no changes in LGN r-wave responses to optic tract stimulation when the cat's vigilance level was shifted from a resting arousal to an attentive one by auditory "bow-wow" stimuli. As for the LGN t-wave, there was a significant decrease in the evoked response during the auditory "bow-wow" stimuli, which is not in agreement with the observations in the present study.

The present observations are not in agreement with those of other authors (3, 13). Horn and Wiesenfeld (3) observed that when the cats were vigilant to an auditory tone, the responsiveness of the visual cortex to the thalamocortical input decreased significantly, while the present experiment showed no changes in the responsiveness of the visual cortex to thalamocortical input. Walley and Urschel (13) found that when responses were evoked by electrical stimulation of the optic chiasma, there was a significant increase in the amplitude of the visual cortex during arousal induced by auditory stimulation. These data are not in agreement with the present experiment and are contradictory to those obtained by Horn and Wiesenfeld (3). Our experiments do not provide an explanation of the differences between experiments, although we can speculate on the possible factors which may account for the observed differences. The results of the present experiment may be accounted for by the lack of control of the cats' attention in the experimental period. The cats demonstrated poor performance working for food reward in the experimental condition. The number of reinforcements obtained by the cats per total trials were 20 percent, 56 percent, 70 percent and 75 percent. The low number of reinforcements indicates that the cats were not very attentive to the auditory discrimination task and this could account for the observed results in this experiment.



LATERAL GENICULATE NUCLEUS

Figure 5. The mean peak-to-peak amplitude of the r-wave (post-synaptic) responses of the lateral geniculate nucleus in microvolts as a function of intensity and attentive state.



AUDITORY CORTEX

Figure 6. The mean peak-to-peak amplitude of the auditory cortex in microvolts as a function of intensity and attentive state.

In addition to the changes in the evoked potentials at the visual cortex, Walley and Urschel (13) found that the enhanced cortical evoked potentials were only observed following a sudden change from a synchronized to a desynchronized EEG. The EEG activity in the present experiment showed no change with increased attention. The high-voltage slow waves having a frequency of 6-12 Hz did not change to low-voltage desynchronized activity having a frequency between 18-25 Hz. An analysis of variance indicated no significant differences between the pre-test-control group and the experimental group for the 6-12 Hz activity ($F = 2.40$, $df = 2/11$) and for the 18-25 Hz activity ($F < 1$). It was apparent in the present experiment that attention to an auditory discrimination task had no systematic effect on EEG activity recorded from the AC or VC at either the high-voltage/low-frequency (6-12 Hz) or the low-voltage/high-frequency (18-25 Hz) activity. It is difficult to account for the lack of alteration in EEG activity obtained in the present experiment since changes in the electrical activity have been observed by other investigators (13, 3). Perhaps the present results can best be accounted for by a lack of attention to the auditory discrimination task; and this lack of attention did not produce a state of heightened EEG arousal as indicated by a low-voltage/high-frequency wave pattern.

SUMMARY

The human operator is placed in many military situations where he must simultaneously monitor a visual display and listen to one or more incoming messages. For example, the air traffic controller must keep track of several objects on his radar screen as well as communicate with his aircraft. Since the human operator's capacity to receive, process, store, and act upon information is limited, some kind of selective process occurs within the central nervous system where relevant sensory information is perceived while irrelevant information is rejected. It is necessary that an individual be able to filter out irrelevant information if he is to continue to function in an integrated manner. When the central nervous system is overloaded, the human operator can become confused, disoriented and unable to perform efficiently. Therefore, it is important that one understand this filtering process, especially in the design of man-machine systems, where human operators must operate controls and respond to information obtained through visual and auditory channels.

The present research continues the investigation of the physiological mechanisms responsible for the filtering process that controls sensory input to the central nervous system. In this experiment the question was raised: does transmission through the visual pathways vary according to whether or not an organism is attentive to an auditory stimulus? In order to answer this question an experiment was designed to evaluate the amplitudes of evoked potentials recorded from the lateral geniculate nucleus, visual cortex and auditory cortex as a function of increased electrical stimulation to the optic tract and attention to an auditory discrimination task.

The results of this experiment show that the increase in attention to an auditory discrimination task had no significant effects on the amplitudes of evoked potentials to optic tract stimulation recorded from the lateral geniculate nucleus (t- and r-waves), visual cortex, and auditory cortex. In addition, it was apparent in this study that attention did not result in a state of heightened arousal as indicated by EEG activity recorded from the visual cortex and the auditory cortex. Although the techniques used in this experiment did not result in changes in the evoked potentials or increased arousal through attention, perhaps alternative techniques could result in a change in attentive state and thus initiate the central inhibitory mechanisms that filter irrelevant sensory information.

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