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ELECTROPHYSIOLOGICAL AND PERCEPTUAL CORRELATES OF SELECTIVE ATTENTION

by

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Abstract

ELECTROPHYSIOLOGICAL AND PERCEPTUAL

CORRELATES OF SELECTIVE ATTENTION

by

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Auditory, visual, and somatosensory evoked responses were recorded from human subjects engaged in shadowing tasks of various degrees of difficulty. The major findings were as follows:

(a) The Average Evoked Response (AER), while a reliable measure of subjective detection of stimulus presentation, cannot be employed alone as a measure of attention; (b) The variance associated with the AER is, along with the AER itself, a reliable correlate of attention; (c) differential degrees of information-processing demands are reflected in the electrocortical responses to non-informative inputs; (d) single channel <u>and</u> multi-channel theories of human information processing apply, but must be qualified by specification of the task employed and the sensory modalities concerned; (e) more precise experimental designs than have been previously employed are necessary to investigate the phenomenon of attention; the shadowing paradigm is well-suited to such exploration.

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I. INTRODUCTION

A. Overview

The research discussed herein was undertaken to determine the relationship between demands imposed upon the attention of human subjects and the responsiveness of the nervous system to otherwise extraneous stimuli. In general terms, the experiments to be reported involved manipulation of information-processing requirements of subjects whose brain responses to discrete stimuli were simultaneously recorded. In addition, the research is addressed to the inter-modal and intra-modal effects of information-processing upon the responsiveness of the nervous system to otherwise extraneous stimuli.

Since the central nervous system is never silent electrically, stimuli must compete for representation with the continuous background activity that is intrinsic to it. This background is observed in the EEG. The presentation of a stimulus (a light flash or auditory click) will result in a change in the background (e.g., alpha blocking) and, although it is a relatively gross measure, the EEG does respond in a systematic way to certain physical features of a stimulus (Robinson, 1966). While the electrical changes produced by a single stimulus presentation are obscured by the large intrinsic signals of the EEG, it is now possible, using the Average Evoked Response (AER), to obtain a record of stimulus-elicited responses by averaging the results of a large number of presentations. The AER is not a record of axonal activity in the nervous system, i.e., it is not formed by a pooling of impulses. Rather it is produced by slow-potential events of synaptic origin.

The AER technique has not been employed without conceptual difficulty. Investigators find and label various numbers of components, with different latencies and, at times, opposite polarities for the same components depending upon the recording convention adopted; i.e., whether negative or positive is up. Such problems are not uncommon in the history of electrophysiological research. However, since evoked potentials recorded on the surface of the scalp are small when compared with the background "noise", the traditional problems are especially vexing in this area.

B. Special Problems

By means of a computer, it is possible to separate time-locked signals generated by a stimulus from the ongoing or spontaneous background activity whose relationship to the stimulus is assumed to be random, i.e., the distribution in time of moment-to-moment fluctuations in the background is assumed to be normal. Using such a technique, investigators have observed not only the larger later components of the evoked potential, but also, in some cases, the initial or primary components. It has not been possible, however, to observe clearly and reliably the initial or primary components to adequate stimuli such as a flash of light. However, it has been found in studies of direct recordings of evoked potentials from the visual cortex of the cat that a single suprathreshold shock to the optic nerve or tract or lateral geniculate nucleus will produce a multi-component response (Chang and Kaada, 1950; Bishop and Clare, 1952; Malis and Kruger, 1956). To a flash of light on the retina, however, the initial, rapid, three or four subcomponents are not obtained (Bishop and Clare reported three; Malis and Kruger reported four). Such initial components seem to be eliminated in the AER by a greater dispersion of impulses generated in the retina than when the optic nerve is stimulated directly (Donchin and Lindsley, 1968). Gastaut (1967) however, found that early components of the visual and auditory average evoked responses (up to 80-100 msec.) do show consistency across subjects. In addition, from 100 to about 300 msec., there are components which have been recorded with reliability, although these are more variable than the earlier components. It is these response components to which the present study is addressed. Beyond 300 msec. there are after discharges, which some investigators have not observed as they have not extended their analysis epoch far enough. As Gastaut points out, the epoch must extend at least 700 or 800 msec. in order to encompass the after discharge. In addition, placement of electrodes is crucial to the reliability and clarity of the AER. Gastaut, et. al. (1967) found that for somatosensory and visual evoked responses, monopolar placements in parietal and occipital regions with ear lobe reference respectively yielded consistency of components. Preliminary studies of auditory evoked potentials yielded results showing areas C_3 and C_4 as providing the most reliable, clear, evoked potentials. The vertex shows a large response but not of the type found in auditory areas. It is possible that the location of the primary auditory cortex, relatively hidden in the Sylvian fissure, and with other active areas on either side of it, makes it somewhat difficult to find a suitable location for recording auditory responses.

C. Attention and the AER

In most research, attention has been implied as a result of the experimental design; i.e., an animal attends to a stimulus when he points his receptors towards it (a cat "looking" at a rat). In human experiments attention is more frequently defined by the verbal instructions given to the subject ("listen to the tone"). The difficulty occurs when an attempt is made to establish an inferred construct of attention and especially of selective attention. Quantification of "competing" inputs have been virtually absent from the literature.

In an attempt to deal with the question of selective attention within a sensory modality, Haider, Spong, and Lindsley (1964) instructed subjects to respond (by pressing a key) to dim light flashes (signal stimuli) which were interspersed among more numerous bright flashes (non-signal stimuli). The bright flashes required no response. AER's to both signal and non-signal stimuli were recorded. The authors found that the AER's to non-signal stimuli decreased in amplitude and increased in latency as detection efficiency decreased. It would then seem that merely attending to some stimulus does not, in itself, result in the enhancement of related evoked responses, but that attention, in addition to aiding the detection of the relevant stimulus will produce enhancement of cortical evoked responses.

Davis (1964) described a similar effect using tone evoked responses recorded from the vertex of the scalp. Subjects were required to discriminate a small change in intensity of a repeated tone, which was presented in groups of four. The initial low frequency presentation constituted a warning tone, the second, third and fourth tones were all of the same higher frequency and intensity except for a small increase or decrease in the intensity of the third tone. The later (80-180 msec.) negative and positive components of the average evoked responses (to the four tones) were found to be much greater in amplitude to the tone whose intensity was to be discriminated. Such findings seem to be consistent with those of Haider, Spong, and Lindsley.

In another study, Spong, Haider, and Lindsley (1965) reported different effects on auditory and visual evoked responses. Recordings were made of the visual response to a light flash (recorded from the occiput) and of the auditory response to clicks (recorded from the temporal areas of the scalp). Alternating flashes and clicks were presented and subjects were instructed to attend to the flash and ignore the clicks; or to press a key in response to flashes; or to count flashes or clicks. In the first task ("attend one and ignore the other") amplitude of the evoked response of the "attending" modality was enhanced compared with the responses from the non-attending system, especially for flash-evoked responses.

These studies suggest that the attention mechanism reflects the meaningfulness of a stimulus, that the effects of attention, as reflected in the average evoked response, are specific to the meaningful stimulus (as in Davis, 1964) and do not appear to generalize to other "non-meaningful" stimuli in an attention-demanding situation.

Garcia-Austt, et. al. (1964) studied the effects of attention and inattention upon visual evoked responses. The authors found that when the general arousal level was lowered or attention was shifted away from the relevant stimulus, the amplitude of the evoked potential decreased, while when attention was more intensely focused upon the relevant stimulus, the evoked potentials were enhanced.

Satterfield (1965) instructed subjects in one experiment to report verbally the occurrance of occasional low intensity clicks while ignoring constant intensity shocks; and in another experiment to perform the same discrimination when shocks were varied in intensity and clicks were constant throughout. In both experiments it was suggested that evoked potential enhancement was a sign of selective or attentional facilitation of the relevant stimulus.

Naatanen (1967) used Satterfield's design (series of alternating shock and click stimuli at .5-1 sec. intervals) and found the same results. The author suggested, however, that the systematic presentation of relevant and irrelevant stimuli allowed subjects to know the nature of forthcoming stimuli and this resulted in preparatory reactions which increased the subjects' alertness at the presentation of relevant stimuli. As a result, Naatanen modified the variable foreperiod reaction-time paradigm: pairs of light flashes separated by variable foreperiods of 1, 2, and 3 seconds were used as warning and reaction stimuli. "Inside" clicks were presented only during the 2 and 3 second foreperiods either 1 or 2 seconds after the visual warning signal. "Outside" clicks were presented during longer (7-10 seconds) intertrial intervals following visual stimuli. Naatanen's prediction that evoked potentials to inside clicks would be enhanced relative to outside clicks was confirmed. He concluded that increased general alertness can enhance evoked potentials to stimuli which are irrelevant to the task requiring the attention. A second experiment by Naatanen was apparently more damaging to the selective attention hypothesis. Clicks or flashes of constant intensity were employed as irrelevant stimuli. The sequence of clicks and flashes was randomly mixed and intervals were varied between 1, 2, or 3 seconds so that subjects could not correctly predict the occurrance of a relevant stimulus. Naatanen did not find significant differences between evoked potentials to relevant vs. irrelevant click stimuli. He concluded that fluctuations in selective attention had no effect on the evoked response and that changes in the amplitude of evoked response are produced by variations in what he termed, non-specific arousal. Hartley (1970) supported Naatanen's findings by showing that AER's to both relevant and irrelevant stimuli are larger in the experimental condition than in control conditions. Hartley posited that attention may have, in the experimental condition, been a common state in all systems.

In contrast to Naatanen (1967), evidence relating AER's to the meaningfulness of stimuli was supplied by John, et. al. (1967). The authors found that: (a) the average visual evoked responses recorded from occipital areas of human subjects are different for a blank visual field than for one containing a geometric form, were different for different geometric forms of equal area; (b) are similar for versions of the same geometric form of unequal area; (c) are different for two different printed words of the same area. The authors believe that such findings suggest that the waveform of evoked responses is not determined solely by the set of peripheral receptors which is stimulated, but also reflects the perceptual content of the stimulus. Sutton et. al., (1967) reported that the waveform of scalp-recorded evoked responses from human subjects varied as a function of the "effective information" provided by the stimulus. Subjects were asked to guess aloud, for each trial, which of two alternative stimuli would be presented (a single or a double click). Waveforms for situations in which subjects were informed in advance about the nature of the clicks displayed marked attenuation compared with waveforms obtained in the guessing situation. This again reflects the role of meaningfulness. In addition, Donchin and Cohen (1967) presented subjects with a 50 msec. light flash superimposed on a fluctuating background. In one condition, subjects were to respond to the flash, and ignore the background. In a second condition, subjects ignored the flash and responded to the background. Stimuli to which subjects responses produced AER's having enhanced late positive components (P300). Attended to stimuli produced larger amplitude AER's than did the same stimuli under conditions of attention divided within the same sensory modality. Karlin (1970) pointed out, however, that in Donchin and Cohen's study the irrelevant flashes intervening between relevant alternations of background should be enhanced if they are analogous to Naatanen's outside clicks, so that the results of Donchin and Cohen do not contradict Naatanen's results.

Eason, Harter, and White (1969) studied the effects of attention and arousal on visually evoked cortical potentials in human subjects and obtained larger AER's to relevant than to irrelevant stimuli. The amplitude of the AER was found to be larger under conditions in which subjects were threatened with shocks to misses than in the absence of such aversive conditions. They suggest that cortical potentials are especially responsive to specific attention and to levels of general arousal. Here, again, the findings support the role of the meaningfulness of the stimulus in studies of averaged cortical responses.

Sheatz and Chapman (1969) required subjects to compare two relevant stimuli (either tones or noises) occurring among two tones and two noises. Subjects were instructed to select the two of lower pitch. Two positive peaks, P150 and P300, were observed; AER's to tones and noises were found to be quite similar. Both peaks were found to be larger when stimuli were relevant than when the identical stimuli were ireelevant, with P300 showing greater effects. The authors interpreted the data as inconsistent with a peripheral gating mechanism. They emphasized, instead, the dependence of the AER on the processing requirements of the task. In addition, they posited that the amplitude of P150 depended more on physical variables, while that of P300 depended principally on psychological variables.

Smith, et. al. (1970) required subjects to attend to one or the other channel and at various times report letters or clicks with AER's recorded to clicks. Their results showed enhancement of P300 when clicks, but not letters, were reported. No differences in AER's were found for those clicks presented to the attended channel as compared with those presented to the rejected (non-attended) channel. Early components (P50-P250) displayed no differences under conditions of selective listening; i.e., there was no attenuation of major components prior to P300 even in the rejected channel. Accordingly, P300 was judged to be a correlate of decision making rather than of stimulus attributes. This interpretation agrees with Sutton's (1967) finding that P300 can be elicited by the absence of a stimulus as much as by its presentation.

Picton, et. al. (1971) studied the click evoked responses of the cochlear nerve as well as cortical AER's concurrently, and found that attention to the clicks during a discrimination task resulted in a significant enhancement of the cortical response. However, they observed no change in the response of the cochlear nerve. They concluded, therefore, that the hypothesis of a peripheral gating mechanism of attention was untenable.

Ford, et. al. (1973) investigated evoked potential correlates of signal recognition between as well as within sensory modalities. Subjects were instructed to respond to relevant stimuli while ignoring all others. The results were that P2 showed no effect, while the N2 and P3 components were differently affected by the relevance of the stimulus. For relevant stimuli, large N2 and P3 components were found; for irrelevant stimuli in the same modality, large N2 and medium P3 components were found; and for irrelevant stimuli in different modalities small or nonexistent N2 and P3 components were found. The data supported the notion that the P3 component is reflective of some cognitive process invoked by psychological operations independent of the physical characteristics of the stimulus.

Expectation is also known to affect the form of the AER. Begleiter (1973) reports that the amplitudes of evoked potentials to identical stimuli are different depending upon the subject's expectations. When a bright or dim stimulus is expected (indicated by a specific signal), the evoked potential resulting from a medium intensity stimulus resembled that evoked by a bright or dim flash.

In the above studies, changes in the focus of attention have been correlated with changes in the amplitude of the average evoked response. Little notice had been given to the statistical structure of these averaged responses; specifically to the variances associated with these averages. Robinson (1973) found that the variance associated with visual evoked responses was significantly lower under attentive conditions than under conditions of passive viewing. Further studies (Robinson and Strandburg, 1973) showed that under attentive viewing (with average visual evoked responses and variances recorded from corresponding areas of the two hemispheres) the two hemispheres responded with nearly equivalent variance, whereas under passive viewing interhemispheric variance was markedly asymmetrical. It was hypothesized that the attentive state is correlated with "subcortical outputs common to both hemispheres and able to synchronize cortical activity generally."

Interhemispheric asymmetry was also studied by Buchsbaum and Fedio (1969) who found that the visual AER's to verbal and nonverbal (random patterns of dots) material were differentially represented in the left hemisphere than in the right hemisphere with verbal stimuli producing shorter latencies. The authors contended that this was consistent with the notion that the cerebral hemispheres assume an asymmetric role in cognitive behavior.

D. Information-Processing Models

In all the studies cited above, the tasks employed to induce the attentive condition have been of short duration, usually on the order of seconds. Never has a task been employed which captures the attention of subjects for minutes at a time, which provides the investigator with a quantitative measure of the task difficulty as well as the performance of the subject. The literature concerning attention has shown a singular lack in the description and nature of the attention-demanding task. The present study, with the aid of developments in cognitive areas, deals with the specification and the effects of degree of attention. A brief review of the literature on cognition bearing on the present research follows.

E. Relevant Studies in Cognitive Psychology:

Models of human information-processing reveal discrepancies between single-channel and multiple-channel hypotheses. Observers receiving simultaneous inputs in one or more sensory systems appear to be able to acquire and retain information from one channel at a time and, within that channel, only in discrete packages or chunks at a time. Broadbent (1952) found that subjects dichotically presented, with three pairs of digits simultaneously, and required to memorize the numbers they had heard, organized their verbal reports not in the order of presentation of the numbers, but by numbers heard in each ear. In tests of recall, subjects gave one ear's sequence first, then the other ear's sequence. Subjects were found to identify correctly the digits from one ear, but not the other. Such results led Broadbent to postulate a model of selective attention (Filter Model), and to contend that there is a perceptual limit to our ability to perceive competing messages; that we can analyze and identify only a limited amount of information at any one time. According to Broadbent, the nervous system acts as a <u>single-channel</u> processor with a limited capacity.

One of the earliest studies illustrating the concept of limited channel-capacity involved a "shadowing" task (Cherry, 1953) in which the subject was given simultaneous messages to the left and right ears. Prior to such dichotic presentations the subject was instructed to "shadow" either the left-ear or the right-ear message. The shadowing task required the subject to articulate, on a word-by-word basis, the speech of another person. Perfect shadowing, then, would require the perfect duplication of everything uttered by the other speaker. Cherry found that there was nearly no recall or recognition of information delivered to the non-shadowed channel. Not only was the subject unable to report the contents of the non-shadowed message but was also, in some cases, oblivious to changes in the language of the message. Often, the subject had very little idea what even the <u>shadowed</u> message was about, especially if the material was difficult. Analogous results have been found when parallel lines of printed text are presented for reading (Neisser, 1969).

According to Broadbent, we deal with one channel of information at a time, selecting from varied sources of impinging information those items that bear a given physical characteristic. However, the question raised by this view is how it is possible ever to switch attention if there is no awareness of unselected inputs.

In an attempt to deal with this, Grey and Wedderburn (1960) have argued that attention is not based on the physical characteristics of information, but upon the psychological attributes. The authors presented subjects with a word, so divided that different syllables were alternately presented to different ears. At the same time, another word was presented in the same manner, beginning in the other ear. Attention switched from ear to ear, and each word was correctly reassembled. That is, subjects did not monitor one channel and reproduce a veritable jumble of syllables. Broadbent and Gregory (1963) posited that the auditory threshold to tones in one ear is raised if subjects are asked to attend simultaneously to digits presented to the other ear.

Peterson and Kroener (1964) performed a series of studies in attempting to determine the extent to which selective attention results in the failure of perception as opposed to impaired memory storage. Subjects were required to shadow a message presented to one ear and their ability to recall elements of a message presented simultaneously to the other ear was tested at various retention intervals. The shadowed message was a series of digits, and while the non-shadowed message also consisted of a series of digits, a letter was substituted for one of the digits in the series. Subjects were instructed to report the letter at the end of the series. The messages were synchronized and presented at a rate of 2 pairs of digits per second. The retention interval was determined by the position of the letter in the series (last position = 0 sec.). Results showed that accuracy of recall declined with increased retention intervals up to 6 seconds, but even at the shortest interval, the accuracy of recall was 52%. The authors suggested that the dichotic paradigm led to failure of perception.

Treisman (1960, 1968, 1969) has suggested that the "... division of attention between two or more inputs and between two or more targets is difficult or impossible when no time is allowed for alternating attention or serial analysis... while division of attention between analyzers is fairly efficient..." Therefore, according to Treisman, while there may be attenuation of competing channels of information in order to reduce the load on some "central analysis process," this still allows the non-selected channel's information to get through.

Miller (1956) reasoned that, if the human observer is thought of as a communication system, when the amount of input information is increased, the transmitted information will first increase, then level off and approach asymptote. The asymptotic value is, according to Miller, the channel capacity of the observer, or the upper limit of the extent to which the observer can match his responses to the stimuli delivered to him. There are thus two ways to increase the amount of information: (a) by increasing the rate of information per unit time, and (b) by increasing the number of alternative stimuli. The point in (b) where confusion begins to occur is, then, the channel capacity. Note, however, that Miller ignores the possible effects of familiar vs. unfamiliar information, which may have different effects upon the attention process.

In addition to the work of Broadbent (1952, 1963) and of Peterson and Kroener (1964), the single channel theory has been upheld by various studies, among them that by Moray (1959), who was interested in how much information might be retained from the "rejected" (non-shadowed) channel. The author found that when English words were repeated up to 35 times in the "rejected channel," there was no retention of them even when subjects were informed that they would later be tested on retention from the non-shadowed channel. Norman (1969), however, posited a limited processing ability for the "rejected" channel. The author pointed out that since subjects often are unable to recall much of the shadowed material, the non-rejected channel contains material that is also, to an extent, rejected. The author also posited that there is a temporary memory for non-shadowed material, but no long-term memory.

Norman's (1969) contention was similar to that which emerged from investigations by Treisman (1964), who studied the effects of varying degrees of similarity between the shadowed and non-shadowed channels. The author found that there was a graded effect on subjects' ability to <u>reject</u> the irrelevant message; i.e., when there was a distinct physical difference between the relevant and irrelevant channels, subjects had no difficulty in shadowing one channel without being "bothered" by the other. The most difficulty in maintaining shadowing occurred when both messages were read in the same language and spoken in the same voice. Similarities in content between the two channels, then, caused interference in shadowing, and resulted in the postulation of a multi-channel processing capability; that all signals must receive a good deal of analysis, as rare "relevant" (similar) signals from the non-shadowed channel would never pass through the attention mechanism without the mechanism having the capability to identify all input signals.

Although Treisman and Geffen (1967) have demonstrated that when subjects shadow a verbal message in one ear they ignore verbal messages in the other ear, Lawson (1966) showed that subjects can report tones arriving in either ear while shadowing.

Further evidence in support of the multi-channel hypothesis was provided by Allport, et. al. (1972) who found that subjects could shadow speech for up to a minute while at the same time engaged in observing visual scenes. Subsequent recognition of the visual stimuli, although significantly different under conditions of divided attention than under conditions of undivided attention, was far more accurate than subsequent recognition of words presented during shadowing. The authors interpret such findings as favoring a multi-channel hypothesis. However, it is again apparent that the authors have concluded that such an hypothesis is independent of the degree of shadowing difficulty.

F. Purpose of the Present Studies:

The neuropsychological studies of attention have differed from cognitive studies of the same process. It has been tentatively shown that the nature of the task (verbal or non-verbal is an important element contributing to the results. Attending to shapes or digits is not comparable to attending to words. The amount of time engaged in the task is also known to be a significant variable (Peterson and Kroener, 1974). Such incomparability has contributed to the delineation of single and multiple channel theories of human attention. In addition, previous investigations have not been addressed to the question of whether or not the stimuli to be attended to, and those to be ignored, occur in the same sensory system or in different sensory systems. "Accordingly, the problem of channel difference as opposed to stimulus difference may be quite complex as there are many daily activities in which two channels must be integrated as well as other activities in which one channel must be enhanced and the other suppressed (Sutton, 1973)." The phenomena demonstrated by the shadowing task suggest its effectiveness in investigations of channel-capacity as well as selective attention. Theories have been proposed which are neural in nature, yet neuropsychological studies have not been addressed to the phenomena revealed by the shadowing task. Neuropsychological approaches to selective attention have not incorporated the data from cognitive research, and as a result, have ignored an important parameter, language, and its effect upon neuroelectric processes and selective attention capacity. Therefore, results appear to be conflicting, with studies addressing one particular parameter of an attention-provoking task and presenting the results as suggestive or descriptive of the attention process as a whole.

The present research, then, attempts to study subjects' performance on the shadowing task which captures attention for minutes at a time, and the resulting neuroelectric potentials evoked by non-informative short duration stimuli presented during the performance of shadowing. In addition, new parameters of the shadowing task in the form of systematic variation of the nature of the material presented to both the shadowed channel and the non-shadowed channel. Average evoked responses are studied as are the statistical properties of the AER's in the form of the variance associated with the averages. In all cases, the material to be shadowed is verbal in nature, rather than composed of digit spans. Specifically, the present study includes a series of experiments which investigates the effects of different degrees of selective attention (as manifested by variations in the nature of the shadowing task) upon evoked responses to short duration stimuli occurring both within the same sensory channel as the shadowing task as well as in different sensory channels. An attempt is made to assess the reliability of the AER as a measure of attention as well as of inter-modal interference. Are the effects of selective attention upon the AER to non-verbal material applicable to tasks involving the processing of language? What are the effects of parametric manipulations of the shadowing task upon resulting AER's in various sensory modalities? What electrophysiological basis exists for the single and multiple channel theories of attention which have grown from research in cognitive areas, and are there limitations which must accompany each theory? Are the effects of sampling an incoming verbal message and initiating and monitoring a spoken output reflected in the evoked potentials of various sensory systems? Is the attention process, then, specific to the sensory channel involved in the shadowing task, or does shadowing result in a generalized effect observable in the AER across other sensory systems?

II. PROCEDURE

A. Method

The research reported herein was divided into four basic experiments, each having three subsections. The basic experiments consisted of the following: In Experiment I, both the shadowed and the non-shadowed messages consisted of material which was taken from technical journals and therefore unfamiliar to the subjects. In Experiment II, the content of the shadowed messages again was unfamiliar to the subjects, while the non-shadowed channel contained highly familiar material such as the Pledge of Allegiance, the lyrics to the National Anthem, popular song lyrics, etc. In Experiment III, the shadowed channel contained highly familiar material while the non-shadowed channel contained unfamiliar material. Finally, in Experiment IV, both the shadowed and non-shadowed channel contained highly familiar material. For each experiment, three subsections are reported (a, b, c) which entail auditory (a), visual (b), and cutaneous (c) AER's. Clicks, light flashes, or cutaneous stimuli were delivered during the shadowing task. Clicks and cutaneous stimuli were delivered either to the side of the body ipsilateral to the shadowed channel or contralateral to the shadowed channel. Visual stimuli were delivered binocularly. In Experiment V, a tactile shadowing task was introduced in which subjects were required to draw with a minimum phase lag, letters of the alphabet which were drawn on his back by the experimenters. Transparencies containing the standard stimuli, when superimposed upon the subject's shadowed replica, allowed measurement of the similarity between the delivered and reconstructed stimulus. It was not possible, in the present study, to determine the temporal overlap between the delivered and the reconstructed signals in the tactile mode. However, subjects were instructed to shadow the tactile message and were informed that pauses in excess of one second would lead to a rejection of their data. The following diagram is illustrative of the research.

Experiment	Shadowed Channel	Non-shadowed Channel
I	Unfamiliar	Unfamiliar
	auditory, visual, somatosensory stimuli and resulting AER's	
II	Unfamiliar	Familiar
	auditory, visual, somatosensory stimuli and resulting AER's	
III	Familiar	Unfamiliar
	auditory, visual, somatosensory stimuli and resulting AER's	
IV	Familiar	Familiar
	auditory, visual, somatosensory stimuli and resulting AER's	
V	Unfamiliar	Unfamiliar
	auditory stimuli and resulting AER's	

1. Subjects: for each subsection (a, b, and c) of each experiment, four college students, naive as to the purpose of the experiment, served as subjects.

2. Apparatus: for subsection (a) of each experiment, Tektronix pulse and waveform generators (model 160 series) provided instantaneous on-off auditory stimuli consisting of 400 Hz tone-clicks of 20 msec. gate duration and 40dB intensity. The clicks were delivered monaurally at a rate of 1 every four seconds. Separate monopolar recordings were taken from areas C_3 and C_4 (International 10-20 system). Placements were equidistant from the midline and ground leads were attached to each ear.

For subsection (b) of each experiment, light flashes (25 mL.) were provided by a Nihon-Kohden photostimulator lamp which subtended a visual angle of 11°. Flash duration was 20 msec., delivered at a rate of 1 every 4 seconds and controlled by Tektronix pulse and waveform generators. Monopolar recordings were taken from left and right occiputs, O_1 and O_2, ground leads were placed on each ear. Viewing was binocular.

For subsection (c) of each experiment, 20 msec. gate duration cutaneous stimuli delivered to subjects' forefingers were provided by a Scientific Prototype tactile stimulator, and delivered at a rate of 1 every 4 seconds. Monopolar recordings were taken from P_3 and P_4 equidistant from the midline, and ground leads were placed on each ear.

Auditory, visual, and somatosensory evoked responses were pre-amplified and then amplified by a PAR-142 system, with high and low frequency roll-offs (-3db) set at 60 and 1 Hz. The Tektronix modules triggered a Fabri-Tek 1074 signal averager which was slaved to a PDP-8/L digital computer programmed to perform statistical analysis (on-line) of the average evoked response data. Such analysis resulted in the display of the average evoked response waveform $\pm$ 1.0 standard deviations around the average (actually it was possible to display either the mean alone, or the $\pm$ 1.0 standard deviations alone, or both. The AER and associated variability were displayed on a Tektronix 504 oscilloscope. Recordings were made with Grass E4G flat disc gold electrodes. Scalp contacts were made with Beckman electrode paste and were tested with an ohm meter (part of the PAR-142 system).

Shadowed and non-shadowed messages were tape recorded on separate channels of a Sony TC-252D stereo taperecorder, and delivered through

Koss Model ESP-6 stereo headphones, with a frequency response range of 27-19,000 Hz $\pm$ 5db.

3. Procedure: In all experiments, subjects were seated in an enclosed room, separate from the experimenter, and were instructed to shadow one of two different messages delivered through headphones. Subjects were encouraged to make as few errors as possible and informed that their performance would be recorded separately on tape so that it may be scored. The degree of shadowing accuracy was determined by the number of words in the message which subjects correctly shadowed. For each subject both left and right channel shadowing trials were given, and under each condition either auditory clicks (to the right or left ear), light flashes, or cutaneous stimuli (to right or left forefinger) were delivered. Therefore, clicks and cutaneous stimuli were delivered to the same side (or channel) as the shadowed message, or to the opposite side or channel (non-shadowed message). Resulting average evoked responses were obtained from 65 presentations of auditory, visual, or cutaneous stimuli. Separate waveforms of the principle components of the AER were obtained for the three classes of stimuli (a) during shadowing, (b) during presentation of clicks, flashes or cutaneous stimuli only in which subjects were required to report any changes in stimulus intensity and/or duration and the number of stimuli for which such changes occurred; actually, no such changes occurred, (c) during passive (merely listening) exposure to the messages, and (d) while subjects counted aloud at a rate of 2 integers per second. C and D were employed as controls in the first experiment, (I(a)), D was employed as a control in Experiments Ib - IVc. At the conclusion of

each block of trials which consisted of 65 presentations of either clicks, flashes, or cutaneous stimuli, subjects were asked to estimate the number of clicks, flashes, or cutaneous stimuli presented as well as what they recalled from the non-shadowed channel (which was written down). Blocks of trials were counter balanced in ABBA, BAAB fashion with stimuli and shadowing on left and right respectively. A five minute rest interval separated each four and one-half minute block of trials. Polaroid pictures of waveforms were taken directly from the face of the oscilloscope. For all experiments, the statistical significance of observed changes in AER's was determined by the sign test comparing AER's obtained from tone-clicks alone with those obtained during shadowing and control conditions at 20 points along the first 400 msec. of the recording epoch. In addition, an analysis of variance was performed on all data. Analysis of data did not include the latencies of the AER's which were not affected in any of the present experiments. P values appearing in Tables 1-13 reflect results of sign tests.

1. Experiment I(a)

Results

Table 1 presents findings from 4 subjects. Data from left and right hemispheres (L.H., R.H.) were obtained (a) during tone-only presentations, (b) during shadowing, and (c) during passive exposure to both sets of messages but made no vocalizations (Control). Figures 1 and 2 show representative waveforms for contralateral and ipsilateral AER's respectively. Each figure shows AER's from left and right hemispheres. For all subjects, auditory AER's in either hemisphere were not observed during shadowing, independent of which ear received the tones. Passive exposure to both messages, however, did not significantly affect auditory AER's, in fact, no latency differences were observed for stimuli presented in the tone-alone vs. passive listening conditions. That the effects were not attributable to mere vocalization can be seen in Table I. AER's to the tone-clicks were recorded as the subject counted aloud at a rate of 2 integers per second, and were found not significantly different from AER's to tones alone. Therefore, neither passive exposure to both messages nor mere vocalization affect auditory AER's.

At the end of each block of trials, subjects were asked to estimate the number of tone-clicks presented while they were shadowing. While each subject has received 65 such tone-clicks, and while, under the non-shadowing conditions subjective estimates were all between 55 and 70, subjects under the shadowing condition reported having heard either no clicks or "a few." The amplitude of principle AER components reflects such subjective reports.

Comparison of AER amplitudes in tone-click alone vs. passive listening + tone-clicks shows that, in some cases, the AER's associated with the latter condition are slightly (0-4 uv.) smaller. This reflects the subjective reports of estimates between 55 and 70 tone-clicks when there were actually 65 such presentations. The difficulty of the task is reflected in that the shadowing accuracy for subjects was between 60% and 75%; i.e., the subjects failed to correctly articulate from 25% to 40% of the relevant message. Under these conditions, the subjects' recall of information delivered to the non-shadowing channel was negligible.

b. AER Related Variance:

The variance accompanying the auditory AER's grows larger under conditions which prevent attentiveness. That is, under conditions in which the tone-clicks are non-attended stimuli, there is an increase in the variability of cortical responses to the tone-clicks.

The data from this experiment support the Broadbent Filter Model of limited channel capacity. However, an important question was raised as a result of the first experiment:

Are such results, within a single sensory modality, applicable to situations in which intra-modal stimulation is used; i.e., will auditory shadowing effects carry over to the AER's produced by stimuli other than within the auditory modality?

The following experiments (Ib, and c) were performed in an attempt to answer this question. The results of this research are described in the following sections.

Table 1: Amplitude of the principle component of the contralateral and ipsilateral auditory average evoked response under conditions of shadowing, tones alone, and control (passive listening)

Contralateral AER's (to non-shadowed channel)

S		A. Tones alone		B. Shadowing		C. Listening Control		P
1	LH	20uV	±8uV	--	±18uV	18uV	±10	.05 bet. A & B NS bet. A & C
	RH	20uV	±8uV	--	±18uV	18uV	±10	.05 bet. A & B NS bet. A & C
2	LH	20uV	±8uV	--	±18uV	20uV	±10	.05 bet. A & B NS bet. A & C
	RH	22uV	±8uV	--	±18uV	17.5uV	±10	.05 bet. A & B NS bet. A & C
3	LH	16uV	±8uV	--	±18uV	16uV	±10	.05 bet. A & B NS bet. A & C
	RH	18uV	±8uV	--	±18uV	16uV	±10	.05 bet. A & B NS bet. A & C
4	LH	14uV	±8uV	--	±18uV	14uV	±10	.05 bet. A & B
	RH	14uV	±8uV	--	±18uV	14uv	±10	NS bet. A & C

Ipsilateral AER's (to shadowed channel)

		A. Tones alone		B. Shadowing		C. Control		P
1	LH	18uV	±8uV	--	±18uV	18uV	±10	.05 bet. A & B NS bet. A & C
	RH	20uV	±8uV	--	±18uV	18uV	±10	.05 bet. A & B
2	LH	20uV	±8uV	--	±18uV	20uV	±10	.05 bet. A & B NS bet. A & C
	RH	22uV	±8uV	--	±18uV	17.5uV	±10	.05 bet. A & B
3	LH	18uV	±8uV	--	±18uV	16uV	±10	.05 bet. A & B NS bet. A & C
	RH	16uV	±8uV	--	±18uV	16uV	±10	.05 bet. A & B
4	LH	15.5uV	±8uV	--	±18uV	14uV	±10	.05 bet. A & B NS bet. A & C
	RH	13.0uV	±8uV	--	±18uV	14uV	±10	.05 bet. A & B

Figure 1: Auditory AER's from one subject under conditions of tones alone, shadowing + tones, and passive listening + tones (control). Each separate figure presents the average waveform (center) bracketed above and below by +1.0 and -1.0 S.D. Waveforms are the result of 65 presentations of tones to the ear that was contralateral to the one receiving messages to be shadowed. Calibration = 8.2 uV/cm division, and 82 msec/cm division (total time base = 820 msec.)

In figure 1 and in all figures the polarity convention observed was that negative is up.

FIGURE 1

CONTRALATERAL AUDITORY EVOKED RESPONSES

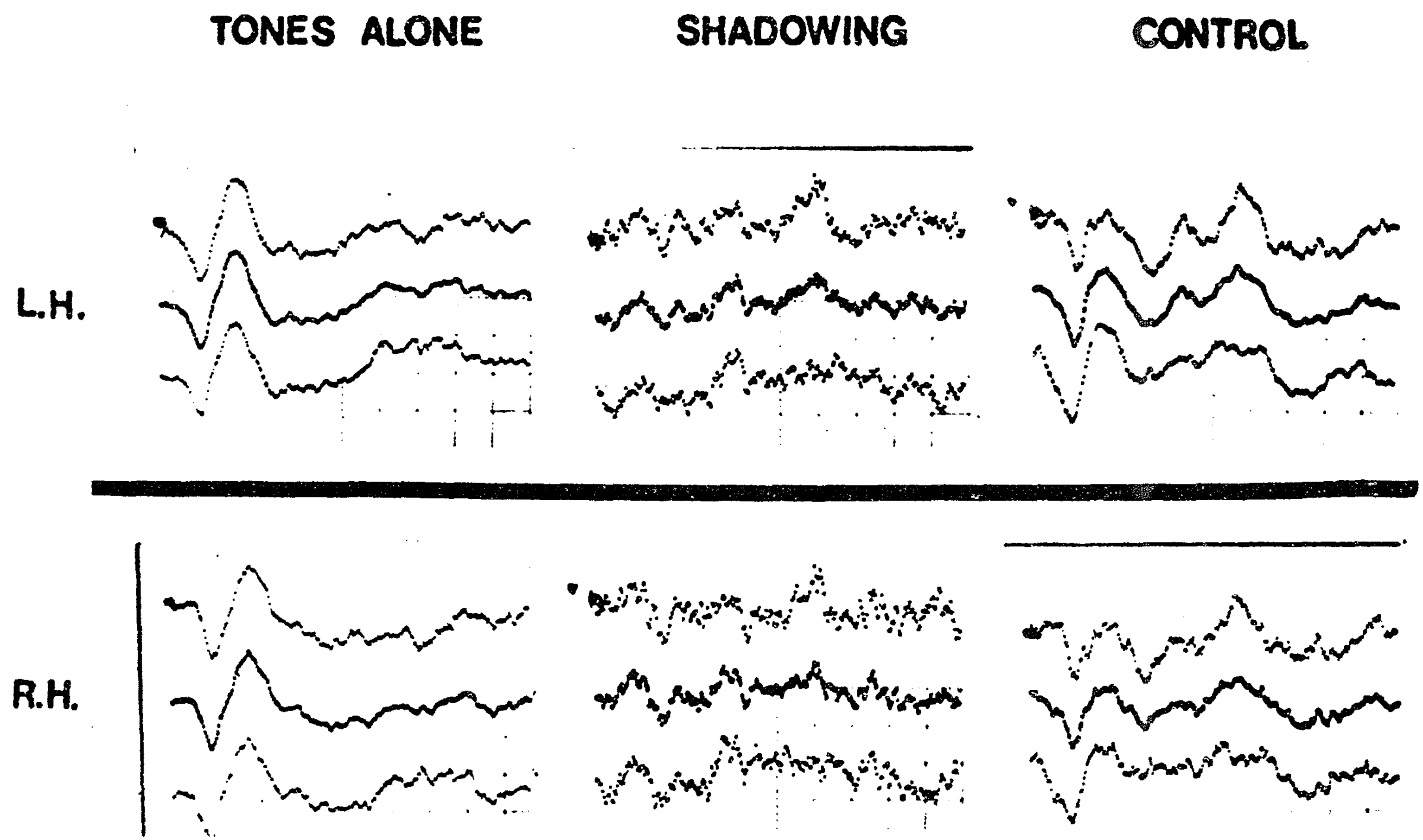
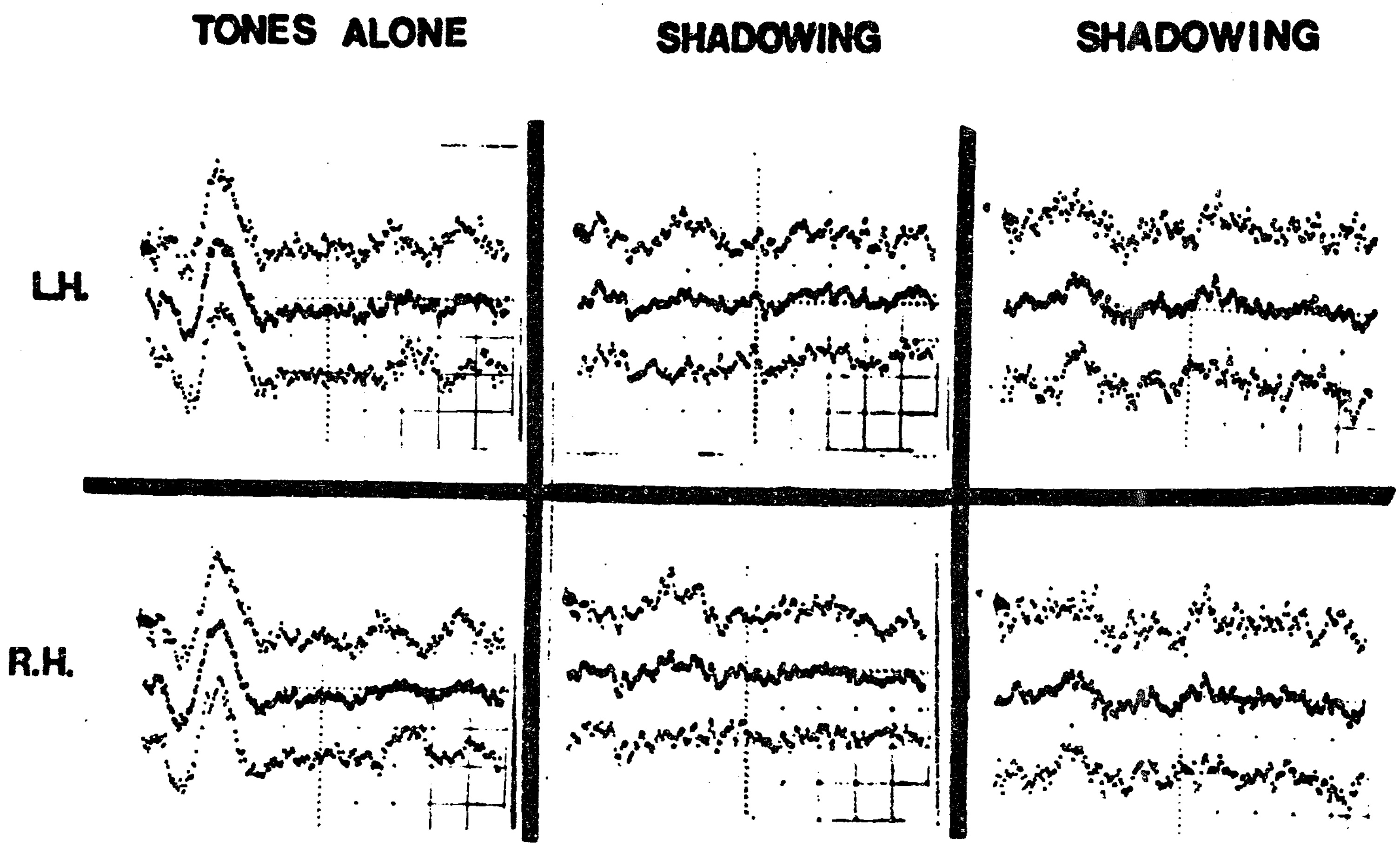


Figure 2: Ipsilateral auditory AER's from one subject under conditions identical to those in Figure 1. For calibration, consult caption for Figure 1.

FIGURE 2

IPSILATERAL AUDITORY EVOKED RESPONSES



2. Experiment 1(b)

The purpose of Experiment 1(b) was: (1) to study the effect on the visual AER of (a) unfamiliar material presented to the shadowed channel and (b) unfamiliar material in the non-shadowed channel; (2) to investigate the effects of auditory shadowing on the variance associated visual AER's.

Results

Table 2 presents findings from four subjects. Data from left and right hemispheres were obtained (a) during flash-only trials, and (b) during shadowing. Figure 3 presents representative waveforms for visual AER's. For all subjects, auditory shadowing (of the same material as used in Experiment 1(a)) had virtually no effect upon the amplitude of the principle components of the visual AER, regardless of which channel was involved in the shadowing task. Visual AER's were observed in both hemispheres independent of the ear to which the subjects were attending. Following each shadowing task, subjects were asked to estimate the number presented. Shadowing difficulty was again demonstrated as shadowing accuracy ranged between 60% and 75%. Recall of the message delivered to the non-shadowed channel was again negligible. Another interesting result of this experiment was that the observable early components of the visual AER (those occurring between 0-80 msec.) were also not affected by shadowing. Again, it would appear that "perceived" number of stimuli is reflected in the amplitude of the visual as well as the auditory AER.

b. <u>AER Related Variance:</u>

As opposed to the variance associated with auditory AER's, the variance associated with visual AER's was not affected by the shadowing task, and seemed to remain constant across conditions. One possible conclusion regarding these data may be that while attention may be reflected in the variance surrounding the AER, that in this experiment, with inter-modal stimulation, subjects were capable (as reflected in accurate estimates of the number of flashes presented) of attending to the light flashes equally as well during shadowing as during flash alone conditions.

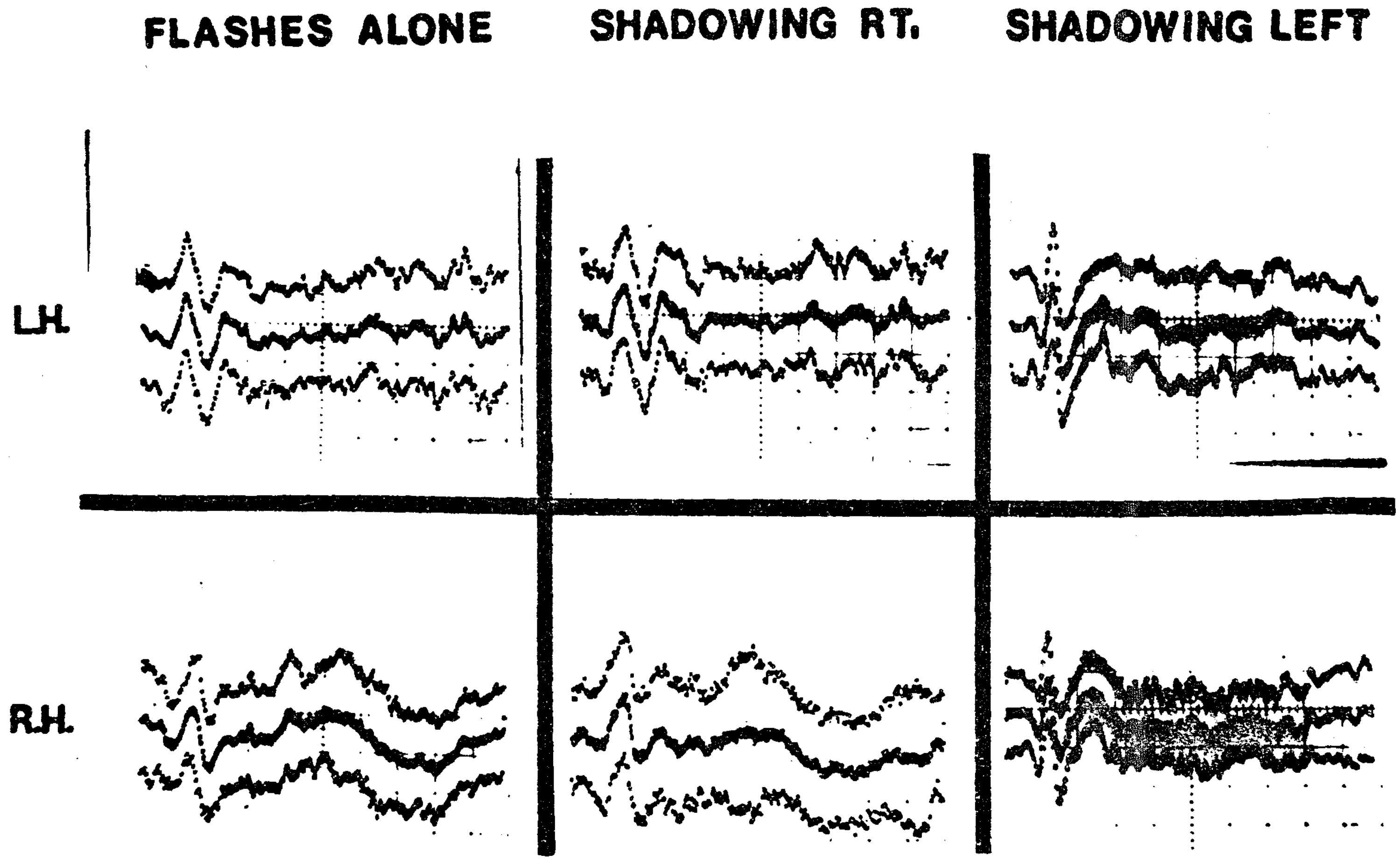
Table 2: Amplitude of the principle component of the visual evoked response under conditions of shadowing vs. non-shadowing

S		A. Flashes alone		B. Shadowing right channel		C. Shadowing left channel		P
1	LH	24.75uV	±8uV	24.75uV	±10uV	24.0uV	±10uV	NS
	RH	16.50uV	±8uV	16.50uV	±10uV	16.5uV	±10uV	NS
2	LH	16.5uV	±8uV	16.5uV	±10uV	16.5uV	±10uV	NS
	RH	16.5uV	±8uV	16.5UV	±10uV	16.5uV	±10uV	NS
3	LH	14.5uV	±8uV	14.5uV	±10uV	14.5uV	±10uV	NS
	RH	10.5uV	±8uV	10.5uV	±10uV	10.5uV	±10uV	NS
4	LH	10.5uV	±8uV	10.5uV	±10uV	10.5uV	±10uV	NS
	RH	10.5uV	±8uV	10.5uV	±10uV	10.5uV	±10uV	NS

Figure 3: Visual evoked responses to 65 light flashes from one subject under conditions of non-shadowing (flashes alone) and shadowing the right and the left channel. Calibrations are identical to those in Figure 1.

FIGURE 3

VISUAL EVOKED RESPONSES



3. Experiment I(c)

The purpose of Experiment I(c) was: (1) to study the effect on the somatosensory AER of (a) unfamiliar material presented to the shadowed channel and (b) unfamiliar material presented to the non-shadowed channel; (2) to investigate the effects of auditory shadowing on the variance associated with somatosensory AER's.

Results

Table 3 presents findings from four subjects. Data were obtained during (a) cutaneous stimuli presented alone, (b) shadowing + cutaneous stimuli, and (c) cutaneous stimuli presented while subjects counted aloud. For three of the four subjects (Ss 1, 2, and 3, who were right handed), the amplitude of the somatosensory AER was affected by shadowing under conditions in which both the cutaneous stimuli and the shadowing were on the right side (AER's drop from 16.5 uV to 8.25 uV). The somatosensory AER's for all subjects were not affected by mere vocalization. In the case of the fourth subject, who was left-handed, the results appeared to be the reverse of those for the right-handed subjects. For the left-handed subject, there was slight attenuation of the somatosensory AER's when cutaneous stimuli and the shadowing were both on the right side, but there was greater attenuation of somatosensory AER's when the shadowing and cutaneous stimuli were on the left side (the AER amplitude dropped from 12 uV to 6 uV) as well as when cutaneous stimuli were delivered to the right side while the subject shadowed the left channel. Figures 4 & 5 present representative waveforms for somatosensory AER's.

Table 3: Amplitude of the principle component (N150-P230) of the somatosensory average evoked response under conditions of shadowing vs. presentation cutaneous stimuli alone.

S		A. Cutan. Stim. Rt.		B. Shad. Left		C. Shad. Rt.		Control	P
1	LH	16.5uV	±8	14.0uV	±14	8.25uV	±14	17 ±8	NS bet. A & B
	RH	16.5uV	±8	14.0uV	±14	8.25uV	±14	16 ±8	.05 bet. A & C .05 bet. B & C
2	LH	16.5uV	±8	16.0uV	±14	8.0uV	±14	16 ±8	NS bet. A & B .05 bet. A & C
	RH	16.0uV	±8	16.0uV	±14	9.0uV	±14	16 ±8	.05 bet. B & C
3	LH	16.5uV	±8	14.0uV	±14	8.25uV	±14	16 ±8	NS bet. A & B .05 bet. A & C
	RH	16.5uV	±8	14.0uV	±14	8.25uV	±14	16 ±8	.05 bet. B & C
4	LH	12.0uV	±8	6.0uV	±14	9.0uV	±14		.05 bet. A & B NS bet. A & C
	RH	12.0uV	±8	6.0uV	±14	9.0uV	±14		.05 bet. B & C

S		A. Cut. Stim. Left		B. Shad. Rt.		C. Shad. Left		Control	P
1	LH	20uV	±8	18uV	±16	16uV	±16	18 ±8	NS bet. A & B
	RH	18uV	±8	18uV	±16	18uV	±16	18 ±8	NS bet. A & C NS bet. B & C
2	LH	16uV	±8	16.5uV	±16	16uV	±16	17 ±8	NS bet. A & B
	RH	16uV	±8	16.5uV	±16	16uV	±16	16 ±8	NS bet. A & C NS bet. B & C
3	LH	16uV	±8	16uV	±16	12uV	±16	16 ±8	NS bet. A & B
	RH	16uV	±8	16.5uV	±16	12uV	±16	16 ±8	.05 bet. A & C .05 bet. B & C
4	LH	12uV	±8	12uV	±16	6.0uV	±16	12 ±8	NS bet. A & B
	RH	12uV	±8	12uV	±16	6.0uV	±16	12 ±8	.05 bet. A & C .05 bet. B & C

NS found between A and Speaking Controls

Figures 4 & 5: Somatosensory evoked responses under conditions identical to Figure 1. Calibrations are identical to those in Figure 1.

FIGURE
4

SOMATOSENSORY EVOKED RESPONSES

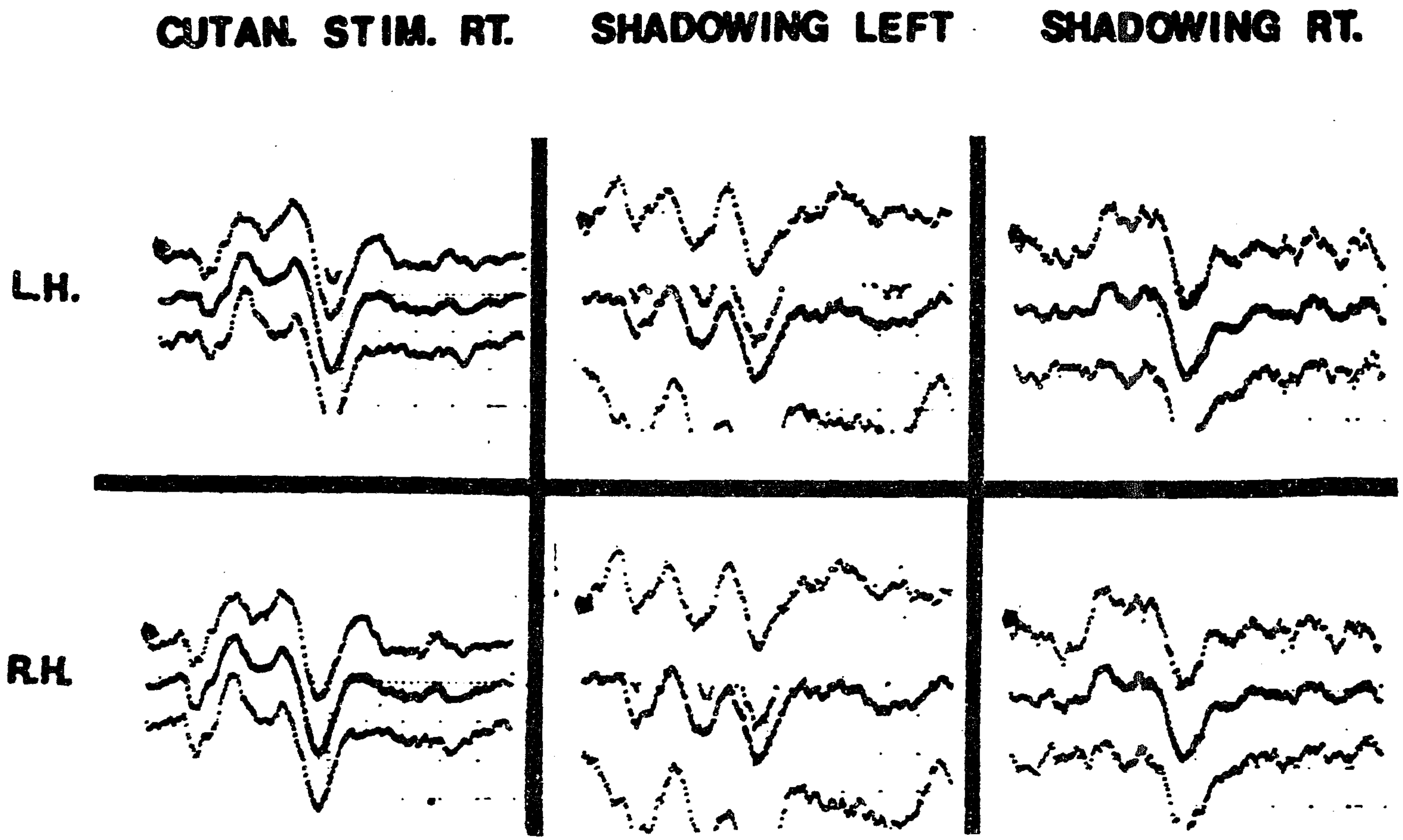
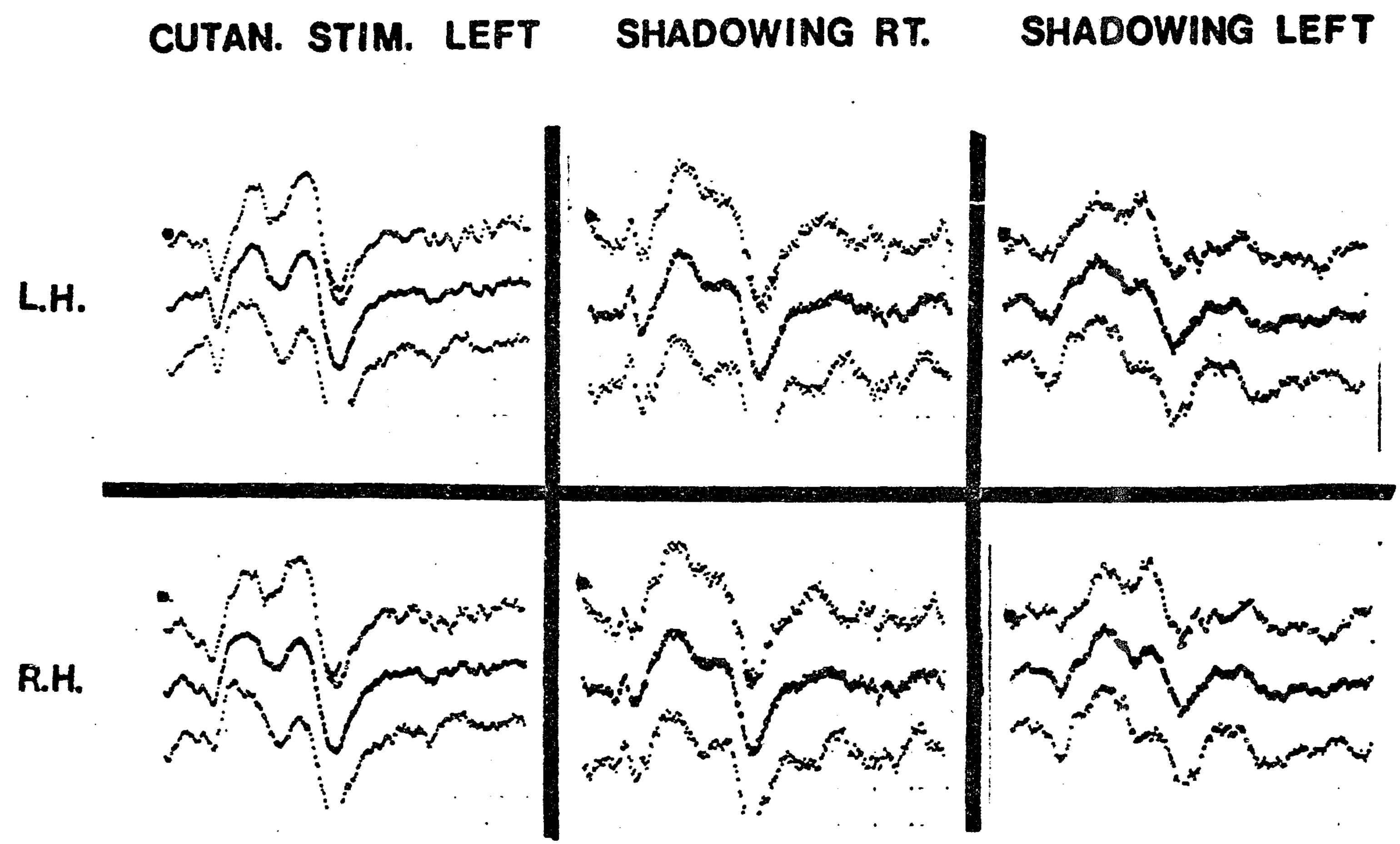


FIGURE 5

SOMATOSENSORY EVOKED RESPONSES



b. <u>AER-related variance</u>

In general, increases in variance were observed when the cutaneous stimuli were delivered to the <u>right side</u> during shadowing conditions. Under such conditions, subjects reported an inability to estimate the number of cutaneous stimuli presented, while during other shadowing conditions when stimuli were delivered to the <u>left side</u> (for right-handed subjects), subjects' estimates were within ten of the actual number of cutaneous stimuli presented. For the one left-handed subject, inability to estimate the number of cutaneous stimuli occurred when such stimuli were delivered to the <u>left side</u> during shadowing of the left channel, as well as when such stimuli were delivered to the right side during shadowing of the <u>left</u> channel.

1. Auditory evoked responses to tone-clicks were not observed; no differences were found relating to which channel received auditory stimuli; increases in the variance surrounding the auditory AER's were found during both shadowing and passive listening conditions; subjects reported a failure to hear clicks during shadowing.
2. Visual AER's to light flashes were unaffected by auditory shadowing; subjects estimated the number of flashes presented within 10 of the actual number; there were no differences in the variance observed during shadowing vs. flash-only conditions.
3. Somatosensory AER's to cutaneous stimuli were differentially attenuated, but not unobserved during auditory shadowing. The degree of attenuation appeared to be laterally specific during shadowing, occurring when stimuli were delivered to the right side for right-handed subjects, and when stimuli were delivered to the left side for the left-handed subject. Variance increases corresponded to the above situations, and to subjects' inability to estimate the number of stimuli delivered, although they reported "feeling them."
4. Across all conditions, no latency effects were observed regarding any of the components of the AER's.

The present research, as well as previous research concerning information-processing and attention, raises the question of whether there is some quantitative relationship between the difficulty of the shadowing task and the magnitude of AER attenuation, the performance of the subjects, and the subjects' recall of information presented to the non-shadowed channel. The effects of parametrically varying the degree of difficulty of the shadowing task are reported in the following sections.

4. Experiment II(a)

The objectives of Experiment II(a) were (1) to study the effect on the auditory AER of (a) unfamiliar material presented to the shadowed channel and (b) familiar material in the non-shadowed channel; (2) to investigate the effects of recall of information from the non-shadowed channel upon auditory AER's; (3) to observe the amplitude and variance of auditory AER's during a shadowing task in which familiar material was delivered to the non-shadowed channel.

Results

Table 4 presents findings from four subjects. Figures 6 & 7 are representative waveforms. Auditory AER's were again not observed during shadowing; the effect appears to be independent of which ear received the tone-clicks (no differential laterality effects were observed). The auditory AER's were observed, however, during trials in which the subjects counted aloud at a rate of 2 integers per second. Subjective estimates of the number of auditory stimuli presented ranged between 50 and 70 during non-shadowing conditions, and from 0 to "a few" during shadowing conditions. In each block of trials, subjects received 65 tone-clicks. The difficulty of the task was measured in terms of shadowing accuracy which ranged from 75%-80%. Subjects did, however, show some recall of information delivered to the non-shadowed ear (about 50% of the content).

b. AER related variance:

Variance associated with auditory AER's again was found to increase under conditions of shadowing vs. tone-click alone presentations.

Table 4: Amplitude of the principle component (P80-N160) of the contralateral and ipsilateral auditory average evoked response under conditions of shadowing vs. tones alone vs. speaking control.

Contralateral AER's

S		A. Tones alone		B. Shadowing		C. Control		P
1	LH	20uV	±8	--	±16	20uV	±8	.05 bet. A & B NS bet. A & C
	RH	16.50uV	±8	--	±16	16.5uV	±8	.05 bet. B & C
2	LH	20uV	±8	--	±16	20uV	±8	.05 bet. A & B NS bet. A & C
	RH	22uV	±8	--	±16	20uV	±8	.05 bet. B & C
3	LH	18uV	±8	--	±16	18uV	±8	.05 bet. A & B NS bet. A & C
	RH	16uV	±8	--	±16	18uV	±8	.05 bet. B & C
4	LH	16uV	±8	--	±16	14uV	±8	.05 bet. A & B NS bet. A & C
	RH	16uV	±8	--	±16	16uV	±8	.05 bet. B & C

Ipsilateral AER's

S		A. Tones alone		B. Shadowing	C. Control		P	
1	LH	22.0uV	±8	-- ±16	22uV	±8	p	.05
	RH	20uV	±8	-- ±16	20uV	±8	p	.05
2	LH	24.75uV	±8	-- ±16	24uV	±8	p	.05
	RH	24.75uV	±8	-- ±16	24uV	±8	p	.05
3	LH	20.5uV	±8	-- ±16	20uV	±8	p	.05
	RH	20.5uV	±8	-- ±16	20uV	±8	p	.05
4	LH	16.50uV	±8	-- ±16	16uV	±8	p	.05
	RH	16.5uV	±8	-- ±16	16uV	±8	p	.05

Figures 6 & 7: Contralateral and ipsilateral auditory AER's under conditions of shadowing unfamiliar material with familiar material presented to the non-shadowed channel. Calibrations are identical to those in Figure 1.

FIGURE 6

CONTRALATERAL AUDITORY EVOKED RESPONSES

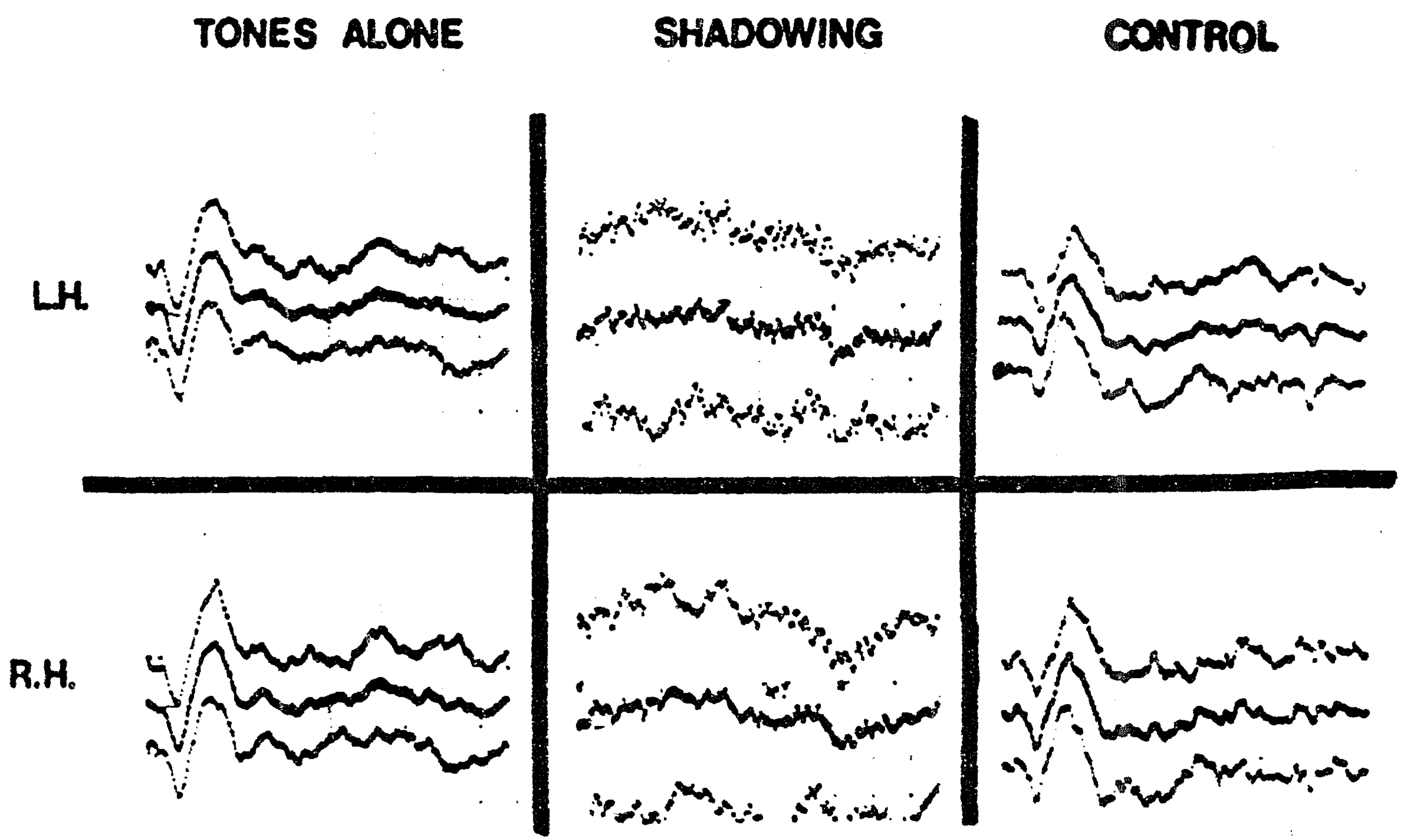
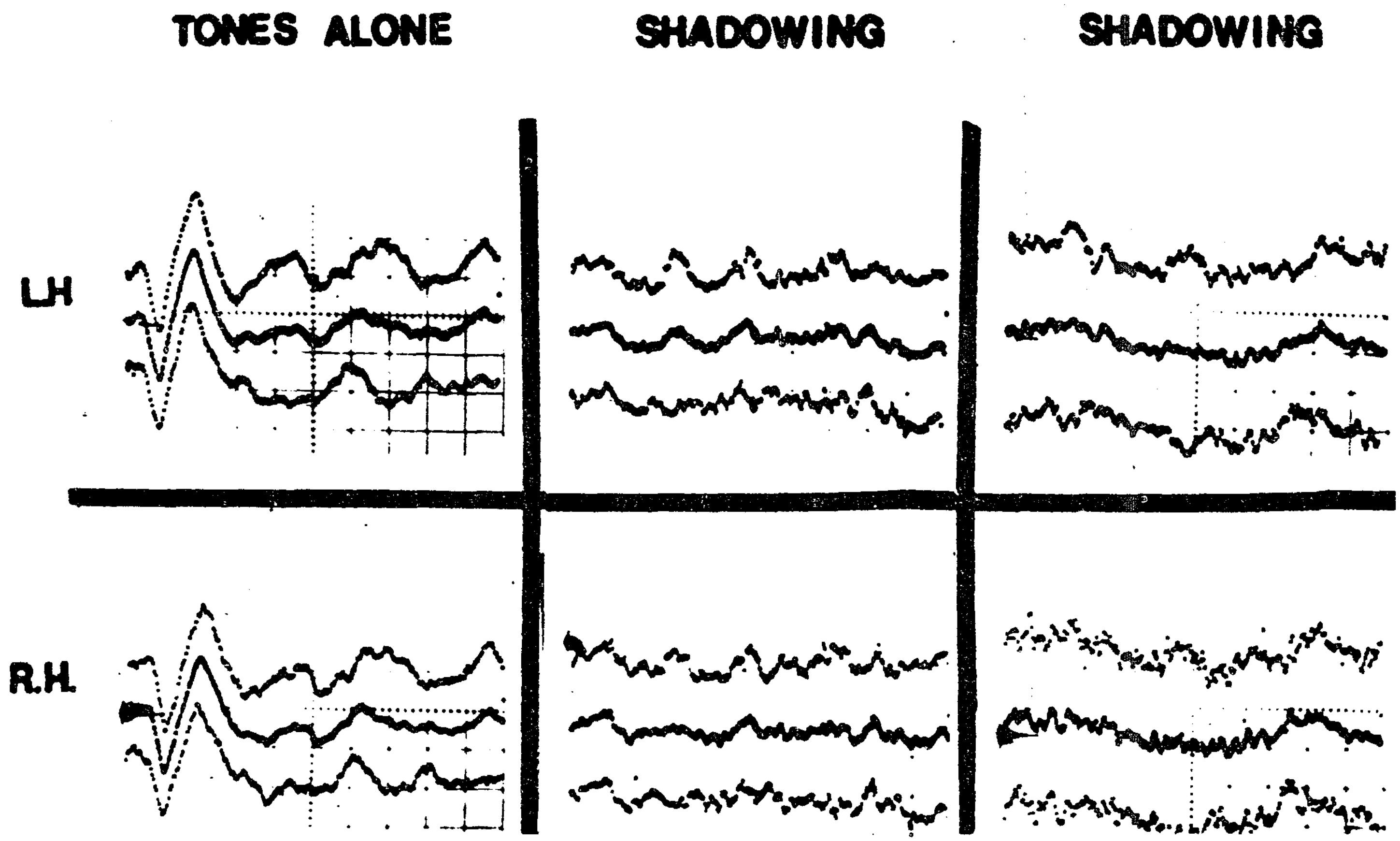


FIGURE 7

IPSILATERAL AUDITORY EVOKED RESPONSES



These data were remarkably similar to those observed in Experiment I(a), however, in the present experiment, subjects did, for the first time, exhibit some degree of recall of information delivered to the non-shadowed channel. Such information was extremely familiar to the subjects.

Although the present shadowing task significantly affected the auditory AER, the question arose as to whether the visual AER's would be affected. The procedure and results of that research are described in the following section.

5. Experiment II(b)

The purpose of Experiment II(b) was (1) to study the effect on visual AER of (a) unfamiliar material presented to the shadowed channel and (b) familiar material presented to the non-shadowed channel; (2) to further investigate the effects of recall of information from the non-shadowed channel upon visual AER's; (3) to observe the amplitude and variance of visual AER's during a shadowing task in which familiar material is delivered to the non-shadowed channel.

Table 5 presents findings from four subjects. Figure 8 is a representative waveform. Data were obtained (a) during flash-alone presentations, and (b) during shadowing. For all subjects, auditory shadowing (of the same material used in Experiment II(a) resulted in the attenuation of the principle component of the visual evoked response. Following the shadowing tasks subjects were asked to estimate the number of flashes presented. Estimates ranged from 45-50. Shadowing accuracy was between 75% and 80% and subjects were able to correctly recall approximately 50% of the messages delivered to the non-shadowed channel.

b. AER related variance:

For all subjects, the variance surrounding the AER's increases during the shadowing tasks as opposed to that for flash-alone presentations. Subjects in the present experiment were, in general, not as accurate in their estimates of the number of flashes presented during the shadowing task as in Experiment I(b).

Having observed that the second auditory shadowing task has a markedly different effect upon the visual AER than did the first shadowing task, the question arose as to what effect such an auditory task would have upon somatosensory AER's. The results of that experiment are described in the following section.

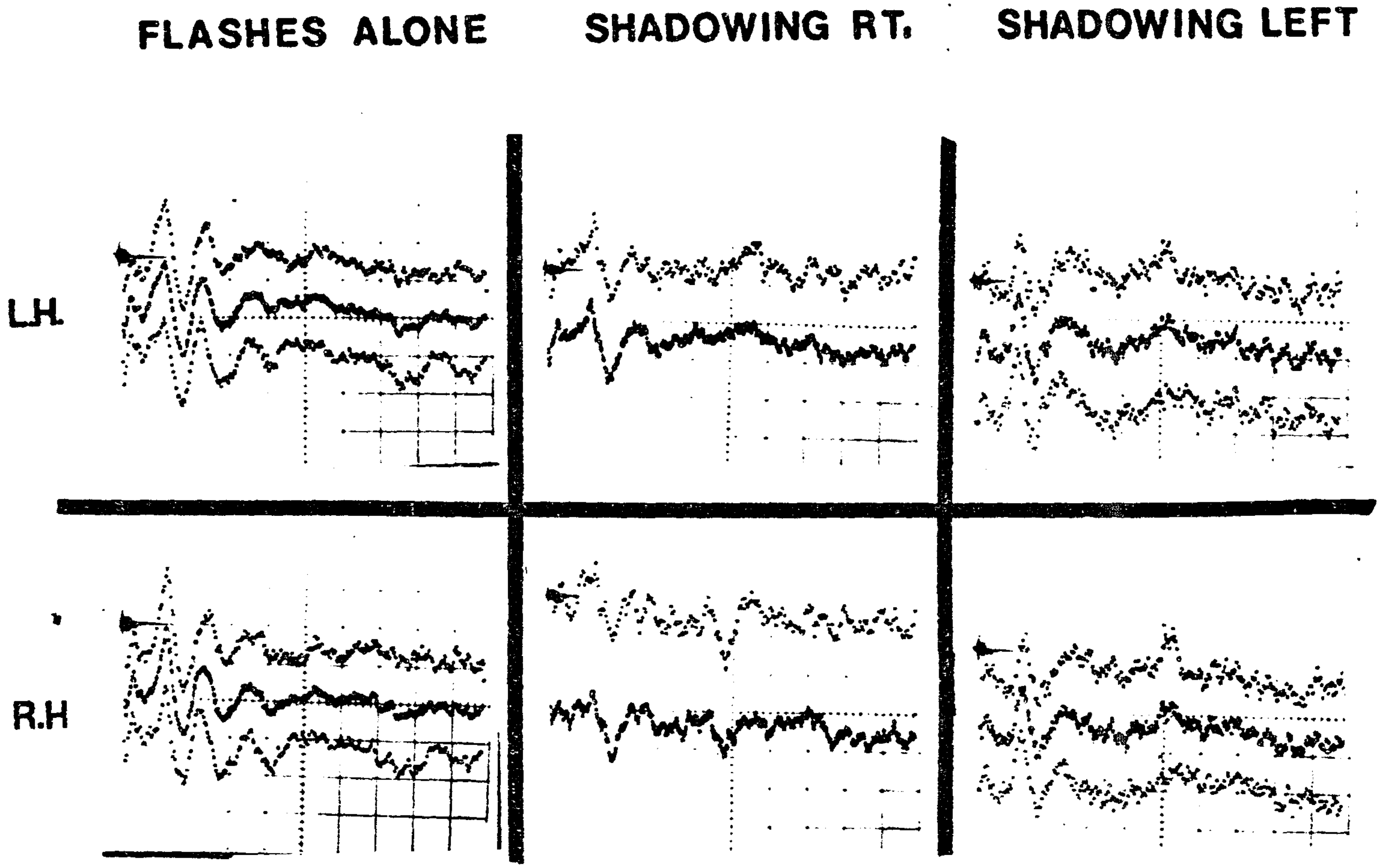
Table 5: Amplitude of the principle component of the visual evoked response under conditions of shadowing vs. non-shadowing

S		A. Flash alone		B. Shad. Rt.		C. Shad. Left		P
1	LH	40uV	±8	33uV	±16	33uV	±16	.05 bet. A & B .05 bet. A & C NS bet. B & C
	RH	33uV	±8	20uV	±16	33uV	±16	.05 bet. A & B NS bet. A & C .05 bet. B & C
2	LH	28.75uV	±8	16.5uV	±16	24.75uV	±16	.05 bet. A & B NS bet. A & C
	RH	24.75uV	±8	16.5uV	±16	24.75uV	±16	.05 bet. B & C
3	LH	20.75uV	±8	16.5uV	±16	12.0uV	±16	.05 bet. A & B .05 bet. A & C NS bet. B & C
	RH	24.5uV	±8	16.5uV	±16	12.0uV	±16	.05 bet. A & B .05 bet. A & C NS bet. B & C
4	LH	20uV	±8	16.5uV	±16	16.5uV	±16	.05 bet. A & B .05 bet. A & C NS bet. B & C
	RH	24.75uV	±8	12.0uV	±16	12.0uV	±16	.05 bet. A & B .05 bet. A & C NS bet. B & C

Figure 8: Visual evoked responses from one subject under conditions of non-shadowing (flashes alone) and shadowing the right and left channel. Calibrations are identical to those in Figure 1.

FIGURE
8

VISUAL EVOKED RESPONSES



6. Experiment II(c)

The purpose of Experiment II(c) was: (1) to study the effect on somatosensory AER of (a) unfamiliar material presented to the shadowed channel and (b) familiar material presented to the non-shadowed channel; (2) to determine if laterality effects can be altered by a shadowing task in which recall of information from the non-shadowed channel is possible; (3) to observe the amplitude and variance of somatosensory AER's during a shadowing task in which familiar material is delivered to the non-shadowed channel.

Results

Table 6 presents findings for four subjects. Figures 9 & 10 are representative waveforms. Data were obtained (a) during presentation of cutaneous stimuli alone (either to the right or left forefinger), (b) during shadowing + cutaneous stimuli, and (c) during subjects' counting aloud + cutaneous stimuli. All subjects were right-handed. For two subjects (3 and 4) auditory shadowing had negligible effects upon the principle component of the somatosensory AER. For the other two subjects, however, differential attenuation of the somatosensory AER's were observed. Such attenuation in the peak-to-peak amplitude was observed to occur when cutaneous stimuli were delivered to the right forefinger during auditory shadowing of both the left and right channels. The somatosensory AER's for all subjects were not affected during mere vocalization.

b. AER related variance:

For all subjects, the variance surrounding somatosensory AER's increased under all shadowing conditions.

Table 6: Amplitude of the principle component of the somatosensory average evoked response under conditions of shadowing and of cutaneous stimuli presented alone.

S		A. Cut. alone left		B. Shad. Left		C. Shad. Rt.		P
1	LH	18.0uV	±10	16.5uV	±18	18.0uV	±16	NS bet. A & B NS bet. A & C NS bet. B & C
	RH	18.0uV	±10	16.5uV	±18	18.0uV	±16	NS bet. A & B NS bet. A & C NS bet. B & C
2	LH	16.5uV	±10	12.25uV	±18	18.0uV	±16	.05 bet. A & B .05 bet. A & C .05 bet. B & C
	RH	16.5uV	±10	12.25uV	±18	18.0uV	±16	.05 bet. A & B .05 bet. A & C .05 bet. B & C
3	LH	18.0uV	±10	18.0uV	±18	20.5uV	±16	NS
	RH	16.5uV	±10	16.5uV	±18	18.0uV	±16	NS
4	LH	12.25uV	±10	12.25uV	±18	12.25uV	±16	NS
	RH	12.25uV	±10	12.25uV	±18	12.25uV	±16	NS

S	Control	
1	18.0uV	±10uV
	18.0uV	±10uV
2	16.0uV	±8uV
	16.0uV	±8uV
3	18.0uV	±10uV
	18.0uV	±10uV
4	12.0uV	±8uV
	12.0uV	±8uV

No significant difference between Shadowing and Speaking controls

Table 6:
(continued)

S		A. Cut. alone Rt.		B. Shad. Left		C. Shad. Rt.		P
1	LH	24.75uV	±10	10.0uV	±18	12.0uV	±16	.05 bet. A & B .05 bet. A & C NS bet. B & C
	RH	24.75uV	±10	16.5uV	±18	20.6uV	±16	.05 bet. A & B NS bet. A & C .05 bet. B & C
2	LH	24.75uV	±10	8.25uV	±18	16.5uV	±16	.05 bet. A & B .05 bet. A & C .05 bet. B & C
	RH	20.60uV	±10	8.25uV	±18	16.5uV	±16	.05 bet. A & B .05 bet. A & C .05 bet. B & C
3	LH	16.5uV	±10	16.5uV	±18	16.5uV	±16	NS bet. A & B NS bet. A & C NS bet. B & C
	RH	16.5uV	±10	16.5uV	±18	17.5uV	±16	NS bet. A & B NS bet. A & C NS bet. B & C
4	LH	16.5uV	±10	12.25uV	±18	16.5uV	±16	NS bet. A & B NS bet. A & C NS bet. B & C
	RH	18.0uV	±10	12.25uV	±18	17.0uV	±16	NS bet. A & B NS bet. A & C NS bet. B & C

	Control	
1	24.0uV	±10
	24.0uV	±10
2	22.0uV	±10
	20.0uV	±10
3	16.0uV	±10
	16.0uV	±10
4	16.0uV	±10
	16.0uV	±10

Figures 9 & 10: Somatosensory AER's under conditions of shadowing unfamiliar material with familiar material presented to the non-shadowed channel. Calibrations are identical to those in Figure 1.

FIGURE 9

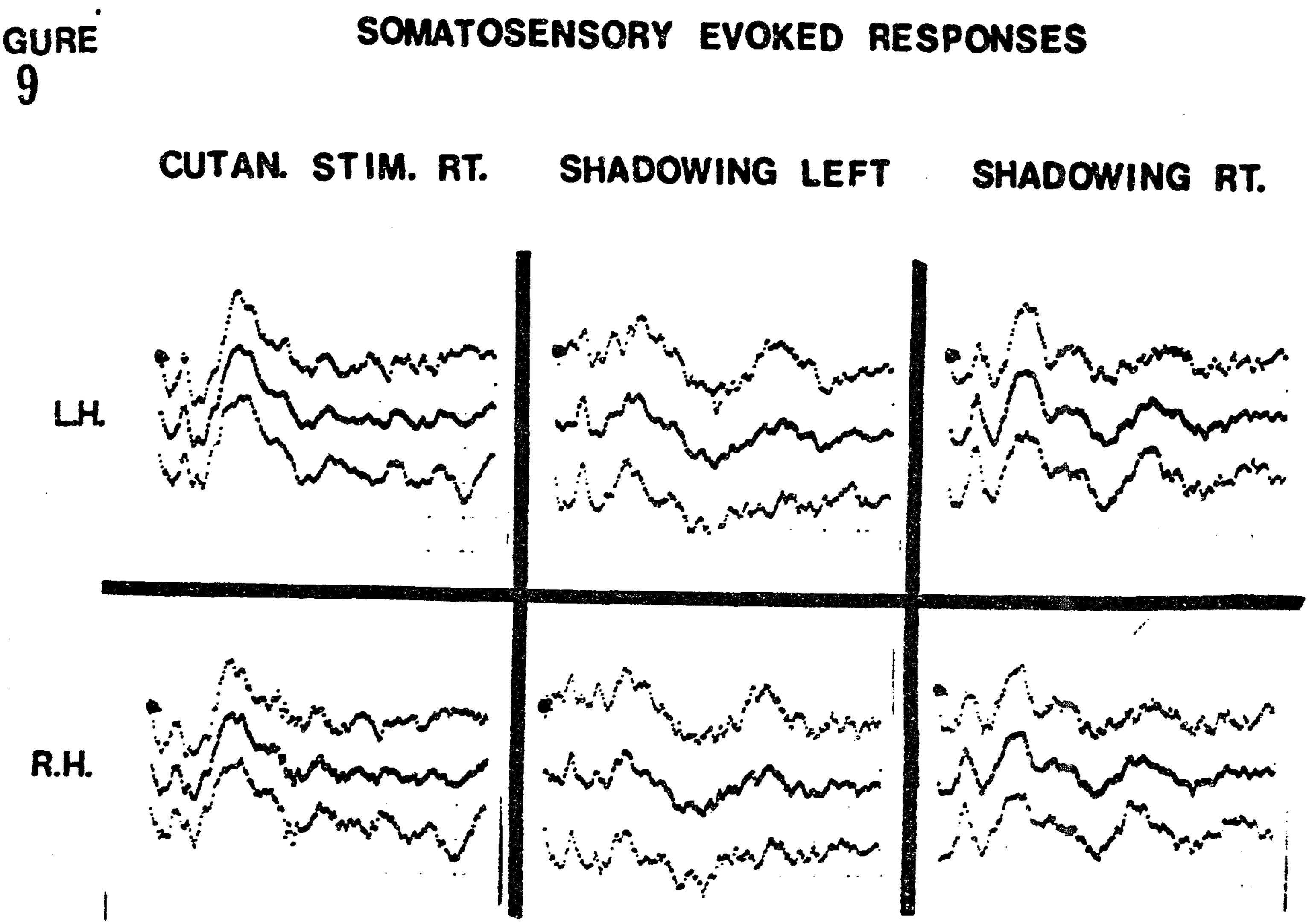

SOMATOSENSORY EVOKED RESPONSES
CUTAN. STIM. RT.
SHADOWING LEFT
SHADOWING RT.
L.H.
R.H.

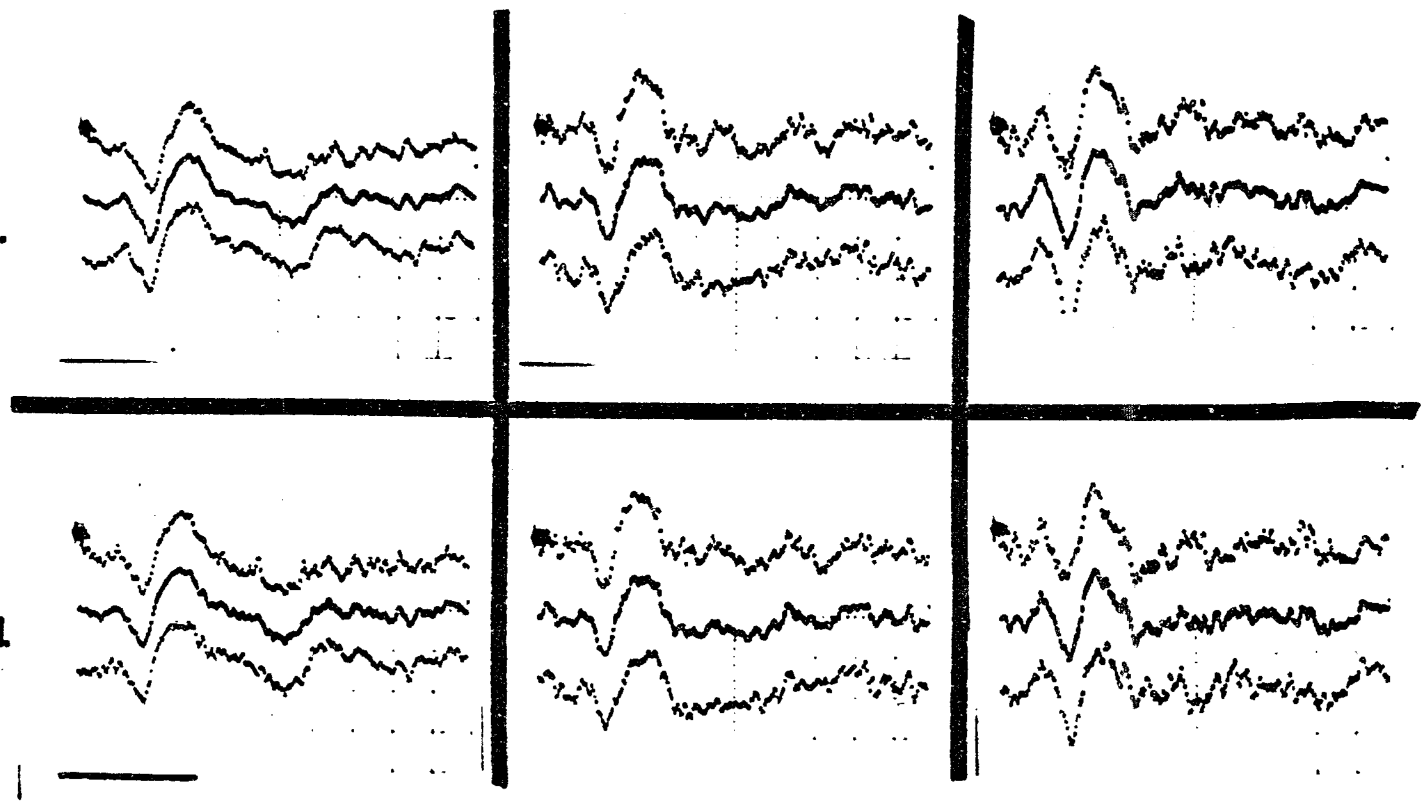
FIGURE
10

SOMATOSENSORY EVOKED RESPONSES

CUTAN. STIM. LEFT | SHADOWING RT. | SHADOWING LEFT

L.H.

R.H.



In summary, for the identical auditory shadowing task, (whose degree of difficulty was less than that in Experiment I) in which subjects' shadowing performance ranged from 75% to 80% correct and recall of 50% of the material presented to the non-shadowed channel was possible,

1. Auditory AER's to tone-clicks were not observed during shadowing.
2. Visual AER's to light flashes were attenuated markedly during shadowing, while subjective estimates of the number of flashes presented ranged from 45-50 (65 were actually presented.)
3. Somatosensory AER's were differentially attenuated in two of four subjects, with two subjects showing no effects of shadowing upon the peak-to-peak amplitude of the principle component of the AER. In the two subjects for whom shadowing did affect the AER's to cutaneous stimuli, the effects were observed when such stimuli were delivered to the right side during auditory shadowing of either the left or the right channels.
4. In all sensory modalities, there were increases in the variance associated with the AER's during shadowing tasks.

In the first two sets of experiments, subjects were required to shadow highly unfamiliar material, with the non-shadowed channel containing unfamiliar, and then familiar material respectively. It was observed that the nature of the information delivered to the non-shadowed channel as well as the degree of difficulty of the shadowed channel affected the AER's to auditory, visual and somatosensory stimuli.

In the following experiments, subjects were required to shadow messages whose content was familiar to them, while the non-shadowed channel contained unfamiliar information. The results of this research are described on the following pages.

7. Experiment III (a)

The purposes of Experiment III(a) were (1) to study the effects on the auditory AER of (a) familiar material presented to the shadowed channel and (b) unfamiliar material presented to the non-shadowed channel; (2) to investigate further the effects of recall of information from the non-shadowed channel upon auditory AER's; (3) to observe the amplitude and variance of auditory AER's during a shadowing task in which familiar material is delivered to the shadowed channel.

Results

Table 7 presents data from four subjects. Figures 11 and 12 are representative waveforms.

For three subjects, auditory AER's were unobserved only when the tone-clicks were delivered to the non-shadowed channel, and these subjects reported having heard no tone-clicks when stimuli were delivered to the non-shadowed channel. When stimuli were delivered to the shadowed channel, however, the auditory AER reappeared, but was markedly attenuated; a finding which coincided with subjects reporting having heard (estimated) between 10-25 tone-clicks.

All subjects demonstrated no recall of the information delivered to the non-shadowed channel; shadowing accuracy was between 95% and 98%. That the effects were not due to mere vocalization can be seen in Figure 11 which shows the amplitude of auditory AER's while subjects counted aloud. These auditory AER's are not significantly different from those obtained when tone-clicks were presented alone.

b. <u>AER related variance</u>:

For all subjects, the variance surrounding contralateral

Table 7: Amplitude of the principle component of the contralateral and ipsilateral auditory average evoked responses under conditions of shadowing, vs. tones alone vs. speaking control

Contralateral AER's

S		A. Tones Alone		B. Shadowing		C. Control		P
1	LH	20uV	±8	--	±16	18.5uV	±8	.05 bet. A & B NS bet. A & C
	RH	16.5uV	±8	--	±16	16.5uV	±8	.05 bet. A & B NS bet. A & C
2	LH	20.0uV	±8	--	±16	16.5uV	±8	.05 bet. A & B NS bet. A & C
	RH	20.5uV	±8	--	±16	18.5uV	±8	.05 bet. A & B NS bet. A & C
3	LH	20.5uV	±8	--	±16	16.5uV	±8	.05 bet. A & B NS bet. A & C
	RH	20.5uV	±8	--	±16	16.5uV	±8	.05 bet. A & B NS bet. A & C
4	LH	16.5uV	±8	--	±14	16.5uV	±8	.05 bet. A & B NS bet. A & C
	RH	16.5uV	±8	--	±14	17.0uV	±8	.05 bet. A & B NS bet. A & C

Ipsilateral AER's

S		A. Tones Alone		B. Shad. Left	&	Shad. Rt.		Control	P
1	LH	20.5uV	±8	8.25uV	±12	8.25uV	±12	18.5 ±8	.05 bet. A & B .05 bet. A & C NS bet. B & C
	RH	20.5uV	±8	8.25uV	±12	8.25uV	±12	18.5 ±8	.05 bet. A & B .05 bet. A & C NS bet. B & C
2	LH	20.5uV	±8	8.25uV	±12	8.25uV	±12	18 ±8	.05 bet. A & B .05 bet. A & C NS bet. B & C
	RH	24.75uV	±8	8.25uV	±12	8.25uV	±12	24 ±8	.05 bet. A & B .05 bet. A & C NS bet. B & C
3	LH	20.5uV	±8	5.0uV	±12	--	±12	20 ±8	.05 bet. A & B .05 bet. A & C
	RH	18.5uV	±8	8.25uV	±12	--	±12	18 ±8	--
4	LH	16.5uV	±8	--	±12	--	±12	16.5 ±8	.05 bet. A & B .05 bet. A & C
	RH	16.5uV	±8	--	±12	--	±12	17.0 ±8	.05 bet. A & B .05 bet. A & C

Figures 11 & 12: Contralateral and ipsilateral auditory AER's to 65 click presentations under conditions of clicks alone, vs. shadowing familiar material vs. speaking control (Figure 11) with unfamilar material presented to the non-shadowed channel. Calibrations are identical to those in Figure 1.

FIGURE 11

CONTRALATERAL AUDITORY EVOKED RESPONSES

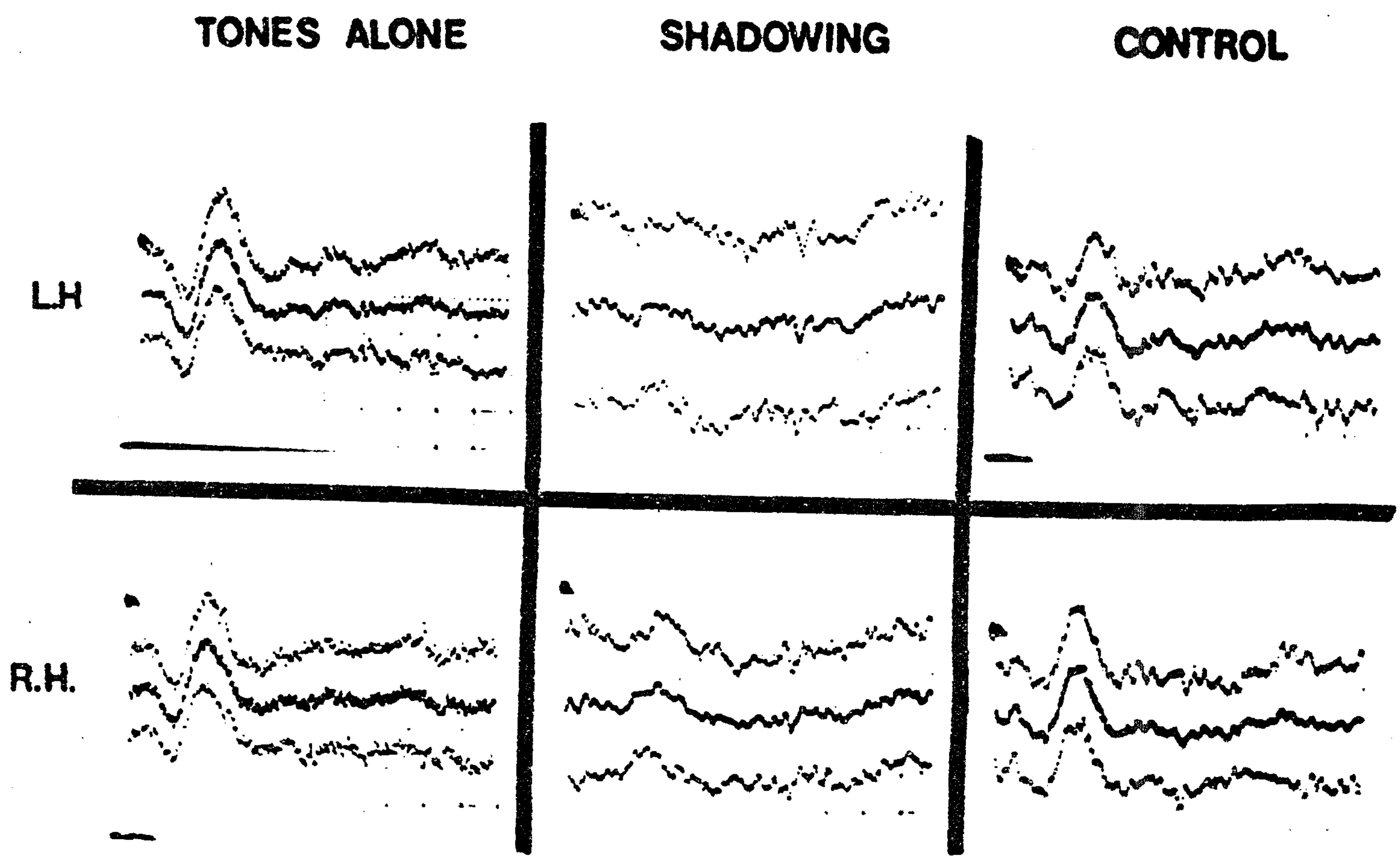
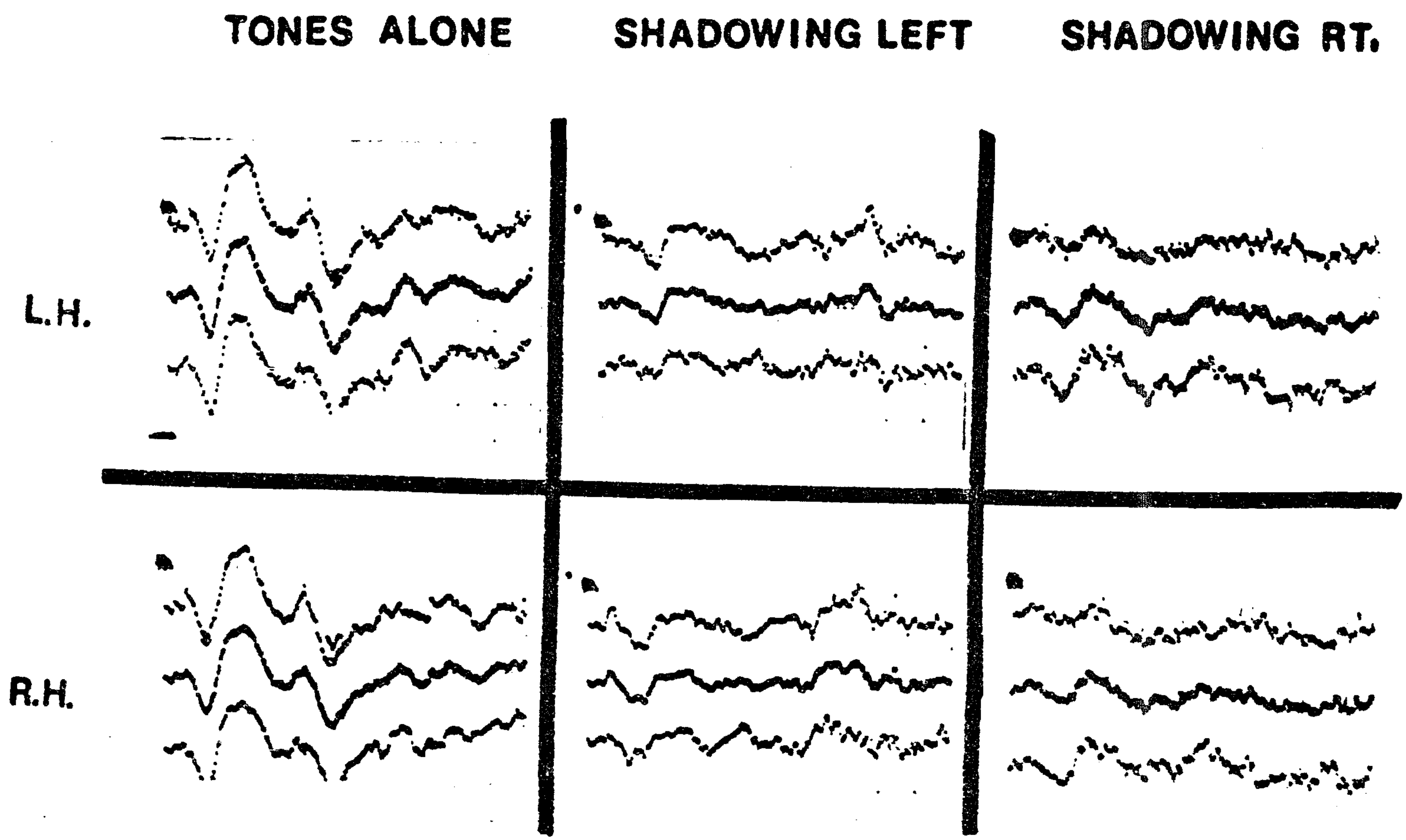


FIGURE 12

IPSILATERAL AUDITORY EVOKED RESPONSES



auditory AER's increased during auditory shadowing.

Since the shadowing task employed in the present experiment resulted in significant effects upon auditory AER's, the question again arose as to whether such a task might affect visual AER's as well. The results of that research are described in the following section.

8. Experiment III(b)

The purpose of Experiment III(b) was to (1) study the effect on the somatosensory AER of (a) familiar material presented to the shadowed channel and (b) unfamiliar material presented to the non-shadowed channel; (2) to investigate further the effects of recall of information from the non-shadowed channel upon visual AER's; (3) to observe the amplitude and variance of visual AER's during a shadowing task in which familiar material is delivered to the shadowed channel.

<u>Results</u>

Table 8 presents findings from four subjects. Figures 13 and 14 are representative waveforms taken from the same subject; the former presents the visual AER $\pm$ 1.0 S.D., the latter presents the visual AER alone. Data were obtained (a) during flash-only presentations, and (b) during shadowing. For all subjects, auditory shadowing of the same material used in the previous experiment resulted in attenuation of the principle component of the visual AER's. For the first subject, the peak-to-peak amplitude of the principle component of the visual AER to light flashes alone = 41.25 uV. During shadowing of the left channel, the visual AER's for the right and left hemispheres were 26.81 uV. and 20.62 uV. respectively. During shadowing of the right channel, visual AER's for the right and left hemispheres were 37.12 uV. and 30.93 uV. respectively. Such laterality differences were not observed among the remaining three subjects. For the second subject, the peak-to-peak amplitude of the visual AER to light flashes alone = 20.5 uV. During shadowing of the left and of the right channel, visual AER's for both hemispheres were 16.5 uV. For the third subject visual AER's to light flashes alone = 20.75 uV.

Table 8: Amplitude of the principle component of the visual evoked response as a function of shadowing vs. non-shadowing

S		A. Flashes Alone		B. Shadow Rt.		C. Shadow Left		P
1	LH	41.25uV	±10	30.93uV	±16	20.62uV	±16	.05 bet. A & B .05 bet. A & C .05 bet. B & C
	RH	41.25uV	±10	37.12uV	±16	26.81uV	±16	.05 bet. A & B .05 bet. A & C .05 bet. B & C
2	LH	20.50uV	±8	16.5uV	±16	16.5uV	±16	NS
	RH	16.50uV	±8	16.5uV	±16	16.5uV	±16	NS
3	LH	20.75uV	±8	12.75uV	±16	14.0uV	±16	.05 bet. A & B .05 bet. A & C NS bet. B & C
	RH	20.75uV	±8	12.75uV	±16	14.00uV	±16	.05 bet. A & B .05 bet. A & C NS bet. B & C
4	LH	24.75uV	±8	16.5uV	±16	10.5uV	±16	.05 bet. A & B .05 bet. A & C .05 bet. B & C
	RH	24.75uV	±8	16.5uV	±16	10.5uV	±16	.05 bet. A & B .05 bet. A & C .05 bet. B & C

Figures 13 & 14: Visual AER's to 65 flash presentations under conditions of flashes alone vs. shadowing familiar material with unfamiliar material presented to the non-shadowed channel.
Figure 13 shows the visual AER $\pm$1.0 S.D.,
Figure 14 shows the visual AER alone. Calibrations are identical to those in Figure 1.

FIGURE 13

VISUAL EVOKED RESPONSES

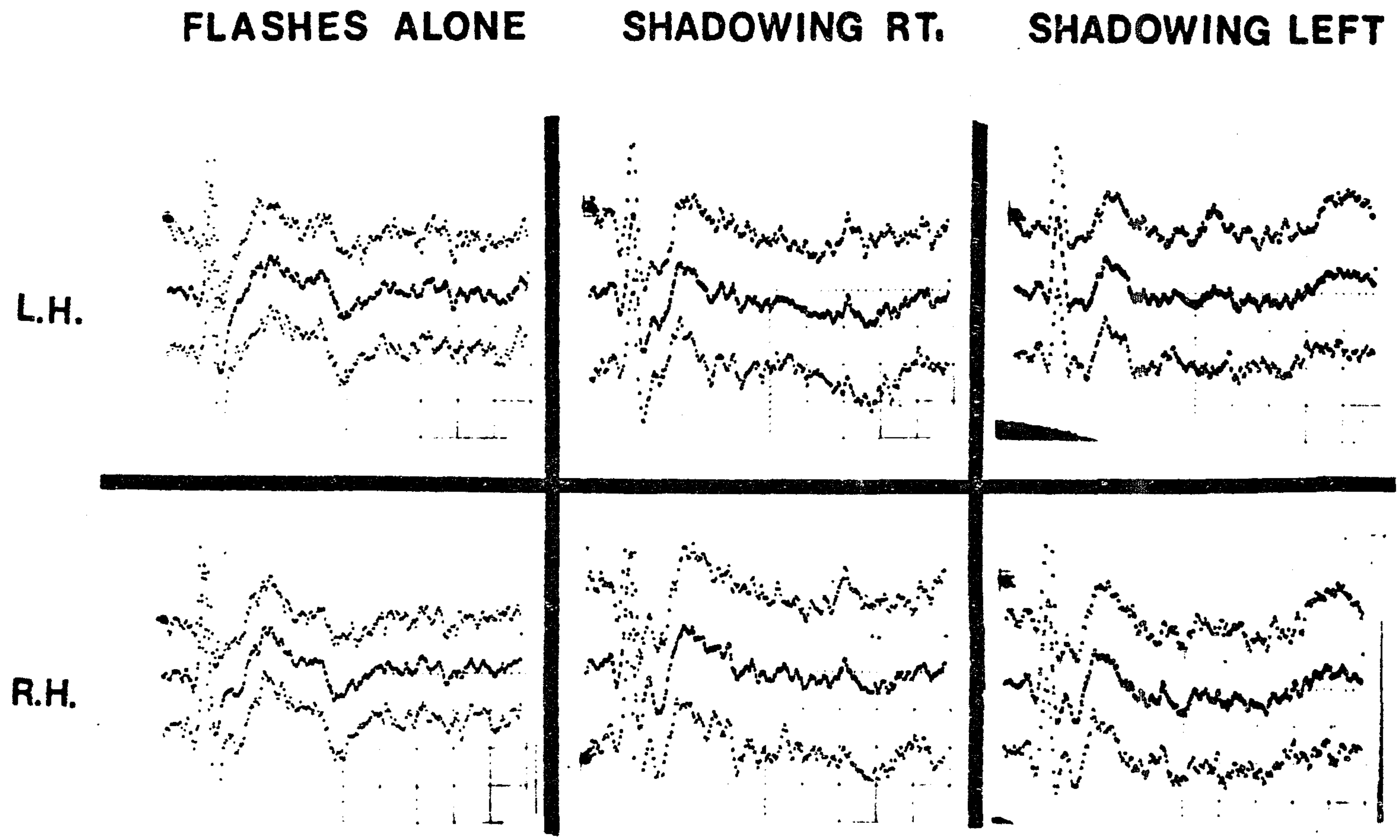
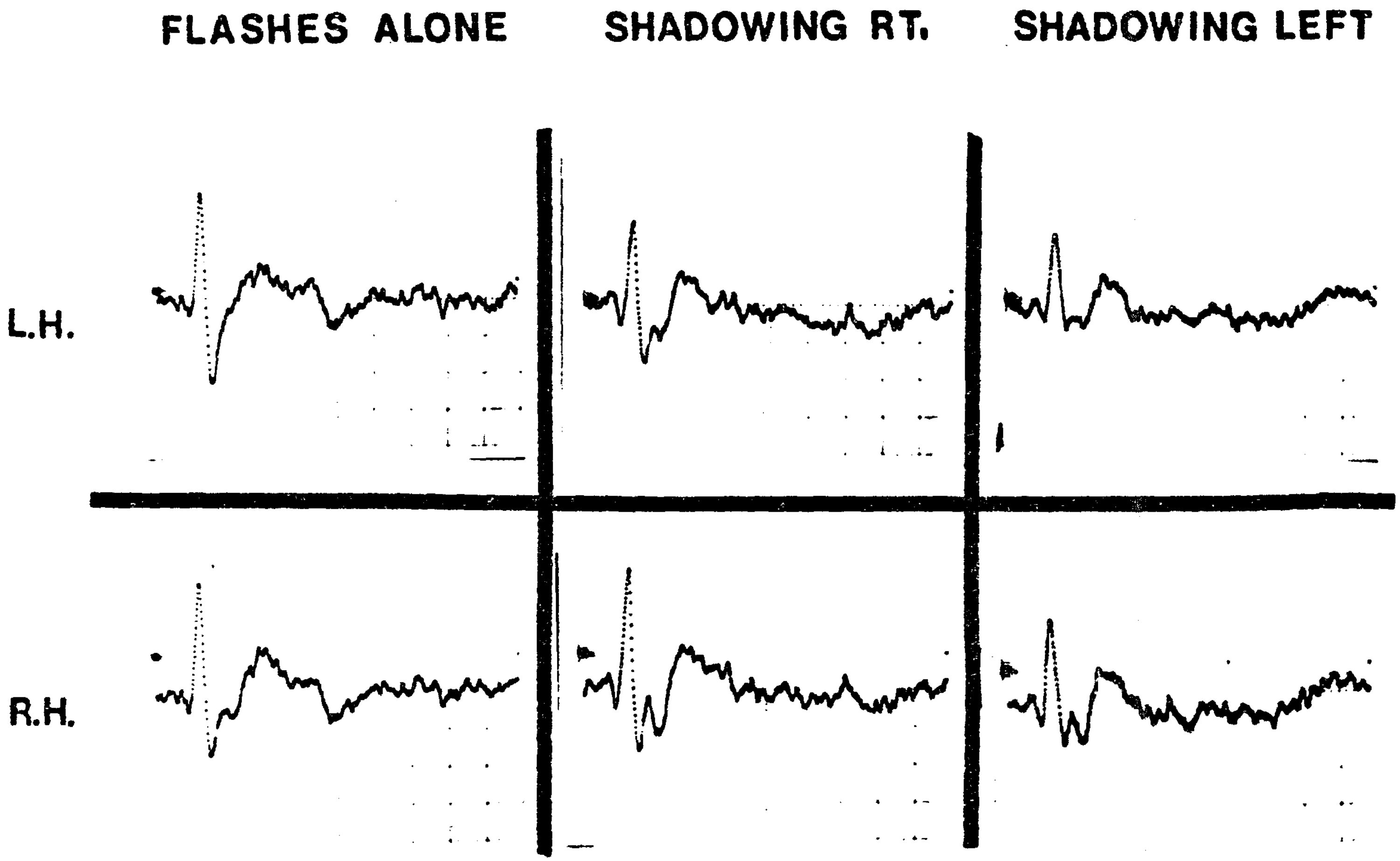


FIGURE 14

VISUAL EVOKED RESPONSES



During shadowing of the left channel the visual AER dropped to 14.0 uV.; while shadowing of the right channel was accompanied by a visual AER of 12.75 uV. For the fourth subject, the visual AER for light flashes alone = 24.75 uV. During shadowing of the left channel, the visual AER dropped to 10.5 uV., while during shadowing of the right channel, the visual AER dropped to 16.5 uV. For two of four subjects, then, the greatest attenuation of the visual AER occurred during shadowing of the <u>left</u> channel. All subjects in the present experiment were right-handed, with the exception of the third subject who was left-handed., and who showed the greatest attenuation of the visual AER during shadowing of the <u>right</u> channel.

All subjects estimated the number of light flashes present at "somewhere between 30 and 40." Actually, 65 such presentations occurred. Recall of the material presented in the non-shadowed channel was negligible, while shadowing accuracy ranged between 95% and 98%.

b. <u>AER related variance</u>:

For all subjects, the variance surrounding the visual AER's showed increases during auditory shadowing, as opposed to that related to visual AER's in the flash-only presentations.

In the following experiment, the identical shadowing task as used in Experiments III(a) and (b) was employed with presentations of cutaneous stimuli.

9. Experiment III(c)

The objectives of Experiment III(c) were: (1) to study the effect on the somatosensory AER of (a) familiar material presented to the shadowed channel and (b) unfamiliar material presented to the non-shadowed channel; (2) to study further the effects of shadowing upon laterality differences; (3) to observe the amplitude and variance of somatosensory AER's during a task in which familiar material is delivered to the shadowed channel.

Results

Table 9 presents data for four subjects. Figures 15 and 16 are representative waveforms. The separate waveforms were obtained (a) during presentation of cutaneous stimuli alone, (b) during shadowing + cutaneous stimuli, and (c) during subjects' counting aloud + cutaneous stimuli. Subjects 1, 2, and 3 were right-handed, while the fourth subject was left-handed. For the first two subjects, attenuation of peak-to-peak amplitude of somatosensory AER's is observed <u>only</u> when cutaneous stimuli are presented to the <u>right</u> forefinger during auditory shadowing. For the first subject, the principle component of the somatosensory AER's dropped from 20.75 uV. (when cutaneous stimuli alone are presented) to 16.50 uV. and 14.90 uV. during shadowing of the left and right channels respectively. For the second subject, somatosensory AER's fell from 20.75 uV. (when cutaneous stimuli were presented to the right side alone) to 16.50 uV. and 12.40 uV. during shadowing of the left and right channels respectively. No changes in somatosensory AER amplitude for subjects 1 and 2 were observed when cutaneous stimuli were presented to the left side during shadowing. The third subject showed a similar attenuation of peak-to-peak amplitude in somatosensory AER's when cutaneous stimuli

Table 9: Amplitude of the principle component of the somatosensory average evoked response under conditions of shadowing, and of cutaneous stimuli presented alone

S		A. Cutan. Stim. Rt.		B. Shadow Left		C. Shadow Rt.		P
1	LH	20.75uV	±8	16.5uv	±16	14.9uV	±16	.05 bet. A & B .05 bet. A & C NS bet. B & C
	RH	20.75uV	±8	16.5uV	±16	14.9uV	±16	.05 bet. A & B .05 bet. A & C NS bet. B & C
2	LH	20.75uV	±8	16.5uV	±16	12.4uV	±16	.05 bet. A & B .05 bet. A & C .05 bet. B & C
	RH	20.75uV	±8	16.5uV	±16	12.4uV	±16	.05 bet. A & B .05 bet. A & C .05 bet. B & C
3	LH	15.0uV	±10	8.25uV	±10	4.12uV	±10	.05 bet. A & B .05 bet. A & C NS bet. B & C
	RH	15.0uV	±10	8.25uV	±10	8.25uV	±10	.05 bet. A & B .05 bet. A & C NS bet. B & C
4	LH	16.5uV	±10	8.25uV	±10	4.12uV	±10	.05 bet. A & B .05 bet. A & C .05 bet. B & C
	RH	16.5uV	±10	8.25uV	±10	4.12uV	±10	.05 bet. A & B .05 bet. A & C .05 bet. B & C

S		A. Cutan. Stim. Left		B. Shadow Left		C. Shadow Rt.		P
1	LH	16.5uV	±8	16.5uV	±16	16.5uV	±16	NS
	RH	16.5uV	±8	16.5uV	±16	16.5uV	±16	NS
2	LH	22.5uV	±8	20.75uV	±16	24.75uV	±16	NS
	RH	20.75uV	±8	18.uV	±16	24.75uV	±16	NS
3	LH	15.0uV	±10	8.25uV	±10	12.25uV	±10	.05 bet. A & B .05 bet. A & C NS bet. A & C
	RH	12.25uV	±10	8.25uV	±10	12.25uV	±10	.05 bet. A & B NS bet. A & C .05 bet. B & C
4	LH	12.62uV	±10	8.25uV	±10	8.25uV	±10	.05 bet. A & B .05 bet. A & C NS bet. B & C
	RH	12.62uV	±10	8.25uV	±10	8.25uV	±10	.05 bet. A & B .05 bet. A & C NS bet. B & C

NS between tones alone and speaking controls

Table 9 (continued)

S	Control
1	20
	20
2	20
	20
3	16.0
	16.0
4	16.0
	16.0

were presented to the right side during shadowing; the AER's fell from 12.62 uV., when tactile stimuli were presented alone, to 8.25 uV. and 6.45 uV. during shadowing of the left and right channels respectively. In addition, the third subject showed no attenuation in peak-to-peak amplitude of somatosensory AER's when cutaneous stimuli were presented to the left side, except when shadowing the left channel (peak-to-peak amplitudes were 12.62 uV., 12.62 uV., and 8.25 uV. for conditions of cutaneous stimuli presented alone to the left side, during shadowing of the right; and the left channel respectively). For the fourth subject, who was left-handed, the effects of shadowing upon the principle component of the somatosensory AER's were observed when cutaneous stimuli were presented to both the left and the right sides. The peak-to-peak AER amplitude for cutaneous stimuli presented alone to the right side was 19.70 uV. During shadowing of the left channel, the peak-to-peak amplitude fell to 8.25 uV., and to 4.12 uV. during shadowing of the right channel. For cutaneous stimuli presented to the left side, the peak-to-peak AER was 12.62 uV. when tactile stimuli alone were presented; as compared with peak-to-peak AER's of 8.25 uV. during shadowing of the left or right channel. That the effects were not due to mere vocalization can be seen in Figure 16 which shows somatosensory AER's under conditions of subjects counting aloud at a rate of 2 integers per second. In addition, the P350 component of the somatosensory AER was unattenuated during shadowing for two of the four subjects. For subjects 1 and 2, estimates of the number of stimuli presented were "between 20 and 30" when stimuli were presented to the right side during shadowing and "between 50-60" when stimuli were presented to the left side during shadowing. The third subject estimated the number of stimuli presented

Figures 15 & 16: Somatosensory AER's ± 1.0 S.D. to cutaneous stimuli presented to the right and left forefingers respectively under conditions of 65 cutaneous stimuli presented alone vs. under conditions of shadowing familiar material with unfamiliar material presented to the non-shadowed channel.

FIGURE
15

SOMATOSENSORY EVOKED RESPONSES

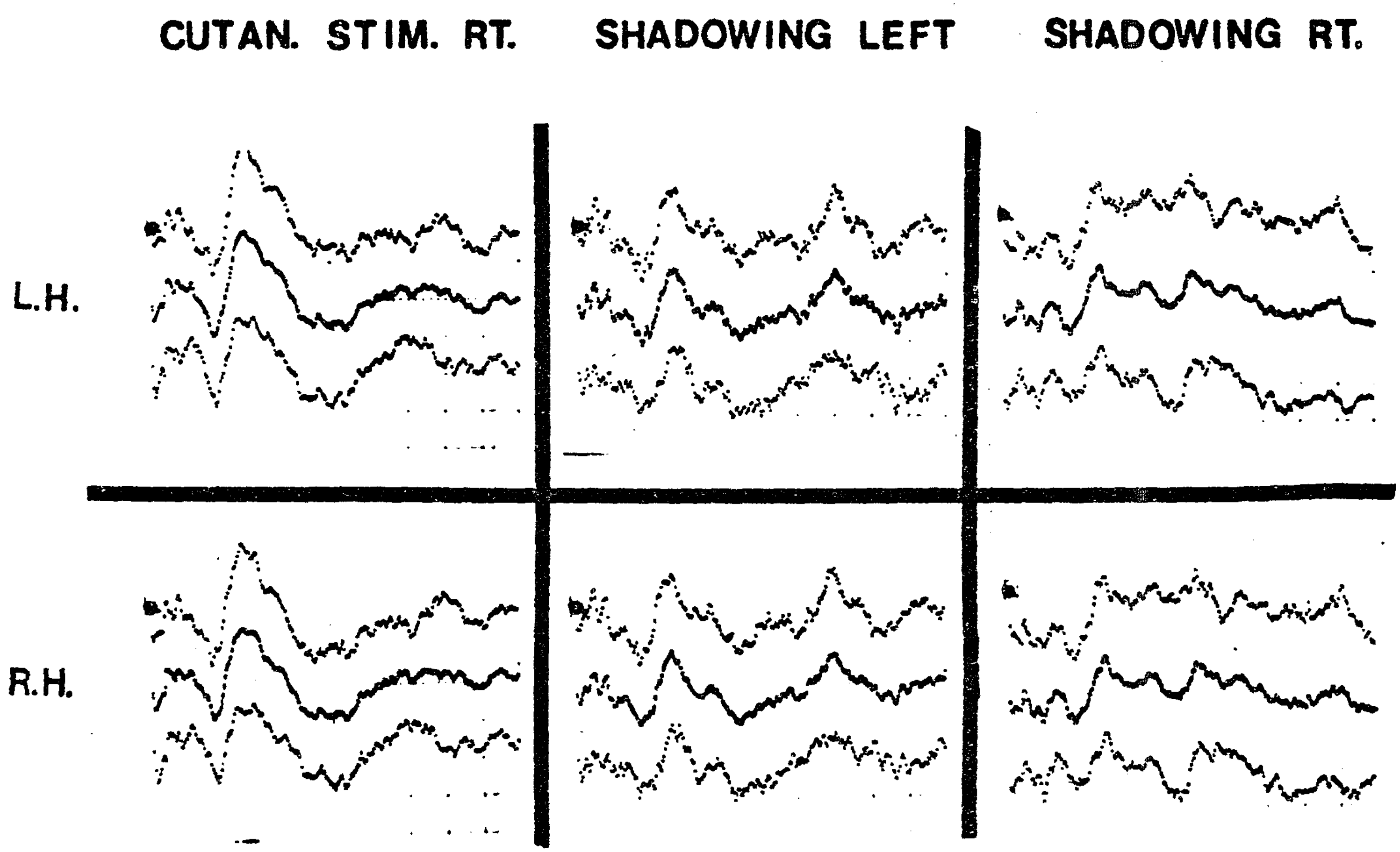


FIGURE 16

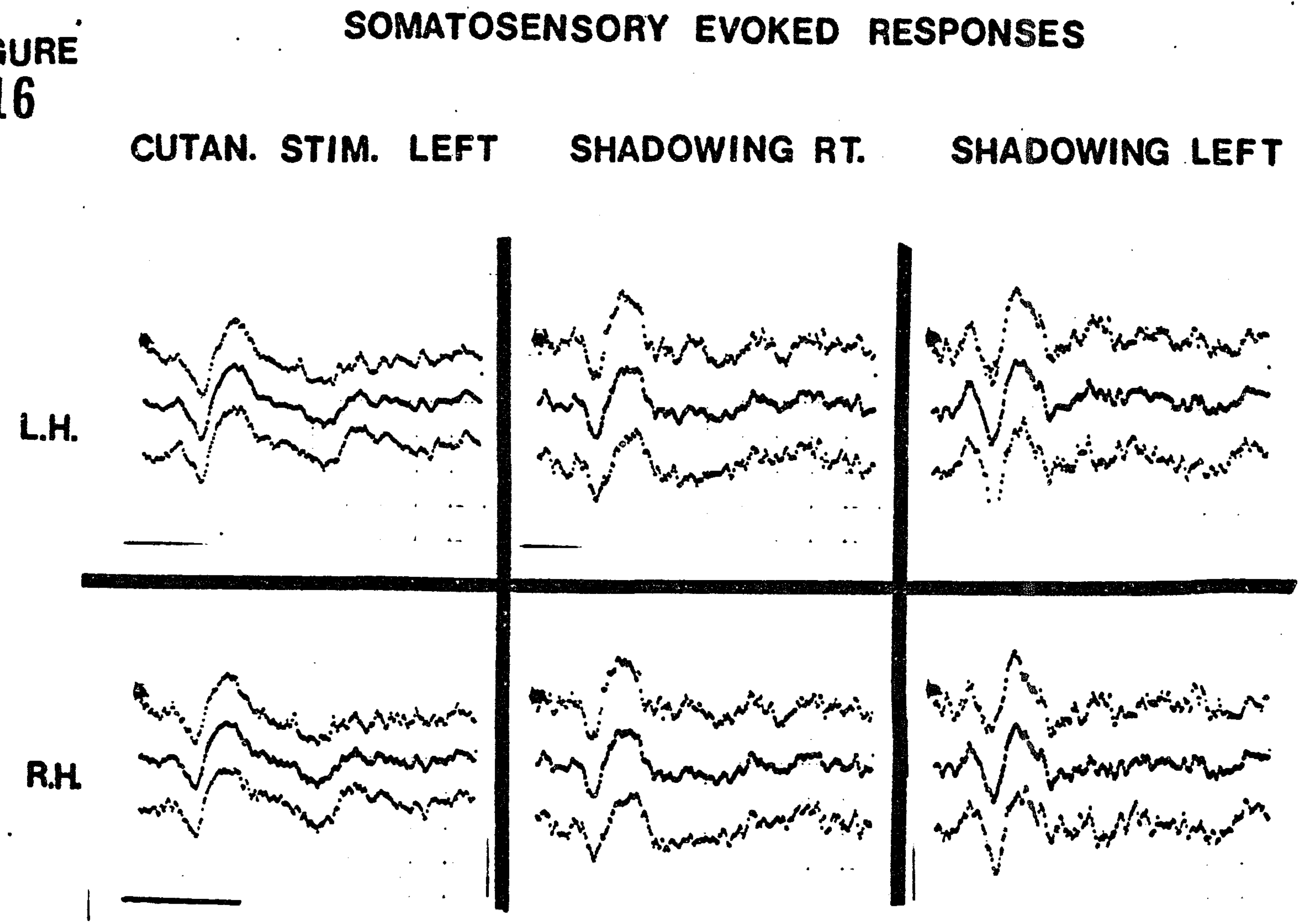
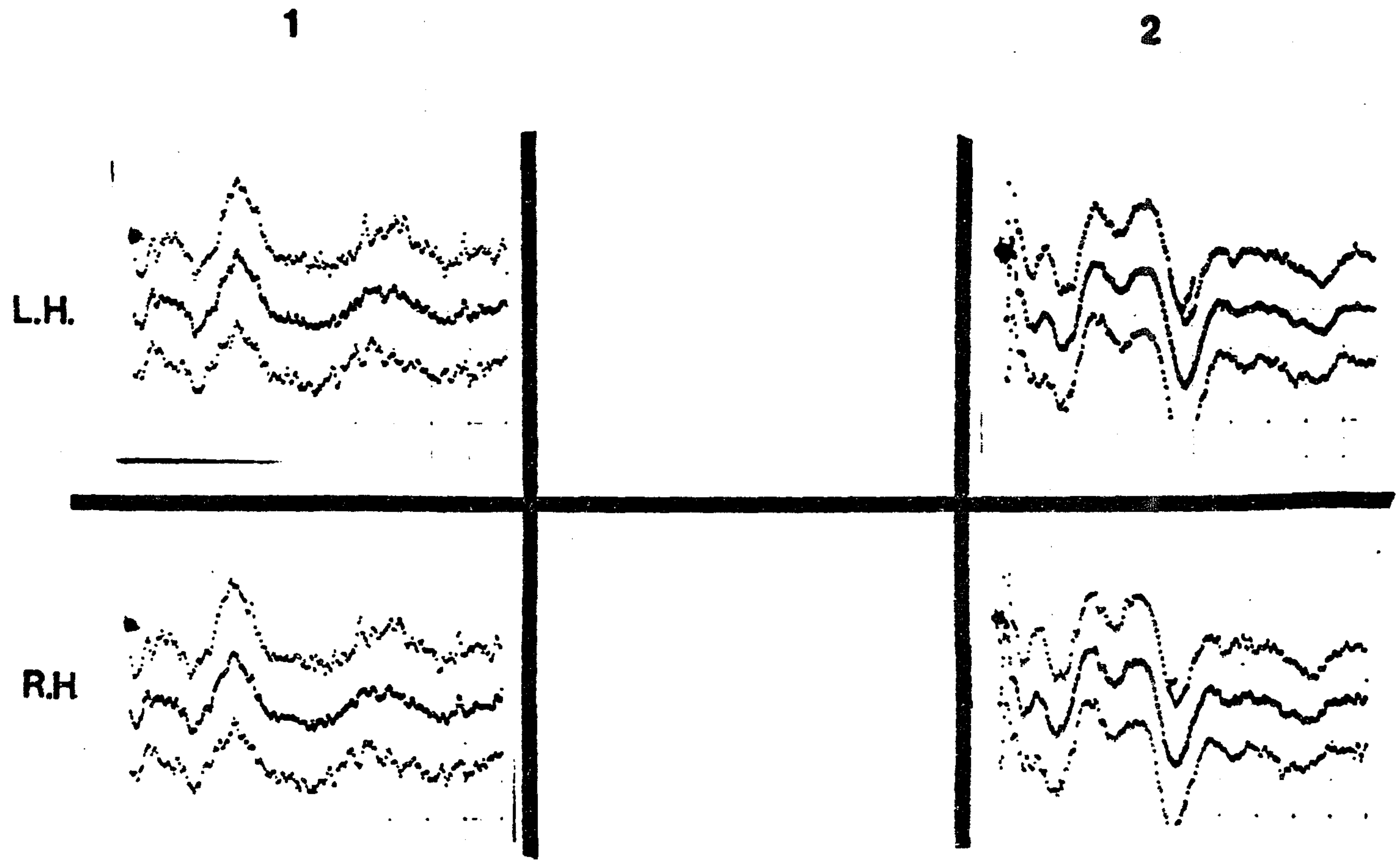

SOMATOSENSORY EVOKED RESPONSES
CUTAN. STIM. LEFT
SHADOWING RT.
SHADOWING LEFT
L.H.
R.H.

Figure 17: Somatosensory AER's to 65 cutaneous stimuli while subject counted aloud at a rate of 2 integers/sec. Calibrations are identical to those in Figure 1.

FIGURE 17

SOMATOSENSORY EVOKED RESPONSES

SPEAKING CONTROL



as being between 20 and 30 when stimuli were presented to the right side during shadowing; between 40 and 50 when stimuli were presented to the left side while shadowing the right channel, and between 20 and 30 when stimuli were presented to the left side during shadowing of the left channel. For the fourth subject, estimates ranged between 20 and 30 during shadowing regardless of which side received the cutaneous stimuli.

All subjects showed shadowing accuracy between 95% and 98%, while recall of the non-shadowed channel was negligible.

b. AER-related variance:

For subjects 1 and 2, the variance surrounding the somatosensory AER's increased during shadowing; while subjects 3 and 4 showed no such changes in variance during shadowing.

In summary, for the identical shadowing task in which subjects' accuracy ranged from 95% to 98% correct, but in which recall of the material presented in the non-shadowed channel was negligible,

1. Auditory AER's to tone-clicks were not observed only when the stimuli were presented to the non-shadowed channel. When tone-clicks were delivered to the shadowed channel, auditory AER's reappeared, although markedly attenuated. Subjects reported having heard no tone-clicks when stimuli were delivered to the non-shadowed channel; while estimates of the number of tone-clicks presented ranged from 15 to 20 when stimuli were presented to the shadowed channel.
2. Visual AER's to light flashes were markedly attenuated during auditory shadowing; some laterality effects were observed: in that for right-handed subjects, attenuation of the visual AER

was greatest during shadowing of the <u>left</u> channel, while for the left-handed subject greatest visual AER attenuation occurred during shadowing of the right channel. Estimates of light flashes presented ranged from 30 to 40 (65 were actually presented).

3. Somatosensory AER's were differentially affected, with two subjects showing attenuation only when cutaneous stimuli were presented to the <u>right</u> side, (subjects were right-handed), one subject showing attenuation of AER's when cutaneous stimuli were presented to <u>either</u> side (subject was left-handed).
4. Increases in the variance surrounding auditory and visual AER's were observed during shadowing, while for somatosensory AER's, variance increases during shadowing were observed for 2 subjects while 2 subjects showed no such increases in variance during shadowing.

In the first three sets of experiments, either one or both channels contained messages unfamiliar to the subjects. The difficulty of the shadowing task and the ability to recall information delivered to the non-shadowed channel was found to have an effect on AER's across sensory modalities.

In the following experiments, subjects were asked to shadow messages whose content was familiar to them, while the non-shadowed channel contained highly familiar information as well. The results of this research are described on the following pages.

10. Experiment IV(a)

The purpose of Experiment IV(a) was: (1) to study the effect on the auditory AER of (a) familiar material to both the shadowed and non-shadowed channels; (2) to study further the effects of recall of information delivered to the non-shadowed channel upon auditory AER's; (3) to observe the amplitude and variance of auditory AER's during a shadowing task in which highly familiar material is delivered to both the shadowed and non-shadowed channels.

Results

Table 10 presents findings from four subjects. Figures 18 and 19 are representative waveforms.

For all subjects, auditory AER's appeared during shadowing of either channel, but the peak-to-peak amplitude of the principle component was markedly attenuated. This finding coincided with subjective estimates of having heard between 5 and 15 tone-clicks. For the first subject, peak-to-peak amplitude of the auditory AER decreased from 16.5 uV. when tone-clicks were presented to the right side alone to 6.65 uV. during shadowing of either the right or the left channel. Presentation of tone-clicks alone to the left side resulted in an AER with a peak-to-peak amplitude of 14.5 uV. Shadowing of the right and left channels resulted in AER's with peak-to-peak amplitudes of 8.25 and 4.8 uV. respectively. Subjective estimates of the number of tone-clicks presented were 70, 5-10, and 2-3 tones for conditions of tone-clicks alone, shadowing the right and left channels respectively. When tones were presented to the right ear, estimates of their number were 60, 4, and 5-7

Table 10: Amplitude of the principle component of the contralateral and ipsilateral auditory average evoked responses as a function of shadowing vs. tones alone

Contralateral Auditory AER's

S		A. Tones Alone		B. Shadowing		C. Control		P
1	LH	16.5uV	±8	6.65uV	±14	17.0uV	±10	.05 bet. A & B NS bet. A & C .05 bet. B & C
	RH	16.5uV	±8	6.65uV	±14	16.5uV	±10	.05 bet. A & B NS bet. A & C .05 bet. B & C
2	LH	24.75uV	±8	8.25uV	±14	20.5uV	±10	.05 bet. A & B NS bet. A & C .05 bet. B & C
	RH	22.7uV	±8	8.25uV	±14	18.5uV	±10	.05 bet. A & B NS bet. A & C .05 bet. B & C
3	LH	17.5uV	±8	8.25uV	±14	16.5uV	±10	.05 bet. A & B NS bet. A & C .05 bet. B & C
	RH	16.5uV	±8	8.25uV	±14	16.5uV	±10	.05 bet. A & B NS bet. A & C .05 bet. B & C
4	LH	16.5uV	±8	10.5uV	±8	16.5uV	±8	.05 bet. A & B NS bet. A & C .05 bet. B & C
	RH	15.0uV	±8	8.25uV	±8	16.5uV	±8	.05 bet. A & B NS bet. A & C .05 bet. B & C

Ipsilateral Auditory AER's

S		A. Tones Alone		B. Shadow. Left & Shadow Rt.			Control		P
1	LH	14.5uV	±8	8.25uV	6.65uV	±8	14	±8	.05 bet. A & B .05 bet. A & C NS bet. B & C
	RH	14.5uV	±8	4.8uV	4.8uV	±8	14	±8	.05 bet. A & B .05 bet. A & C NS bet. B & C

Table 10

S		A. Tones Alone		B. Shadow Left &		Shadow Rt.	Control		P
2	LH	22.7uV	±8	8.25uV	±14	10.31uV	20.5	±14	.05 bet. A & B .05 bet. A & C NS bet. B & C
	RH	22.7uV	±8	8.25uV	±14	10.31uV	20.5	±14	.05 bet. A & B .05 bet. A & C NS bet. B & C
3	LH	16.5uV	±8	8.25uV	±14	4.12uV	16	±14	.05 bet. A & B .05 bet. A & C NS bet. B & C
	RH	14.4uV	±8	6.65uV	±14	4.8uV	14	±14	.05 bet. A & B .05 bet. A & C NS bet. B & C
4	LH	16.5uV	±8	10.55uV	±14	8.25uV	16	±14	.05 bet. A & B .05 bet. A & C NS bet. B & C
	RH	16.5uV	±8	7.84uV	±14	8.25uV	16	±14	.05 bet. A & B .05 bet. A & C NS bet. B & C

Figures 18 & 19: Contralateral and ipsilateral auditory AER's ± 1.0 S.D. to 65 click presentations under conditions of clicks alone vs. shadowing familiar material vs. speaking control. Familiar material was presented to the non-shadowed channel. Calibrations are identical to those in Figure 1.

FIGURE
18

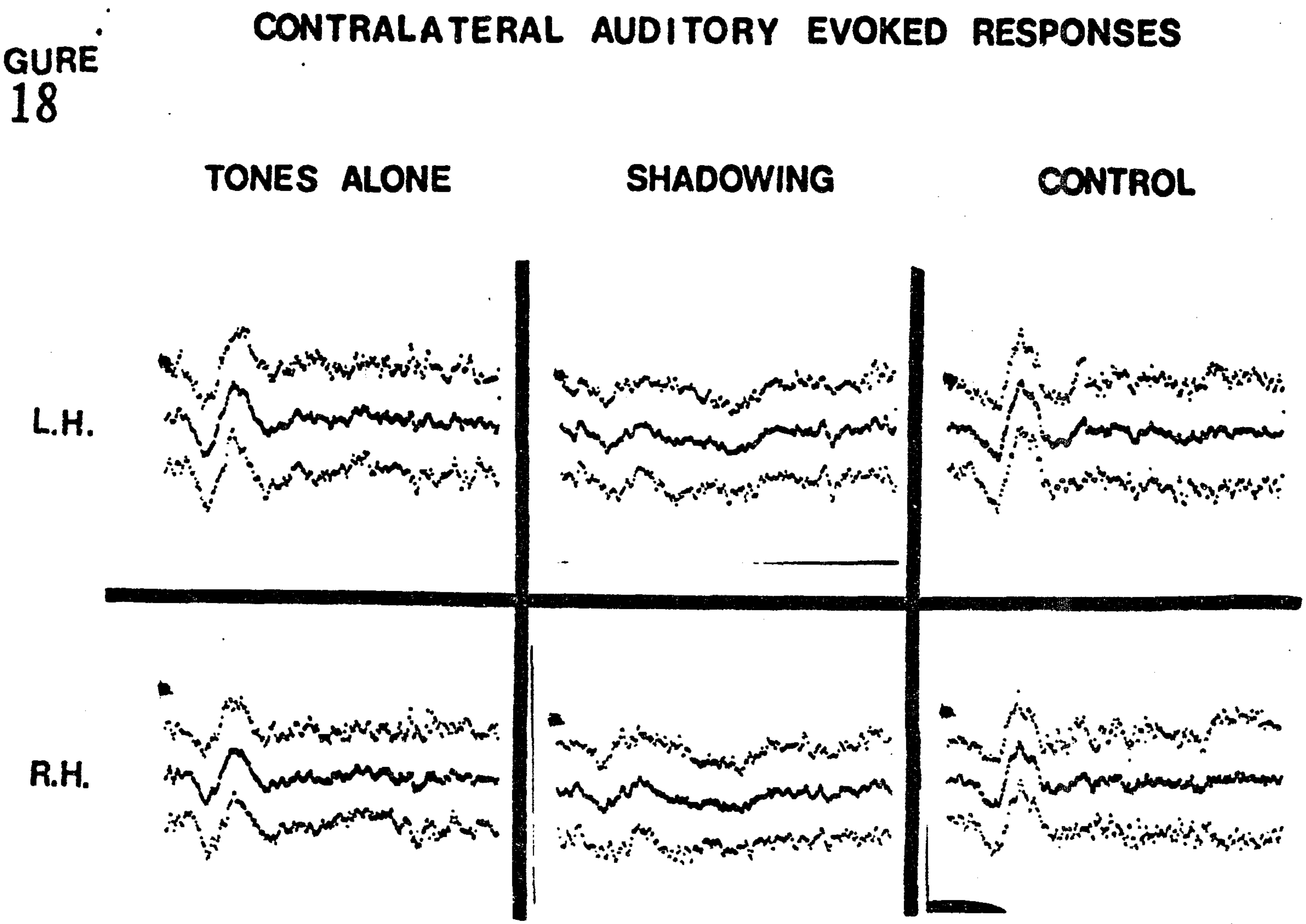
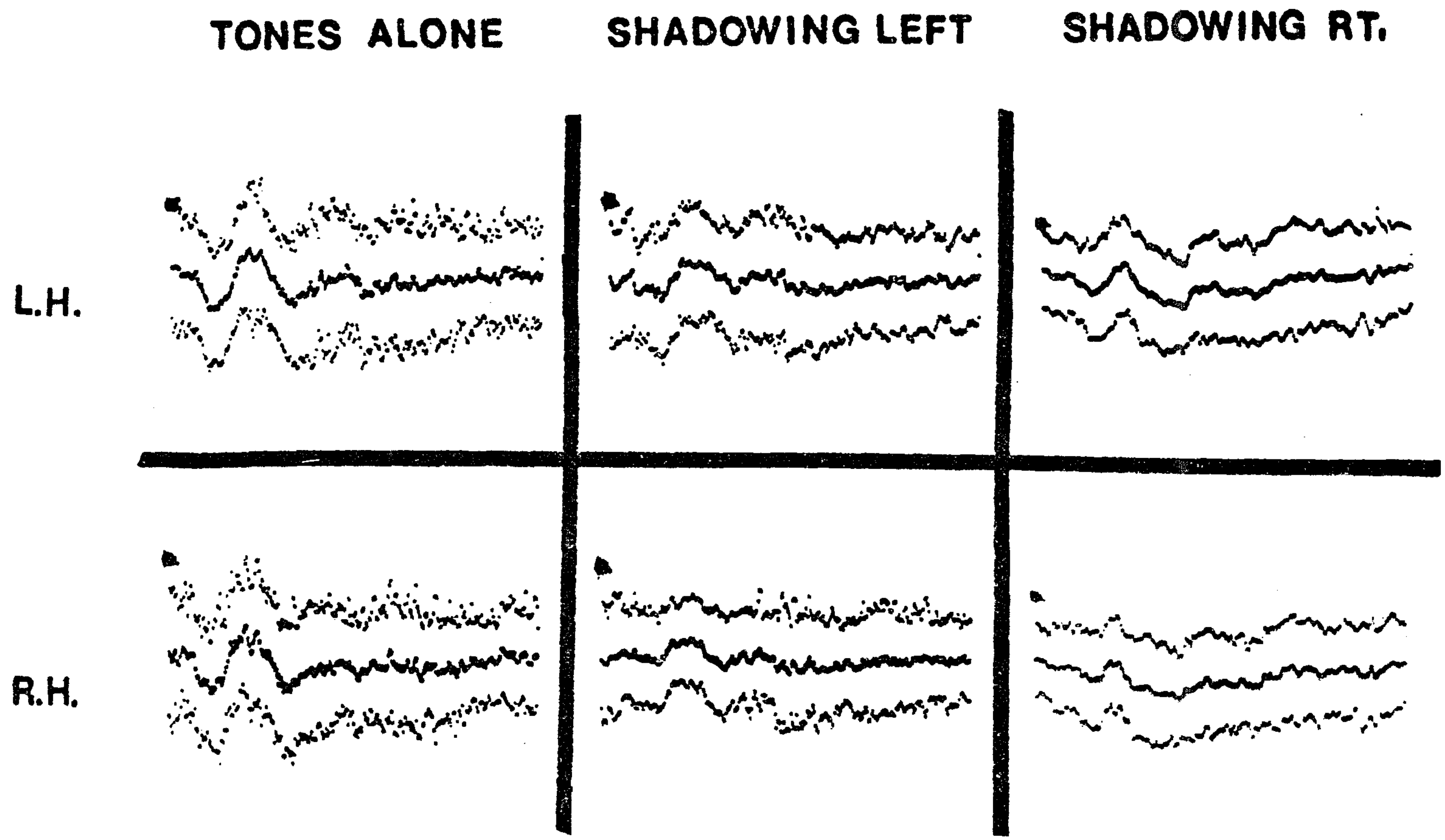

CONTRALATERAL AUDITORY EVOKED RESPONSES
TONES ALONE
SHADOWING
CONTROL
L.H.
R.H.

FIGURE
19

IPSILATERAL AUDITORY EVOKED RESPONSES



for conditions of tone-click alone, and shadowing of the left and right channels respectively.

For the second subject, amplitude of the principle component of the auditory AER was 22.7 uV. when tone-clicks to the right ear were presented alone as compared with AER's of 8.25 uV. and 10.31 uV. during shadowing of the left and right channels respectively. For tone-click presentations to the left ear, AER's were 22.7 uV. when stimuli were presented alone as compared with AER's of 6.4 uV. during shadowing of the right and left channels respectively. Subjective estimates of the number of tone-clicks presented were 50-60 when tones alone were presented as compared with 5-10 during all shadowing conditions.

For the third subject, the peak-to-peak amplitude of the auditory AER was 14.4 uV. when tone-clicks to the right ear were presented alone as compared with AER's of 8.25 uV. and 4.8 uV. during shadowing of the left and right channels respectively. Subjective estimates of the number of tone-clicks presented were 60, 10-15, and 10-15 for tone-clicks presented alone and shadowing of the left and right channels respectively. For tone-click presentations to the left ear, AER's were 16.50 uV. when stimuli were presented alone as compared with 4.12 uV. during shadowing of the right channel. Estimates of the number of tone-clicks presented were 60-70 when stimuli were presented alone as compared with 5-10 during shadowing of the right channel.

For the fourth subject, the peak-to-peak amplitude of the auditory AER was 16.5 uV. when tone-clicks alone were presented to the right ear, as compared with AER's of 10.55 uV. and 8.25 uV. during shadowing of the left and right channels respectively. Subjective estimates of the number of tone-clicks presented were 70, when tone-clicks were presented alone, 5-10 during shadowing of the left channel, and 5 during shadowing of the right channel. When tone-clicks alone were presented to the left ear, the auditory AER was 16.5 uV. as comapred with AER's of 7.84 uV. during shadowing of the right channel and 11.20 uV. during shadowing of the left channel. Subjective estimates of the number of tone-clicks presented were 70 when such stimuli were presented alone, 5-10 during shadowing of the right channel, and 10 during shadowing of the left channel.

Subjects demonstrated recall of between 50% and 60% of the material delivered to the non-shadowed channel, and shadowing accuracy was between 95% and 99%. That the effects were not due to simple vocalization can be seen in Figure 17 which shows the amplitudes of auditory AER's while subjects counted aloud. These auditory AER's were not significantly different from those obtained when tone-clicks were presented alone.

b. AER-related variance:

Increases in the variance surrounding auditory AER's during shadowing were observed in three of four subjects, while one subject revealed no changes in variance across all experimental conditions.

Such changes in the characteristics of the auditory AER raised questions as to the possible effects of present shadowing task upon the visual AER. The results of that research are described in the following section.

11. Experiment IV(b)

The purpose of Experiment IV(b) was: (1) to study the effect on the visual AER of (a) familiar material presented to both the shadowed and non-shadowed channels; (2) to observe amplitude and variance of visual AER's during a shadowing task involving highly familiar material presented to both channels; (3) to investigate further the effects of recall of non-shadowed material upon the principle components of the visual AER.

Results

Table 11 shows findings from four subjects. Figures 19 and 20 are representative waveforms.

For all subjects, auditory shadowing of the same material used in the previous experiment resulted in attenuation of visual AER's. For the first subject, the amplitude of the principle component of the visual AER to light flashes only was 30.35 uV. During shadowing of the left and then of the right channel, peak-to-peak amplitudes of the visual AER were 20.62 uV. and 20.62 uV. respectively. The subject estimated the number of flashes presented as 60, 30 and 35 for conditions of flash-alone, shadowing left channel, and shadowing the right channel respectively.

For the second subject, the peak-to-peak amplitude of the principle visual AER component to light flashes alone was 16.5 uV. During shadowing of the left and then the right channel, the peak-to-peak amplitudes of the visual AER were 12.0 uV. and 10.4 uV. respectively. The subject estimated the number of light flashes presented as 70 during flash-only presentation, and as 25-35 during both shadowing tasks. Actually 65 flashes were presented.

Table 11: Amplitude of the principle component of the visual evoked response under conditions of shadowing vs. non-shadowing

S		A. Flashes Alone		B. Shadow Rt.		C. Shadow Left		P
1	LH	30.35uV	±8	20.62uV	±16	20.62uV	±16	.05 bet. A & B .05 bet. A & C NS bet. B & C
	RH	30.35uV	±8	20.62uV	±16	20.62uV	±16	.05 bet. A & B .05 bet. A & C NS bet. B & C
2	LH	16.5uV	±8	12.uV	±9	10.4uV	±9	.05 bet. A & B .05 bet. A & C NS bet. B & C
	RH	16.5uV	±8	8.25uV	±9	8.25uV	±9	.05 bet. A & B .05 bet. A & C NS bet. B & C
3	LH	19.75uV	±8	16.5uV	±8	16.5uV	±8	.05 bet. A & B .05 bet. A & C NS bet. B & C
	RH	19.75uV	±8	16.5uV	±8	16.5uV	±8	.05 bet. A & B .05 bet. A & C NS bet. B & C
4	LH	20.5uV	±8	12.5uV	±9	12.5uV	±9	.05 bet. A & B .05 bet. A & C NS bet. B & C
	RH	20.5uV	±8	12.5uV	±9	12.5uV	±9	.05 bet. A & B .05 bet. A & C NS bet. B & C

Figure 20: Visual evoked responses from one subject under conditions of non-shadowing (flashes alone) and shadowing the right and left channel. Calibrations are identical to those in Figure 1.

FIGURE 20

VISUAL EVOKED RESPONSES

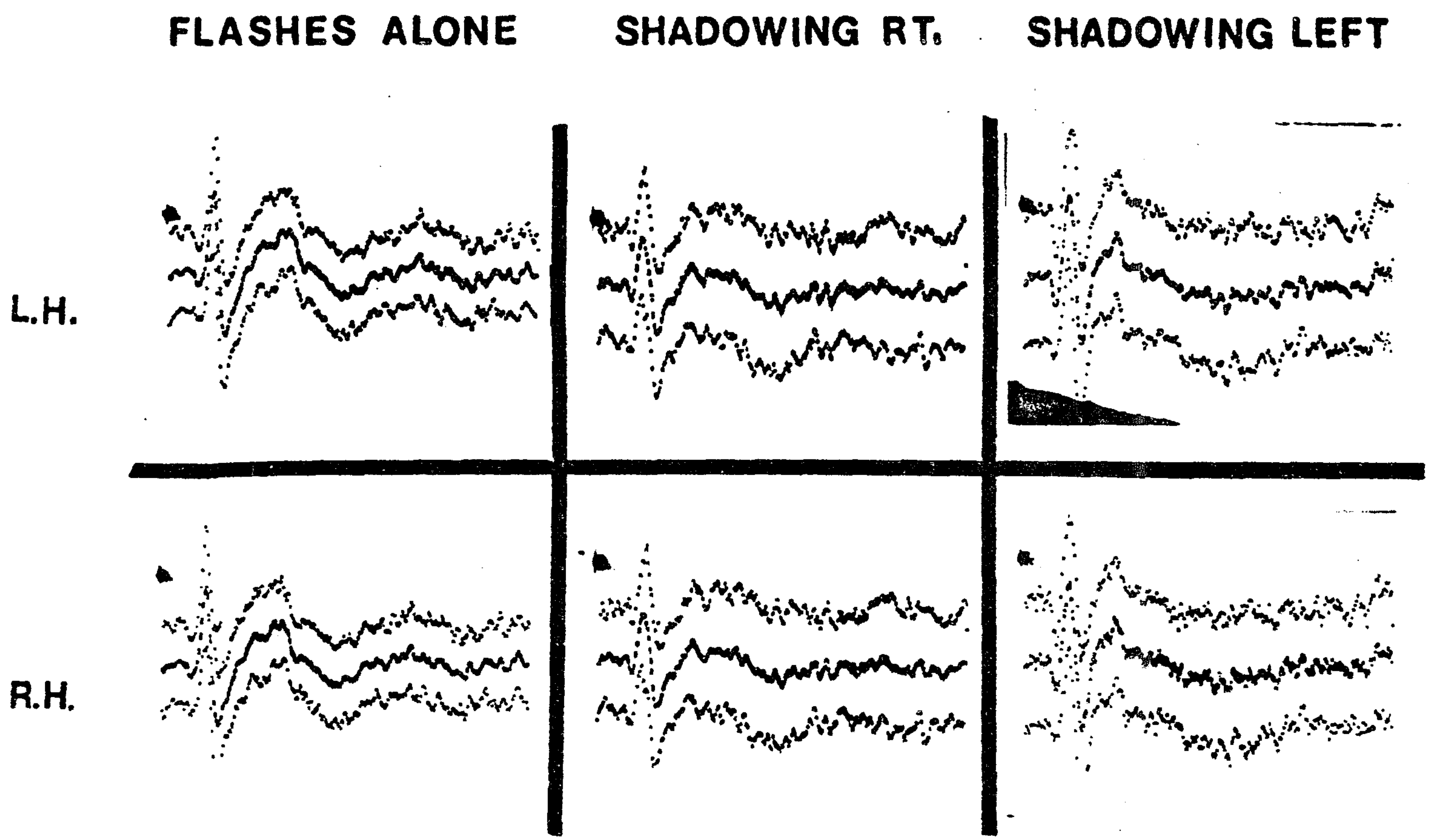
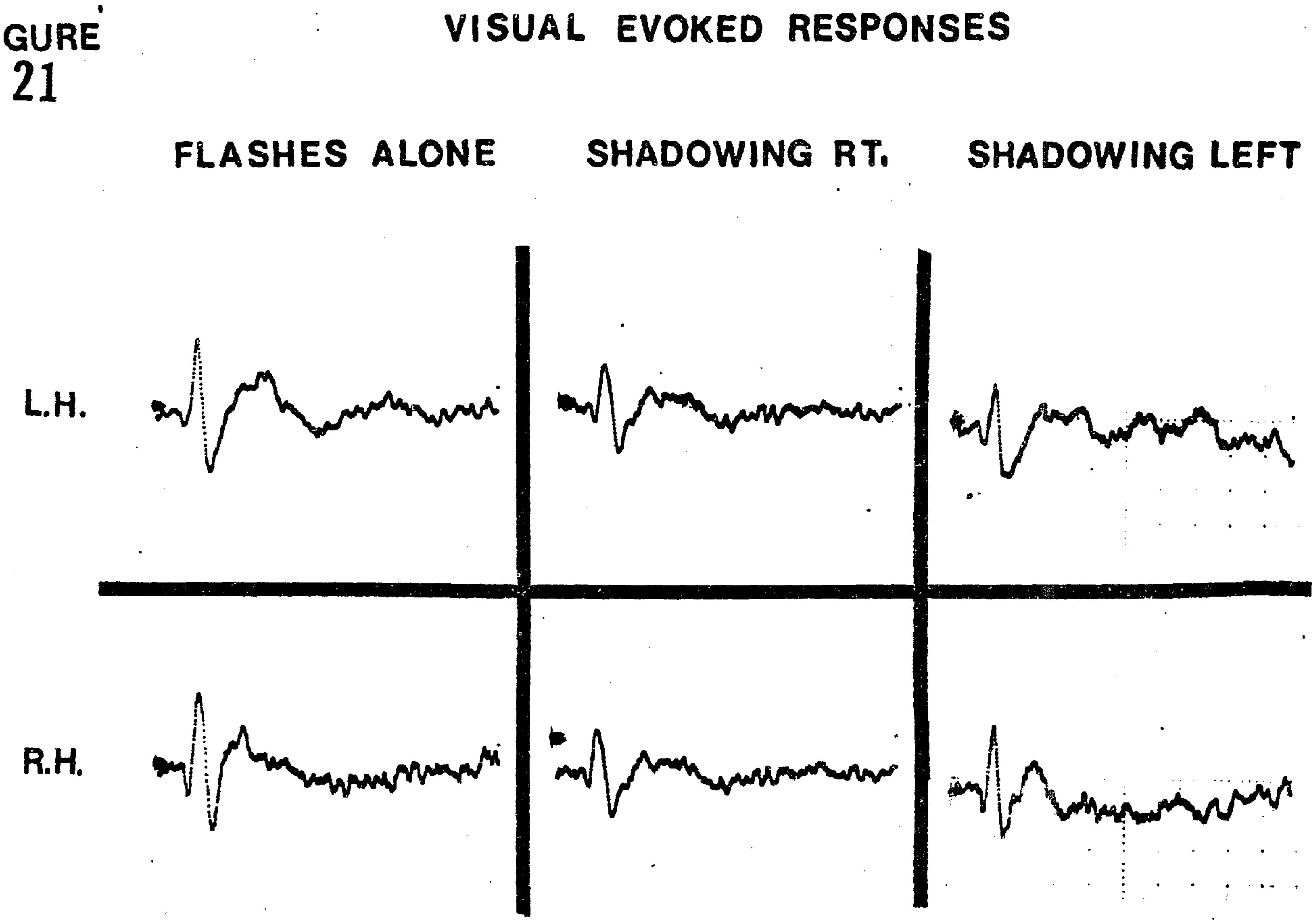


Figure 21: Visual evoked responses (means only) from one subject under conditions of non-shadowing (flashes alone) and shadowing the right and left channel. Calibrations are identical to those in Figure 1.

FIGURE 21


VISUAL EVOKED RESPONSES
FLASHES ALONE
SHADOWING RT.
SHADOWING LEFT
L.H.
R.H.

Peak-to-peak amplitude of the visual AER to light flashes alone for the third subject was 19.75 uV. During shadowing of the left and then the right channels, peak-to-peak amplitudes of the visual AER were 16.50 uV. and 16.25 uV. respectively. Subjective estiamtes of the number of light flashes presented were 55 for the flash-only condition and 30-40 during shadowing of either channel. For the fourth subject, peak-to-peak (N80-P160) amplitude of the visual AER was 20.5 uV. for flash-only presentation; while during shadowing of either channel, the visual AER peak-to-peak amplitude was 12.5 uV.

Shadowing accuracy ranged between 96% and 99%, while recall of information delivered to the non-shadowed channel ranged from 50% to 60%.

b. <u>AER-related variance</u>:

For three of four subjects, shadowing produced no changes in the variance surrounding the visual AER, while an increase in variance during shadowing was noted for one subject.

In the following experiment, the identical shadowing task as used in Experiments IV(a) and (b) was employed with presentations of cutaneous stimuli.

12. Experiment IV(c)

The purpose of Experiment IV(c) was: (1) to study the effect on the somatosensory AER of (a) familiar material presented to both the shadowed and non-shadowed channels; (2) to study further the effects of shadowing upon laterality differences; (3) to observe the amplitude and variance of somatosensory AER's during a task in which familiar material is delivered to both the shadowed and non-shadowed channels; (4) to study further the effects of recall of non-shadowed material upon somatosensory AER's.

Results

Table 12 shows findings from four subjects. All subjects were right-handed. For all subjects, attenuation of somatosensory AER's was observed during auditory shadowing independent of which side received cutaneous stimuli. For the first subject, during presentation of cutaneous stimuli to the right side alone, the amplitude of the principle component somatosensory AER was 24.75 uV. During shadowing of the left and then the right channel, the somatosensory AER's were 8.25 uV. and 9.85 uV. respectively. For cutaneous stimuli delivered alone to the left side, the amplitude of the somatosensory AER was 17.30 uV. During shadowing of the right channel, the peak-to-peak amplitude of somatosensory AER's was 18.9 uV. for the left hemisphere, and 11.75 uV. for the right hemisphere. During shadowing of the left channel, the amplitude of the somatosensory AER was 11.75 uV. for the left hemisphere and 9.85 uV. for the right hemisphere. Subjective estimates of the number of cutaneous stimuli presented were 55 when tactile stimuli were presented alone, and 20-30 during shadowing.

Table 12: Amplitude of the principle component of the somatosensory average evoked response under conditions of shadowing vs. cutaneous stimuli delivered alone

S		A. Cutan. Stim. Rt.		B. Shad. Left		& Shad. Rt.		C. Control		P
1	LH	24.75uV	±8	8.25uV	±18	9.85uV	±18	24	±8	.05 bet. A & B NS bet. A & C .05 bet. B & C
	RH	24.75uV	±8	8.25uV	±18	9.85uV	±18	24	±8	.05 bet. A & B NS bet. A & C .05 bet. B & C
2	LH	24.75uV	±6	16.50uV	±12	11.45uV	±12	24	±8	.05 bet. A & B NS bet. A & C .05 bet. B & C
	RH	24.75uV	±6	16.50uV	±12	11.45uV	±12	24	±8	.05 bet. A & B NS bet. A & C .05 bet. B & C
3	LH	18.10uV	±8	14.90uV	±18	5.6uV	±18	17.5	±8	.05 bet. A & B NS bet. A & C .05 bet. B & C
	RH	18.10uV	±8	14.90uV	±18	12.25uV	±18	17.5	±8	.05 bet. A & B NS bet. A & C .05 bet. B & C
4	LH	16.5uV	±10	12.25uV	±18	--	±10	16	±8	.05 bet. A & B NS bet. A & C .05 bet. B & C
	RH	16.5uV	±10	15.0uV	±12	12.25uV	±10	17	±8	.05 bet. A & B NS bet. A & C .05 bet. B & C

S		A. Cutan. Stim. Left		B. Shad. Left		& Shad. Rt.		C. Control		P
1	LH	16.5uV	±8	12.37uV	±18	16.5uV	±18	16.5	±8	.05 bet. A & B NS bet. A & C .05 bet. B & C
	RH	16.5uV	±8	8.25uV	±18	12.25uV	±18	16.5	±8	.05 bet. A & B NS bet. A & C .05 bet. B & C
2	LH	16.5uV	±6	15.0uV	±12	10.25uV	±12	16.5	±8	NS bet. A & B NS bet. A & C .05 bet. B & C
	RH	15.0uV	±6	12.25uV	±12	12.25uV	±12	16	±8	NS bet. A & B NS bet. A & C NS bet. B & C
3	LH	20.5uV	±8	16.5uV	±18	16.5uV	±18	20	±8	.05 bet. A & B NS bet. A & C NS bet. B & C
	RH	20.5uV	±8	16.5uV	±18	16.5uV	±18	20	±8	.05 bet. A & B NS bet. A & C .05 bet. B & C

Table 12

S		A. Cutan. Stim. Left		B. Shad. Left & Shad. Rt.		C. Control		P
	LH	20.5uV	±10	16.5uV	±12	6.5uV	±10	20 ±8	.05 bet. A & B NS bet. A & C .05 bet. B & C
4									
	RH	18.5uV	±10	10.5uV	±12	4.12uV	±10	17.5±8	.05 bet. A & B NS bet. A & C .05 bet. B & C

For the second subject, the peak-to-peak amplitude of the somatosensory AER fell from 24.75 uV. during presentation of cutaneous stimuli alone to the right side, to 16.50 uV. and 11.45 uV. during shadowing of the left and right channels respectively. When cutaneous stimuli were presented to the left side, the peak-to-peak amplitude of the somatosensory AER was 16.5 uV. when such stimuli were presented alone. During shadowing of the right channel, the peak-to-peak amplitude of the somatosensory AER was 15.0 uV. for the left hemisphere and 12.25 uV. for the right hemisphere. During shadowing of the left channel, the AER amplitude was 10.25 uV. for the left hemisphere, and 12.25 uV. for the right hemisphere. Subjective estimates of the number of cutaneous stimuli presented were 60 when tactile stimuli were presented alone, and 20-30 during shadowing.

The peak-to-peak amplitude of the somatosensory AER for the third subject was 18.10 uV. when cutaneous stimuli alone were delivered to the right side. During shadowing of the left channel the peak-to-peak amplitude of the somatosensory AER was 14.90 uV., shadowing of the right channel resulted in somatosensory AER's of 12.25 uV. for the right hemisphere and 5.6 uV. for the left hemisphere. When cutaneous stimuli were delivered to the left side, somatosensory AER's were: 20.5 uV. during delivery of cutaneous stimuli solely, 16.5 uV. and 14.85 uV. for the left and right hemispheres respectively during shadowing of the right channel; and 16.5 uV. during shadowing of the left channel. Subjective estimates of the number of cutaneous stimuli delivered were 55 when stimuli alone were presented, 20-30 when stimuli were delivered during shadowing.

For the fourth subject, the somatosensory AER was 16.5 uV. when cutaneous stimuli alone were delivered to the right side. During shadowing of the left and then of the right channle, the peak-to-peak amplitude of the somatosensory AER was 12.37 uV. and 8.25 uV. respectively. In the case of the former, the subject's estimate of the number of stimuli delivered was "between 40 and 50," while in the latter case, the estimate was "about 30." The peak-to-peak amplitude of the somatosensory AER for cutaneous stimuli delivered to the left side was 20.5 uV. when such stimuli were delivered alone, 6.25 uV. and 4.12 uV. for the left and right hemispheres respectively during shadowing of the right channel; and 16.5 uV. and 10.5 uV. for the left and right hemispheres respectively during shadowing of the left channel. The subject estimated the number of stimuli delivered as "about 30" during shadowing trials in which stimuli were delivered to the left side, and as 60 during trials in which stimuli alone were presented. In addition, the P350 component was not attenuated during shadowing in three subjects.

Shadowing accuracy for all subjects was between 95% and 99%, while recall of the material delivered to the non-shadowed channel ranged from 50% to 60%.

b. AER-related variance:

For three of four subjects, the variance surrounding the somatosensory AER's increased during shadowing; one subject showed no such increases in variance.

13. Experiment V(a)

The purpose of Experiment V(a) was: (1) to determine the effects of a tactile shadowing task upon auditory AER's; (2) to observe the amplitude and variance of auditory AER's during a tactile shadowing task in which the information-processing demands were heavy.

Procedure: Subjects were seated in an enclosed room and were instructed to shadow one of two different series of alphabet letters drawn on their backs. Shadowing was accomplished by the subject reproducing, in writing, what he felt drawn on the side of the back to be shadowed. Subjects were encouraged to make as few mistakes as possible. For each subject, both left-side and right-side shadowing trials were given, and, under each of these conditions, auditory tone-clicks were delivered to the right ear or to the left. Resulting auditory AER's were obtained (a) during tactile shadowing, (b) during tone-click alone presentations, and (c) during passive exposure.

Results

Table 13 presents findings for three subjects.

For the first subject, peak-to-peak amplitudes of the principle components of the auditory AER was 19.7 uV when tone-clicks alone were delivered to the right channel. During tactile shadowing of the left, and then of the right side, the peak-to-peak amplitude of the auditory AER was 20.9 uV and 16.5 uV respectively. Subjective estimates as to the number of tone-clicks heard were 70, 40, and 20-30 respectively. When tone-clicks were presented alone to the left side, the

Table 13: Amplitude of the P80-N160 component of the contralateral and ipsilateral auditory average evoked response as a function of shadowing vs. tones alone

Contralateral AER's

S		A. Tones Alone		B. Shadowing		C. Control		P
1	LH	19.7uV	±8	20.9uV	±8	16.5uV	±8	NS
	RH	19.7uV	±8	16.5uV	±8	16.5uV	±8	NS
2	LH	16.5uV	±8	16.5uV	±8	16.5uV	±8	NS
	RH	18.5uV	±8	17.0uV	±8	17.0uV	±8	NS
3	LH	16.5uV	±8	12.5uV	±8	15.0uV	±8	NS
	RH	15.0uV	±8	12.0uV	±8	16.5uV	±8	NS

Ipsilateral AER's

S		A. Tones Alone		B. Shad. Left		C. Shad. Rt.		P
1	LH	16.5uV	±8	16.5uV	±8	17.0uV	±8	NS
	RH	16.5uV	±8	15.0uV	±8	17.0uV	±8	NS
2	LH	15.0uV	±8	12.5uV	±12	12.0uV	±12	NS
	RH	12.5uV	±8	17.5uV	±12	12.5uV	±12	NS
3	LH	16.5uV	±8	6.25uV	±16	9.85uV	±16	.05 bet. A & B NS bet. A & C .05 bet. B & C
	RH	15.0uV	±8	6.25uV	±16	9.85uV	±16	.05 bet. A & B NS bet. A & C .05 bet. B & C

peak-to-peak amplitude of the auditory AER was 19.7 uV. During shadowing of the right and then the left sides, the peak-to-peak amplitude of the auditory AER was 16.65 uV. and 20.5 uV respectively. Subjective estimates of the number of tone-clicks heard were 60, 20-30, and 40-50 respectively.

For the second subject, the peak-to-peak amplitude of the auditory AER was 16.5 uV when tone-clicks alone were presented to the right side. During tactile shadowing of the left and then of the right side, the peak-to-peak amplitude of the auditory AER was 16.5 uV and 17.0 uV respectively. Subjective estimates of the number of tone-clicks heard were 60, 50-60, and 20-30 respectively. When tone-clicks were presented alone to the left side, the peak-to-peak amplitude of the auditory AER was 14.9 uV. During tactile shadowing of the right and then of the left side, the peak-to-peak amplitude of the auditory AER was 12.5 uV and 12.0 uV respectively. Subjective estimates of the number of tone-clicks presented were 50-60, 40-50, and 40-50 respectively.

For the third subject, who was left-handed, the peak-to-peak amplitude of the auditory AER was 15.0 uV when tone-clicks were presented alone to the right ear. During tactile shadowing of the left and then of the right side, the peak-to-peak amplitude of the auditory AER was 12.5 uV and 12.0 uV respectively. Subjective estimates of the number of tone-clicks heard were 60, 55, and 20-30 respectively. When tone-clicks were presented alone to the left ear, the peak-to-peak amplitude of the auditory AER was 15.0 uV. During tactile shadowing of the right and then of the left side, the peak-to-peak amplitude of the auditory AER was 6.25 uV and 9.85 uV respectively. Subjective estimates of the number of tone-clicks heard were 55-60, 10-15, and 15 respectively.

b. <u>AER-related variance</u>:

Increases in the variance associated with the auditory AER during shadowing were observed for one subject; slight increases in variance were observed for one subject; while no changes in the variance were observed for a third subject.

SUMMARY OF RESULTS

In experiments I-IV a, b, and c sign tests were conducted to establish whether or not waveforms generated by clicks, flashes, or cutaneous taps alone were significantly different from waveforms generated by identical stimuli during auditory shadowing. In the following table, the results of such tests are summarized.

Experiment	Number of Tests Run	Significant Differences in AER Shadowing vs. Non-Shadowing	Significant Differences in Variance
I (a)	16	16	16
I (b)	8	0	0
I (c)	16	6	6
II (a)	16	16	16
II (b)	21	14	14
II (c)	32	11	11
III (a)	22	22	11
III (b)	14	12	6
III (c)	24	22	12
IV (a)	24	24	18
IV (b)	16	16	4
IV (c)	32	27	24

In addition, an analysis of variance was performed and the following table summarizes the results of that analysis:

Source	D.F.	S.S.	M.S.	F	P
Shadowing vs. Non-Shadowing (C)	3	14079.77	4693.25	543.75	.01
Modality (Aud., Vis., Cutan.)(M)	2	11471.78	5735.9	8.71	.025
C x M	6	4791.8	798.6	46.17	.01
Level of Shadowing Difficulty(D)	3	1616.45	538	6.06	.025
C x D	9	373.9	41.5	3.39	.01
M x D	6	1777.3	296.2	4.08	.01
C x M x D	18	1664.6	92.47	12.9	.01
Hemisphere x C (H)	3	9.28	3.09	1.19	NS
H x C x D	9	17.30	1.92	.64	NS
H x C x M	6	12.75	2.12	.99	NS
H x C x M x D	18	49.04	2.72	1.87	NS

While there were no overall hemispheric differences, significant differences in AER's to non-informative stimuli were found as a function of shadowing, of shadowing difficulty, and as a function of the modality in which the non-informative stimuli occurred.

In the following summary tables, the mean amplitude (in uV) of the principle component of the auditory, visual, and somatosensory AER's respectively are averaged across subjects and hemispheres. The averages are presented with associated variance, and the number of significant sign tests.

Auditory (Tables 1,4,7,10)

Contralateral (to shadowed channel)

	A. Tones Alone		B. Shadowing		C. Control		P
Both Unfamiliar (Exp. 1)	19	±8	--	±18	17	±10	7AB
Shadowing Unfamiliar Non-Shadowing Familiar (Exp. 2)	19	±8	—	±16	18	±8	4AB 4BC
Shadowing Familiar Non-Shadowing Unfamiliar (Exp. 3)	19	±8	--	±15	17	±8	8AB
Both Familiar (Exp. 4)	19	±8	8	±12.5	18	±8	4AB 4BC

Ipsilateral (to shadowed channel)

	A. Tones Alone		B. Shadowing		C. Control		P
Both Unfamiliar (Exp. 1)	18	±8	--	±18	17	±10	8AB
Shadowing Unfamiliar Non-Shadowing Familiar (Exp. 2)	21	±8	--	±18	20	±8	8AB
Shadowing Familiar Non-Shadowing Unfamiliar (Exp. 3)	20	±8	8	±16	19	±8	3AB 3AC
Both Familiar (Exp. 4)	18	±8	7.6	±12	17	±8	4AB 4AC

Visual (Tables 2,5,8,11)

	A. Flashes Alone		B. Shad. Rt.		C. Shad. Lt.		P
Both Unfamiliar	16	+8	16	±9	15	±10	
Shadowing Unfamiliar Non-Shadowing Familiar	27	±8	19	±16.5	21	±16.5	7AB 5AC 2BC
Shadowing Familiar Non-Shadowing Unfamiliar	27	±8.5	20	±16	16	±15	6AB 6AC 4BC
Both Familiar	22	±8	15	±10.5	15	±10.5	8AB 8AC

Somatosensory (Tables 3,6,9.12)

Cutaneous Stimulus to Right Forefinger

	A. Stim. Rt.		B. Shad. Lt.		C. Shad. Rt.		Control		P
Both Unfamiliar	15	±8	12.5	±18	9	±15	16	±8	1AB 3AC 4BC
Shadowing Unfamiliar Non-Shadowing Familiar	21	±10	12	±18	17	±16	20	±9	4AB 3AC 3BC
Shadowing Familiar Non-Shadowing Unfamiliar	18	±9	12	±12	10	±12	18	±9	8AB 8AC 4BC
Both Familiar	21	±8	14	±15	10	±14.5	21	±8	8AB 8AC 8BC

Cutaneous Stimulus to Left Forefinger

	Stim. Lt.		Shad. Lt.		Shad. Rt.		Control		P
Both Unfamiliar	16	±8	13	±18	16	±16	16	±8	2AB 2BC
Shadowing Unfamiliar Non-Shadowing Familiar	16	±9	15	±18	17	±16	16	±9	2AB 2AC 2BC
Shadowing Familiar Non-Shadowing Un-familiar	17	±10	13	±14	15	±13	18	±9	4AB 2AC 2BC
Both Familiar	19	±8	14	±15	12	±14	18	±8	6AB 3AC 2BC

III. Discussion

The present research indicates that <u>both</u> single-channel and multi-channel theories of human selective attention find support electrophysiologically. Each theory has limited applicability, and the design of the experiment is crucial to subsequent findings. That the shadowing task induces selective attention is suggested by the inability to observe auditory AER's when tone-clicks were delivered to either the non-shadowed or the shadowed channel. Subjects in this task reported having heard no tones. The AER components of relevance, P80 to N160, were not observed nor were later (P300) components. Shadowing was accompanied by increases in the variance surrounding the AER. Such results are unaffected by the side to which the signals are delivered. The effects are the same, also, in both hemispheres, irrespective of the ear receiving either the material to be shadowed or the clicks. However, under the identical conditions visual AER's are unaffected. That is, conditions that reliably render unobservable all principle components of the auditory AER have no effect upon the visual AER.

To this point the AER data would appear to support a Broadbent-type theory. Simultaneous processing requirements imposed upon a single channel exceed the capacity of the system with the effect that one of the messages or inputs fails to register. At the same time, the signals can gain access to a central "decision-circuit" via a different channel (modality).

That the matter is not so simple, however, is clear from further research. In the earlier studies, the demands of the shadowing task were such that subjects were able to articulate only from 60-75% of the delivered message. Estimates of the number of clicks that has presented ranged from "none" to "a few." None of the non-shadowed material was recalled. However, when the difficulty of the shadowing task is reduced, i.e., when shadowing accuracy increases to 75-80% by employing highly redundant materials, the results change. First, on the average, subjects can recall as much as 50% of the information delivered to the non-shadowing channel. Still, however, they do not report hearing clicks or, at most, hearing more than "a few." And, again, auditory AER's are not in evidence. But, under these same conditions, visual AER's begin to display attenuation. Moreover, the effect is revealed in the fact that subjects estimate the number of flashes at between 40 and 50 whereas, in the earlier studies, estimates were (correctly) between 60 and 70. That is, consistent with other research, the subjective and the neuroelectric evidence are correlated. But, paradoxically, as the auditory task is made easier, the effect upon visual processing is greater.

The trend is displayed again in experiments in which the redundancy of shadowed messages is increased further; i.e., the level at which shadowing accuracy is now from 95% to 98%. Under these conditions (a) auditory AER's appear when clicks are delivered to the ear receiving the shadowed message but not when the clicks are delivered to the ear receiving the non-shadowed message and (b) subjects report a number of clicks (15-20) when these have been delivered to the ear receiving the shadowed material but not otherwise. Again, under these conditions of reduced auditory loading, visual AER's are attenuated, although they are not when the auditory demands are higher.

Additionally, when highly redundant materials are presented to both channels such that shadowing accuracy is between 95% to 98% and subjects are capable of recalling 50% of the information delivered to the non-shadowing channel, the results change still further. Under these conditions (a) auditory AER's though attenuated, appear when clicks are delivered to either the ear receiving the shadowed message or the ear receiving the non-shadowed message and (b) subjects report a number of clicks (15-20) when these have been delivered to either the ear receiving the shadowed message or the ear receiving the non-shadowed message. Visual AER's are again attenuated under these conditions of reduced auditory loading.

Auditory shadowing significantly attenuates somatosensory evoked responses and the effect is independent of the side of the body receiving the cutaneous stimulus. This effect, however, is not transitive in that tactile shadowing does not reliably reduce the amplitude of auditory AER's.

Three different subjects were studied to determine the effects of tactile shadowing on auditory AER's. Note that for two of these subjects (both right-handed), tactile shadowing has no significant effect on auditory AER's but that for one of the subjects (a left-handed subject) the ipsilateral auditory AER is significantly reduced under conditions of tactile shadowing.

Under conditions of auditory shadowing, the subject is unaware of extraneous acoustic signals, is not able to estimate their frequency, and displays no auditory AER in response to them when shadowing unfamiliar material. It is only under these conditions that visual AER's remain unaffected. However, once the subject confronts highly familiar (non-informative) messages, he is better able to detect otherwise extraneous auditory signals and, at the same time, he displays small increases in the amplitude of auditory AER's and small but significant decreases in the amplitude of visual AER's.

In several of our studies in which lefthanded subjects were (not intentionally) included, laterality effects correlated with handedness in the AER data. I am, however, reluctant to make much of handedness effects based only on the results from a few subjects.

What is clear from the findings is that the extant theories of information-processing require modification and that extant generalizations regarding AER correlates of attention require even greater qualification. It is quite clear, for example, that studies suggesting a simple relationship between AER amplitude and the "relevance" of the input must be re-examined, as must be studies of only the AER amplitude and selective attention.

Harter and Salmon (1971) and Spong, Haider, and Lindsley (1965) have shown respectively that the amplitude of the evoked response to a stimulus was attenuated when that stimulus was made irrelevant and another signal from the same or a different modality is made relevant. Such reports are not confirmed by the present research as visual evoked response amplitude was not attenuated when light flashes were made irrelevant by a difficult shadowing task. In addition, no increases in variances associated with the visual AER's were observed during shadowing as opposed to flash-alone conditions.

Ford, et. al. (1973) reported the late positive component of the AER to be non-existent if the stimulus was (a) irrelevant and (b) in a different sensory modality than the relevant stimulus. The present research implies that such reports may be incomplete in that in Experiment IIIc in which <u>cutaneous</u> stimuli were irrelevant during <u>auditory</u>

shadowing, the P_3 component of the somatosensory AER was not attenuated during shadowing in two of four subjects. The effect of the relevant stimulus upon the amplitude of P_3 to an "irrelevant" stimulus may reside in the nature of the "relevant" channel information.

Smith, et. al. (1970) found no differences in the AER to clicks presented to the attended channel as compared to those in the rejected channel in that no attenuation of major pre-P300 components was observed even in the rejected channel. As was stated previously, AER's to tone-clicks were observed neither in the shadowed channel nor in the non-shadowed channel. On the basis of such results a difference between selective listening and shadowing is evident in both the electrophysiological responses as well as in the verbal reports of the subjects.

In previous studies in which the amplitude of the AER has been correlated with attention (Davis, 1964), it has been observed that the attention process (in a task requiring discrimination of two tones) seems only to apply to the "different tone." One would assume that a discrimination problem would require attention to <u>both</u> tones in order to judge whether <u>one</u> of the tones is different from the other. Indeed, we are not informed as to the nature of AER's to the "different" tone taken alone. In addition, such studies rely on inferred definitions of attention, whose span lasts for seconds. The present findings support the notion that the AER is a reliable measure of <u>perceived</u> stimulation; that meaningfulness (in the sense of perception rather than mere stimulation) is reflected in such cortical responses. Such data are in substantive agreement with those of Harter and White (1967). The present findings also provide further support for the speculations of John et.

al. (1967) who contend that the waveform of the AER reflects the per-ceptual content of the stimulus. The peak-to-peak amplitude of the AER correlates significantly with reports of detection of stimuli. However, the peak-to-peak amplitude alone cannot be employed as a measure of attention as produced by shadowing as it has been defined previously in the literature. Empirical demonstration of, for example, divided attention is necessary. The shadowing task successfully provides such a demonstration. During such tasks, when they are of a difficult nature, the variance associated with the AER is a significant indicator of the decrease in neural synchrony, of activity that is less organized than that accompanying an attentive state (Robinson, 1973).

The present findings do agree in part with the notion of the nervous system as a single-channel processor with a limited capacity as stated by Broadbent (1952). Controversies in the cognitive literature may also be informed by the present findings. Lawson (1966), for example, has reported that subjects engaged in shadowing tasks can detect tone-pips delivered to either ear and, on the basis of this finding, has suggested that the blocking of information is unique to verbal material. Treisman and Geffen (1967), on the other hand, have employed unfamiliar materials and have discovered that tone-pips are very effectively blocked. In light of our findings, it would appear that the variable of consequence here is not some fixed feature of information-processing but the different effects upon information-processing systems produced by familiar vs. unfamiliar materials. In our studies, unfamiliar messages render unobservable every component of the auditory AER in both hemispheres and independently of the ear receiving the shadowed message.

Only when this message becomes highly familiar is there recall of the unshadowed information and auditory AER's to clicks. In an attempt to account for their theoretical position, Broadbent and Gregory (1963) reported that the auditory threshold to tones was raised in one ear if subjects were asked to attend simultaneously to digits presented to the other ear. The authors posited that the division of attention away from the tones reduced the effective signal-to-noise ratio, thus raising the threshold in the non-attended channel. In discussing the findings related to shadowing, the same theory may be applied with a minor modification. If shadowing is seen as reducing the effective S/N ratio, then the detection model may be seen to apply within a sensory channel, thus the filtering out of irrelevant from relevant stimuli occurring in the same modality may be accomplished. Such a model may depend, to a great extent, on the time involved in the performance of the shadowing task.

Treisman (1960, 68, 1969) has stated that "the division of attention between two or more inputs... is difficult or impossible when no time is allowed for alternating attention or serial analysis..." In the first series of experiments, difficult, unfamiliar material was shadowed by subjects who reported having heard no clicks while shadowing and who remembered nothing of the non-shadowed channel. In contrast, in the fourth series of experiments, subjects shadowed familiar material, reported hearing "some" of the clicks presented, and were able to recall approximately 50% of the material presented to the non-shadowed channel (which was also familiar). The degree of familiarity of the material may have provided the necessary time for subjects to switch their attention to both the non-shadowed channel and to the clicks, thus supporting Treisman's position.

Moray (1973) has described the nuances of the shadowing task in a way which adds further support to the present discussion: "If the observer were to shadow the message, his information load would be greater ... (in that) he must now sample the incoming message, initiate his response, and must also monitor his spoken output, since without such monitoring the spoken response will not be coherent speech. Under such conditions it is likely that these tasks will... so occupy the sampling mechanism that there will be almost no time to sample any other sources, and material in such other sources will be missed."

In the present research, it has been shown that neither the amplitude nor the variance of visual AER's is affected merely by making flashes "irrelevant" in an auditory shadowing task. If our effects are to be understood in terms of the variable of "relevance," then that variable must be applied not to the stimulus but to the channel responsible for processing the information. It is simply not the case, as some have put forth (Ford, 1973), that the late-positive AER component is eliminated when stimuli are irrelevant or presented to modalities different from the one engaged in the processing of signals. In our research, we reliably obtain the late (P3) component of tactile AER's during an auditory shadowing task in which the tactile signal is "irrelevant" and is, of course, processed by an "irrelevant" modality.

In still other studies of attention and the AER, there have been hypotheses recommending no differences in the attending and non-attending channel, but here again, it appears that the principle factor has been the failure to provide a measurable and demanding control over the subject's attentiveness.

Although the high frequency activity associated with the AER was missed due to amplifier band pass limitations, the slow activity was observed in that the amplifiers approached the d.c. level at the low end. Such limitations notwithstanding, the present study does agree with many investigators (Davis, 1964; Spong, Haider, and Lindsley, 1965; etc.) who have reported enhancement of AER's to "attended to" stimuli. The attended to stimuli in such studies has usually been a stimulus which is different (in intensity, or pitch) from the other "unattended" stimuli. As such studies do not discuss the nature of the AER's to the attended stimuli when such stimuli are presented alone, the question of the reason for enhanced AER's to such stimuli is left open (enhancement may be due to the novelty of the attended stimulus re the other unattended stimuli; possible effects of habituation are not discussed). Generally, the present findings are in substantial agreement with the earlier literature in relation to the AER as an indicator of a perceived, meaningful stimulus; however, the AER in itself, does not appear to indicate the degree of attention invested in such stimuli.

One of the most reliable effects obtained in research of the present variety is the increase in AER variance associated with shadowing. The subject attending to a message provides AER's to stimuli presented to a different modality but these AER's, although generally of unaffected amplitude and latency, are statistically noisier. Because of this, it seems warranted to conclude that, under those conditions in which amplitude is affected, the affects are to be understood not in terms of diminished responding by the system but in terms of diminished <u>synchrony</u>. Pribram and McGuinness (1975), who have recently proposed structural features of neural transmission as the appropriate analogues of such state-variables as attention, find support in the present findings. Kahneman's concept of the "allocation of spare capacity" (1973) also converges on the findings reported above. It is only when highly redundant messages are presented and, as a result, the constraints on the auditory system are lessened, that the attenuation of visual AER's occurs. On this account, redundancy in the nervous system is the equivalent of noise -- hardly a new notion -- and attention is the process by which noise is attenuated. The gross cortical sign of this is indirectly revealed in the form of increased response variability in the treatment of extraneous inputs. It is directly revealed by reduced variability of responses to the signal being processed "attentively." It is not stretching the radar equation too far to note that the nervous system, too, is band-limited and that the price it pays for opening up the bandwidth is reduced resolution. Under conditions demanding sustained and exacting attention (i.e., conditions calling for the resolution of stimulus elements), the modality involved is most band-limited and, therefore, least variable in its successive responses to sequential inputs. It is precisely under such conditions that a complex signal-processing system, "allocating its spare capacity", would go into a broad-band "coasting" mode and would respond most variably to discrete inputs. The data presented herein are suggestive of just this sort of operation and are, accordingly, unsupportive of rigid models of information-processing. The concept of a sensory system as a single-channel processor can be apt, therefore, only if qualified to this extent: simultaneous intramodal signals, given equal _a priori_ weights, will be processed on a time-sharing basis but the system will remain accessible to inputs delivered to other modalities. That is, while sensory systems may operate on a single-channel basis, the central nervous system does not and it, after all, must determine which peripheral channels will serve as sources of information.

While attention has been widely investigated and physiological mechanisms have been sought as correlates of the behavioral state, experimental designs which have sought to isolate the phenomenon have been lacking in precision. As Sutton stated (in Donchin and Lindsley, 1968) "... it is necessary to avoid experimental designs that rely on instructions to produce complex psychological states, e.g., 'to attend or to ignore the difference between two tones,' or 'to imagine squares or circles,'..." The shadowing task precludes the subjective decision as to what should be attended; shadowing performance and degree of subjective recall of non-shadowed material provide objective indicators as to that which the subject is attending during the task. Therefore, the state of attention must be well defined, indeed, induced by the task such that the possibility of subjective non-adherence to rather loose instructions is precluded. Further, the subject's performance should supply investigators with an index of the attentive condition. In the many investigations of selective attention undertaken in the past twenty years, the experimental designs have included some "relevant" channel to be attended to and an "irrelevant" channel to be ignored by the subject. It follows from the present research that all "relevant" channels are not necessarily equivalent in their demands upon subjects merely because they share the distinction of being "relevant." It has been demonstrated that the nature of the task can vary and can produce different results within the category of "relevant" channel. Therefore, it is the contention here that the information within the relevant channel and the non-relevant channel themselves is the key to an understanding of the process of selective attention rather than the fact of relevancy vs. non-relevancy in and of itself; instructions merely to attend or not to attend are not enough. The task itself must provide a control for subjects' performance. Hartley (1970) discusses such weaknesses as they apply to AER studies, and points out the efficacy of "behavioral" experiments on selective attention in which "... the combined information of both the relevant and irrelevant channels is in excess of the capacity of the decision channel, i.e. to respond successfully to one channel, the subject must reject most or all of the information on the other..." The shadowing task deals with such criteria admirably, and provides an adequate response variable as an indication of what the subject is doing. Much of the previous research in the neuropsychological realm has lacked such precision; while cognitive studies (which invoke neural explanations, some of which have been proven erroneous) do not address the neural processes, but infer them based on strictly behavioral results. The present research demonstrates the need for both disciplines to coalesce, to an extent, in terms of converging operations (Garner, et. al. 1956).

> "Once again we have to view attention as an intensely dynamic system, the properties of which are changing from moment to moment even within a run of an experiment. If so, attention returns to the central position in psychology to which Titchener (quoted by Swets and Kristoffersen, 1970)

assigned to it. Now, however, it is not so much the absolute monarch of the nervous system as a duly elected leader of the cognitive processes, and like all good leaders constantly adjusts its aims to carry out the aspirations of the people, changing its policies according to the general will... and the nature of attention? Perhaps it is neither the tangled jungle nor the 18th Century garden, but rather the Garden of Delights of Hieronymous Bosch, full of strange and intricately carved creatures, some more fantastical than others, but in the end, undoubtedly intelligible if only we could just find that one clue..."

(Moray, 1973)

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