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A DIRECT COMPARISON OF EVENT RELATED POTENTIALS DURING AUDITORY AND VISUAL CONTINUOUS WORD RECOGNITION MEMORY TASKS

by

REGAN FONG

A dissertation submitted to the Graduate Faculty in
Psychology in partial fulfillment for the Degree of Doctor
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Abstract

A DIRECT COMPARISON OF EVENT RELATED POTENTIALS DURING AUDITORY AND VISUAL CONTINUOUS WORD RECOGNITION MEMORY TASKS

by

REGAN FONG

Advisor: Professor Wilma Winnick

Brain event-related potential (ERP) studies of recognition memory have consistently shown that correctly identified old items elicit greater positivity than new items. This is referred to as the old/new effect and is argued to reflect processes related to memory retrieval. To date, there have been no ERP studies of recognition memory that have directly compared the old/new effect in the visual and auditory modalities. In this study, ERPs were recorded from 30 electrode sites while participants (n=16) were engaged in visual and auditory continuous word recognition memory tasks. The expected old/new effect, with greater late positivity to correctly recognized old words was observed in both modalities, although scalp topography was significantly different. While the visual old/new effect was restricted to midline sites and maximal over the parietal region, the auditory old/new effect involved more lateral sites and was maximal over the occipital region. The timing of the old/new effect was the same across modalities with a peak at 600 ms. In addition, old words elicited greater late negativity (1100-1500 ms) over the left hemisphere than new words, suggesting the activation of verbally mediated post-retrieval processes specific to old responses. Overall, the findings suggest that the old/new effect represents a common cognitive mechanism in the two modalities (i.e., successful retrieval of information from memory), and that a different pattern of neural generators contribute to each.

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A Direct Comparison of ERPs During Auditory and Visual Continuous Word Recognition Memory Tasks

The effect of modality on memory performance has received relatively sparse attention in memory research. Subjective reports of superior visual or auditory learning/memory performance have been quantified and documented in studies using normal volunteers (e.g., Glanzer & Cunitz, 1966; Murdock, 1968; Penney, 1975) and brain lesioned patients (Shallice & Warrington, 1977; Warrington & Shallice, 1969). Findings from these studies suggest that visual and auditory short-term memory processes involve separate neural paths and representations.

Until recently, investigation of the neural basis of memory was restricted to studying patients with neurological disorders (e.g., Scoville & Milner, 1957), or by examining the consequences on memory performance of brain lesions in animal models (e.g., Mishkin, 1998; O'Keefe & Nadel, 1978; Zola-Morgan & Squire, 1984). With the advent of functional neuroimaging techniques, it has become possible to study the neural counterparts of memory processes in healthy normal volunteers. The introduction of positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) has provided a means of studying the involvement of specific brain regions during the performance of memory tasks.

Although these methods provide good spatial resolution in terms of the brain regions and structures that are involved, their temporal resolution is limited (i.e. since they are dependent upon hemodynamic measures, they are unable to detect changes that may be active for only tens of milliseconds). In contrast, brain event-related potentials (ERPs), which measure the electrical brain activity associated with cognitive processing, provide information with a high degree of temporal resolution. The limitation of ERPs is that only inferences can be made about which specific brain regions are involved with a particular cognitive task.

The major aim of the current study was to compare auditory and visual recognition memory processes by recording brain ERPs obtained during a word recognition memory task in the two modalities. To date, the majority of ERP studies of recognition memory have utilized the visual modality for stimulus presentation. There has been no systematic evaluation of word recognition memory in the auditory modality. The evidence for separate auditory and visual processing streams in short-term memory tasks implies the activation of different neuronal structures in the two modalities. Thus, it is of great interest to compare the

ERP activity associated with cognitive processes which contribute to visual and auditory recognition memory.

First, a review will be presented of behavioral studies demonstrating the important role of modality on memory performance. Next, will follow a summary of the evidence for modality-specific processing in implicit memory and its relation to recognition memory processes. Finally, a survey of neuroimaging studies including PET investigations of memory retrieval and ERP studies of recognition memory will be summarized.

Auditory-Visual Comparisons

Of the historically earliest laboratory experiments, the reaction time experiment carried out many parametric comparisons, with modality as a prominent feature. Two early reviews (Teicherner, 1954; Woodworth, 1933) cautioned about inadequate equating of the stimuli in the two modalities but come to the tentative conclusion that auditory reaction time seems to have an advantage over visual in reaction time measurement.

Auditory and visual differences have been pursued further as current memory systems have been identified. Of the two memory systems initially identified, visual (iconic) and auditory (echoic) sensory memory tasks have been compared and sharp differences have been distinguished (Haberlandt, 1999, p.131). Short-term and long-term memory have been distinguished in terms of information format. Acoustic for short-term and semantic (i.e., visual-verbal) for long-term systems.

Studies that have examined the effects of presentation modality on memory performance have primarily focused on differences between the visual and auditory comparisons. Evidence from these studies suggests that auditory and visual information are processed and stored in the brain by different neural pathways(Penney, 1975,1989). A well established and robust finding in the literature is the observation that auditory presentation of stimuli results in greater recall than visually presented stimuli. This superior recall is consistently found for the last few items of a list in short-term memory tasks(Corballis, 1966; Murdock, 1967; Madigan, 1971; Routh, 1971). One interpretation of the modality effect is that it reflects an auditory, sensory store, called the precategorical acoustic store, or PAS (Crowder & Morton, 1969). The PAS was postulated to maintain a sensory trace of the last one or two items for a few seconds, and that this sensory trace supplemented the information maintained through rehearsal in short-term memory. Although a sensory trace exists for both auditory and visual modalities, it has been found to persist for a longer time for auditory than visual stimuli (Cowan, 1984; Engle & Roberts, 1982).

In an attempt to understand the relationship between mode of presentation and memory performance, a number of studies have identified a memory trace that is established after sensory and perceptual processing as distinct from a trace produced by the subject's recoding of the item (Penney, 1975). This points to the importance of demonstrating that there is a critical difference between tasks in which stimuli are presented auditorily and tasks in which visually presented stimuli are silently read by subjects. The short-term memory trace laid down when the subject silently articulates visually presented items does not contain the same form of information as the trace when the item is heard. Similar to the phonological code in Baddeley's model of working memory (1983), the silent articulation of visually presented items is also thought to be represented by a phonological code that includes information regarding words, phonemes, and articulation. In contrast, the acoustic code, includes information regarding the sensory properties of the stimulus. Whereas the phonological code is common to both auditorily and visually presented information, the acoustic code is unique to stimuli that are heard.

The importance of modality (usually vision and audition) in the organization of short-term memory has been stressed in numerous studies (Broadbent & Gregory, 1961; Murdock & Walker, 1969; Nilsson, 1973; Ronnberg, Nilsson, & Ohlsson, 1982). In all of these studies, subjects demonstrated a tendency to recall mixed-mode lists by grouping items by the modality in which they were presented. For example, Penney (1980) presented lists of 10 digits to subjects such that presentation modality changed after every 2nd digit. Some subjects were instructed to report the digits in their correct order within each modality while others were required to report the digits in the actual order of presentation. A strict serial report produced much lower recall than did reporting the items separately by modality. The fact that subjects experienced difficulty organizing mixed-mode lists along a dimension other than modality, suggests that organization by modality is fundamental to the organization of short-term memory and not merely an optimal retrieval strategy(Penney, 1989).

Information in the auditory stream is said to be represented automatically in the acoustic and phonological codes. That is, the entry of an auditory item into short-term memory cannot be prevented. Several investigators have provided evidence that even unattended auditory messages are stored for short periods of time (Treisman, 1964; Norman, 1969; Glucksberg & Cowan, 1970). Further evidence that information is represented automatically in the auditory stream comes from the observation that subjects cannot ignore a redundant auditory item (e.g., a suffix) affixed to the end of an auditory memory list (Norman, 1969; Smith & Groen, 1974; Smith & Burrows, 1974). No matter how hard subjects try to block out the suffix, a drastic decrease in recall of items was found near the end of a memory list. If processing of the suffix at the end of the list is automatic, and the same processing mechanisms are required for retention of other information, the suffix will necessarily produce interference. It has been demonstrated that the amount of interference produced by the suffix is greater when it is similar to items from the list (Penney, 1989).

Additional evidence of separate processing streams for visual and auditory information comes from the demonstration of different selective interference effects for auditory and visual short-term memory. A number of studies have demonstrated a selective impairment in recall of auditorily presented information by auditory distraction. For example, when subjects study a list of words that were presented auditorily, an auditory distractor task reduces the recall of recent auditory items more than a visual distractor task (Gathercole, Gregg, & Gardiner, 1983; Ronnberg & Ohlsson, 1980; Watkins & Watkins, 1980). In contrast, visual selective interference effects are demonstrable only under certain conditions. Since visually presented information is also represented by a phonological code, interference effects of visually presented verbal distractors are only observed when subjects are forced to rely solely on the visually based code. This can be accomplished through the use of irrelevant articulation, which interferes with the recoding of visual items into a phonological code. Subjects are more susceptible to visual distractors when they are required to engage in irrelevant articulation (Martin & Jones, 1979).

Studies using a dual-task design clearly demonstrate that it is easier to divide attention between two concurrent tasks requiring processing of verbal stimuli when stimuli are presented in the auditory in one task, and the visual modality in the other, than when all stimuli are presented to one modality (e.g., Allport, Antonis, & Reynolds, 1972; Rollins & Thibadeua, 1973; Rollins & Hendricks, 1980). These findings suggest that there are modality-specific processing resources that are independent from each other. When subjects are required to perform two tasks in the same modality, the pool of resources from which they draw upon simultaneously to complete the tasks, becomes depleted. Consistent with the hypothesis that separate processing streams exist for visual and auditory information, it is easier and less demanding for subjects to perform simultaneous tasks in different modalities.

Neuropsychological case studies have also obtained differential levels of impairment in retention of auditorily and visually presented verbal materials. In particular, there have been a number of published case studies describing the memory deficits in two patients, K.F. and P.V. who suffered from lesions involving the left posterior parietal region (Shallice & Warrington, 1970; Warrington, Logue, & Pratt, 1971; Warrington & Shallice, 1969; Basso, Spinnler, Vallar, & Zanobio, 1982; Valler & Baddeley, 1984). The most obvious deficit characterizing both K.F. and P.V. was an extremely low auditory digit span. Neither patient was able to repeat two auditorily presented items consistently. Their performance improved, though not to normal levels, when visual presentation was used. The existence of separate processing streams was invoked to account for their deficits of impaired formation or retention of acoustic and phonological codes. During auditory presentation, the acoustic code was not available to these patients to aid recall; while during visual presentation, they were still able to rely upon visually based codes.

Penney (1989) has postulated a model of short-term memory based on these different modality effects. This model emphasizes the active processing which underlies short-term memory, rather than conceptualizing a passive storage area of decaying information. The main hypothesis of this model is that these processing mechanisms are specific to either the auditory or the visual stream, and that these two streams have different properties and capabilities which represent information in different ways. In addition to being separate, these two processing streams are argued to operate differently as well. That is, within the auditory stream, information is most strongly organized along a temporal dimension that is manifested in the strong association between successive items (Penney, 1980). In contrast, for the visual mode, items presented simultaneously are more strongly associated than those in succession (Penney, 1975).

The basis for Penney's model of short-term memory (1989) comes from a proceduralist view of memory. According to a procedural account, information and its representation in memory are dependent upon the way in which it was acquired (Kolers & Roediger, 1984). Applying this viewpoint to her model, Penney (1989) argued that the processing of an item in short-term memory develops from and is continuous with perceptual processing. The perceptual processing provides the basis of the memory trace, while meaning is added later.

The comparisons gleaned from the literature suggest almost universal findings of auditory-visual differences in the memory systems reviewed. However, using a distinction offered by Cowan (1995), the memory tasks reviewed fall close to the category of sensory-perceptual memory. To provide a better basis for comparison with the present task, auditory-visual differences must be sought for memory that is more conceptual in nature. Such a sensory-perceptual/conceptual distinction has been provided in the last two decades by research comparing explicit and implicit memory (Schacter, 1987; Roediger & McDermott, 1993).

Auditory/Visual Effects in Explicit and Implicit Memory

Auditory-visual comparisons have been carried out in both the priming task that almost defines implicit memory and in comparisons across the two types of memory test. For the complete array of priming tasks, audition has provided lower scores than vision (Rajoram & Roediger, 1993). When a modality change is introduced from study to either explicit or implicit test, the implicit test suffers a loss but the explicit is unaffected (Blaxton, 1987). Such dissociations suggest a data-driven basis for implicit tasks and a conceptual basis for explicit. This distinction may prove relevant to this study of recognition memory (an explicit memory task).

Evidence from studies of implicit memory are consistent with the notion of modality specific processing streams. Tulving and Schacter (1990) have argued that a perceptual representation system (PRS) is responsible for implicit memory functioning. Their PRS is composed of several domain specific subsystems (e.g. visual word form, auditory word form and structural description) which represent information about the form and structure, but not the meaning of words and objects (i.e. it operates at a presemantic level). Schacter (1992) supports a division of the visual and auditory word form systems into lateralized subsystems: a left-hemisphere component that operates on abstract (but modality-specific) word-form information, and a right-hemisphere component that operates on highly specific visual or auditory perceptual information.

Schacter & Church, (1992) studied auditory priming using word identification and stem completion tasks. In the word identification task, subjects heard previously studied and nonstudied words masked by white noise, followed by the attempt to identify them. In the stem completion task, subjects heard the initial syllable of studied and nonstudied words and responded with the first word that came to mind. To investigate whether priming on these tasks depends on semantic-level processes, subjects heard a series of spoken words during the study phase of the experiment and either performed a semantic encoding task (e.g. rating the number of meanings associated with the word) or a nonsemantic encoding task (e.g. rating the clarity with which the speaker enunciated the word). Implicit and explicit memory tests were administered after brief delays of several minutes. Explicit memory performance was found to be superior following semantic compared to nonsemantic encoding tasks, whereas the magnitude of priming on identification and completion tasks was either less affected or entirely unaffected by the manipulation of the encoding task (i.e. level of processing), suggesting the operation of separate memory systems.

Evidence in support of the idea that priming is based largely on a perceptually driven system comes from experiments on study/test modality shifts. After target words had been studied visually, priming scores on auditory-word identification tasks (Ellis, 1982; Jackson & Morton, 1984) and auditory stem completion (Bassilli, Smith, & MacLeod, 1989) were reduced significantly relative to auditory-study conditions indicating modality specificity for repetition priming.

Rajaram & Roediger (1993) have reported a study comparing the magnitude of priming on visual stem completion and visual word identification tests following different study conditions. The aim of the study was to examine the degree of transfer that occurred for same-same and same-different conditions. They found that the greatest amount of priming of visual stem completion occurred from visual presentation of words during the study phase, the next greatest from auditory presentations, and the least from pictorial presentations. These findings suggest that it is the similarity of surface features of study and test events that promotes repetition priming.

Church & Schacter (1994) reported that study-to-test change within a single speaker's voice influence both priming of auditory stem completion and auditory identification of words degraded with a low-pass filter. As an example, in one experiment the emotional intonation of the speaker's voice was varied so that the target words were either spoken in the same emotional intonation at study and test (e.g., angry-angry), or they were spoken in different emotional intonations (e.g., angry-happy). Priming was significantly higher in the same-intonation condition than in the different-intonation condition, while explicit memory for the words was not affected by the intonation manipulation.

Schacter and Church (1992) suggested that the left- and right hemisphere subsystems subserve abstract and perceptually specific components of auditory priming, respectively. Several types of empirical evidence link the right hemisphere with access to voice information: patients with right hemisphere lesions have voice-recognition impairments and difficulties in processing voice prosody, and studies of normal subjects using dichotic-listening techniques have shown a left-ear advantage for processing intonational information (e.g., Blumstein & Cooper, 1974).

To test their hypothesis of hemispheric specialization for auditory processing, Schacter, Aminoff, and Church (1992) used a dichotic version of the auditory stem completion task. They hypothesized that priming effects would be reduced by study-to-test changes in the speaker's voice when test stimuli were presented to the left ear but not when they were presented to the right ear. During the study phase, subjects made clarity-of-enunciation judgments concerning a series of words spoken by male or female voices. They were then given the auditory-stem-completion task: stems representing studied or nonstudied target words were presented to either the left or right ear, a nontarget distractor stem was presented to the opposite ear (to inhibit the hemisphere ipsilateral to the target stimulus), and subjects were instructed to respond with the first word to come to mind in response to the stem presented to either the left ear or the right ear. In support of their hypothesis, they found that for right ear (left hemisphere) presentations, the same amount of priming in the same- and different-voice conditions. For left ear (right hemisphere) presentations, significant priming was observed in the same-voice condition but no priming was found in the different-voice condition.

Several important points come from studies of implicit memory. First, there is strong evidence that perceptually based information is transferred between study and test stimuli in implicit memory. Second, the transfer of this kind of modality-specific information occurs at an unconscious level and does not influence performance on explicit memory tasks which are more sensitive to conceptually driven factors (e.g., level of processing). This has been a major factor in distinguishing between different types of memory (i.e. implicit and explicit), and has been used to argue for the concept of multiple memory systems.

Dual Process Theory of Recognition Memory

Dual process theories of recognition memory argue that two different processes may be employed as a basis for decisions in a recognition memory task (Mandler, 1980). *Recollection*, defined as the retrieval of a prior episode including its context, is one basis on which a test item may be correctly identified. However, since target items are those that repeat, an item may be judged old on the basis of the *familiarity* engendered by the re-presentation of that item. The familiarity component is argued to derive from the "relative fluency" with which repeated test items are processed (Mandler, 1980; Jacoby & Dallas, 1981). Because information related to the target item has been previously processed, it is argued that it becomes easier for the brain's perceptual system to process the identical stimulus which seems to "jump out" at the subject. This does not necessarily have to occur at a conscious level, and in fact is thought to be a relatively automatic process that is similar to processes involved in implicit perceptual learning tasks.

To test the argument that perceptual fluency contributes to recognition judgements, Johnston, Dark and Jacoby (1985) examined recognition performance for perceptually degraded words and nonwords. They found that irrespective of the items' actual old/new status, words or nonwords that were "fluently perceived" (indexed by how quickly they were identified) tended to be judged old. Thus, they argue that the ease with which items are perceived contributes to feelings of familiarity and consequently the judgement that an item has been previously encountered.

To support their dual-process theory of recognition memory, Jacoby and Dallas (1981) were able to distinguish two classes of variables that differentially influence recognition and implicit perceptual memory. The first factor included variables known to influence explicit but not implicit memory, such as level of processing. As expected, this factor did not affect implicit perceptual learning; however, it did influence recognition memory performance. The second class of variables, which included the physical and perceptual properties of stimuli, had parallel effects on implicit and recognition memory. Thus, by demonstrating the influence of factors known to differentially contribute to explicit and implicit memory, they were able to provide evidence to support the dual-process model of recognition memory.

A number of experiments have demonstrated the contribution of perceptual fluency to recognition judgements (e.g., Jacoby & Dallas, 1981). Since there is also evidence that sensory information is maintained between study and test for perceptual learning tasks, the mode of presentation (i.e., visual or auditory) can be said to play an important role in recognition memory.

Event-related Brain Potentials and Memory

Brain event-related potentials represent electrophysiological changes that occur in response to a particular event. One advantage of using ERPs to study memory is that they provide a method of examining electrical changes that occur in the brain with a high degree of temporal resolution as various kinds of responses occur.

Electrophysiological correlates of memory retrieval processes have been examined by measuring ERPs while subjects make judgments of old or new to presented stimuli. ERPs elicited by correctly identified old items are found to be more positive when compared to correctly identified new items (e.g., Bentin, McCarthy, & Wood, 1985; Besson, Kutas,

& VanPetten, 1992; Friedman, 1990a; Friedman, 1990b; Rugg, 1987; Rugg & Nagy, 1989; Karayanidis, Andrew, Ward, & McConaghy, 1991; Smith & Halgren, 1989). This old/new effect begins around 400 msec poststimulus and continues for 300-400 msec, encompassing the N400 and P600 components. That is, stimulus repetition produces an increase in P600 and an attenuation of N400 amplitude (Smith & Halgren, 1987; Smith & Halgren, 1989). This finding has been observed when either words (e.g., Friedman, 1990a; Rugg & Nagy, 1989) or pictures (Friedman, 1990b; Zhang, Begleiter, Porjesz, Wang, & Litke, 1985) are used as stimuli.

Many experiments have attempted to demonstrate that the old/new effect represents processes related to memory retrieval rather than other task-related factors such as subjective probability or the semantic properties of items. One variable supporting that the old/new effect reflects mnemonic processes is the latency at which it begins. That is, the shift in positivity precedes the average reaction time for the subject's response. Since the shift occurs before the subject responds, and it is related to behavioral performance, it has been interpreted to represent the process or processes involved in the subject's ability to discriminate old from new items (Paller & Kutas, 1992; Rugg & Nagy, 1989; Smith, 1993; Smith & Halgren, 1989).

Another method that has been used to try to separate the recollection and familiarity components of recognition memory has been to compare ERPs associated with "*remember*" and "*know*" responses (Smith, 1993). In this paradigm, after subjects make an old judgement, they are also required to indicate whether they actually remember a previous encounter with the item (remember), or if they just have a feeling (know) that they have seen the item before. It is argued that remember responses reflect processes related to conscious recollection while know responses reflect processes related to the familiarity component of recognition memory. Old/new effects in ERP studies are found for both remember and know responses, but are significantly larger for the remember condition (Smith, 1993). This was interpreted as evidence supporting the notion that the ERP old/new effect represents processes underlying recollection and not familiarity. The fact that an old/new effect was also demonstrated in the know condition however, suggests that this interpretation is incorrect, or that the paradigm is an imperfect measure of recollection.

In an attempt to circumvent the pitfalls of introspection required by the "Remember/Know" paradigm, investigators have varied the context of presentation during study as a way of determining whether a judgement was based on a recollective experience or just a general feeling (Wilding, Doyle, & Rugg, 1995; Wilding & Rugg, 1997a; Wilding & Rugg, 1997b). For example, Wilding, Doyle, and Rugg (1995) presented words auditorily and visually and had subjects indicate, for old responses, what modality the item had been presented during study. They found the old/new effect for items whose study modality was correctly identified, but not for items whose study modality was incorrectly identified. They argued that these findings indicate the ERP old/new effect is associated with recognition memory based on recollection and not familiarity.

The evidence so far provides strong support that the ERP old/new effect reflects processes related to memory retrieval; however, whether it represents the conscious recollection or familiarity components of recognition memory has yet to be resolved. An interpretation of the old/new effect as an index of conscious recollection requires that differences exist between the ERPs elicited by correctly and incorrectly identified old words. That is, if the old/new effect were to represent the conscious recollection of an item, then one would expect distinct ERPs based upon behavioral performance. A recent study by Rugg et. al.

(1998) compared ERPs elicited by correctly and incorrectly identified old words in a study-test paradigm. They found no significant difference in the old/new effect between correctly and incorrectly recognized old words over the parietal region. Activity in overlying frontal sites however, did dissociate correct and incorrect responses; correctly identified old words elicited greater positivity (in the same latency range; 300-500 ms) than new words. This effect was not observed for old words that were incorrect. These results led the investigators to argue that the parietal old/new effect is a correlate of implicit memory, while the frontal old/new effect represents explicit memory processes. A similar analysis performed by Johnson et. al. (1998) revealed different findings. In contrast to the results of Rugg et. al. (1998), incorrectly classified old words were smaller in amplitude and longer in latency than correctly classified old words. The ERPs elicited by incorrect old words were the same, in amplitude and latency, as correctly categorized new words. These findings argue that the parietal old/new effect does not reflect an implicit memory process.

The Old/New Effect and the Temporal Lobes

One problem that creates difficulty in interpretation of the ERP old/new effect, is that it occurs over a relatively long period of time. This makes it difficult to determine precisely what cognitive processes are actually reflected by the increased positivity to repeated items. Because subjects are performing a recognition memory task, the focus has been on medial temporal lobe (MTL) structures as possible generators for the scalp ERP repetition effect. The availability of patients with temporal lobe epilepsy who are about to undergo surgery, has provided a means by which to examine this question further. A number of investigators have recorded ERPs using depth electrodes placed in and around MTL structures and have found ERP components that are more positive to repeated items and are similar in morphology and latency to the scalp N400 and P600 components (Guillem, N'Kaoua, Rougier & Claverie, 1995; Rugg, Roberts, Potter, Pickles & Nagy, 1991; Smith, Stapleton & Halgren, 1986; Smith & Halgren, 1989). Large amplitude ERP components and the presence of polarity inversions suggest a local generator source, particularly in the amygdala and hippocampus. This is consistent with the known importance of these structures in memory functioning (e.g., Squire & Zola-Morgan, 1991; Mishkin, 1978).

Further evidence in support of MTL structures as a generator source, comes from observations of the effects of temporal lobe epilepsy on the scalp ERP repetition effect. In general, having seizure foci in the temporal lobes does not significantly impact the scalp ERP repetition effect, while temporal lobectomies and/or seizure activity that results in extensive damage of white matter, significantly reduces or abolishes the scalp ERP repetition effect (Puce, Andrews, Berkovic & Bladin, 1991; Rugg et al., 1991; Smith & Halgren, 1989; Smith, et al., 1986). Smith and Halgren (1989) reported that unilateral anterior temporal lobectomy (ATL) in the left hemisphere impaired both recognition accuracy and eliminated the ERP old/new effect. In addition, the rate at which repeated trials improved performance remained unaffected in these patients, suggesting that the anterior temporal lobe contributes to the recollection aspect of recognition memory and not the familiarity component which increases with multiple repetitions. Rugg et al., (1991) found similar results with the exception that they did not find any strong lateralizing effects. That is, the old/new effect was smaller in both the left and right temporal lobectomy patients.

Although there has been an emphasis on MTL structures, studies have demonstrated that the N400 component varies in amplitude from frontal to posterior locations depending upon the task and/or stimulus. To try to localize some of the possible generator sources, Guillem et al., (1995) measured recordings from prefrontal, parietal, anterior temporal, posterior temporal, and occipital regions using depth electrodes in presurgical epilepsy patients during a recognition memory task for pictures. They found that the occipital and temporal-occipital regions do not contribute to the scalp N400/P600 old/new effect. Regions of the brain that are involved with perceptual or motor control processes that may influence the overall scalp ERP amplitude without contributing to memory processes, included inferior and posterior temporal lobe structures and the supplementary and premotor areas. Structures known to play an important role in memory, including the anterior temporal, prefrontal and possibly parietal regions, were found to contribute to the ERP old/new effect. The investigators argued that these structures not only generate the ERP components but likely interact with each other to give rise to scalp ERP old/new effects. Thus, these results parallel dual process theories, which suggest involvement of both perceptual fluency and conscious recollection in recognition judgements.

Paradigms for Study of Old/New Effect

Since measurement of the old/new effect derives from the basic recognition experiment, this paradigm suggests itself for the purpose of providing ERP recordings. Involved is usually a study period presenting the items, followed after an interval by a test period that presents items seen before (old) and new items not included in the study list. The participant identifies each item as old or new by voice or by key press.

An alternative, quite appropriate to the present study, is the continuous performance task, introduced by Shepard and Teghtsoonian (1961) for the purpose of measuring retention under steady state conditions. In this paradigm, participants are presented with a single mixed block of items in which some of the items are seen for the first time and others repeat and are seen a second time. Instructions are to indicate on every trial whether a word is new (never presented before in the series) or old (presented earlier in the series). One advantage of using this format is that old and new items are presented within the same block of trials. This removes the need for an uncontrolled and potentially disruptive delay period between study and test. In addition, one can also examine the effects of various lags on memory performance; lag refers to the number of items intervening between successive presentations of a particular word. The continuous nature of presentation and ability to compare old and new items within the same block, also makes this paradigm ideally suited for collection of ERP data.

PET Studies of Memory Retrieval

With the increased use of PET as a technique to study memory processes, investigators have refined and developed experiments that attempt to elucidate brain regions which mediate sub-processes of memory tasks such as retrieval of information. A consistent finding in PET studies which measure brain activity associated with memory retrieval has been the activation of the right prefrontal cortex. This has been demonstrated for words (e.g., Shallice et. al., 1994; Squire et. al., 1992; Tulving, Kapur, Craik, Moscovitch, & Houle, 1994; Tulving et. al., 1994) and faces (Grady et al., 1995) using a variety of different memory tasks (e.g. word-stem completion, paired associates, sentence recognition).

Another consistent finding in PET studies of memory retrieval has been the activation of the medial parietal region (the precuneus). This is of particular interest in the context of the current study since the ERP old/new effect, which is also thought to reflect memory retrieval, is maximal over parietal electrode sites. It has been hypothesized that precuneus activation is associated with the use of visual imagery as a mnemonic strategy for retrieval (Grasby et. al., 1993). This suggestion was primarily based upon feedback provided by participants in these early studies. Findings from experiments aimed at testing this idea, however, have been mixed. For example, Fletcher, Shallice, Frith, Frackowiak, & Dolan (1996) showed that the activation of the precuneus area varied as a function of the imaginability of words. That is, they demonstrated significantly greater precuneus activation for words that were highly "imaginable" (e.g., king, car, train) as compared to "non-imaginable" abstract words (e.g., justice, close, law). In contrast, Buckner, Raichle, Miezin, & Peterson (1996) failed to demonstrate any significant effects of imagery on precuneus activation. Consistent with this, Krause et. al., (1999) also showed equally significant precuneus activation for highly imaginable and abstract words. Furthermore, they examined the effects of presentation modality (auditory and visual) on precuneus activation levels and found no significant difference, concluding that the precuneus has a specific function in episodic memory retrieval as a multimodal association area. Thus, the findings from PET studies of memory retrieval point to the precuneus as a possible generator source that is modality independent.

Purpose of Study

The evidence reviewed thus far, indicates the existence of separate processing streams for auditory and visual short-term memory, and that recognition memory judgements are influenced by the perceptual characteristics of items to be remembered. To date, the majority of ERP studies examining cognitive processes related to recognition memory have been done in the visual modality. Little is known about the ERP correlates of auditory word recognition memory processes, or whether an old/new effect would even be observed in this modality. No study has directly compared auditory and visual ERP old/new effects, a comparison of interest in light of the behavioral evidence suggesting separate auditory and visual processing streams, and the implication that different neural pathways are involved in each.

The present study has undertaken this direct comparison of visual and auditory recognition memory processes with particular interest in whether the ERP old/new effect is modality dependent. To accomplish this, a systematic comparison of visual and auditory recognition memory processes will be conducted by using the same stimuli in both modalities. Since there is strong evidence that MTL structures represent a major generator source for the ERP old/new effect, its presence should not be dependent upon stimulus modality. Research in monkeys and humans have identified a system of anatomically related structures within the medial temporal lobe that is important for memory (for review, see Zola-Morgan & Squire, 1993). Results from these studies have demonstrated that input to these MTL structures come from multimodal association cortices. This is consistent with the notion that the old/new effect reflects a high-level cognitive operation (i.e. memory retrieval). If however, as the behavioral data suggest, two separate processing streams exist for visual and auditory stimuli, the scalp topography of the old/new effect should differ between modalities. In addition, the scalp topography of earlier ERP components (e.g., N1 and N2) should exhibit modality-specific processing.

The use of a continuous recognition paradigm allows for the evaluation of different time delays (lags) between the repetition of a word. Previous studies using this format have found no effect of lag on the ERP old/new effect when stimuli were presented visually (Friedman, 1990a, 1990b). Consistent with this, no lag effects are expected for the visual modality. Given the stronger sensory memory trace for acoustic than visual information (Cowan, 1984; Engle & Roberts, 1982), one might expect a lag effect for words presented in the auditory modality. However, since words will be continuously presented in a series, one after the other, there is little opportunity for an acoustic sensory trace to influence recognition memory. Therefore, no significant lag effect is expected in the auditory condition.

Method

Participants

ERPs were recorded from 22 volunteers (12 men and 10 women) who were paid $15/hr for their participation. All participants were screened to exclude those with current or past neurologic or psychiatric disorders. Hearing acuity was also assessed using standard audiometric procedures. All participants were required to have a difference of less than 10-dB between ears at threshold and a hearing loss no greater than 25 dB at 500, 1 000, or 2 000 Hz. Two subjects (1 male, 1 female) who performed the task at below chance levels were not included, while four additional subjects were excluded because of excessive artifact in the EEG data caused by eye blinks (1 male, 1 female) and noise from faulty electrode connections (2 males).

The ages of the remaining 16 participants (8 male and 8 female) whose data were analyzed and appear in this report, ranged from 24 to 40 years (mean=31.69, SD=6.16). Mean education level was 17.38 (SD=1.41). All participants were right-handed as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971), with a mean score (+100 is completely right-handed) of 80. There were no significant differences between men and women for age, $\underline{F}(1,14)=1.90$, $\underline{p}=0.19$, education level, $\underline{F}$ $(1,14)=0.119$, $\underline{p}=0.74$, or handedness, $\underline{F}$ $(1,14)=0.590$, $\underline{p}=0.46$.

Stimuli, Stimulus Presentation, and Design

A pool of 320 nouns (word frequency range of 50-375 per million; concreteness rating ranged between 247-670) selected from the MRC Psycholinguistic database (Coltheart, 1981), was used to generate four lists of 80 words (see Appendix A). Word frequency values were based on Kucera and Francis (1967) norms, while concreteness ratings were based upon the Paivio, Yuille, & Madigan (1968) norms. Values for word frequency and concreteness were balanced across lists. Each list was constructed so that an equal number of words (n=17) repeated following a short lag (8 intervening items) and a long lag (24 intervening items). Thus, each list had 34 words that repeated, 17 at each lag, and 46 words that were new and did not repeat. No word was repeated more than once, and there was no overlap between lists. The order of presentation for each list was randomized for each subject so that the short and long lags were equally distributed throughout the list. Each participant was presented with two of the lists in the auditory modality and the other two lists in the visual modality.

In the visual condition, words were presented in foveal vision on a computer monitor (400 ms duration; 2 s interstimulus interval), subtending a vertical angle of 0.95°, and horizontal angles ranging from 3.3° to 8.7°. A fixation cross in the center of the screen was visible between stimulus exposures to indicate stimulus location. All items were in black on a light grey background.

Auditory stimuli (median duration = 411 ms; range = 229-718ms; 2 s interstimulus interval) were presented binaurally through headphones at a comfortable listening level. A fixation cross in the center of the screen was present throughout the task. In order to control for the variability in emotionality and intonation that occur in a human voice, auditory stimuli were constructed using a computer generated voice (from the commercially available

"Dragon Naturally-Speaking" software program) and recorded at a sampling rate of 16KHz.

The presentation order for the four word lists, modality (auditory and visual) and the selection of response buttons (left or right for old/new responses) were determined by a Latin Square design. Two different presentation orders were used: Auditory-Visual-Visual-Auditory (AVVA), and Visual-Auditory-Auditory-Visual(VAAV)(see Table 1).

Table 1 - Latin Square for assignment of word lists, modality, and response keys for the 16 participants.

Male Participants

SUBJECT	V	A	A	V
1	1 (L/R)	2 (L/R)	4 (R/L)	3 (R/L)
3	2 (R/L)	3 (R/L)	1 (L/R)	4 (L/R)
5	3 (L/R)	4 (L/R)	2 (R/L)	1 (R/L)
7	4 (R/L)	1 (R/L)	3 (L/R)	2 (L/R)

SUBJECT	A	V	V	A
2	1 (L/R)	2 (L/R)	4 (R/L)	3 (R/L)
4	2 (R/L)	3 (R/L)	1 (L/R)	4 (L/R)
6	3 (L/R)	4 (L/R)	2 (R/L)	1 (R/L)
8	4 (R/L)	1 (R/L)	3 (L/R)	2 (L/R)

Female Participants

SUBJECT	V	A	A	V
1	1 (L/R)	2 (L/R)	4 (R/L)	3 (R/L)
3	2 (R/L)	3 (R/L)	1 (L/R)	4 (L/R)
5	3 (L/R)	4 (L/R)	2 (R/L)	1 (R/L)
7	4 (R/L)	1 (R/L)	3 (L/R)	2 (L/R)

SUBJECT	A	V	V	A
2	1 (L/R)	2 (L/R)	4 (R/L)	3 (R/L)
4	2 (R/L)	3 (R/L)	1 (L/R)	4 (L/R)
6	3 (L/R)	4 (L/R)	2 (R/L)	1 (R/L)
8	4 (R/L)	1 (R/L)	3 (L/R)	2 (L/R)

V=visual A=auditory;
Word Lists 1 -4;
Left or Right for (old/new button press)

Word Recognition Memory Task

The continuous word recognition memory paradigm described earlier was used. In the present study, participants were presented with a continuous series of words. They were instructed for each word to indicate, by pressing one of two separate buttons on a response pad as each word was presented, whether it was new (never presented before in the series) or old (presented previously). They were informed that there would be no overlap between blocks and that they should try to respond to every stimulus as quickly and accurately as possible. Each subject received four separate blocks composed of 114 trials; two in the auditory modality and two in the visual modality (i.e. AVVA or VAAV). Response buttons for old/new responses were balanced within each subject. That is, the response buttons for old/new were switched after the first two blocks. For example, a subject who used the right hand for old and the left hand for new responses, would be switched to the left hand for old and right hand for new responses during the final two blocks. Responses were accepted from 200 ms post-stimulus onset until the next stimulus onset within a fixed 2.0 s interstimulus interval (ISI).

Data Acquisition and Recording Procedures

Scalp EEG was recorded from 13 lateral pairs of electrodes (FP1, FP2; F3, F4; F7, F8; FC5, FC6; FT9 FT10; C3, C4; T7, T8; CP5, CP6; TP9, TP10; P3, P4; P7, P8; P9, P10; O1, O2) and from 4 midline electrodes (Fz; Cz; Pz; Oz) using an electrode cap (Electro Cap International, Inc.) with a nose electrode serving as the reference and an Fpz ground. Standard Beckman Ag/AgCl electrodes at supra- and infra-orbital sites surrounding the right eye were used to monitor eye blinks and vertical eye movement (bipolar), and electrodes at right and left outer canthi monitored horizontal eye movements (bipolar). All electrode impedances were maintained at 5kΩ or less and were recorded through a Grass Neurodata acquisition system at a gain of 10kΩ (5kΩ for horizontal eye channel and 2kΩ for vertical eye channel), with a bandpass of .01-30 Hz. A PC-based EEG acquisition system (Neuroscan) was used to continuously sample the data at 200 Hz during the task. Responses and response latencies were recorded online along with the EEG data for later analyses. Recording epochs of 2,000 ms (300 ms pre-stimulus baseline) were extracted off-line. Individual averaged ERP waveforms were digitally low pass filtered at 12.5 Hz (-24 dB/octave).

Data Reduction and Analysis

Epochs contaminated by eye movements or other movement-related artifacts were excluded from analyses offline using a rejection criterion of 100µV on any channel. Blinks were corrected on a trial-by-trial basis using a linear correction routine (linear regression; Semlitsch, Anderer, Schuster, Presslich, 1986). Individual averaged ERP waveforms were computed for each condition (old/new) in each modality (visual/auditory) for artifact-free trials (correct responses only). Only items that were correctly identified for both new and old responses were included in the ERP averages, resulting in an average of 41.38 (*SD*=9.0) and 41.63 (*SD*=9.5) trials for old and new items in the auditory condition, and 46.75 (*SD*=6.8) and 45.88 (*SD*=7.5) trials for the corresponding items within the visual condition.

Criteria for measurement of identified ERP components were obtained by inspection of the grand average and individual subject waveforms. The following time windows were used to compute averaged voltages with respect to a 200 ms pre-stimulus baseline: N1 (100-160 ms), N2 (290-430 ms), late positivity (400-700 ms), and late negativity (1100-1500 ms). The time window for the late positivity was also based upon the peak old/new effect in both modalities (600 ms).

ERP averaged voltages were submitted to repeated measures analysis of variance (ANOVA)(BMDP4V; Dixon, 1992) with gender (males/females) as a between-subjects factor, and condition (old/new), modality (visual/auditory), hemisphere (left/right), lag (short/long), and site (13 symmetric pairs of electrodes, excluding midline electrodes) as within-subjects factors. A separate analysis of ERP averaged voltages involving the four midline electrodes (Fz, Cz, Pz,Oz) was also submitted to repeated measures ANOVA (BMDP4V; Dixon, 1992) with gender (male/female) as a between-subjects factor, and condition (old/new), lag (short/long), modality (visual/auditory), and site (Fz/Cz/Pz/Oz) as within-subjects factors. Greenhouse-Geisser epsilon ($\underline{\varepsilon}$) correction was used to evaluate F ratios for within-subject effects involving more than 2 degrees of freedom (Vasey and Thayer, 1987). Significant interactions involving site were examined through simple effects at each site to locate the source of the interaction. To assess whether overall amplitude differences contributed to differences in topography, significant interactions involving site or hemisphere were re-analyzed after normalizing the data using the root mean square method (Glaser & Ruchkin,1976). A summary table of significant ERP effects can be found in Appendix B.

For the analysis of the behavioral data, response latencies (mean reaction times of correct responses) and percentages of correct responses were submitted to repeated measures ANOVA with gender (male/female) as between-subjects factors, and condition (old/new), lag (short/long), and modality (visual/auditory)as within-subjects factors.

RESULTS

Behavioral Data

Table 2 summarizes the accuracy scores for correct responses for old and new items across both visual and auditory modalities. The participants' ability to distinguish old from new items was well above chance and did not vary according to modality or lag. There was also an equally low rate of false alarms across modalities as evidenced by the high rate of correct responses to new items. No significant gender main effects or interactions of gender with modality or lag were observed. As can be seen in Figure 1, the overall level of task difficulty was the same across modality.

Table 2 - SUMMARY: Accuracy for Old and New Responses

Grand Means[a]	**AUDITORY (%)**				**VISUAL (%)**			
	Old		**New**		**Old**		**New**	
	Short Lag	Long Lag	Short Lag	Long Lag	Short Lag	Long Lag	Short Lag	Long Lag
Males	79.8	82.4	95.2	93.8	79.4	77.9	91.9	92.6
	(10.5)	(5.0)	(3.8)	(5.8)	(11.1)	(10.3)	(6.6)	(4.7)
Females	78.0	80.2	92.6	89.3	78.3	80.5	94.5	93.0
	(13.6)	(12.3)	(7.0)	(5.9)	(13.5)	(12.1)	(5.8)	(6.8)

Effect[b]	
Condition	F=23.35(p<.0001)
Gender	F=0.02 (p=.90)
Modality	F=0.31 (p=.59)
Lag	F=0.54 (p=.48)
Gender x Modality	F=0.58 (p=.46)
Gender x Lag	F=0.19 (p=.67)
Gender x Condition	F=0.00 (p=.98)
Modality x Condition	F=0.67 (p=.43)
Modality x Lag	F=0.55 (p=.47)
GenderxModalityxLag	F=0.56 (p=.47)
GenderxModalityxCondition	F=0.02 (p=.88)

[a] Standard deviations in parentheses

[b] For all effects, *df* = 1, 14.

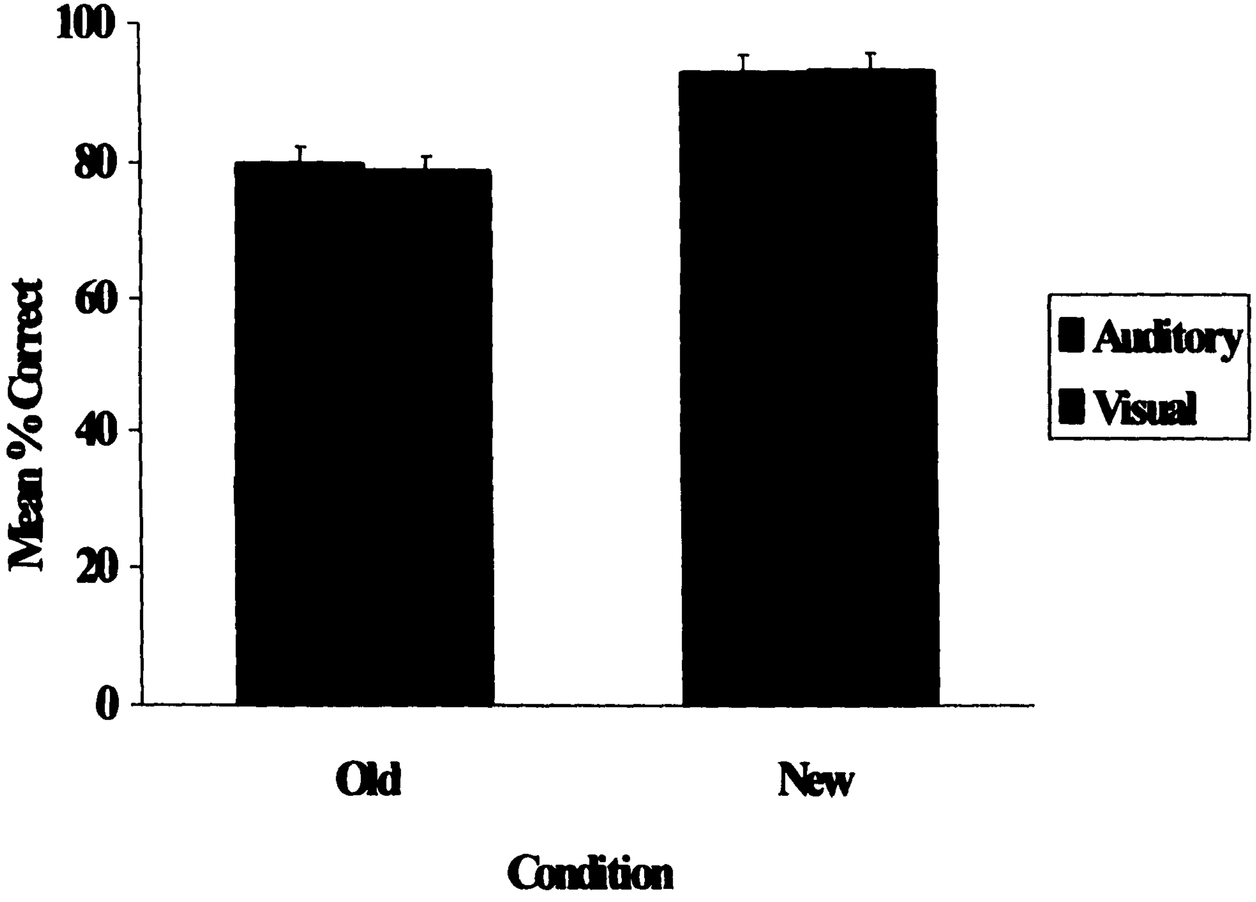

Figure 1. Mean Correct Responses to Old and New Items in the two modalities.

A summary of response latencies for correctly identified old and new items can be seen in Table 3. The average response latency to correctly identified old and new items for the two modalities can be seen in Figure 2. Response latency was significantly longer in the auditory task than the visual task; $F(1,14)=148.25$, $p<0.0001$. Male participants tended to respond more quickly than the females; $F(1,4)=4.87$, $p=0.05$. There was also an overall main effect of condition in that participants responded more quickly to new items than old; $F(1,14)=8.44$, $p=0.01$. There was no significant main effect of lag, and there were no significant interaction effects involving modality or gender.

To summarize, accuracy scores were found to be equivalent across auditory and visual modalities as well as across lag. The mean latency for auditory identification was found to be significantly longer than for visual.

Table 3 - SUMMARY: Response Latencies for Old and New Responses

Grand Means[a]	AUDITORY (ms)				VISUAL (ms)			
	Old				Old			
	Short Lag	Long Lag	New	Filler[c]	Short Lag	Long Lag	New	Filler[c]
Males	851.2 (34.9)	862.5 (61.8)	880.0 (63.0)	895.9 (58.0)	690.9 (85.5)	693.3 (78.7)	633.4 (73.0)	645.7 (77.3)
Females	957.6 (107.0)	977.0 (114.8)	931.0 (96.8)	962.7 (87.1)	780.7 (94.4)	771.3 (73.7)	687.5 (97.6)	703.5 (77.8)

Effect[b]	
Gender	F=4.87 (p=.05)
Modality	F=148.25(p<.0001)
Condition	F=8.44 (p=.01)
Lag	F=0.51 (p=.49)
Gender x Modality	F=0.11 (p=.74)
Gender x Lag	F=0.01 (p=.91)
Gender x Condition	F=2.61 (p=.13)
Modality x Lag	F=1.28 (p=.28)
Gender x Modality x Lag	F=0.36 (p=.56)
Gender x Modality x Condition	F=0.80 (p=.39)

[a] Standard deviations in parentheses

[b] For all effects, *df* = 1, 14.

[c] "Filler" refers to new items that did not repeat.

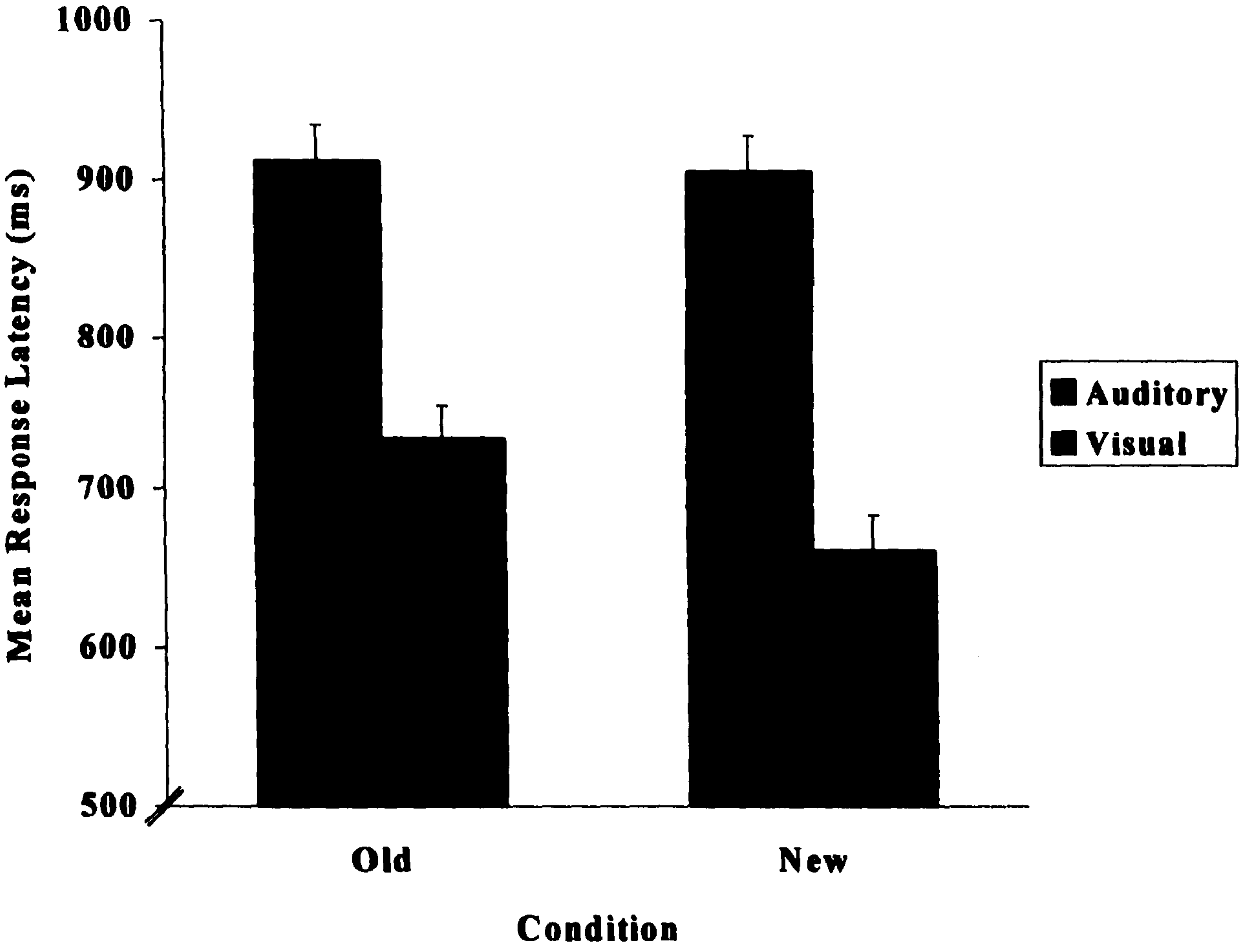

Figure 2. Mean Response Latency for Old and New Items as a function of modality.

Grand Average ERP Waveforms

ERP waveforms averaged for all 16 participants across levels of condition (old/new) for the auditory and visual modalities are shown in Figure 3. Distinctive ERP components were identified as N1, N2, late positive potential (LP), and late negativity (LN). Peak latencies and topography of individual components varied according to modality. Peak latencies for the auditory condition were as follows; N1 (125 ms), N2 (390 ms), LP (680 ms), and LN (1200 ms). Peak latencies for the visual condition were as follows; N1 (150 ms), N2 (330 ms), LP (615 ms), and LN (1000 ms). A prominent P2 component was also seen in the auditory condition (peak latency 215 ms).

For visually presented words, N1 was maximal over inferior parietal sites (P9/10), and greater over the left than right hemisphere. The distribution of N1 in the auditory modality was also lateralized over the left hemisphere, however, it was relatively more anterior, with maxima overlying central sites (C3/4,CZ).

An auditory P2 component, which was maximal over central sites (CZ, C3/4), followed the N1 component. This can be easily seen in the auditory condition but not the visual where it was less prominent.

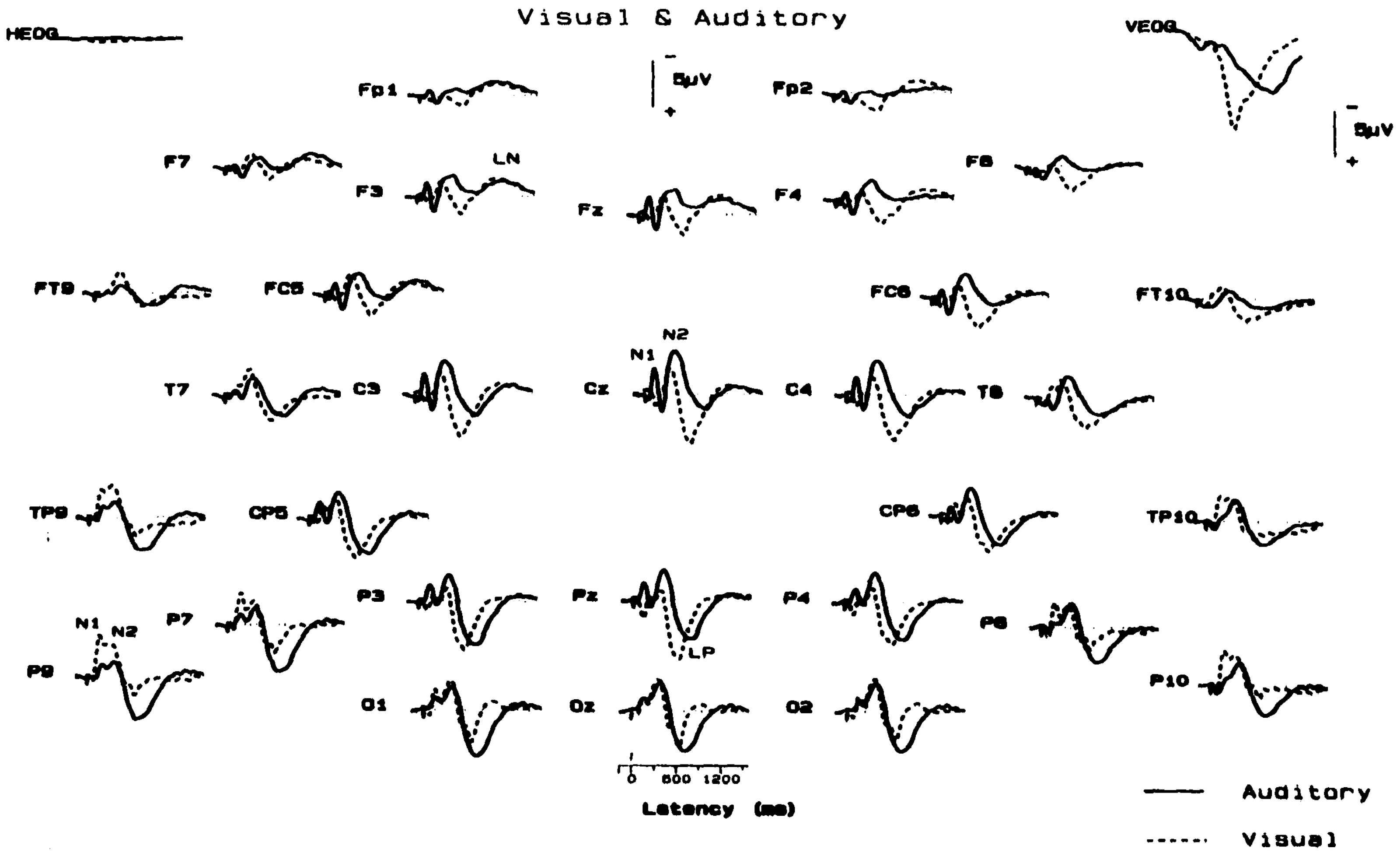

Figure 3. Grand average event-related potentials (ERPs) for auditory (solid line) and visual (dashed line) modalities at all recording sites. ERP components are indicated at F3, CZ, PZ, and P9.

Overall, the N2 component was more widely distributed than N1. In the visual modality, N2 was maximal over temporoparietal sites (TP9/10,P9/10), and was greater over the left than right hemisphere. The auditory N2 on the other hand, was relatively symmetrical and was most prominent over medial central-posterior sites (CZ,C3/4,PZ,P3/4,OZ,O1/2).

The early negativities were followed by a LP potential that was markedly different with respect to topography and peak latencies between modalities. For the visual condition, the LP potential was maximal over medial parietal sites (PZ), corresponding to the classical P3b component. In contrast, the LP potential in the auditory condition was more widely distributed and posterior in its focus, with maximal amplitude over parietal-occipital sites (P9/10,P7/8,O1/2,OZ). Peak latency was much earlier for the visual modality (615 ms) than the auditory (680 ms).

For both visual and auditory modalities, there was a long-latency frontal negativity, onsetting at approximately 1,000 ms and lasting through to 1,500 ms. This negativity was equally present for both modalities and was greater at sites overlying the left than right frontal region (e.g., compare F7, F3, FC5 with F8, F4, FC6 sites).

Old-New Effects

Grand average ERP waveforms comparing old and new conditions in the visual and auditory modalities are presented in Figures 4 and 5. Examination of the early negative components in both modalities show that new words seem to elicit greater negativity for the N1 and N2 components. Enhanced negativity for the visual N1 appeared most prominently over temporoparietal sites (TP9,P9,P7), while for the auditory N1 this enhancement was greatest at central sites (CZ, C3, C4). For N2, this effect was largest at medial sites overlying central and posterior regions for both visual and auditory modalities.

Comparison of ERPs for the LP potential in the visual modality demonstrated the characteristic old/new effect of increased positivity to correctly identified old items compared to new items. This difference was most prominent along midline sites, with the greatest difference observed at parietal sites. An old/new effect was also seen for the auditory modality. In comparison to the visual modality, however, the old/new effect for auditorily presented words was distributed more laterally and posteriorly, encompassing parietal and occipital sites. There was also a difference in peak latencies between old and new conditions in the auditory modality, with old words eliciting an earlier late

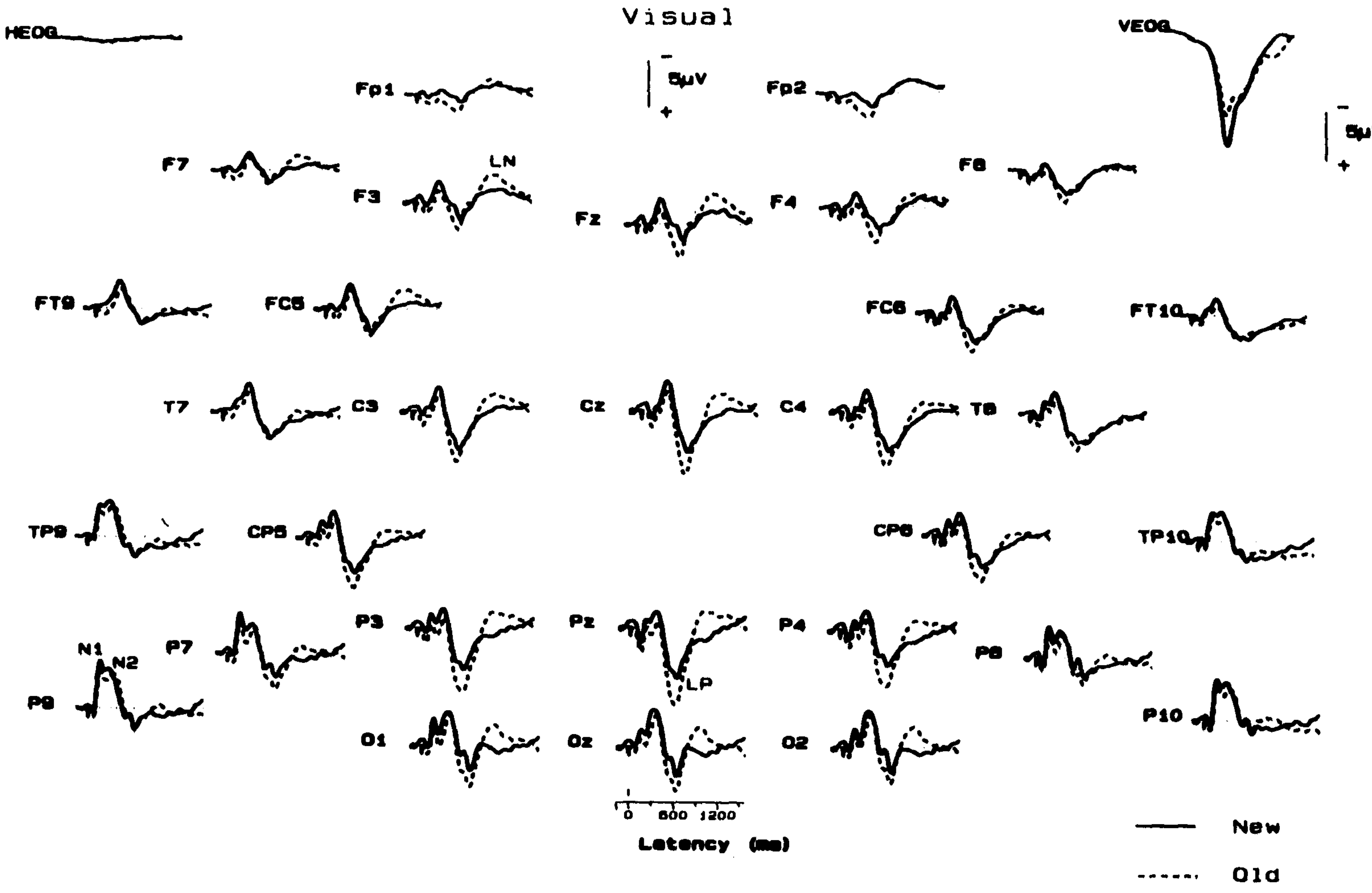

Figure 4. Grand average event-related potentials (ERPs) for new (solid line) and old (dashed line) words for the visual modality at all recording sites. ERP components are indicated at F3, PZ, and P9.

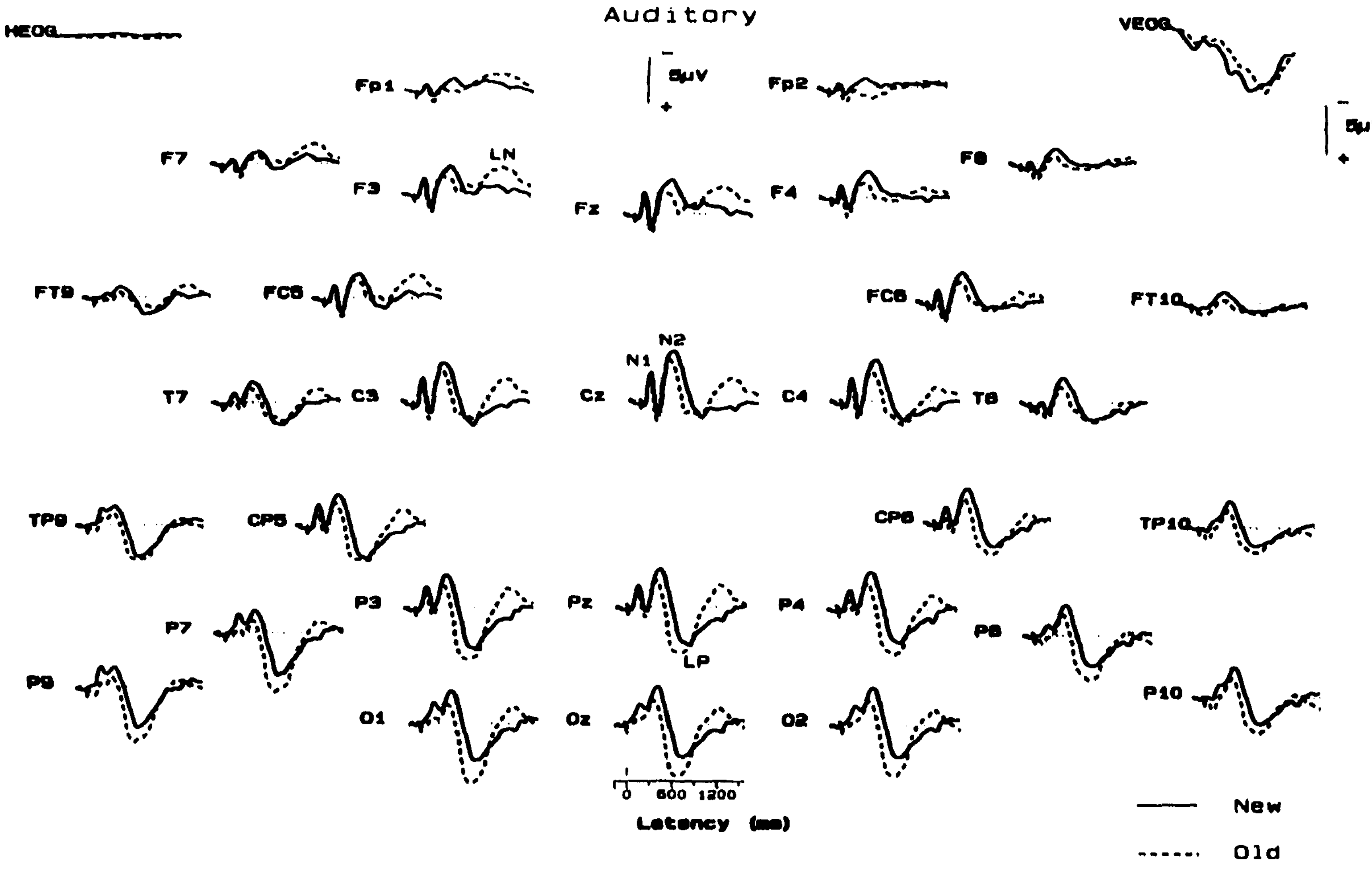

Figure 5. Grand average event-related potentials (ERPs) for new (solid line) and old (dashed line) words for auditory modality at all recording sites. ERP components are indicated at F3, CZ, and PZ.

positive component (703 ms) than new words (757 ms). Figure 6 shows the old/new effect for visual and auditory modalities. One can see from this figure, that despite the marked difference in latency of the late positive potential for old and new items in the auditory modality, the latency of the old/new effect was approximately the same for both modalities with a peak at around 600 ms.

An old/new effect for both modalities was also observed for the late negative potential (1100-1500 ms). The ERPs elicited by old items were more negative during this time period than for new words. Figure 6 demonstrates that this old/new effect for the late negativity was most pronounced along midline sites and appeared larger over the left than the right hemisphere. The peak latency for this effect was earlier for the visual modality, with a 1000 ms peak for the visual modality and the auditory modality coming later at 1200 ms.

Statistical Analyses

Results from repeated measures ANOVA will be reported in separate sections for each ERP component starting with the earliest (N1). Each section begins with results involving midline electrodes. This is followed by results

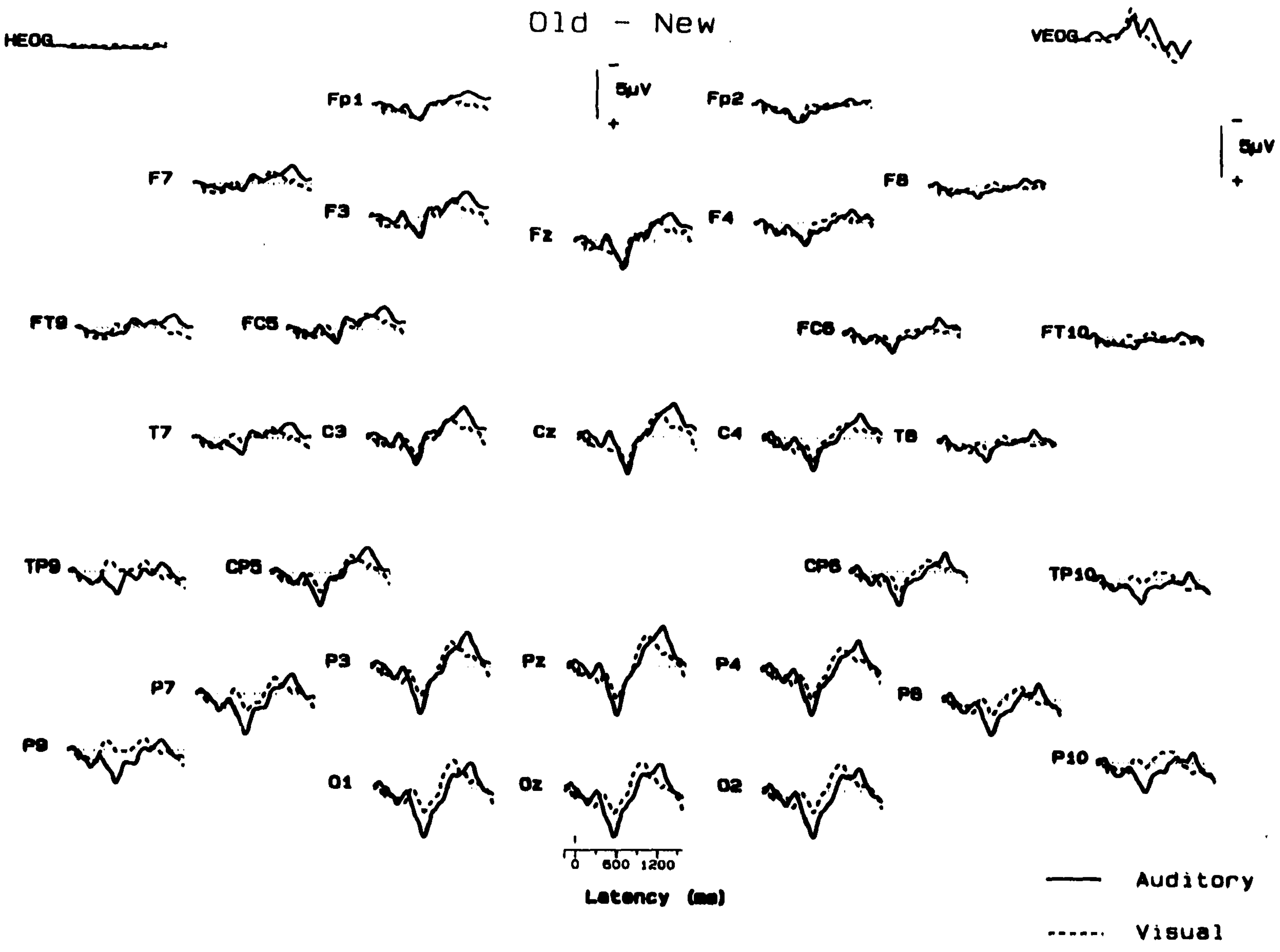

Figure 6. ERP Old/New Effect for auditory (solid line) and visual (dashed line) modalities.

including the remaining lateral electrodes which provides information regarding overall scalp topography and hemispheric asymmetries.

ANOVA Results for N1 Mean Amplitude (100-160 ms)

A topographical difference of mean N1 amplitude for auditory and visual modalities was supported by an analysis of midline electrodes, which resulted in a significant modality x site interaction, $F_{3,42}=8.33$, $p=0.008$, $\epsilon=0.41$ (simple effects of modality at FZ, $F_{1,14}=20.19$, $p=0.0005$; CZ, $F_{1,14}=29.65$, $p=0.0001$; PZ, $F_{1,14}=25.76$, $p=0.0002$). Along midline sites, mean N1 amplitude peaked over occipital sites (Oz) in the visual condition, while in the auditory condition, the mean N1 amplitude peaked over central sites (Cz). This difference in topography between modalities was present after normalizing the data for overall amplitude differences.

A separate analysis involving the 13 lateral pairs of electrodes also revealed a significant difference in topography of mean N1 amplitude across modalities. This was supported by a highly significant modality x site interaction, $F_{12,168}=15.25$, $p=0.0001$, $\epsilon=0.14$ (simple effects of modality at FP1/2, F7/8, F3/4, FC5/6, CP5/6, C3/4, TP9/10, P9/10, P3/4, all $F_{1,14}>11.8$, all $p<0.004$). In the visual condition, N1 amplitude was most prominent over lateral temporoparietal sites (TP9/10, P9/10), whereas in the auditory condition N1 amplitude was greatest over medial central-parietal sites (C3/4,P3/4). In addition, there was an overall main effect of hemisphere, $F_{1,14}=9.92$, $p=0.007$, indicating greater mean N1 amplitude over the left hemisphere than the right. Again, these topographical differences between visual and auditory modalities remained significant after normalizing the data to control for overall amplitude differences.

There was a significant main effect of condition, $F_{1,14}=6.33$, $p=0.02$, whereby new words elicited larger mean N1 amplitude than old words. There was also a significant condition x lag x site interaction, $F_{12,168}=3.81$, $p=0.02$, $\varepsilon=0.24$, however, this interaction was not supported after normalization of the data. Overall, there was no main effect of lag or gender on mean N1 amplitude.

ANOVA Results for N2 Mean Amplitude (290-430)

Analysis of midline electrodes for mean N2 amplitude yielded a significant modality by site interaction, $F_{3,42}=5.41$, $p=0.02$, $\varepsilon=0.52$ (simple effects of modality at CZ,$F_{1,14}=4.55$, $p=0.05$; at PZ, $F_{1,14}=5.13$, $p=0.04$), indicating greater mean N2 amplitude over the central (CZ) and parietal

(PZ) regions in the auditory modality compared to the visual. This is best illustrated in Figure 9 by comparing the activity at PZ for visual and auditory modalities. These findings remained significant after normalization of the data. There was a trend for the overall mean N2 amplitude to be greater for new than old words, $F_{1,14}=3.17$, $p=0.10$. There were no significant effects of lag or gender along midline sites.

Analysis of lateral sites indicated significant topographical differences in mean N2 amplitude between modalities. This was statistically supported by a significant modality x site interaction, $F_{12,168}=4.71$, $p=0.02$, $\epsilon=0.16$ (simple effects of modality at FT9/10, $F_{1,14}=6.46$, $p=0.02$). This topographical difference between modalities remained significant following normalization of the data, $F_{12,168}=5.80$, $p=0.005$, $\epsilon=0.19$ (simple effects of modality at FT9/10, $F_{1,14}=11.85$, $p=0.004$; C3/4, $F_{1,14}=7.79$, $p=0.01$; P3/4, $F_{1,14}=7.27$, $p=0.02$). While mean N2 amplitude was most prominent over medial sites (C3/4, P3/4) for the auditory modality, the visual N2 was maximal over lateral temporoparietal sites (P9/10, TP9/10).

Mean N2 amplitude was greater over left fronto-temporal sites than the right. This was supported by a highly significant hemisphere by site interaction, $F_{12,168}=7.19$,

$p=0.0001$, $\epsilon=0.34$ (simple effects of hemisphere at FP1/2, $F_{1,14}=8.85$, $p=0.01$; F7/8, $F_{1,14}=10.18$, $p=0.007$; F3/4, $F_{1,14}=5.43$, $p=0.04$; FT9/10, $F_{1,14}=10.01$, $p=0.007$). In contrast to the visual modality, the auditory N2 showed the opposite asymmetry of being greater over the right hemisphere than the left over temporoparietal sites (TP9/10). This was supported by a significant modality x hemisphere interaction, $F_{1,14}=4.64$, $p=0.05$. This interaction was slightly weaker following normalization of the data, $F_{1,14}=3.38$, $p=0.09$, suggesting that overall amplitude differences between auditory and visual modalities contributed to this effect.

There was also a significant modality x condition x site interaction, $F_{12,168}=3.92$, $p=0.02$, $\epsilon=0.20$, indicating a difference in the topography of old and new differences between visual and auditory modalities. Examination of simple effects revealed old/new differences for the visual modality only, as evidenced by a significant condition x site interaction, $F_{12,168}=3.18$, $p=0.04$, $\epsilon=0.22$. As can be seen in Figure 9, old/new differences in the visual condition were greatest over frontal and central sites. There were no main effects of condition, lag, or gender on mean N2 amplitude.

ANOVA Results for Late Positive Potential(400-700 ms)

The topographical distribution of the LP potential along midline sites differed across modalities as evidenced by a significant modality x site interaction, $F_{3,42}=19.19$, $p=0.0001$, $e=0.47$ (simple effects of modality at FZ, $F_{1,14}=19.35$, $p=0.0006$; CZ, $F_{1,14}=51.38$, $p<0.0001$; PZ, $F_{1,14}=46.30$, $p<0.0001$). Figure 7 shows the topography of the late positive component along midline sites for the visual and auditory modalities. In the visual condition, there was a sharp peak in mean amplitude at the PZ site, while in the auditory condition the LP potential did not peak over parietal regions, but continued to increase from frontal to occipital regions. One can also see in Figure 7 that, for both visual and auditory modalities, the greatest difference between old and new words occurred where the LP potential was largest. There were no significant lag or gender effects on the mean amplitude of the LP potential along midline sites.

ANOVA of the mean amplitude measures corresponding to the LP potential at lateral sites gave rise to a main effect of condition, $F_{1,14}=11.77$, $p=0.004$. This effect was due to greater positivity in ERPs elicited by correctly identified old words compared to correctly identified new words. A significant modality x condition x site interaction was

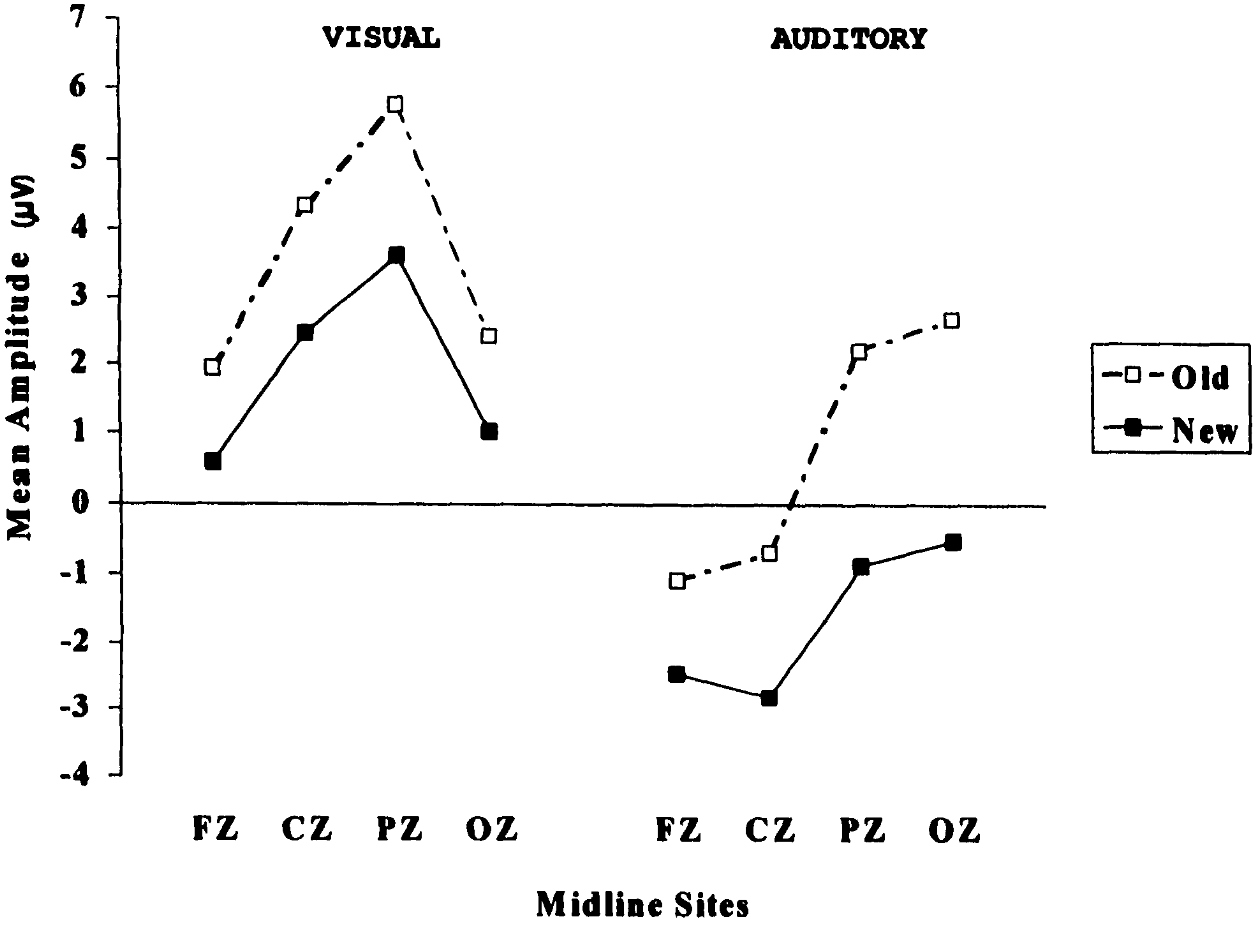

Figure 7. Mean amplitude of Late Positive Component along midline sites for new (solid lines) and old (dashed lines) words for visual and auditory modalities.

found, $F_{12,168}$=6.97, p=0.003, ϵ=0.17, indicating a difference in topography of the old/new effect across modality. Examination of simple interaction effects of modality x condition showed that the old/new effect was significantly larger for the auditory modality compared to the visual at posterior and lateral sites (TP9/10, $F_{1,14}$=14.74, p=.002; P9/10, $F_{1,14}$=15.82, p=.001; P7/8, $F_{1,14}$=14.63, p=.002; O1/2, $F_{1,14}$=10.27, p=.006). Comparison of the old/new difference in Figure 9 shows how in the visual condition, differences were largest over midline central and parietal sites, whereas in the auditory condition, the old/new differences were apparent over a wider area of the scalp with a maximum at parietal and occipital sites. This difference in topography remained highly significant following normalization of the data, $F_{12,168}$=7.91, p=0.002, ϵ=0.17.

ANOVA Results for LP Old/New Differences (400-700 ms)

Additional analysis of the old/new difference waveforms for the LP potential was performed to further examine the topographical distribution of the LP old/new effect across modalities. Differences in scalp topography of the visual and auditory old/new effects was supported by a significant modality x site interaction, $F_{12,168}$=7.16, p=0.003, ϵ=0.17. Examination of simple effects revealed that modality differences were most reliable at lateral sites overlying the parietal-occipital region (TP9/10, $F_{1,14}$=15.96, p=0.001; P9/10, $F_{1,14}$=16.54, p=0.001; P7/8, $F_{1,14}$=16.43, p=0.001; O1/2, $F_{1,14}$=11.29, p=0.005. Differences in scalp topography were still observed following normalization of the data evidenced by a significant modality x site interaction, $F_{12,168}$=5.84, p=0.005, ϵ=0.20.

ANOVA Results for Late Negative Potential (1100-1500 ms)

Analysis of the mean amplitude for the late negativity along midline electrodes resulted in a significant main effect of condition, $F_{1,14}$=5.01, p=0.04, indicating greater late negativity for old words than new words. Figure 8 demonstrates the greater negativity to old words at all midline sites for the visual and auditory modalities. Although a significant condition x site interaction, $F_{3,42}$=4.63, p=0.02, ϵ=0.59, suggested a difference in topography of the old and new conditions along the midline, this finding was not supported after normalization of the data. This indicates that old/new differences were equally present at all midline sites. There were no main effects of modality, lag, or gender.

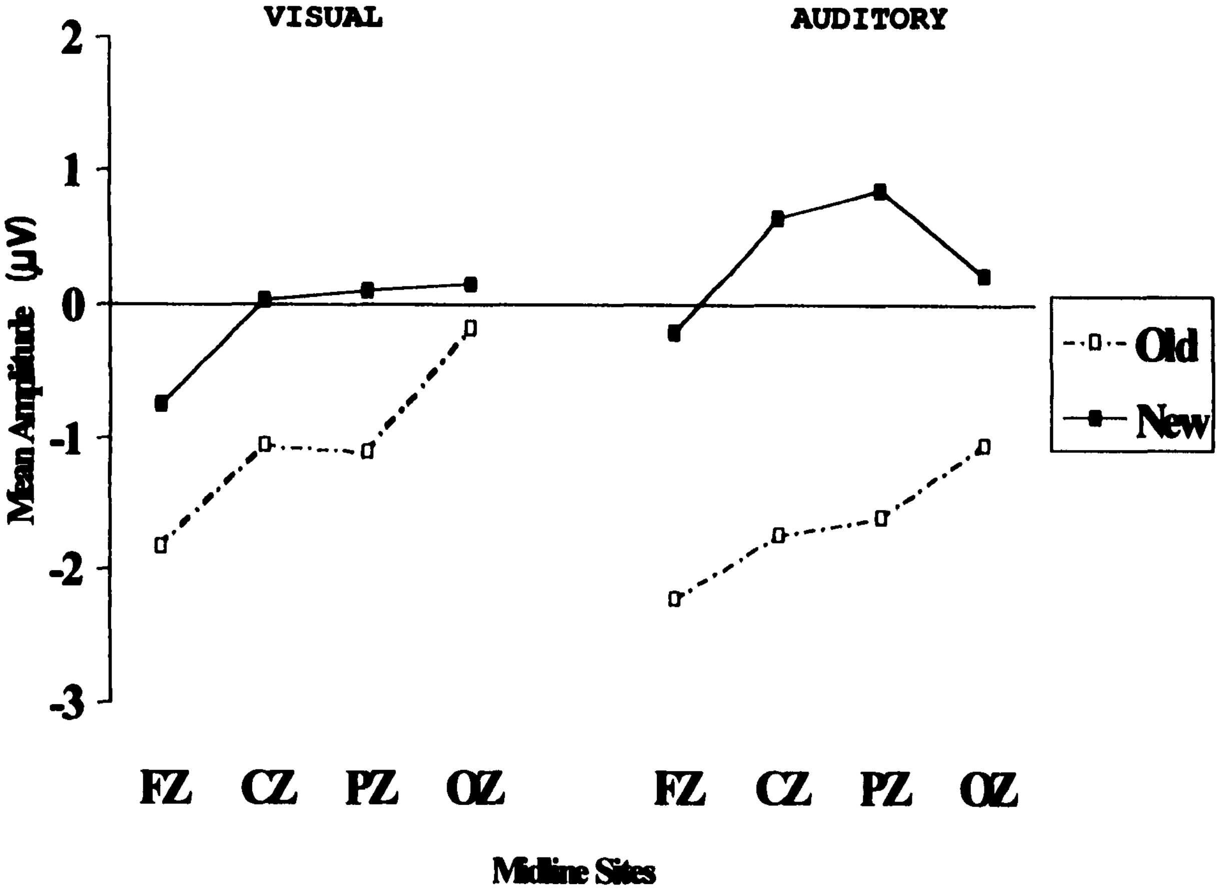

Figure 8. Mean amplitude of Late Negative Potential along midline sites for new (solid lines) and old (dashed lines) words for visual and auditory modalities.

A separate analysis of variance for lateral sites resulted in a highly significant main effect of hemisphere, $F_{1,14}$=12.88, p=0.003, indicating greater negativity over the left hemisphere. There was a significant condition by site interaction, $F_{12,168}$=10.77, p=0.0002, ε=0.18, which indicated greater mean late negativity for old than new words at medial central sites (i.e. at C3/4, $F_{1,14}$=5.22, p=0.04). There was also a significant condition x hemisphere interaction, $F_{1,14}$=8.02, p=0.01, indicating a larger laterality effect (left hemisphere greater than right) for correctly identified old words as compared to new words. There was no significant effect of modality, lag, or gender on mean late negative amplitude.

ERP Topographies

Figure 9 illustrates scalp topographies corresponding to each ERP component, using the averaged data within each time window, under visual and auditory modalities for each condition. Dark blue colors represent greater negativity, while pink colors represent greater positivity. Differences in scalp distribution between visual and auditory modalities can be seen for N1, N2, and the LP potential. One can see that the early negativities (i.e. N1 and N2) in the visual modality were most prominent over left temporoparietal

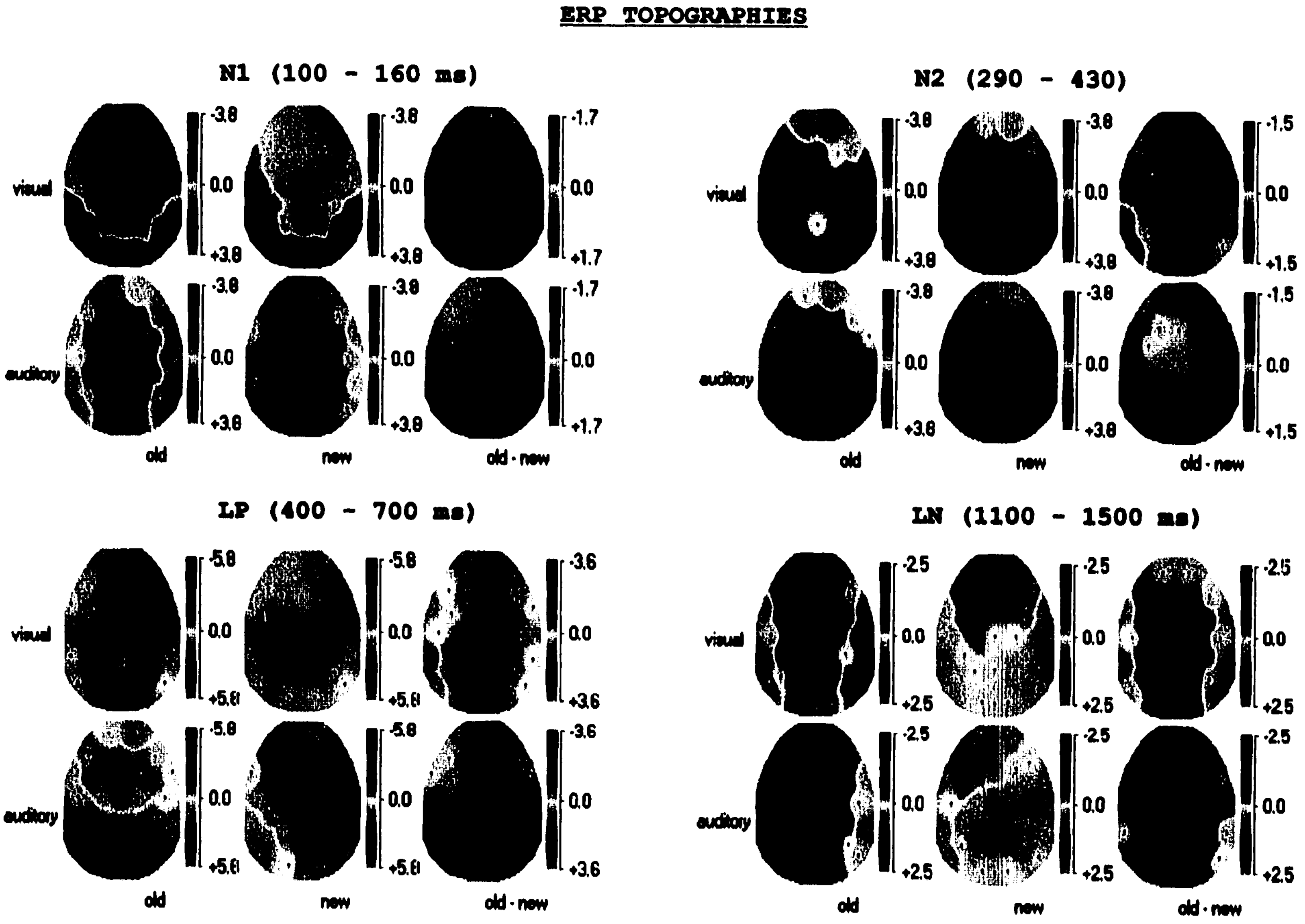

Figure 7. Topographical color maps of each major component for old and new conditions, as well as the old-new difference.

sites, while in the auditory modality, they peaked over central-parietal sites. Modality-specific processing was also demonstrated for the LP potential, in that the late positivity was maximal over medial central and parietal sites for the visual modality, whereas in the auditory modality, the late positivity was more laterally distributed and greatest over the parietal-occipital region. In contrast, the topographical distribution of the LN potential was similar across modalities with largest amplitude over left hemisphere sites.

For the N1, N2, and LP potential, one can see that old items elicited greater mean positivity than new items. This is reflected in the old-new maps (indicated by the red and pink colors). The LN potential on the other hand, demonstrated the opposite effect of greater mean negativity for old words than new (indicated by the blue colors). Inspection of the old-new maps for the LN potential shows that the old/new differences are lateralized over the left frontocentral region in both modalities.

Differences in topography of the old/new effect for N2 and LP potential for visual and auditory modalities can be seen in Figure 9. For the visual N2, there was a focused area of negativity at the CZ site for new words that was absent for old words. This greater mean positivity for old words extends along the midline to frontal sites as well, and can be seen in the old-new map for N2. In contrast, the auditory N2 extends more posteriorly for new items. Topographical differences, across modality, in the old/new effect for the LP potential are also evident in the old-new maps. Here, one can see that old/new differences in the visual modality were most prominent at central-parietal sites along the midline. In contrast, the greatest old/new differences for the auditory modality were over parietal-occipital sites. Similar topography of the old/new differences for the LN potential across modality are also revealed in the old-new maps.

Discussion

As expected, an old/new effect for word recognition was demonstrated by greater late positive amplitude to old items in the visual modality. These findings replicate observations from previous studies using a continuous word recognition paradigm (e.g., Friedman, 1990a; Kayser et al., 1999). In fact, a direct comparison of component structure with those of Kayser et al. (1999) revealed striking similarities in morphology and topography of all the major ERP components. This provides a solid basis for the subsequent comparison in the auditory modality.

Behaviorally, the difficulty levels for auditory and visual tasks were equivalent. That is, recognition of old and new items was the same whether visual or auditory stimuli were used, eliminating the possibility that differences in task difficulty contribute to the ERP findings. The only significant behavioral differences observed were longer response latencies for the auditory condition when compared to the visual condition. This was not unexpected, since the identification of auditorily presented words requires information processing that is serial in nature. In order for a word to be identified, participants were necessarily required to wait until the entire word had been heard before definite recognition could be made. In contrast, all the necessary information for word identification is present when words are presented visually. As soon as the word is presented on the screen, the participant is able to process it immediately rather than waiting for more information. Thus, the different response latencies reflect the differences in information processing requirements for the visual and auditory modalities. This difference was also apparent in the ERP waveforms, where the peak latency and duration of the LP potential for the visual condition was much shorter than for the auditory condition.

Consistent with other studies employing auditory (e.g., Wolpaw & Penry, 1975; Woods, 1995) and visual stimuli (Kayser et al., 1999), the scalp distribution of the N1 component was found to be modality-specific. The auditory N1 component in the present study showed a maximal mean amplitude over central sites, while the visual N1 was maximal over lateral temporoparietal sites. These differences in topography reflect the activation of different neural generators responsible for the early processing of auditory and visual stimuli. The linguistic nature of the stimuli was reflected by greater mean N1 amplitude over the left hemisphere for both modalities. All participants were right-handed, increasing the likelihood that the left hemisphere was dominant for language processing.

There was an unexpected main effect of condition on the N1 component, whereby new words elicited larger mean N1 amplitudes than old words for visual and auditory stimuli. Since the old and new words that went into the ERP averages in the present study were matched (i.e. only words that were correctly identified on both occasions were used), this condition effect is not likely to be due to stimulus differences between old and new words. It is difficult to conceive of a mechanism that would explain differences in processing that occurs this early which is dependent upon the old/new status of a word. The basis of this effect is unknown and it will require replication.

As with the N1 component, mean N2 amplitude displayed a modality-specific scalp distribution, with the visual modality eliciting an N2 component that was more prominent over temporoparietal sites, while for auditory stimuli, N2 was greatest over medial sites in the central-posterior region. These findings indicate that within the N2 time window (290-430 ms), information processing, for the most part, remains modality-specific and driven by the characteristics of the stimuli. For visually presented words, mean N2 amplitude was greater over the left hemisphere than the right. This replicates the findings from Kayser et al. (1999), who demonstrated the same laterality effect for the N2 component. This asymmetry favoring the left hemisphere is probably related to early phonetic processing. Consistent with this interpretation, Kayser, Tenke, and Bruder (1998) found a left lateralized N2 component for an oddball task using phonemes, while for a tonal oddball task, N2 was maximal over the right hemisphere. There was a trend for mean N2 amplitude to be greater over right temporoparietal sites in the auditory condition. This is somewhat unexpected since Bruder et al.

(1999) found larger N2 amplitude over left than right temporoparietal sites in a dichotic listening task using syllables. The use of a computer synthesized voice in the present study likely accounts for the lack of a left lateralized N2 component. Since the generated voice was unique in its prosodic quality (similar to a British accent), additional processing regarding the acoustic properties of the words may have been necessary. Evidence from lesion studies indicates dominance of the right temporal lobe in the analysis of prosody and intonation of speech sounds (Blumstein & Cooper, 1974; Milner, 1971; Fujii, Fukatsu, & Watabe,1990). The lateralization of the N2 over the right temporoparietal region may reflect this additional processing.

Previous studies have described an attenuation of a CZ maximum N400 component for old words. Because the latency window for the N2 component in the present study overlaps with what other investigators have described as an N400 (e.g., Guillem et al., 1995; Smith & Guster, 1993), or N300 component (Friedman, 1990a, 1990b), it was possible that old/new differences related to the N400 component would be observed. Consistent with these previous studies, there was a trend for mean N2 amplitude to be greater for new than old words at midline sites. This is best illustrated for the visual condition in Figure 9 where a focused area of negativity at the CZ electrode site is present for new words and not old. The negativity that is seen at the CZ electrode site appears to be isolated from the other areas of negativity overlying lateral temporoparietal and occipital sites, suggesting the activation of two separate components (i.e. N2 and N400) that overlap in time. It is likely that the negativity and old/new effect at CZ represents the N400 component. In fact, as expected, there were no old/new differences at the lateral temporoparietal sites which correspond with the peak of the visual N2. This could not be seen for the auditory modality, since the topography of the auditory N2 was also maximal over central sites.

A modality-specific scalp distribution remained apparent for the time window encompassing the LP potential (400 - 700 ms). This is in agreement with Johnson (1989) who also described modality-dependent generators for the P3 component using a standard oddball paradigm. In the current study, the midline topography for the visual modality showed a parietal (PZ) peak that is characteristic of the well-known P3b component. The midline topography for the auditory modality was markedly different, showing a gradual increase from frontal (FZ) to occipital (OZ) areas. This maximum over OZ for auditory stimuli was also described by Chao, Bohlman, and Knight (1995) who examined recognition memory for environmental sounds. Similar to the present data, P3 amplitude in their study was also larger over posterior electrode sites and peaked at OZ.

Old words elicited greater positivity than new words between 400 and 700 ms after stimulus onset in both modalities. This replicates findings from previous studies using visually presented words (e.g., Rugg & Nagy, 1989; Friedman, 1990a; Kayser et al., 1999), pictures (Friedman, 1990b; Schloerscheidt & Rugg, 1997), faces (Begleiter, Porjesz, & Wang, 1995; Smith & Halgren, 1987), and geometric figures (Beisteiner, et al., 1996). Findings from the present study add to this list an old/new effect for verbal auditory material. Direct comparison of the old/new effect between the visual and auditory modalities revealed strikingly similar peak latencies across modalities despite the marked difference in latency of the LP potential. While the latency for the visual old/new effect matched the peak latency of its late positive component, the auditory old/new effect occurred earlier than its LP peak. In the auditory condition, correctly identified old words elicited an earlier and larger LP potential than correctly identified new words. This difference in latency between old and new words presented in the auditory modality can be interpreted as a reduction in required processing time for repeated words as a result of earlier recognition during the initial part of the word.

The time window for the LP potential in the present study was primarily chosen in order to capture the peak old/new effect in both modalities. As we have demonstrated, the peak auditory old/new effect did not coincide with its peak LP potential. Due to this discrepancy, this window may not have been optimal in describing the LP potential for the auditory modality; however, it still provides a good measure of the old/new effect.

The similarity in peak latency of the old/new effect suggests a common cognitive mechanism that does not depend upon modality. The difference in scalp topography, however, indicates that the pattern of neural generator activity responsible for the old/new effect is different for visual and auditory modalities. Given the complexity of the proposed functional process that is indexed by the old/new effect (i.e. memory retrieval), it is reasonable to assume that the effect is not driven by a single neural generator. In fact, Johnson, Kreiter, Russo and Zhu (1998) have described distinct patterns (spatial and temporal) of neural generator activity related to different aspects of memory retrieval that contribute to the old/new effect. With this in mind, it is likely that the old/new effect in the visual and auditory modalities reflect the same cognitive process (i.e. memory retrieval), but because of modality-specific processing demands, different patterns of neural generator activity contribute to the old/new effect. Alternatively, because the timing of the old/new effect was so similar across modalities, one could argue that the activity indexed by the old/new effect had a common set of neural generators, but that because of early differences resulting from the activation of different perceptual systems, reflected in different scalp distributions, the resulting topographies of the old/new effect were different for the auditory and visual modalities. Since the cognitive process represented by the old/new effect does not occur in a vacuum, the scalp topography will necessarily be different because the ongoing activity to which the old/new effect is being "added" to is different. One argument against this hypothesis, however, comes from the observation that auditory and visual short-term memory performances can be dissociated in brain-injured patients (Warrington & Shallice, 1969). If short-term episodic memory for visual stimuli share the same neural generators as auditory, then one would always see similar memory impairment across modalities.

The modality-specific topography of the old/new effect is also consistent with the differences in the operation and organization of the visual and auditory processing streams described by Penney (1980); associations for items presented in succession are stronger for auditory information, while associations for simultaneously presented information are stronger in the visual modality. The easiest way to account for these differences in operational properties, is through the activation of different neural pathways for each processing stream. The modality-specific scalp topography of the old/new effect not only reflects the obvious differences in perceptual processing, but also differences with how information is represented in memory for each modality.

Consistent with other studies which found no influence of lag on the visual old/new effect (Friedman, 1990a; Friedman, 1990b; Kayser et al., 1999; Rugg & Nagy, 1989), there was no significant effect of lag in the present study. As expected, there was also no influence of lag on the auditory old/new effect. Since repeated words at the short and long lags involved the use of intervening items, it was argued that there would be no difference because the intervening items would interfere with the potential benefits of any sensory memory trace. Results from a study examining recognition memory for environmental sounds completed by Chao et al. (1995) support this hypothesis. In their study, differences between old items which followed a long lag (4-12 sec) and those that were immediately repeated were observed. They found that the N4 component was elicited by repeated stimuli following the long delay but not after immediate repetition. They argued that this lag effect on the N4 component reflects the additional activation of limbic memory systems required for initial encoding and retrieval at long retention intervals, suggesting that immediately repeated items did not require involvement of limbic memory structures due to the presence of a sensory trace.

One point that could be raised with respect to old/new differences observed in continuous recognition memory paradigms, is that the difference in memory load between new and old words may account for the old/new effect. The absence of any significant lag effects, however, argues against this possibility. If differences in memory load contribute to the old/new effect, then differences should also be observed between short and long lags.

By demonstrating the important role that modality has in eliciting the old/new effect, we have brought into question whether this effect is restricted to the late positivity or whether it occurs earlier. According to

Penney (1989), the processing of an item in short-term memory develops from and is continuous with perceptual processing. That is, the perceptual processing of an item provides the basis for its memory trace. If this is the case, then retrieval of information from short-term memory should include reactivation of those neural structures responsible for the perceptual processing of the stimulus. This chain of reasoning is supported by the observation that old/new differences (i.e. greater positivity to old words) are seen as early as N1 in the present study. If the perceptual properties of a studied item are tightly integrated with its representation in memory, then it is reasonable to expect that initial processes which contribute to recognition can occur during perception. Furthermore, although the peak old/new effect coincided with the LP peak in the visual modality, this was not the case for auditory stimuli where the peak old/new effect occurred earlier than the corresponding peak for the LP potential. This provides additional evidence that old/new differences begin before the late positivity and is therefore not unique to this component.

Following the LP potential was a slow rising late negativity overlying medial frontotemporal electrode sites of the left hemisphere, which was greater for old than new words. This condition effect was seen equally in both modalities and did not differ significantly in scalp distribution across modalities. Considering the long latency of this effect following the motor response, it is very likely that this activity represents a post-retrieval process. A similar condition effect on the late negativity has been described in other studies of recognition memory using words (e.g., Friedman, 1990a), pictures (Friedman, 1990b), and faces (Smith & Halgren, 1987). The fact that this effect has been observed with different types of visual stimuli, and now in the present study with auditory stimuli, suggests that it is unrelated to stimulus type, but that it has more to do with the difference between making an old and new response. Friedman (1990b) suggested that this effect may reflect the lack of further processing required for old compared to new words. Since participants knew they would not encounter an old word again, further processing of that item for later recognition was not required, and may account for the differences in late negative activity between the two conditions. Another possibility is that the greater late negativity for old items represents processes related to performance appraisal. That is, there may be a greater tendency for participants to evaluate the accuracy of old responses than new ones. If reaction time can be taken as an indirect measure of confidence level, then the faster response latencies for new items would indicate that participants were generally more confident in making a new decision than an old decision. Consistent with this interpretation, reaction times for new items were also faster in the two studies by Friedman (1990a, 1990b). Reaction time data for new items was not reported in the study by Smith & Halgren (1987). The strong laterality effect over the left hemisphere argues for the continued activation of language areas in evaluating responses. The use of facial stimuli, however, did not yield significant laterality effects (Smith & Halgren, 1987) suggesting that stimulus type (i.e. words or pictures) plays an important role in the topography of the LN old/new effect.

In summary, the present study provided a direct comparison of the ERP old/new effect in the visual and auditory modalities. The well-known old/new effect for the LP potential was present for both modalities. There was, however, a significant difference in scalp topography, indicating the contribution of a different pattern of neural generators. The most striking finding was that, despite the difference in scalp topography, the timing of the old/new effect was the same across modalities, suggesting the activation of a common higher level cognitive process (i.e.

successful retrieval of information from memory) that is modality independent. This is consistent with activation of medial temporal lobe structures which receive input from multimodal association areas and are known to play an important role in memory function. Another possibility is the precuneus region which was activated during memory retrieval in PET studies and has been shown to be modality independent (Krause et. al., 1999).

An old/new effect lateralized over the left hemisphere for the late negativity was interpreted as being a possible reflection of post-decision evaluation processes. Although this finding has been described elsewhere, it has not been studied extensively and will require further investigation in order to understand what this activity represents.

Prior to the present study, little was known regarding the ERP correlates of word recognition memory in the auditory modality. Now that we have characterized the auditory ERP old/new effect by direct comparison with the visual, this paradigm can be used as a tool in future research to investigate the neural bases of these memory systems.

These findings also have implications for studies in patient populations that demonstrate deficiencies in auditory processing. As an example, a prior study of word recognition memory in schizophrenia found no difference in the old/new effect between patients and controls for visually presented words (Kayser et al., 1999). Given the evidence for impaired verbal learning abilities (Saykin et al., 1991; Colombo et al., 1993; Goldberg et al., 1993) and for structural abnormalities of the temporal lobes in schizophrenia (e.g., Barta et al., 1990, 1997), further studies employing the auditory modality may provide a more sensitive measure of the pathophysiology of memory processes in this disorder.

Appendix A

List 1

account
atom
bag
beach
beard
bench
blanket
bride
bunk
camp
cash
charter
chest
cloth
coast
complex
concept
cotton
cousin
dealer
degree
dish
drive
dust
empty
exchange
fast
fish
flow
folk
football
gas
grade
heat
ideal
insect
item
journey
joy
lake
legend
load
mark
mistake
motion
navy
neck
nerve
note
ocean
outcome
output
partner
pass
pilot
planet
player
portion
pot
prize
regard
risk
sand
scale
secret
shadow
shell
shop
smile
smoke
station
style
suburb
supper
surprise
tape
text
truck
wheel
wonder

List 2

actor
appeal
baby
bank
base
bay
beat
birth
block
bone
budget
cat
cheek
circle
cloud
comfort
comment
concern
cow
crime
curve
design
dream
driver
duty
fabric
fat
favor
finding
fist
flight
flux
gift
grace
grass
impulse
jacket
join
lady
loan
loss
luck
mixture
motel
movie
notion
onset
park
patient
pay
pencil
pleasure
poet
pope
railroad
reading
reply
road
scholar
search
sergeant
servant
shift
skin
soil
start
step
stick
stone
stop
strike
sugar
survey
talk
teacher
threat
track
vote
watch
wish

List 3

absence
advice
amount
angle
bath
belt
box
brush
bullet
bus
channel
check
childhood
coat
concert
contest
count
crop
culture
date
disk
dozen
dress
drop
farmer
fate
feed
fence
file
fraction
friend
grain
habit
host
insight
jet
kid
liquid
lumber
merchant
merit
milk
mine
nut
pace
paper
passage
passion
pick
planning
pocket
post
priest
rank
remark
rise
rock
safety
second
shade
shock
sky
slave
speaker
sport
stomach
stream
strip
suit
talent
target
tension
theme
throat
touch
traffic
transfer
whiskey
wire
witness

List 4

acre
adult
angel
band
beer
bit
bread
breath
builder
call
campus
captain
chain
chicken
code
coffee
contact
copy
cover
crowd
cut
deep
desk
drink
drug
estate
event
fashion
fight
foot
fort
fun
gain
grant
guess
hat
impact
instant
judge
justice
lesson
license
limit
mass
meal
mud
neighbor
norm
notice
outlook
painter
painting
pistol
plastic
plate
plot
pride
request
river
salt
seat
shape
sheet
sketch
skill
snake
storm
struggle
substance
taste
temple
test
tip
travel
trend
trust
vision
visit
wide
writing

Appendix B

Table B1 - Summary of ERP Analyses: ANOVA F Ratios

N1

Midline	df	F	p
Modality x Site	3,42	8.33	.008
Lateral			
Modality x Site	12,168	15.25	.0001
Hemisphere	1,14	9.92	.007
Condition	1,14	6.33	.02
Cond x Lag x Site	12,168	3.81	.02

N2

Midline	df	F	p
Modality x Site	3,42	5.41	.02
Lateral			
Modality x Site	12,168	4.71	.02
Hemisphere x Site	12,168	7.19	.0001
ModalityxCondxSite	12,168	3.92	.02
Modality x Hemisphere	1,14	4.64	.05

LP

Midline	df	F	p
Modality	3,42	19.19	.0001
Lateral			
Condition	1,14	11.77	.004
ModalityxCondxSite	12,168	6.97	.003

LN

Midline	df	F	p
Condition	1,14	5.01	.04
Lateral			
Condition x Site	12,168	10.77	.0002
Hemisphere	1,14	12.88	.003
Condition x Hemisphere	1,14	8.02	.01

References

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