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The slow wave of the cortical evoked response in man and the focus of attention

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THE "SLOW WAVE" OF THE CORTICAL EVOKED RESPONSE IN MAN AND THE FOCUS OF ATTENTION

by

Robert Jesse Cunitz

A Thesis

Presented to the Graduate Faculty

of Lehigh University

in Candidacy for the Degree of

Master of Science

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Abstract

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Two basic experimental conditions were used. Single clicks were presented successively in either a random left ear-right ear sequence or in an alternating left ear-right ear sequence. Electronically averaged cortical evoked responses were obtained separately for left and right ear clicks. Ten adult male subjects were used for both conditions. Fourteen additional adult male subjects were used in a partial replication of the original study.

The subjects demonstrated significantly greater evoked responses to the subjectively more important stimuli, i.e. the stimuli heard in the ear to which they were to attend, during the alternating stimulus conditions. Random stimulus conditions did not exhibit similar significant differ-

ences.

The following conclusions may be warranted on the basis of the findings:

(1) Subjects cannot selectively attend to only one ear at a time.

(2) Either general cortical occlusion or middle ear muscle contraction affect the size of the "slow wave." Both factors probably operate as the amount of the reduction appears to be greater than the reduction reported for the middle ear muscles alone.

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This thesis is accepted and approved in partial fulfillment of the requirements for the degree of Master of Science.

May 12, 1964
(date)

Josef Brozek
Professor in charge

Francis J. Wuest
Head of the Department

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R.J.C.

Lehigh University

May, 1964

Table of Contents

Figures

Tables

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Introduction

Hsiang-Tang Chang (1959) defines the evoked potential as "...the detectable electrical change of any part of the brain in response to deliberate stimulation of a peripheral sense organ, a sensory nerve, a point on the sensory pathway, or any related structure of the sensory system." Many investigators have shown the effects of attention and distraction upon the size of the evoked response. Research has been performed with animal and human subjects: distracting stimuli have been presented in both the same, as well as different, sense modalities as the evoked response producing stimuli.

An early experiment (Hernández-Peón, Scherer, Jouvet, 1955), using cats as subjects, showed that there was a reduction in the cochlear nucleus evoked potentials in response to clicks when a mouse in a glass jar was exposed to the view of the cats. Other investigators have shown a similar reduction in evoked potentials when two sensory pathways were stimulated; one with stimuli producing evoked responses and the other with a distracting stimulus (Hernández-Peón, Guzman-Flores, Alcarez, and Fernández-

Guardiola, 1956; Gershuni, Kozhevnikov, Maruseva, Avakyan, Radionova, Altman, and Sorko, 1960). The reduction in the evoked potentials was found as far out on the periphery as the first sensory synapses.

Palestini, Davidovich, and Hernández-Peón (1959) showed that potentials evoked by light flashes were reduced when a mouse in a jar was introduced in the field of vision of a cat. Similar results were found by Hernández-Peón (1960) using somatic stimuli (light electrical shock and nociceptive distracting shocks).

Hernández-Peón (1963) noted that "It is evident that sensory impulses are blocked at the lowest levels of the central sensory pathways when attention is focussed upon a stimulus of a different sensory modality. Furthermore, a selective blocking occurs within a given sensory pathway when attention is focussed upon another stimulus of the same modality." The process of selective attention is thought to be the result of the centrifugal influence of the brain stem reticular formation upon the sensory transmission pathways (Hernández-Peón, 1961).

Palestini et al. (1959) suggested that the attended stimulus is never blocked and may even be facilitated. Galambos, Sheatz, and Vernier (1956), using conditioning techniques, also showed a facilitation of the evoked response when the stimuli acquired significance. Gerken and Neff (1960) believed the enlarged evoked response to be due to sensitization and not to facilitation. Another possible explanation was presented by Jane, Smirnov, and Jasper (1962) who said that increased alertness facilitates and sharpens the cortical and geniculate evoked responses: "excessive non-specific activation causes decreased evoked potentials probably due to occlusive blockage and possibly with the participation of inhibitory processes." This approach takes into account the animals' general state of arousal.

Jouvet (1961) implanted electrodes in the occipital cortex of 12 patients. Using a flash rate of one per second, he recorded blocking of the visual evoked response with nociceptive, olfactory, and auditory distracting stimuli. Mental multiplication also reduced the response, but counting of the flashes enhanced it. Hernández-Peón and Donoso (1959) using a three-per-minute flash rate, with electrodes implanted in the occipital lobes, noted a reduction of the response under the following conditions: mental arithmetic, lively conversations, strong visual imagery, and a combination of hunger and emotional excitement.

Larsson (1960) and Garcia-Austt (1961) found a positive relationship between the significance of clicks to a subject and the evoked response to those clicks. The startle blink was also correlated with both variables. Garcia-Austt (1961) noted a reduction in the evoked response to flashes while the subject was observing a tone stimulus or doing mental calculations. Similar results were obtained by Van Hof, Van Hof-Van Drien, Mark, and Rietveld (1962) and Gershuni (1957). On the other hand, Davis (1963) found that "...attending to clicks or counting them made no gross alteration." Geisler (1960) also obtained negative results. However, he observed only the first 40 milliseconds of the evoked response whose short latency appeared to be highly resistant to change (Larsson, 1960).

A confirmatory study by Morlock (1963) at the Walter

Reed Laboratory used modern computer averaging techniques to carry out a systematic exploration of the attention continuum. A series of square-wave clicks, at a rate of one per 1.6 seconds, were presented to five subjects. The clicks were one millisecond long and approximately 60 db. above auditory threshold. Four tasks, scaled by the demand on the sensory attention of the subjects, were used: (1) a vigilance task in which the subjects were to detect slight changes in the amplitude of the clicks, (2) a task in which the subjects were to blank their minds to all thoughts, (3) counting without regard to the clicks, and (4) a mental addition task with self-generated numbers.

Analysis was made of the evoked response recorded from the vertex (C_Z) since this location gives the most reliable waveforms and the greatest amplitudes. The component of the evoked response, most sensitive to manipulation (Fig. 1), was the slow wave component, described by Davis, Davis, Loomis, Harvey, and Hobart, (1939) and Van Hof, et al. (1962), whose peak to peak latencies, from the time of the click, were 90-milliseconds negative to 180-milliseconds positive (Fig. 2 and Fig. 3). An earlier positive component (40-60-milliseconds), which was not seen in all subjects, did not vary between the four attention conditions.

Fig. 1

The slow-wave evoked response during

four tasks

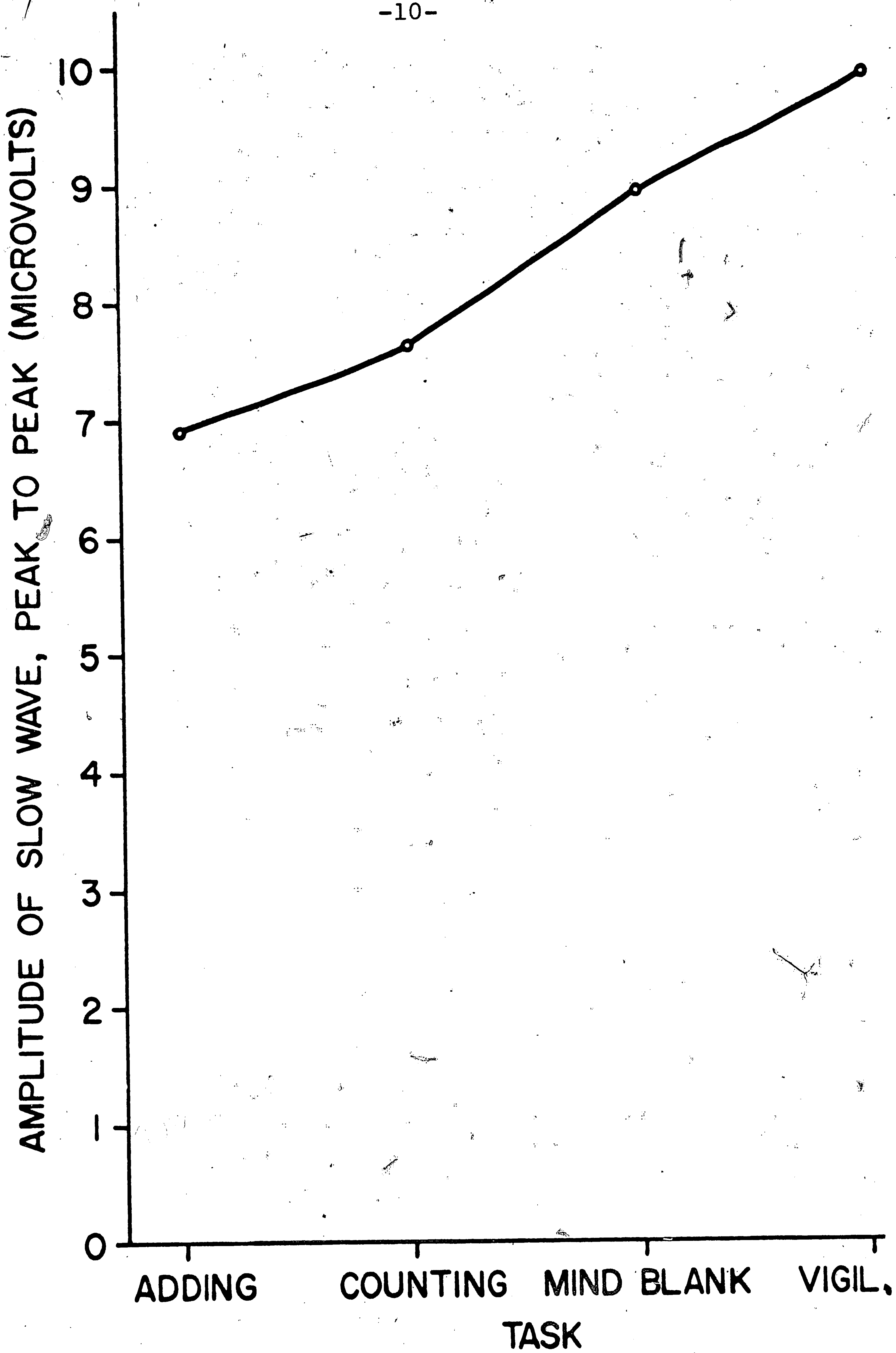

AMPLITUDE OF SLOW WAVE, PEAK TO PEAK (MICROVOLTS)
0
1
2
3
4
5
6
7
8
9
10
ADDING
COUNTING
MIND BLANK
VIGIL.
TASK

Fig. 2

Averaged evoked responses during

four tasks

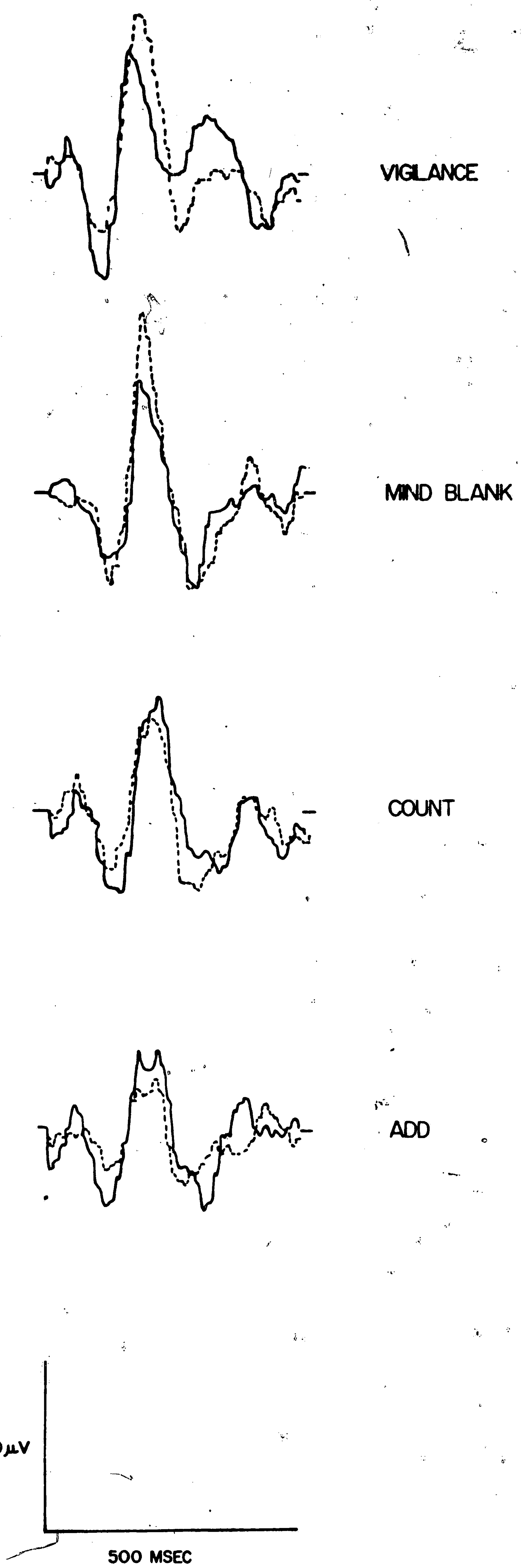
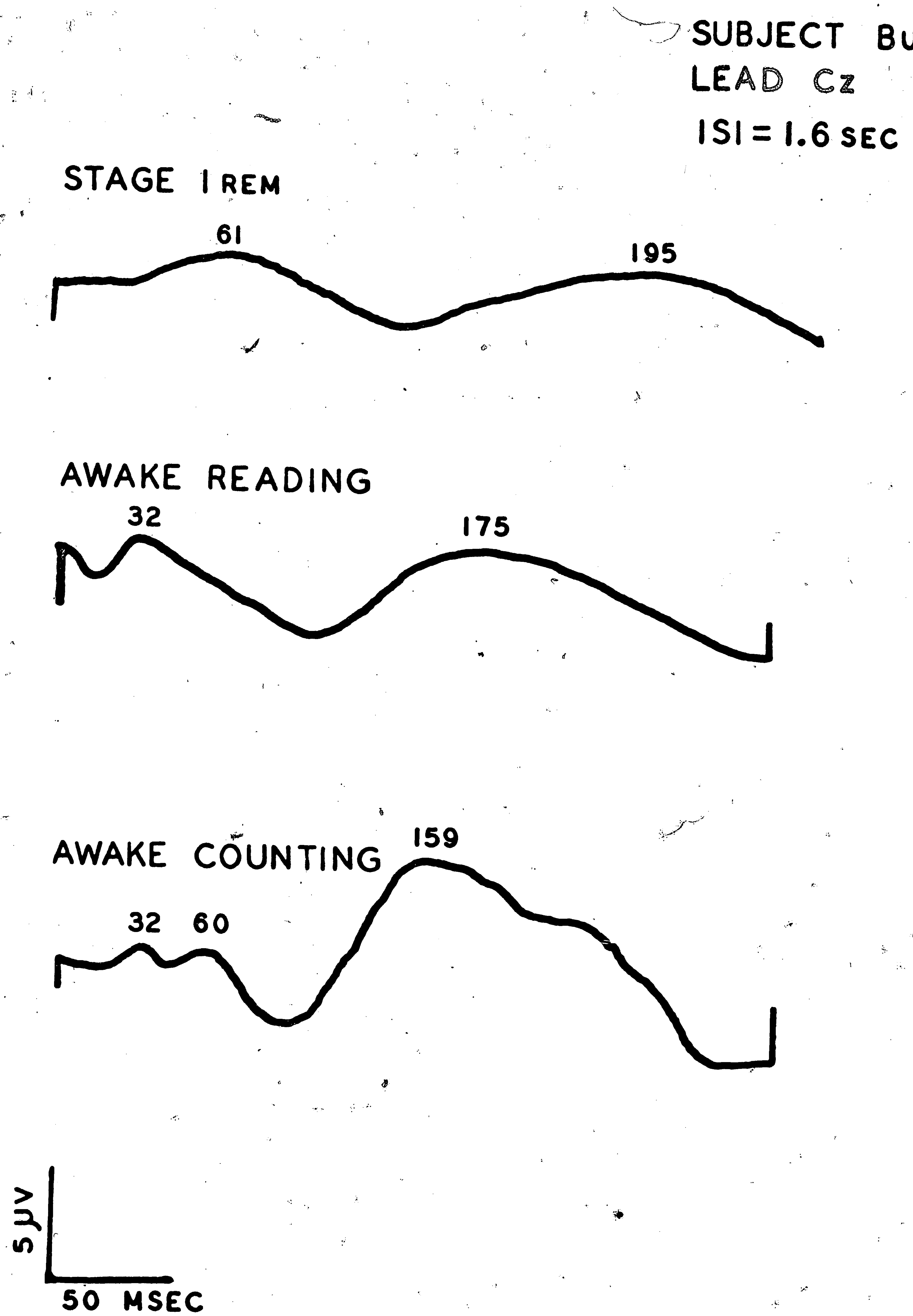

VIGILANCE
MIND BLANK
COUNT
ADD
10µV
500 MSEC

Fig. 3

Averaged evoked responses showing latencies

in three experimental conditions


SUBJECT Bu
LEAD Cz
ISI = 1.6 SEC
STAGE I REM
61
195
AWAKE READING
32
175
AWAKE COUNTING
159
32
60
5 μV
50 MSEC

The present study was designed to investigate the effect of directed aural attention upon the cortical evoked response in man, with special reference to the selective attention mechanism within the auditory modality. In this investigation the effects of arousal, noted by Jane, et al. (1962) were eliminated by presenting both relevant and irrelevant, i.e., attended and ignored, stimuli in such a manner that an increase in general arousal level would affect the size of the evoked responses to both types of stimuli. As an additional control of the importance of the stimuli, part of the subjects were given financial and "knowledge of results" incentives.

The subjects listened to clicks which were presented every 1.5-seconds. The clicks were presented, in either an alternating or a random sequence, to the left and right ears. The subjects were told to pay attention to the clicks on one side only and to ignore the clicks on the other side. Their task was to detect infrequent, slight amplitude decrements which occurred only in the attended ear.

The study was partially replicated to verify the results.

Procedures

A total of ten adult male college students were used as subjects. The subjects were divided randomly into two groups of five. One group was assigned to a "payoff" and "knowledge of results" condition and the other to a "no payoff" and "no knowledge of results".[1] Each subject was tested individually on two separate days, at least a week apart. Stimuli, in the form of brief (1-millisecond, square wave) clicks were presented in a random left-right sequence on the first day and in a regularly alternating left-right sequence on the second day. The clicks were approximately 60 decibels above auditory threshold and 1.5-seconds apart. Sixteen trials of 220 clicks each were presented to the subjects at each sitting. Either one, two, or three critical stimuli were randomly distributed throughout each 5.5-minute trial and presented only in the attended ear. There were two minutes between trials and a ten minute break after the eighth trial. With the ninth trial, "payoff" conditions for correct detections of the

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1. All subjects received $5.00 for each day's testing. The payoff group, however, won $.15 for each correct response and lost $.15 for each missed stimulus. A running balance was relayed to the subjects after each trial through his headphones.

critical stimuli were applied to the payoff group. Thus, during the first half of both days' testing, neither "pay-off" nor "knowledge of results" were present. During the second half of each day, five of the subjects were paid and told following each trial, how they had performed on the task.

Preliminary instructions (Appendix A) were given to the subjects by means of a tape recorder while the electrodes were being applied. The instructions were designed to familiarize the subjects with the procedure of electrode application and to insure that the subjects would be able to relax during the experiment. After the electrodes were applied, the subjects were led into the shielded recording cage and seated in a comfortably upholstered wooden arm chair. The electrodes were plugged into the jack box, a response microswitch placed in the subject's hand, and headphones placed over his ears. The lights in the cage were then turned off and the subjects left alone in the cage. All further instructions (Appendix A) were tape recorded and played back to the subjects, at the appropriate times, through the headphones.

The subjects were then instructed (Appendix A) to listen to all the clicks which could be heard and to mentally mark and make note of each one; i.e. to concentrate on each one. On the first day, clicks were presented in the two ears in a random left-right sequence, on the second day, in an alternating sequence (Appendix B).

At the outset, each day, two control trials were given, each consisting of 220 stimuli. There were a total of 110 clicks to each ear per trial. There were approximately two minutes between the two trials. These two trials were used to establish the initial level of the evoked response. (Appendix B).

After the two control trials, the subjects were instructed (Appendix A) to press a microswitch upon hearing a click which was slightly softer (minus 2 decibels) than the other clicks. They were told that a signal tone would appear to the ear in which the critical "soft"clicks would be presented and that critical clicks would appear only in the signalled ear. The subjects were advised that it was considerably easier to detect the critical clicks if they ignored the clicks in the opposite ear. A signal tone was presented in the left headphone. Then, 48 clicks were presented. Every fourth click was a "soft" click and the series of 48 clicks was repeated until the subjects were detecting each critical stimulus and pressing their response switch. The same process was repeated for the right ear. (Appendix B)

The main part of the experiment was then ready to start. A tone appeared for five seconds in the ear to which the subjects were to attend. There was a five second pause and then the clicks started. Two hundred and twenty clicks were presented, 110 to each ear, and 1.5 seconds apart (Appendix B).

Apparatus

A simple, convenient method of programming the presentation of the stimuli and of analyzing the evoked response was needed.

A Packard Bell PB 250 digital computer was used to punch a series of holes in a paper tape. The paper tape accommodated six channels (holes) of control information across its width. The holes in channel one were used to turn the signal tone on and off. Channels two and three directed the stimuli to the right or left ear, and the EEG to inputs 1 or 2, respectively, of the analyzing computer. The number of holes in channels two and three were equalized for the first 200 holes in a trial so as to produce an equal number (100) of right and left ear clicks in each trial. The last 20 holes were not equalized since the responses to these clicks were not analyzed; during this time and the subsequent two minutes (inter-trial-interval), the averaged evoked responses accumulated in the analyzing computer were written out. Channel four triggered the click. Channel five controlled the insertion of a voltage divider in the headphone circuit which produced the critical "soft" click. Channel six was not used.

During an experimental session, the master (paper) control tape was "read" and advanced every 0.5-seconds by a Friden SP-2 high speed tape reader. The presence or absence of holes in the paper tape determined whether a click was presented, the duration of the inter-stimulus interval, the presentation of the tone signal, the presentation of the critical stimuli, and the duration of the inter-trial interval.

The reader contacts on the Friden device were connected to a series of relays. Foringer Type 1552 Bistable Relays were used as the primary branches of the relay "control" tree. These in turn controlled the Foringer Type 1184 DPDT Relays which directly activated the stimulus presentation devices and the switching of the EEG.

The EEG was recorded monopolarly from vertex (C_Z) and mastoid electrodes. Two ground electrodes were used, one on the left and one on the right earlobe. Grass 1/4" EEG electrodes were used. Two cascaded (connected in series) Tektronix FM 122 DC amplifiers were used to bring the EEG signal level up to the two or three volts needed for computer analysis.

The subject's EEG was monitored with a Tektronix 360 Monitoring Oscilloscope. When a click was presented to the right ear, the output of the Tektronix amplifiers was directed into channel one of the analyzing computer. The EEG response to a left ear click was directed into channel two of the analyzing computer.

Stimulus presentation, the sweep of the analyzing computer, and the sweep of the monitoring oscilloscope were also controlled by holes in the paper tape. When a hole appeared in Channel 4, which represented a click, a Tektronix 162 Waveform Generator was triggered by a 45 volt negative pulse. The waveform generator put out a negative-sawtooth (0.5 seconds duration). This sawtooth triggered two Type 161 Tektronix Pulse Generators. One of the pulse generators supplied a one-millisecond negative pulse to synchronize the computer. The other pulse generator supplied a one-millisecond positive pulse which was amplified by an Eico HF-86 Audio Amplifier. The output of the amplifier (click) was shunted to the proper side of a pair of Live Tone Stereo Headphones by other relays.

The Friden Tape Reader was advanced every 0.5-second by a Grayson Stadler Model E1100H Interval Timer. The signal tone was generated by a Hewlett-Packard Model 202C Low Frequency Oscillator at 1000-cps.

The analyzing computer, which was used "on-line", was a CAT Model 400B. This is a Computer of Average Transients. It was set so as to sum and take averages of 200,0.5 second periods of the EEG immediately following a click. One hundred click responses were summed separately for each ear in a different channel of the CAT. Each 0.5-second period was divided into 200 equal parts. Each part was 2.5-milliseconds long. The EEG voltage, converted to digital form, for each separate time interval was stored in the memory of the CAT. The evoked response, which has a constant latency, was built up in the memory. The background EEG, being random in character, was averaged out. The result, the evoked responses, was plotted on paper using an X - Y plotter. It could also be observed on the oscilloscope screen of the CAT. The size and shape of the evoked responses was then measured directly from the X - Y plots. The CAT memory was "dumped" after each write out and the evoked responses from the next trial entered.

Foringer Type 1704 counters were used to record the number of responses, the number of critical stimuli, and the number of correct responses in each trial. A Wollensak magnetic tape recorder was used to give instructions to the subjects and to give the subjects knowledge of results.

Results

A typical example of the effects of instructions on the evoked response is presented in Fig. 4. The "averaged" electrical activity for 500-milliseconds after the click is shown. The measured difference between the first negative peak (90 milliseconds after the click) and the second positive peak (180 milliseconds after the click) "slow wave" was investigated. The click was presented at the start of the pictured response. The responses shown in Fig. 4 were those of a single subject to the alternating stimulus sequence. On the top line are the responses from a control trial in which the subject was instructed to attend to both the left and the right ear clicks. The peak to peak amplitudes of the "slow waves" are approximately equal. The responses on the middle line are the result of instructions, on the first experimental trial, to attend to the left-ear clicks and to ignore the right-ear clicks. The response to the ignored right ear stimuli is considerably smaller than that to the attended ear. In the second experimental trial the subject was told to attend to the clicks in his right ear (bottom line). Here, the ignored ear response has almost disappeared.

The number of trials on which the "slow wave" response to the attended ear stimuli was greater than the "slow wave" response to the ignored ear stimuli was determined for each subject. This number will be referred to as A>I. The results are summarized in Table I.

A χ^2 was calculated to test the difference between the number A>I, obtained during the random stimulus sequence trials, and 8, the theoretical chance number. A significant* χ^2 (23.00, df=10) was found. Instructions to attend to the left ear or the right ear during the random stimulus presentation sequence inhibited the evoked response to the stimuli heard in the attended ear.

A similar χ^2-test was performed for the alternating stimulus presentation sequence. In this case as well, a significant* χ^2 (47.75, df=10) resulted but the difference was in the opposite direction. Instructions to attend to

*.05 level of significance

Fig. 4

An example of the effects of instructions

on the size of the evoked response

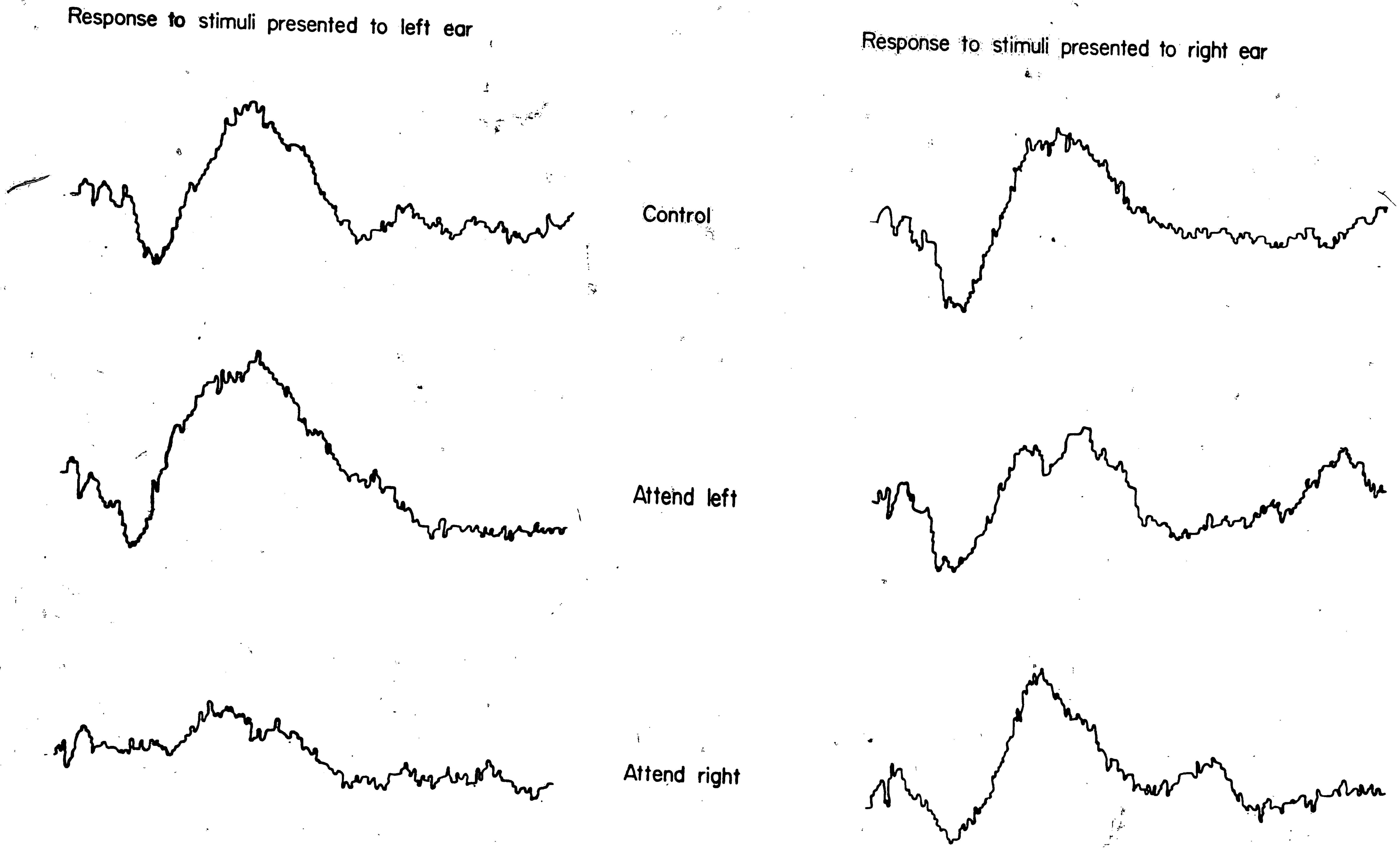

Response to stimuli presented to left ear
Response to stimuli presented to right ear
Control
Attend left
Attend right

Table I

The number of trials in which the attended-ear evoked response was greater than the ignored-ear evoked response.

(A>I)

Subject	Stimulus Sequence: Random	Alternating
1	8	10
2	5	12
3	6	16
4	5	12
5	4	9
6	8	16
7	4	11
8	2	11
9	9	6
10	7	6
Mean	5.8	10.9

the left or right ear during the alternating stimulus presentation sequence inhibited the evoked response to the stimulus heard in the ignored ear.

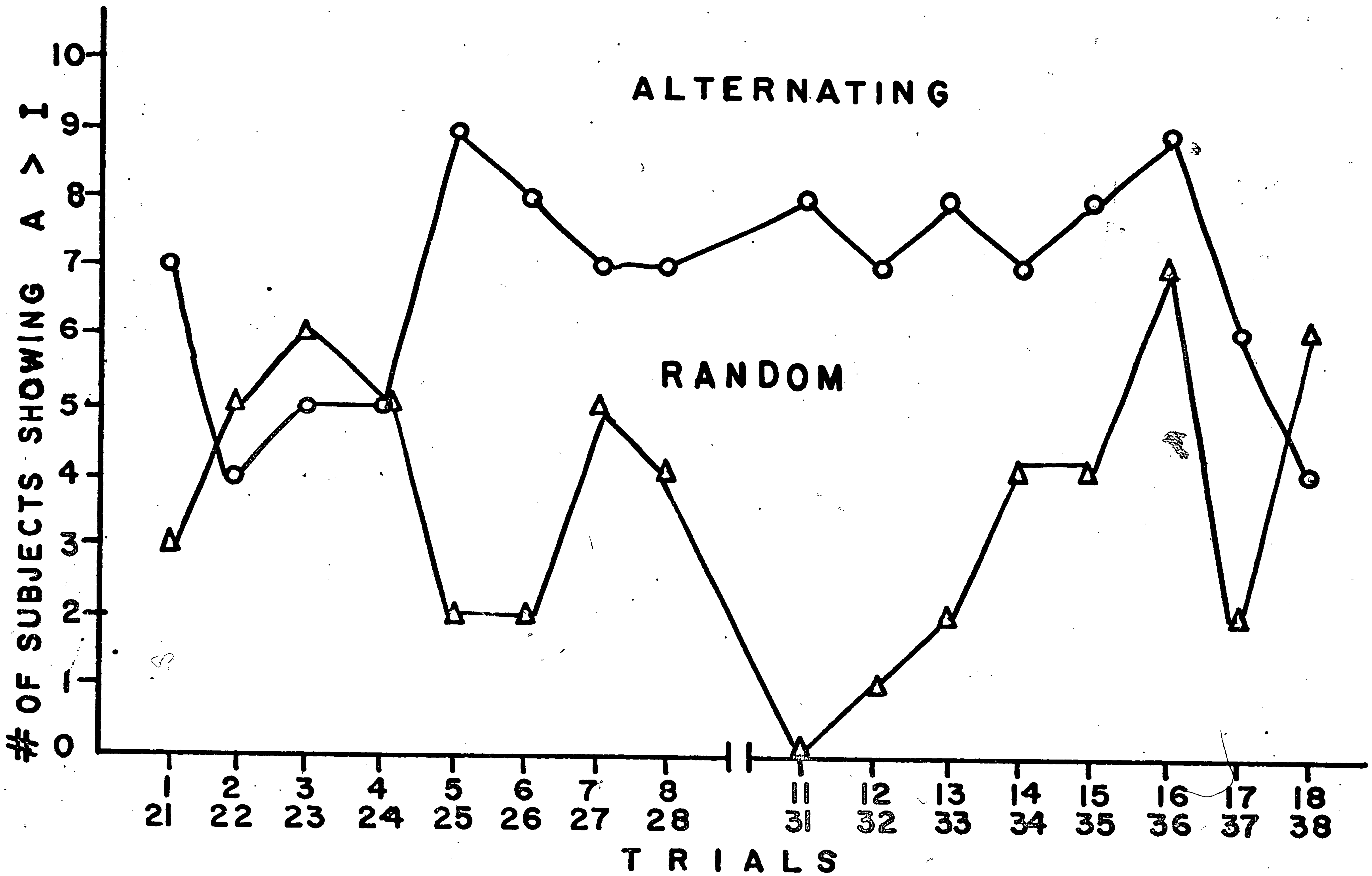
Eight of the ten subjects showed a shift in the inhibition of the stimulus from the attended to the ignored ear when the stimulus sequence changed from random to alternating.

Figure 5 is a graph of the number of subjects showing the attended-ear evoked response greater than the ignored-ear evoked response as a function of trial number and type of stimulus presentation. More subjects showed the effect of attention during the middle of the experimental session than during the beginning or the end of the session. The subjects seem to require several trials to learn the task and appear to fatigue at the end of the session. The latter idea is supported by the "recovery" of most subjects after the ten minute break at the end of the eighth trial.

Payoff and knowledge of results, used to increase the subject's motivation, had no significant effect on the number A>I during the last eight trials. The mean number A>I for the random stimulus presentation paid group was

Fig. 5

The number of subjects showing an attended-ear evoked response which is greater than the ignored-ear evoked response by trial and type of stimulus presentation sequence


ALTERNATING
RANDOM
OF SUBJECTS SHOWING A > I
10
9
8
7
6
5
4
3
2
1
0
1 21
2 22
3 23
4 24
5 25
6 26
7 27
8 28
11 31
12 32
13 33
14 34
15 35
16 36
17 37
18 38
TRIALS

2.6; the mean number A>I for the unpaid group was also 2.6. During the alternating stimulus sequence the mean number A>I of the paid group (4.6) was closer to the theoretical chance number (4) than was that of the unpaid group (6.8) (Table II).

A Spearman Rank Correlation Coefficient was used as a measure of the relationship between the following variables: (1) errors of ommission during the random stimulus sequence and the number A>I (rho=.05); (2) errors of ommission during the alternating stimulus sequence and the number A>I (rho=.49); (3) errors of commission during the random stimulus sequence and the number A>I (rho=.38); (4) errors of commission during the alternating stimulus sequence and the number A>I (rho=.54) None of the coefficients obtained were significantly different from 0.00*(Table P, McNemar).

Neither the number of errors of ommission nor the number of errors of commission changed significantly as a result of differences in the stimulus presentation sequence. The number of errors of ommission changed from 74 (random) to 77 (alternating). The number of errors of commission

*.05 level of significance

Table II

The number of trials in which the attended-ear evoked response was greater than the ignored-ear evoked response for the last eight trials during conditions of varied incentive. (A>I)

Not Paid	Stimulus Sequence	
Subject	Random	Alternating
1	2	6
2	3	8
3	2	8
4	3	6
5	3	6
Mean	2.6	6.8

Paid	Stimulus Sequence	
Subject	Random	Alternating
6	3	8
7	2	5
8	1	5
9	4	3
10	3	2
Mean	2.6	4.6

changed from 219 (random) to 137 (alternating). A sign-test was calculated for both changes; neither change was significant*.

The difference between the number of errors of ommission on the last eight trials for the paid group and for the unpaid group during either stimulus sequence was tested with the Mann-Whitney U test. Neither difference was significant* U=0.77 alternating; U=0.62 random. Payoff and knowledge of results had no significant* effect during the last eight trials on the number of errors of commission during the random and alternating stimulus sequence (U=0.55 and U=1.00 respectively).

There were two major reasons for performing a partial replication of the study. The first was a desire to verify the finding of a greater response from the ignored-ear clicks during the random stimulus sequence as this finding was contrary to those found in the literature. The second reason was to check on the possibility that the reversal in the size of the responses to the attended ear, when the stimulus sequence was changed from random to alternating, was the result of all subjects being exposed to the random

*.05 level of significance

conditions prior to exposure to the alternating conditions.

Accordingly, three additional subjects were tested on the random stimulus presentation sequence for two consecutive days. The proportion of the number of trials in which the attended-ear evoked response was greater than the ignored-ear evoked response divided by the number of trials (16) was computed for these subjects. One subject had a proportion A>I/16 equal to .75 on the first day and .44 on the second day. The change in the proportions from the first to the second testing is opposite to a hypothesis of the existence of significant sequential effects. The second subject exhibited almost no change in the proportion A>I/16 (.44 the first day and .50 the second day) and the third subject changed against the sequence hypothesis (.79 the first day, .67 the second day). Thus, the test results of the three additional subjects tend to negate the possibility of an experimental condition sequence effect.

A varying number of trials were presented to each of nine additional subjects using the random stimulus sequence presentation (Table III). These nine subjects were tested

Table III

The results of the partial replication; the number of trials each subject was presented and the number of trials in which the attended ear evoked response was larger than the ignored ear evoked response.

Alternating Stimulus Sequence

Subjects	Number of Trials	A>I
1	4	3
2	16	11
3	21	19
4	10	7
5	12	9
	63	49

A>I/63=.78

Random Stimulus Sequence

Subjects	Number of Trials	A>I
1	3	2
2	9	6
3	5	3
4	15	7
5	5	2
6	16	5
7	32	19
8	32	15
9	23	17
Total	140	76

A>I/140=.54

on a total of 140 trials of which 76 showed the attended ear evoked response to be larger. The proportion A>I/140 (.54) is very close to the theoretical chance proportion (.50). The data for these nine subjects, then do not confirm the results obtained from the ten original subjects during random stimulus conditions.

A varying number of trials (Table III) were presented to each of five subjects using the alternating stimulus sequence presentation. On 49 of the 63 trials the attended ear evoked response was greater than the ignored ear evoked response. The number A>I=49 was significantly* greater than the theoretical chance number A>I (31.5) (χ^2=21.61, df=5).

The partial replication yielded results which were in accord with the original experimental results for the alternating stimulus sequence presentation. However, repeating the random sequence of stimuli to a new group of subjects resulted in only chance differences between the attended and ignored stimulus evoked responses. There was, then, a failure to replicate, using the same equipment, laboratory, personnel, subject population, etc., the results of the original experiment during the random stimulus sequence

*.05 level of significance

presentation. To repeat, there was a successful replication of the results of the alternating stimulus sequence presentation condition of the original experiment.

Discussion and Summary

The present study was performed in order to determine whether there was a relationship between the amplitude of the "slow wave" of the cortical evoked response in man and the "focus of attention." The manipulation of the relevance, i.e. importance, of "click" stimuli demonstrated such a relationship.

Morlock (1963) indicated that the amplitude of the evoked potential is a positive function of the relevance of the stimuli to the subject's task. The evoked potential was at its lowest amplitude when the stimuli were totally irrelevant to the task. The amplitude of the evoked response increased as the stimuli became more relevant and was greatest when the task involved the stimuli themselves. Morlock's finding is consistent with the results of other investigators although the concept of relevance is not usually introduced by others. Thus, two stimuli which are physically identical could trigger different evoked responses if one were made relevant and the other not.

The results from the alternating presentation of stimuli in the present investigation seem to support the hypothesized effects of stimulus relevance. The results from the random presentation however, showed no changes due to directed attention. It is thought that the failure to replicate the findings under conditions of random presentation in the main study together with the fact that these results are contrary to the results of other investigators is an indication of no difference in the evoked response to attended and ignored stimuli when the stimuli are presented in a random sequence.

The available literature suggests three possible mechanisms which might have affected the present findings. The first of these involves Hernández-Peón's concept of selective attention within the auditory modality. He states that "...a selective blocking occurs within a given sensory pathway when attention is focussed upon another stimulus of the same modality." The evoked potential to attended-ear stimuli should have been higher during either sequence if selective blocking did operate within the auditory sense modality. However, a selective attention mechanism fails to account for similar ignored and attended-ear evoked responses in the "random" case.

The cortical evoked response is the result of the recruitment of cortical neurons in a massive rhythmic discharge triggered by short, high intensity stimulation. The second possible mechanism is a process which occurs when the cortical response is reduced by the involvement of cortical neurons in other activities. This is called occlusion. It is possible to account for the "alternating" and "random" sequence results with an occlusion explanation. The assumption is made that the subjects have "fallen into" the rhythm of one relevant stimulus every third second. During the period between relevant stimuli the subjects may direct their thoughts and attention to anything but the irrelevant stimulus. Thus, when the relevant attended-ear click, about which they must make a judgement, is presented, the subjects are "ready" for it and a massive cortical discharge occurs. When an irrelevant click occurs the discharge is reduced because (1) the subject pays no attention to the click or (2) he concentrates on other matters. As a consequence, the click input is cortically occluded.

The third mechanism may be one that was suggested by Galambos and Rupert (1959). These investigators reported that the musculature of the middle ear may contract and thus reduce the sensory input to the cortex by mechanical attenuation. In the present study, there would have had to have been a rhythmic contraction of the middle ear muscles synchronized with the irrelevant, ignored stimuli. Here, as in the occlusion hypothesis, every stimulus in the random trials may be relevant and the subjects must attend actively to each one. Such activity on the part of the subjects would result in equal "attended" and "ignored" evoked responses.

No significant relationship could be demonstrated between the size of the evoked response and performance on the vigilance task. This, however, does not mean that no such relationship exists. It may be possible by the examination of the single, and not the 100 averaged, responses just prior to an error of ommission or a correct response to show such a relationship.

It was also impossible to demonstrate the usual effects of increased motivation upon performance as well as upon the relative sizes of the evoked responses. This failure may have been due to any or all of the following reasons: (1) A small number, 5, of subjects were tested in both the "paid" and "nonpaid" groups; (2) the subjects were all advanced undergraduate or graduate students and appeared to be highly motivated and interested at the start; or (3) the difference between the standard and critical stimuli was too large thus making the task very easy.

Appendices

Appendix A

Tape recorded instructions to subject

During attachment of electrodes:

This experiment will take about two hours. We will now attach four electrodes to you. These will be used to record the small electric currents present on the top of your scalp. There is absolutely no chance of your receiving a shock of any kind from these electrodes and, at the end of the experiment, they will be easily removed.

There will be one electrode attached to the top of your head, one to each ear and one just below the left ear. When we are finished applying the electrodes, you will be brought into our special recording room and the electrode wires will be connected to our recording equipment. We will then place a pair of earphones on your head and the door will be shut and the lights turned out.

*We want you to sit as comfortably as possible and to relax with your eyes shut while in the recording room. After a few minutes, you will hear clicks through the headphones. We want you to pay attention to each one. Concentrate on hearing them. They will last for several minutes. There will be a break and they will start once more. Again, listen to each one carefully, concentrating on every click.

At the end of this second period of clicks, there will be a short pause. Then you will hear a series of clicks in only one ear. There will be three regular clicks, which are the same as the ones you've heard before, and then a special one. This special click will be slightly softer than the others. Whenever you hear this one, from that point on in the experiment, please press the button which you will be holding in your hand. The series will repeat several times so that you can become familiar with it. That is, three regular, one special, three regular, one special, and so on. The click will then be switched to the other ear. Again, the same series will be repeated. Press the button only when you hear the soft click and at no other time. It is very sensitive so do not rest your thumb on top of it or we will think that you are hearing the special click all the time. Press it just once for each special click and then take your thumb off it.

At this point, after having presented two sessions of clicks in which you paid attention to all the clicks, and a session in which you were shown what the special clicks sound like, we will get down to the main business of the experiment. (repeat twice to * and finish ----and give you further instructions then----)

After control and practice trials:

You will now hear clicks, one at a time in either ear. They will not be in any order so that you may hear, for example, four or five clicks in the left ear before hearing one in the right or several in the right before hearing one in the left. ≠

Before each session, you will hear a tone on just one side. The tone will signal you to listen for the special clicks on that side only. The special clicks will come only into the ear for which the tone has signalled you to listen. We want you to try to block out the sound of the clicks from the opposite ear. Do this by concentrating only on the clicks from the ear with the tone. Press the button only when you hear the special click. Please try to stay relaxed and to keep your eyes closed. There will

≠ This sentence was deleted when an alternating presentation was given.

be a break about an hour from now and you will be able to walk around a bit, smoke or have a drink of water.

(repeat once)

After break at end of eight trials:

We will now give you a chance to earn some extra money today. Please do not have any qualms about taking it as it is coming from the Army grant which is financing this experiment.

*You now have five dollars and may make more by pressing the button when you hear the special click. Each correct press will be worth fifteen cents. However, you will lose fifteen cents for each incorrect press of the button. The sessions will be the same as before the break. Try to stay relaxed with your eyes closed.

You will be able to improve your earnings by concentrating only on the ear which the tone has signalled you to listen to and by blotting out the clicks from the opposite ear.

We will tell you how you are doing after each session and how much money you have earned. If you feel that you do not want to go on and make some more money, you may leave now with the five dollars you have already earned.

(repeat once to *)

Appendix B

Table IV

Stimuli presentation sequence, Day 1, Random

I Control trial 1

Control trial 2

II Demonstration of critical stimuli: 48 left ear, 48 right ear, 12 critical stimuli in each ear every fourth click

III

Trial	Attend L (left) or R(right)	# of critical stimuli
1	L	1
2	R	3
3	R	3
4	R	3
5	L	2
6	L	2
7	R	3
8	L	2

<u>10 minute break</u>

Trial	Attend L (left) or R(right)	# of critical stimuli
11	L	1
12	R	2
13	L	2
14	R	1
15	R	2
16	R	3
17	L	2
18	L	3

Appendix B cont.

Table V

Stimuli presentation sequence, Day 2, Alternating

I Control trial 1

Control trial 2

II Demonstration of critical stimuli: 48 left ear, 48 right ear, 12 critical stimuli in each ear every fourth click

III

Trial	Attend L (left) or R (right)	# of critical stimuli
21	L	1
22	R	3
23	R	3
24	R	3
25	L	2
26	L	2
27	R	3
28	L	2

10 minute break

Trial	Attend L (left) or R (right)	# of critical stimuli
31	L	1
32	R	2
33	L	2
34	R	1
35	R	2
36	R	3
37	L	2
38	L	3

Appendix C

Table VI

Summary of Data: Random Stimulus Presentation Sequence

An attended-ear response greater than an ignored-ear response is designated by "A". An ignored-ear response greater than an attended-ear response is denoted by "I". No difference in the responses is denoted by "O". Subjects 1,2,3,4, and 5 were not paid or given knowledge of results. Subjects 6, 7, 8, 9, and 10 were paid and given knowledge of results.

Trials

Subjects	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	#A	#I	prop. A>I/16
1	A	A	A	A	I	I	A	A	I	I	I	I	A	A	I	I	8	8	.50
2	I	I	I	I	I	I	A	A	I	I	I	I	A	A	I	A	5	11	.31
3	A	A	A	A	I	I	O	I	I	I	I	A	I	A	I	I	6	9	.38
4	A	I	I	A	I	I	I	I	I	I	A	I	I	I	A	A	5	11	.31
5	I	I	I	I	I	A	I	I	I	I	I	A	A	I	I	A	4	12	.25
#A	3	2	2	3	0	1	2	2	0	0	1	2	3	3	1	3	28		.35
6	I	A	A	A	I	I	A	A	I	I	I	A	I	A	I	A	8	8	.50
7	I	I	A	I	I	I	I	A	I	I	I	I	I	I	A	A	4	12	.25
8	I	I	I	I	I	I	A	I	I	I	I	I	I	A	I	I	2	14	.12
9	I	A	A	A	A	A	I	I	I	A	A	I	A	A	I	I	9	7	.56
10	I	A	A	I	A	I	A	I	O	I	I	A	I	A	I	A	7	8	.44
#A	0	3	4	2	2	1	3	2	0	1	1	2	1	4	1	3	30		.35
Total #A	3	5	6	5	2	2	5	4	0	1	2	4	4	7	2	6	58		.36

Table VII

Summary of Data: Alternating Stimulus Presentation Sequence

An attended-ear response greater than ignored-ear response is designated by "A". An ignored-ear response greater than an attended-ear response is denoted by "I". No difference in the responses is denoted by "O". Subjects 1,2,3,4, and 5 were not paid or given knowledge of results. Subjects 6,7,8,9, and 10 were paid and given knowledge of results.

Trials

Subjects	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	#A	#I	prop. A>I/16
1	I	A	I	I	A	A	I	A	A	A	A	A	A	A	I	O	10	5	.67
2	I	A	I	I	A	A	A	I	A	A	A	A	A	A	A	A	12	4	.75
3	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	16	0	1.00
4	A	I	A	I	A	A	A	A	A	I	I	A	A	A	A	A	12	4	.75
5	A	I	A	O	I	I	I	A	A	I	A	A	A	A	A	I	9	6	.56
#A	3	3	3	1	4	4	3	4	5	3	4	5	5	5	4	3	59		.75
6	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	16	0	1.00
7	A	I	A	I	A	A	A	A	A	A	A	I	A	A	I	I	11	5	.69
8	A	I	I	A	A	A	A	A	A	A	A	A	I	A	I	I	11	5	.69
9	I	I	I	A	A	A	I	I	I	A	I	I	I	A	A	I	6	10	.38
10	A	I	I	A	A	I	A	I	I	I	A	I	A	I	I	I	6	10	.38
#A	4	1	2	4	5	4	4	3	3	4	4	2	3	4	2	1	50		.63
Total #A	7	4	5	5	9	8	7	7	8	7	8	7	8	9	6	4	109		.69

Table VIII

Summary of Data: Random Stimulus Presentation Sequence;
The Number of Errors of Ommission (eo)

Subjects 1,2,3,4, and 5 were not paid or given knowledge of results. Subjects 6,7,8,9, and 10 were paid and given knowledge of results.

Trials

Subjects	1	2	3	4	5	6	7	8	#eo	9	10	11	12	13	14	15	16	#eo	total eo
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	1	1	1	0	1	0	0	5	0	2	1	0	0	0	0	1	4	9
3	1	1	1	0	2	1	2	1	9	0	1	0	1	1	0	0	0	3	12
4	0	0	0	1	0	0	1	1	3	0	1	1	1	1	2	2	0	8	11
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1
#eo	3	2	2	2	2	2	3	2	18	0	4	2	2	2	3	2	1	16	34
6	1	0	0	0	0	1	0	2	4	0	0	0	0	0	0	1	1	2	6
7	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1
8	1	3	2	0	1	0	0	1	8	0	0	1	1	0	0	0	0	2	10
9	0	0	0	1	2	1	3	0	7	0	1	0	1	0	1	0	1	4	11
10	1	3	3	3	1	1	0	0	12	0	0	0	0	0	0	0	0	0	12
#eo	3	6	5	4	4	3	3	3	31	1	1	1	2	0	1	1	2	9	40
TOTAL #eo	6	8	7	6	6	5	6	5	49	1	5	3	4	2	4	3	3	25	74

Table IX

Summary of Data: Random Stimulus Presentation Sequence;
The Number of Errors of Commission (ec)

Subjects 1,2,3,4, and 5 were not paid or given knowledge of results. Subjects 6,7,8,9, and 10 were paid and given knowledge of results.

Trials

Subjects	1	2	3	4	5	6	7	8	#ec	9	10	11	12	13	14	15	16	#ec	total ec
1	7	4	2	4	4	5	3	1	30	2	2	1	3	1	1	1	3	14	44
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1
3	1	6	6	1	1	1	5	2	23	3	2	0	2	1	0	0	2	10	33
4	5	11	9	4	3	1	2	4	39	3	1	1	1	1	1	1	0	9	48
5	1	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0	0	2	3
#ec	14	21	17	9	8	7	10	7	93	8	5	2	6	3	4	3	5	36	129
6	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
7	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
8	1	1	0	2	7	4	4	6	25	1	0	0	2	0	1	0	0	4	29
9	8	1	3	2	8	2	0	3	27	6	2	4	3	3	0	2	1	21	48
10	0	2	0	0	2	0	1	0	5	2	0	1	0	0	1	2	0	6	11
#ec	9	5	4	4	17	6	5	9	59	9	2	5	5	3	2	4	1	31	90
Total ec	23	26	21	13	25	13	15	16	152	17	7	7	11	6	6	7	6	67	219

Table X

Summary of Data: Alternating Stimulus Presentation Sequence;
The Number of Errors of Ommission (eo)

Subjects 1,2,3,4, and 5 were not paid or given knowledge of results. Subjects 6,7,8,9, and 10 were paid and given knowledge of results.

Trials

Subjects	1	2	3	4	5	6	7	8	#eo	9	10	11	12	13	14	15	16	#eo	total eo
1	0	2	1	0	0	0	2	0	5	0	0	0	0	0	1	1	1	3	8
2	0	1	1	0	0	0	0	1	3	0	1	2	1	1	2	1	1	9	12
3	0	1	1	3	2	0	0	1	8	0	0	1	0	0	0	0	0	1	9
4	0	1	0	1	0	1	1	0	4	0	0	1	0	0	0	0	0	1	5
5	0	0	0	2	0	0	0	0	2	0	0	0	0	2	2	0	0	4	6
#eo	0	5	3	6	2	1	3	2	22	0	1	4	1	3	5	2	2	18	40
6	0	0	1	1	1	2	0	2	7	0	0	0	0	0	2	0	1	3	10
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	1	1	0	0	1	1	0	4	0	0	0	0	0	0	0	0	0	4
9	0	2	1	0	0	1	0	0	4	0	1	0	0	1	2	0	1	5	9
10	0	2	2	2	0	1	1	1	9	0	0	0	0	0	3	1	1	5	14
#eo	0	5	5	3	1	5	2	3	24	0	1	0	0	1	7	1	3	13	37
Total eo	0	10	8	9	3	6	5	5	46	0	2	4	1	4	12	3	5	31	77

Table XI

Summary of data: Alternating Stimulus Presentation Sequence; The Number of Errors of Commission (ec)

Subjects 1,2,3,4, and 5 were not paid or given knowledge of results. Subjects 6,7,8,9, and 10 were paid and given knowledge of results.

Trials

Subject	1	2	3	4	5	6	7	8	#ec	9	10	11	12	13	14	15	16	#ec	total ec
1	2	1	0	1	3	2	0	2	11	0	0	3	0	0	1	6	4	14	25
2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1
3	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1
4	11	5	5	6	8	2	4	8	49	0	0	2	0	1	0	0	1	4	53
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
#ec	13	6	5	7	11	4	4	10	60	0	0	6	0	2	1	6	5	20	80
6	0	0	0	1	1	2	1	1	6	0	0	0	0	1	0	0	0	1	7
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	1	0	0	0	0	0	1	2	0	0	0	0	2	0	0	0	2	4
9	7	3	2	1	5	5	4	3	30	4	1	1	0	1	0	1	0	8	38
10	3	1	1	1	0	0	0	0	6	0	0	0	0	0	0	0	2	2	8
#ec	10	5	3	3	6	7	5	5	44	4	1	1	0	4	0	1	2	13	57
Total ec	23	11	8	10	17	11	9	15	104	4	1	7	0	6	1	7	5	33	137

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Vita

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