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RECOGNITION MEMORY, REMEMBER/KNOW JUDGMENTS
AND RETRIEVAL OF CONTEXT IN YOUNG AND OLDER
ADULTS: AN ERP STUDY

BY

CHARLOTTE T. TROTT

A dissertation submitted to the Graduate Faculty in Psychology in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York.

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Abstract

RECOGNITION MEMORY, REMEMBER/KNOW JUDGMENTS
AND RETRIEVAL OF CONTEXT IN YOUNG AND OLDER
ADULTS: AN ERP STUDY

by

Charlotte T. Trott

Advisor: Walter Ritter

According to dual process theories of recognition memory, memory judgments can be made on the basis of episodic-(contextual) or familiarity-(automatic) based processes. Recognition that an item has been previously experienced (item memory) is thought to depend on medial-temporal lobe structures. Memory for the context in which that item occurred appears to involve the frontal lobes. Older adults perform more poorly than younger adults on direct memory tests. There is evidence that normal aging is associated with a decline in frontal lobe functioning. It is possible that the difficulty older people have with explicit memory is due to a decline in frontal lobe functioning leading to a greater deficit in contextual- compared to familiarity-based processing.

Sixteen young (21-28) and 16 older women (65-81) studied two lists of sentences, each with 2 unassociated nouns. In a subsequent mem-

ory test, they made old/new recognition judgments. For nouns judged old, Remember (contextual) vs. Know (familiarity), and list (temporal source) judgments were elicited. The groups did not differ in the percentage of correctly recognized old nouns (hits) or Remember vs. Know judgments, but the elderly were significantly poorer at correctly identifying the source of hits. Two ERP old/new effects were dissociable on the basis of latency, scalp distribution and age. For both young and old at posterior sites (400-800 ms), hits associated with Remember, Know, and list judgments elicited more positive ERPs than foils. The groups differed at prefrontal sites (800-1800 ms) where, for the young only, hits were associated with greater positivity than foils regardless of type of subsequent judgment, and hits with list incorrect were more positive than those with list correct.

The posterior old/new effect seen in both age groups may index item retrieval. The later, prefrontal effect seen only in the young may reflect the search for contextual information. The data suggest that the Remember, Know and list judgments reflect similar, but not identical, underlying neural and cognitive substrates. The lack of the prefrontal effect in older subjects is consistent with the hypothesis of a deficit in source memory contingent upon an age-related change in frontal lobe function.

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INTRODUCTION

Recognition:

According to dual process theories of recognition, memory judgments are thought to depend on two distinct components or processes. One is an explicit, episodic-based component requiring elaboration and awareness of the study context. The other is a familiarity-based component that is presumed to occur more automatically and does not require awareness of the study context (Atkinson & Juola, 1973; Graf & Mandler, 1984; Jacoby & Dallas, 1981; Mandler, 1980). Familiarity based processes are thought to depend on activation of preexisting mental representations. Episodic-based memory processes, on the other hand, may utilize preexisting representations, but they are also thought to involve memory for new associations. These involve an association between the item or event and some aspect of the context in which the item or event occurs. Therefore, a new association may be formed between the item or event and certain thoughts or feelings, other simultaneously occurring items or events, or other aspects of the context in which it occurs (e.g., perceptual details or temporal spatial information) (Johnson, Hashtroudi & Lindsay, 1993).

Tulving (1985) developed a paradigm to investigate the role of awareness in recognition memory using introspective judgments. If, when the subject recognized a word, he also had a "conscious recollection" of it occurring on the study list, he would say he "Remembered" (R) the word.

Conscious recollection was described as recalling something associated with the word at the time of study, e.g. its position in the list or other perceptual details, a subjective association, or a thought about it.

Subjects would make a "Know" (K) judgment when they were sure that a word was on the study list, but did not have a "conscious recollection" of it. A number of researchers have investigated the variables that produce dissociations between R and K responses. R, but not K, judgments are influenced by such manipulations as levels of processing, the generation of words compared with reading words, and divided attention during study (Gardiner, 1988; Gardiner & Parkin, 1990). K, but not R judgments are influenced by the type of word used to mask the target word. Subjects gave more K responses to recognized words masked by the words themselves than they did to words masked by different words (Rajaram, 1993). Other variables have opposite effects on R and K responses. For example, more R judgments were given to previously studied, recognized words than to previously studied, recognized non-

words. The opposite was true for K judgments (Gardiner & Java, 1990).

R judgments are influenced in the same direction by the same variables that influence direct measures of memory (e.g. recall). Likewise, K judgments are influenced in the same way and by the same variables that influence indirect, perceptual memory tasks (e.g. tachistoscopic identification, lexical decision). Rajaram (1993), therefore, proposed that R judgments may be based on the episodic- and K judgments on the familiarity-based components of recognition memory.

Since R and K judgments are subjective, there is some dissatisfaction with them as measures of episodic- and familiarity-based recognition (Rugg, 1994). In addition, R judgments can be based on memory for any aspect of subjective or objective context. Thus, it is unknown what contextual associations may lead to R judgments.

Memory for a specific aspect of context (e.g. which list the item was on at study) provides a more objective and controlled way to index an episodic-based process. If a subject judges an item as old and also recalls the study list, one can argue that the item was recognized on the basis of episodically based processes. The opposite is not true, however. Failure to recall the study list does not rule out episodic-based processing. If R judgments and memory for an objective aspect of context could be shown

to measure the same process, while K judgments reflect some other process, there would be greater confidence in using R/K judgments to dissociate the hypothesized recognition memory processes.

Aging:

Older adults consistently perform more poorly than young adults do on tests of episodic memory (e.g. recall). Indirect tasks such as tachistoscopic identification or lexical decision, which are thought to rely on perceptual fluency or familiarity based processes, reveal small or nonexistent age related memory differences on measures of repetition priming (Salthouse, 1982; Light, 1991; Light & Singh, 1987). Older subjects also perform more poorly than young adults do on recognition tests. Their decreased performance on this type of test may reflect a decline in either the episodic and/or the familiarity based components of recognition memory. Using the R/K paradigm to examine this question, Parkin & Walter (1992) found that the proportion of R judgments to correctly recognized old words decreased with age, even when recognition accuracy between the young and old was equated by using a subgroup from each age group. If R judgments do reflect episodic processing, this finding suggests that an age related decrease in

recognition memory may be based on a decline in the episodic-based processing component. This would be consistent with findings that older subjects show performance deficits on tests such as recall that are thought to require episodic processing, and a minimal or non-existent decrease on indirect tests that are thought to be dependent on familiarity-based processing.

An essential element of episodic memory is memory for the context in which the event occurred. A number of studies have found that older subjects demonstrate difficulty remembering various aspects of source or context including spatiotemporal information (see Light, 1991 and Johnson, Hashtroudi, & Lindsay, 1993 for reviews). An age related decrease in the episodic component of recognition memory would also be consistent with these findings (See the following two sections for a further discussion of aging and memory for context.)

The Frontal Lobes and Memory for Context:

The role of the medial temporal lobe system in explicit memory is well documented (see Cohen & Eichenbaum, 1993 for a review). Recognition that an item has been previously experienced (item memory) is thought to depend on the medial/temporal and diencephalic structures

(Janowsky, Shimamura & Squire, 1989; Milner, Corsi, & Leonard, 1991). However, there is accumulating evidence that memory for the source or context in which an item was experienced (source memory) may involve the frontal lobes (Schacter, 1987; Shimamura, 1995; Squire, 1994). For example, patients with frontal lesions are able to perform as well as normal controls in judging whether information is old or new. However, they have difficulty with explicit memory for the source or context in which that information was retrieved. A relationship between frontal lobe damage and impairment of memory for spatiotemporal context has been demonstrated in non-human primates, human patients with frontal lobe damage, and amnesics with frontal involvement.

Research with nonhuman primates has demonstrated a relationship between damage to the dorsolateral prefrontal cortex and impaired spatiotemporal memory (Fuster, 1985, Schacter, 1987).

Human patients with frontal damage show impairment on tasks of temporal discrimination, e.g. recency judgments (Janowsky, Shimamura & Squire, 1989; McAndrews, & Milner, 1991; Milner, Corsi, & Leonard, 1991; Milner & Petrides, 1984; Milner, Petrides, & Smith, 1985; Shimamura, Janowsky & Squire, 1990), temporal ordering (Lewinsohn, Zieler, Libet, Eyeberg & Nielson, 1972;) list differentiation (Butters,

Kaszniak, Glisky, Eslinger & Schacter, 1994), frequency of occurrence (Smith & Milner, 1988) & delayed comparison tasks with unique or recurring stimuli (described in Milner, 1964).

Amnesic patients with evidence of frontal pathology exhibit impaired memory for spatiotemporal context that is disproportionate to their deficits in recall or recognition memory (see Schacter, 1987 for a review). This has been demonstrated with three different kinds of measures: 1) experimental vs extra-experimental source (Janowsky, Shimamura & Squire, 1989; Schacter, Harbluk & McLachlan, 1984; Shimamura & Squire, 1987); temporal order within a list (Hirst & Volpe, 1982; Huppert & Piercy, 1976; Shimamura, Janowsky, & Squire, 1990); and list differentiation (Squire, 1982).

Recent neuroimaging studies have provided additional support for the role of the prefrontal cortex in memory. Based on findings from a number of neuroimaging studies, Tulving, Kapur, Craik, Moscovitch, and Houle (1994) proposed a model of hemispheric encoding/retrieval asymmetry (HERA). They suggested that the left prefrontal cortex is more involved in semantic retrieval and encoding novel aspects of this retrieved information into episodic memory than is the right prefrontal cortex, and the right prefrontal cortex is more involved in episodic retrieval than is the

left prefrontal cortex. PET studies reviewed by Buckner & Tulving (1995), Nyberg, Cabeza, R., & Tulving, E. (1996), and Cabeza and Nyberg (1997) support this distinction. They found a consistent pattern of activation of the left prefrontal cortex in semantic retrieval and episodic encoding, and right prefrontal activation in episodic retrieval.

The functional role of the prefrontal cortex in episodic retrieval is not clear. Four studies have suggested that this region may be involved in guiding retrieval or searching for episodic information (Schacter, Savage, Alpert, Rauch, and Albert, 1996; Schacter, Buckner, Koutstaal, Dale & Rosen, 1997; Kapur, Craik, Jones, Brown, Houle, & Tulving, 1995; Nyberg, Tulving, Habib, Nilsson, Kapur, Houle, Cabeza, and McIntosh, 1995). Schacter et al. (1997) used blocked and event-related fMRI procedures to compare brain activity during true recognition of previously studied words and false recognition of semantic associates. Subjects studied 36 lists of 14 semantically related words presented auditorily. Approximately 45 minutes later subjects made old/new judgments for two previously studied words from each of the 36 lists and two words semantically related to each list. There were 2 blocked (e.g., all old or all new items) and 6 mixed trial recognition blocks, each with 18 visually presented words. Schacter et al. (1997) found increased activation in the

anterior prefrontal cortex in response to correctly identified old words as well as to semantic associates (lures) falsely called old. Compared with activation in other regions, the prefrontal activation had a late onset and prolonged duration. There was a trend in the blocked conditions for there to be greater activation on the right when lures were called old than when truly old items were correctly recognized. Maximum activation occurred only after the old/new judgment, suggesting that it had less to do with item identification than with post retrieval processes.

In another study by Schacter et al. (1996), young & old subjects studied words under semantic and non-semantic encoding conditions. This led, respectively, to high and low levels of recall. During word stem cued recall, successful item recall (high minus low recall and high recall minus baseline) was associated with activation in the hippocampal formation in both groups. Right frontal activation was associated with efforts to retrieve studied words (low recall minus baseline). In the young adults this frontal activation was centered on Brodman Area 10, right greater than left. Old subjects showed some activation in the left Brodman Area 10, but their greatest activation was located in more posterior frontal areas (right area 46, right motor and left Broca's Area) that were not activated in the young. The authors concluded that: (1)

hippocampal activation reflected age-invariant, successful retrieval of studied items; (2) the age differences in frontal lobe activation during retrieval attempts may reflect differences in retrieval strategies between young and old subjects.

The evidence thus suggests that item memory may be subserved primarily by the medial/temporal and diencephalic structures while the prefrontal cortex is involved in retrieval of, or attempts to retrieve source or contextual information.

Two types of neuropsychological tasks have been found to be particularly sensitive to frontal lobe dysfunction. These are card sorting and fluency tests. The Wisconsin Card Sorting Test (WCST, Heaton, 1981; Heaton et al., 1993) is one of the tests used most frequently to evaluate cognitive impairments associated with frontal dysfunction (Stuss & Benson, 1986). This test requires a subject to infer a correct sorting principle from verbal feedback, to recognize when the principle changes, and to discover and implement a new, correct principle. Weinberger, Berman & Zec (1986) examined regional cerebral blood flow (rCBF) in the dorsolateral area of the prefrontal cortex in relation to performance on the WCST. Normal adult subjects showed an increase in dorsolateral rCBF while taking the WCST when compared to a resting condition and

to performing a number-matching task. In unmedicated schizophrenic patients, WCST performance was correlated negatively with change in rCBF volume. A number of researchers have reported impaired WCST performance in patients with frontal lobe lesions. Milner (1964) found that, compared with patients having posterior cerebral injury, those with dorsolateral frontal lobe excision were significantly more impaired on the WCST. Although the frontal patients often could verbalize the sorting principles, they were unable to use this information to guide their behavior. This resulted in increased perseverative errors and the completion of fewer sorting categories. Milner & Petrides (1984) found similar deficits on the WCST in patients with superior-frontal excisions, but not in patients with unilateral orbital or inferior frontal-lobe lesions. Other studies have shown more impairment on the WCST in patients with frontal lobe damage when compared with normal controls (Heaton, 1981; Heaton et al., 1993; Janowsky, J.S., Shimamura, Kritchevsk, & Squire, 1989; Robinson et al., 1980), patients with nonfrontal lesions (Heaton, 1981; Heaton et al., 1993; Robinson et al., 1980), and patients with Korsakoff's amnesia (Janowsky, J.S., Shimamura, Kritchevsk, & Squire, 1989; Leng & Parkin, 1988). Although the WCST is particularly sensitive to frontal lobe damage, diffuse brain damage can produce

similar deficits (Robinson et al., 1980). Thus, while frontal lobe pathology is more likely to be associated with impaired performance on the WCST than are nonfrontal disorders, impaired performance on the WCST can be considered diagnostic of frontal dysfunction only when normal functioning is observed on tests of overall cognitive functioning, e.g., intelligence tests (Stuss & Benson, 1986). In addition, while patients with frontal pathology are more likely than normal subjects to have impaired WCST performance, normal performance on the test does not rule out frontal pathology (Milner & Petrides, 1984; Stuss & Benson, 1986). Heck & Bryer (1986) reported the case of a 41 year old woman with bilateral orbital and dorsolateral frontal atrophy who performed normally on the WCST. Anderson, Damasio, Jones and Tranel (1991) found that the performance of patients with frontal pathology ranged from poor to normal on the WCST.

Tests of verbal fluency have also been found to be sensitive to frontal lobe pathology, particularly pathology of the dominant hemisphere (Benton, 1968; Milner, 1964; Milner & Petrides, 1984). These tests are thought to reflect divergent thinking (Milner & Petrides, 1984). Phonological tests of verbal fluency require the production, within a time limit, of as many words as possible that begin with a certain letter.

Semantic verbal fluency tests require the production of words from a semantic category. Milner (1964) found that patients with left frontal lobectomies that spared Broca's area performed very poorly on a phonological word fluency test compared with patients with left temporal lobectomies even though they had no evidence of aphasia. Patients with right frontal lobectomies performed as well as those with left temporal lobectomies. Benton (1968) also found that patients with left or bilateral frontal lesions performed worse on a phonological word fluency test than did patients with right frontal lesions. A recent fMRI study found consistent activation of the middle frontal gyrus during a phonological verbal fluency task (Pujol, Vendrell, Deus, & Kulisevsky, Marti-Vilalta, Garcia, Junque, & Capdevil, 1996). By contrast a semantic fluency test revealed less consistent activation both over brain areas and across subjects.

Eslinger & Grattan (1993) identified two forms of cognitive flexibility, spontaneous and reactive. Spontaneous flexibility was defined as the ready flow of ideas and answers to a question and was associated with performance on an alternate use fluency test. This test requires the production, within a time limit, of as many different uses as possible for a common object such as a brick. Reactive flexibility was defined as the

ability to shift cognition and behavior in response to the demands and context of a situation and was measured by performance on the WCST (perseverative errors). Performance on both types of tests was impaired by frontal lobe lesions when compared with patients with posterior lesions and normal controls. Performance of the basal ganglia lesion group was as impaired as that of the frontal group on the WCST, but not on the fluency test. On that test the performance of the basal ganglia lesion group equaled that of the posterior lesion group, but was worse than the performance of normal controls. Thus, both frontal lobe and basal ganglia lesions resulted in impaired reactive flexibility (WCST perseverative errors). On the other hand, frontal lobe lesions caused greater impairment in spontaneous flexibility (fluency test) than did lesions of the basal ganglia. Eslinger & Grattan (1993) concluded that the frontal lobes appeared to mediate spontaneous flexibility, while reactive flexibility required both the frontal lobes and the basal ganglia for its operation.

Aging, the Frontal Lobes, and Memory for Context:

There is evidence that normal aging may be associated with a decline in frontal lobe functioning. This evidence comes from

neurophysiological, imaging, and neuropsychological research. Haug et al. (1983) showed a decrease of neuronal density in the prefrontal cortex and in the thalamus and basal ganglia, two structures with extensive connections to the frontal lobes (See Squire, 1987 and Ivy, MacLeod, Petit, & Markus (1992) for reviews of neurophysiological changes in aging). Neuroimaging studies have shown demyelination in the periventricular white matter around the frontal horns of the lateral ventricle in older subjects (Gerard & Weisberg, 1986). Reduction in cerebral blood flow is most pronounced in the prefrontal cortex in older people (Gur, Gur, Obrist, Skolnick, & Reivich, 1987). Loss of brain volume particularly in the frontal regions has been shown in normal, successful older people (Coffey et al., 1992). Ford, Sullivan, Marsh, White, Lim, & Pfefferbaum (1994) found a correlation between MRI measures of frontal gray matter volume and an ERP measure of brain activity. The amplitude of the P300 elicited by a startling, novel noise was positively correlated with frontal, but not parietal gray matter volume.

In a PET study, Cabeza, Grady, Nyberg, McIntosh, Tulving, Kapur, Jennings, Houle, & Craik (1997) compared rCBF in young and old subjects during encoding of word pairs and subsequent recognition

and recall. In the young they found the typical left lateralized frontal activity during encoding, and right lateralized frontal activity during retrieval. They found age-related reductions in activation in the left prefrontal and temporo-parietal areas during encoding and the right prefrontal regions during retrieval. In addition, they found an age-related increase in activation during recognition in the cuneus/precuneus region. They suggested that the reductions in activity seen in old subjects may reflect altered memory networks during both encoding and retrieval. The increased activation during recognition may reflect either less efficient strategies in old subjects or beneficial compensatory activity.

Stuss, Craik, Sayer, Franchi, & Alexander (1996) compared middle-aged patients with unilateral left, unilateral right and bilateral frontal lesions to normal young, middle-aged, and older adults on list learning using recall and recognition retrieval. Words were studied in three different conditions: blocked category, random category and unrelated lists. On most tasks the performance of the older controls and the unilateral right patient group were equivalent. The list learning impairment of these two groups was most obvious on the less structured lists. Both groups had deficits on measures of strategy, monitoring and efficiency that placed them below the other control groups, but superior to

the other patient groups. However, the unilateral right patient group had additional deficits in monitoring that were not seen in the normal older group. The Stuss et al. (1996) data suggest that normal aging does result in deficits of recall, recognition and organization that are similar to those seen in patients with right frontal lobe lesions.

The above studies provide evidence that normal aging is accompanied by neurophysiological changes in the frontal lobes, and differences in the particular frontal regions that are activated during memory encoding and retrieval. In addition, normal old subjects have shown deficits in strategy, monitoring and efficiency during list learning that are similar to those exhibited by patients with right frontal lesions. The results of these studies suggest that impaired memory performance seen in normal aging may be due, in part, to a decline in frontal lobe functioning.

If the frontal lobes are involved in memory for source, and the functioning of the frontal lobes declines in normal aging, it is possible that the difficulty the elderly have in remembering the source of information may be related to such a decrease in frontal lobe functioning with age (McIntyre & Craik, 1987). Although there is no direct neurophysiological data demonstrating an age related relationship

between decrease in frontal lobe functioning and increased difficulty remembering source or context, there are several neuropsychological studies that indicate such a relationship (Craik, Morris, Morris & Loewen, 1990; Glisky, Polster & Routhieaux, 1995; Parkin & Walter, 1991; Parkin & Walter, 1992; Spencer & Raz, 1994). In all of these studies, memory for some aspect of context was found to be correlated with some measure of performance on the WCST, and sometimes the Controlled Oral Word Association Test (a phonological word fluency test often referred to as the CFL or FAS depending on the words used Benton & Hamsher, 1976). However, neither WCST nor CFL/FAS performance was correlated with item memory, i.e. memory for facts. Glisky et al. (1995) used a number of neuropsychological tests to form composite measures of frontal and medial temporal lobe functioning. They then compared the recognition memory of elderly subjects with high and low scores on the two composite measures. The WCST and the CFL contributed to the frontal composite measure. They found a double dissociation between item (memory for sentences) and context memory (memory for voice in which the sentence was spoken). Item memory was correlated with measures of medial temporal, but not frontal lobe functioning, whereas memory for context was correlated with the measure

of frontal, but not temporal lobe functioning.

If "Remember" judgments to correctly recognized items are based on memory for context, then one would also expect a correlation between frontal lobe dysfunction and proportion of "Remember" judgments in the elderly. Parkin & Walter (1992) found a positive correlation in their oldest group (mean age 81.6 yrs) between proportion of "Remember" judgments and performance on the modified WCST. All of the older subjects (ages 64 - 86) gave more familiarity based "Know" judgments than did the young subjects (ages 19 - 23), but only the oldest group showed the correlation between proportion of "Remember" judgments and better performance on the WCST. No correlation was found between proportion of "Remember" judgments and verbal fluency (CFL).

The research cited above provides evidence of a decline in frontal lobe functioning in the elderly, and a suggestion that this may account for at least some of the difficulty they have with episodic memory, i.e. with memory for source or context. In addition, the studies by Parkin & Walter (1992) and Glisky et al. (1995) suggest that the decreased performance found in the elderly on recognition tests is the result of a decline in episodic- rather than familiarity-based processing.

Event Related Potentials in Recognition Memory:

Event related potentials (ERPs) are sensitive to the recent repetition of a word. When words are repeated within intervals of up to at least 40 minutes (Rugg & Nagy, 1989), the ERP waveform is more positive compared with the waveform for new, unstudied words (ERP old/new effect) (Domalski, Smith & Halgren, 1991; Friedman, 1990, 1992; Friedman, Berman & Hamberger, 1993; Heit, Smith & Halgren, 1988, 1990; Johnson, Pfefferbaum & Kopell, 1985; Karis, Fabiani, & Donchin, 1984; Neville, Kutas, Chesney & Schmidt, 1986; Paller, & Kutas, 1992; Paller, Kutas, & Mayes, 1987; Potter, Pickles, Roberts & Rugg, 1992; Rugg, 1990, Rugg & Doyle, 1992, 1993; Rugg, Roberts, Potter, Pickles, & Nagy, 1991; Rugg & Nagy, 1989; Sanquist, Rohrbaugh, Syndulko & Lindsley, 1980; Smith, 1993; Smith & Guster, 1993; Smith & Halgren, 1989; Smith, Stapleton, & Halgren, 1986). The divergence between the old (previously studied) and new word (previously unstudied) waveforms begins approximately 250-300 msec poststimulus and continues for at least 400 to 500 msec. This old/new effect is thought to span two components, the N400 and the P3 (peaking around 600 msec poststimulus onset) (Friedman, et al., 1993; Rugg 1990; Smith & Halgren, 1989). Several researchers have interpreted their ERP

repetition data as reflecting either the episodic- or the familiarity-based components of recognition memory (Friedman, 1990; Friedman et al., 1993; Paller & Kutas, 1992; Potter et al., 1992; Rugg & Doyle, 1992; Rugg & Nagy, 1989; Smith, 1993; Smith & Halgren, 1989; Van Petten, Kutas, Kluender, Mitchiner & McIsaac, 1991; Wilding, Doyle & Rugg, 1995). However, there is little agreement in these discussions as to which recognition process the ERP old/new effect reflects.

Smith (1993) directly compared the ERP waveforms thought to be based on episodic recognition with those thought to be based on familiarity-based recognition. He asked subjects to make subjective R and K judgments for words they identified as old in a recognition memory test. The average voltage of the ERP waveforms was measured in two latency windows: early (400-550 ms), and late (550-700 ms). The ERP old/new effect for all correctly identified old words compared with correctly identified new words was significant in both time windows. In the early time window, there was no difference in amplitude between waveforms associated with R and those associated with K responses. However, in the late window (550 -700 ms), the waveform associated with R responses was significantly more positive than that associated with K responses. Smith (1993) interpreted these data as evidence that the

ERP old/new effect is sensitive to episodic-based processing. Rugg (1994) suggested that Smith's (1993) data do not imply that the late ERP old/new effect is specific to episodic processing since the ERPs associated with R and K judgments both showed a late old/new effect, and the scalp distributions were indistinguishable. Rugg's (1994) observation is based on the assumption that R and K judgments reflect different underlying processes. Another possibility is that R and K judgments reflect gradations of an episodic process in which some items evoke more recollection than others (Rugg, 1994). In that case, Smith's (1993) ERP old/new effect associated with R judgments would reflect more detailed recollection than would the ERP old/new effect associated with K judgments. Rugg (1994) further suggested that the ERP old/new effect may index awareness that an item has been presented earlier, whether this awareness is based on episodic- or familiarity-based recognition.

Wilding & Rugg (1996) used an objective aspect of context, namely memory for the modality of presentation, as a measure of episodic-based recognition. Subjects first performed a modified, auditory lexical decision task in which half of the stimuli were spoken by a female and half by a male voice. Subjects indicated, by pressing one of four

buttons, whether the item was a word or non-word and whether the voice was female or male. In the visual recognition test, subjects judged each item as old or new. For those judged old, they also attempted to recall the voice in which the word had been presented during study. In Experiment 2 only, subjects also had the option, for both the old/new and the voice judgments, to indicate “don’t know” via a third button. This was done to eliminate trials in which subjects correctly guessed that an item was old or correctly guessed the voice source. Wilding & Rugg (1996) theorized that it is likely that episodic- rather than familiarity-based processes underlie the recognition of those items that are correctly judged old and assigned to the correct study voice. They further theorized that if the ERP old/new effect reflects episodic based processing, that effect should be larger for old items that are correctly recognized and assigned to the correct study voice (hit/hit) than for old items that are correctly recognized, but assigned to the incorrect study voice (hit/miss).

They found two topographically and temporally distinct ERP old/new effects for correctly identified old words. The early old/new effect began at approximately 400 ms, had a left parietal maximum and lasted < 1 sec. The later old/new effect began at approximately the same

time, had a right frontal maximum and was still large at the end of the recording epoch (1434 ms). The early parietal effect was present for hit/hit and hit/miss words. The effect was larger when a correct voice judgment was made, but there was no topographic difference between hit/hit and hit/miss waveforms. The later frontal effect was reliable only for hit/hit waveforms. When the option of “don’t know” was allowed in Experiment 2, the early old/new effects were enhanced and the later frontal effect was present for both hit/hit and hit/miss categories. Both early and late effects were larger for hit/hit than for hit/miss waveforms. Topographic differences between the early and late old/new effects were significant for both hit/hit and hit/miss waveforms. By eliminating guessing (via the “don’t know” option) in both the old/new and source judgments, the larger old/new effects for waveforms associated with hit/hit compared with hit/miss judgments cannot be attributed to different levels of confidence when subjects make the various decisions.

The authors interpreted their findings as supporting the association of the ERP old/new effects with episodic-based recognition. They found no support for the dual process model of recognition memory. Instead, following a model proposed by Moscovitch (1992, 1994), they hypothesized that the early ERP old/new effect may reflect output from

the hippocampus, which is sufficient to identify an item as old. The magnitude of this effect may correlate with the amount of data retrieved. The later ERP old/new effect was interpreted as subsequent output from the frontal lobes, which is necessary to identify contextual information. They suggested that it, too, may be a graded process.

There are two ERP studies of source memory in older subjects (Senkfor & Van Petten, 1996, and Mark & Rugg, in press). Senkfor & Van Petten (1996) reported research designed to dissociate item and source memory using ERPs. In the study phase of the first experiment, subjects heard 136 concrete nouns, half spoken in a female and half in a male voice. They were to form a mental picture of each object and push one of two buttons to indicate if it was larger or smaller than a 10" x 10" square. During the item recognition test, half of the old words were repeated in the same voice as at study and half in a different voice. Half of the 136 new words were spoken in a male and half in a female voice. Subjects were to make old/new judgments. The second experiment was the same as the first with two exceptions. At study subjects heard only 17 words per block, and during the voice (i.e., context) recognition test they made judgments of old word-same voice, old word-different voice, or new word. Senkfor & Van Petten (1996) found ERP old/new effects

for correctly identified old words during both item and context recognition tests. They were maximal between 400 to 800 msec, and largest at temporal sites. Because the old/new effect was similar for both tasks, they interpreted it as reflective of old/new word recognition. The effect was similar in amplitude and topography for hit/hit and hit/miss waveforms in the context recognition task. The similarity in amplitude between these conditions is in contrast to the findings of larger amplitude for Remember vs. Know and hit/hit vs. hit/miss waveforms found by Smith (1993) and Wilding & Rugg (1996), respectively. The waveforms of the old subjects showed this early old/new effect only in the context recognition task. It was smaller in amplitude than that of the young, but similar in scalp distribution.

During the source recognition task, Senkfor & Van Petten (1996) found two other effects, both in the 800 to 1400 msec range. There was an old/new effect for correct old words, whether or not source was correctly recognized. This occurred only at the prefrontal sites and was reduced in amplitude for old subjects. They interpreted this effect as a search for source information. At other, more posterior sites (temporo-parietal), correct source recognition (hit/hit) resulted in a more positive ERP waveform than did failure to recognize the source (hit/miss). (This was

not a old/new effect per se, but a difference between waveforms to old words with and without correct source recognition. The difference in positivity would result in a larger amplitude difference wave for the hit/hit trials than for the hit/miss trials.) At lateral sites, it was slightly larger on the right. They interpreted the hit/hit-hit/miss difference as a voice retrieval effect. Old subjects showed no ERP evidence of this effect. Senkfor & Van Petten (1996) did not discuss the hypothesized episodic-vs. familiarity-based recognition processes. Item recognition could be based on either process. The early old/new effect was similar in all conditions in which it occurred. However, the absence of this effect in the old combined with their item accuracy of 80% during the recognition test suggests that, in this instance, item recognition may have been based on a process different from that indexed by the early old/new effect. The reduction of the voice search and voice retrieval effects in older subjects is consistent with their reduced source accuracy during source recognition. Source memory performance is generally thought to reflect episodic-based processing. Although one must be cautious in attributing scalp recorded ERPs to underlying sources within the brain, the prefrontal voice search effect would be consistent with frontal involvement in source memory. The reduction of this effect in the older subjects would be

consistent with a hypothesis of frontal lobe locus of episodic memory decline with age.

Mark & Rugg (in press) utilized a voice source paradigm to examine ERP correlates of R/K and correct/incorrect voice source judgments. During study, subjects heard 40 words/block, half spoken by a male and half by a female. They repeated the word and indicated whether it had been presented by a male or female voice. Then, depending on the voice, they rated the word as pleasant/unpleasant or as active/passive. The assignment of task to gender was counterbalanced across subjects. At test, words were presented visually and subjects made old/new judgments. For words judged old, a subsequent judgment was required. In half of the test blocks subjects made a subsequent R/K judgment, and in half they indicated whether the word had been presented by a male or female voice at study. The age groups did not differ in corrected hit rate, but the young were significantly better at correctly identifying the source. The proportion of hits with R judgments did not differ between groups. A preliminary analysis showed no difference in either age group between ERPs elicited by correctly identified old items with a subsequent R judgment and those with a subsequent correct voice judgment. Thus, waveforms for these two tasks were combined into a

correctly identified old waveform for each subject. The resulting correct old waveforms thus excluded correctly identified old items with subsequent K or incorrect voice judgments. (ERP waveforms for these two judgment categories could not be formed because of insufficient trials.) As in the Wilding & Rugg (1996) study, the investigators found two old/new effects: an early left temporo-parietal effect and a more extended right frontal effect. Neither effect differed between age groups in magnitude or topography. They did find that the posterior, but not the frontal effect, onset approximately 100 ms later in the old subjects. The authors concluded that: 1) the subjective (R/K) and objective (voice source) methods of identifying trials in which episodic retrieval occurred refer to functionally equivalent cognitive processes; 2) the memory processes subserved by the hippocampus and by the prefrontal cortex are relatively unchanged with age.

The finding by Mark & Rugg (in press) of an ERP old/new effect between 500 and 800 msec for correctly identified old words is similar to what Smith (1993) and Wilding & Rugg (1996) found in their studies. Remember (Smith, 1993) and list correct judgments (Wilding & Rugg, 1996) were more positive than know or list incorrect judgments. This was not true in the Senkfor & Van Petten (1996) study where the amplitudes

were the same for correctly identified old words with and without correct source attribution. In the Mark & Rugg (in press) study, the old/new effect could not be calculated for hits with K or with incorrect source judgments. The finding by Mark & Rugg (in press) of a right frontal old/new effect that did not differ in magnitude or topography between groups is in contrast to the finding by Senkfor & Van Petten (1996) of a reduction in amplitude in the old age group for this effect. Mark & Rugg (in press) suggested that this difference may be due to the lower proportion of trials in the Senkfor & Van Petten (1996) study in which actual recollection (corrected for guessing) occurred. In the Mark & Rugg (in press) study, older subjects identified the correct voice 71.5% of the time. When corrected for guessing this was reduced to 43%. In the Senkfor & Van Petten (1996) study, the corresponding figures were 60% and 20%.

These four studies leave several major issues that are as yet not satisfactorily resolved. The first issue is the validity of the remember/know distinction in dissociating episodic- and familiarity-based recognition memory processes. It has been hypothesized that older adults have more difficulty with memory for context and thus rely more on familiarity-based processing than do younger adults. Correlations of

know judgments with putative measures of frontal lobe functioning have been used to suggest that a decline in frontal lobe functioning may underlie this source memory difficulty in old subjects. However, R/K judgments are relatively subjective and have not yet been objectified satisfactorily using additional contextual criteria. Second, it is not clear whether remember/know judgments reflect cognitively and physiologically different memory processes that correspond to those that are hypothesized to underlie recognition memory, or reflect a single, graded continuum. The third issue is the extent to which the ERP old/new effect reflects either episodic- or familiarity-based processing, and what, if any, are the age-related differences.

The current study is based on the paradigm used by Howard, Heisey & Shaw (1986) to investigate the priming of new associations in young and older adults and on Tulving's (1985) Remember/Know (R/K) distinction. The experiment utilized behavioral and ERP measures to compare subjective (i.e., R/K) and objective (i.e., List) judgments as methods for dissociating the two hypothesized processes of recognition memory in young and elderly subjects. In each of eight study-test blocks, subjects studied two lists of sentences of the form Noun1, Verb, Noun2 (e.g., The dragon sniffed the fudge). Following this, subjects made

old/new recognition judgments to old nouns from the study sentences intermixed with an equal number of new (i.e., foil) nouns. For nouns that a subject judged to be old, i.e., seen in the previous study phase, the subject also was asked to make (R/K) judgments and identify the list in which the word had been studied.

Based on the preceding research, the following predictions were made:

- 1) If, compared with young subjects, older subjects rely more on familiarity than on episodic based processes, this will be reflected in their producing a larger proportion of Know responses to nouns judged old than will young subjects.
- 2) Younger subjects will perform better than older subjects on both item and source recognition. If, compared with young subjects, older subjects have relatively greater impairment on source than on item memory, this will be reflected in a larger difference between groups in the proportion of hits with list correct (source memory) than in the discrimination between old and new items (item memory).
- 3) If the ERP old/new effect reflects episodic-based processing, it will be larger for hits+List Correct than for hits+List Incorrect.
- 4) If Remember & Know judgments differentiate episodic- and

familiarity-based processes, and these two processes are reflected qualitatively in the ERPs, then the old/new effect associated with hits+Know judgments will differ topographically from the old/new effect associated with hits+Remember.

5) If a decline in frontal lobe functioning in the elderly is related to increased reliance on familiarity-based processing, the elderly will evidence a significant negative correlation between performance on the putative measures of frontal lobe functioning (WCST & CFL) and proportion of K judgments. Likewise, they will show a significant positive correlation between performance on those same measures and the proportion of Remember judgments as well as the proportion of hits+List Correct.

6) If frontal lobe functioning is decreased in the elderly compared with the young, and this is reflected in the ERPs, the elderly will show a smaller or absent late old/new effect at prefrontal scalp sites.

METHODS

Subjects:

Sixteen young (21-28 yrs.) and 16 older women (65-81 yrs.) were recruited through ads placed in local newspapers, and notices posted in

the Columbia Presbyterian Medical Center and the surrounding area. All subjects signed informed consent and were paid for their participation. They all reported themselves to be native English speakers who were in good physical and mental health and free from medications known to affect the central nervous system.

Screening Procedures:

All subjects were of at least average intelligence and achieved a score of 50 or better, out of a possible 57, on the Modified Mini-Mental Status examination (mMMS, Mayeux, Stern, Rosen & Leventhal, 1981). For purposes of expediency, and because the IQ was obtained primarily to rule out subjects with below average intelligence, short forms of the WAIS-R were utilized to obtain IQ estimates. For young subjects, IQ scores were estimated from the scaled scores of the Vocabulary and Block Design subtests of the Wechsler Adult Intelligence Scale-Revised, WAIS-R (Wechsler, 1981). This method was chosen for young subjects because of the relatively good correlations of these IQ estimates with IQs from a full administration. For the age range of the young subjects (21-28 yrs), the Vocabulary scaled score has a correlation of .83 with Verbal IQ and the Block Design scaled score has a correlation of .69 with

Performance IQ. Full Scale IQs were estimated from the sum of the Vocabulary and Block Design scaled scores using the IQ equivalents calculated by Brooker and Cyr (1986). Over all WAIS-R ages, this estimate of Full Scale IQ has a mean reliability of .94 and a mean validity of .91. Based on these correlations, the estimate of Performance IQ will be the least valid estimate of true IQ. Because the age of some of the older subjects was above the age range for which IQs can be estimated using the above procedure, a WAIS-R modification of the Satz-Mogel (1984) short form was used to estimate their IQs (Adams, Smigielski & Jenkins, 1984). In this administration the number of items within each subtest are reduced by one half to one third. After correcting for overlapping items, this short form has correlations with the complete form of .90 for Verbal and Full Scale IQ, and .80 for Performance IQ. This short form was modified by giving three subtests in their entirety-- Vocabulary, Block Design and Digit Span. This modification would raise the correlations with the complete form, and allows a direct comparison with young subjects on these three subtests. For the three subjects who were older than 74 (76, 81 and 84 years) and thus did not fall within the ages normed by Wechsler (1981), IQ estimates were based on the norms developed by Ivnik et al. (1992) for subjects 74 - 84 years old. These

norms were based on data collected in Mayo's Older Americans Normative Studies (MOANS). For subjects between ages 56 and 75, i.e., subjects for whom both WAIS-R AND MOANS IQs could be calculated, correlations between the IQs based on the two sets of normative data were .99 for Verbal, .97 for Performance and .98 for Full Scale IQ. A semi-structured interview (SHORT-CARE, Gurland, Golden, Teresi & Challop, 1984) was administered to older subjects to ensure that they were free from depression and dementia, and not limited in the activities of daily living. See Table 1 for details.

Table 1. Demographic and neuropsychological screening data for young and old subject groups

MEASURE	YOUNG		OLD	
	MEAN	SD	MEAN	SD
Age (years)	24.63	2.34	70.75	5.65
Education (years)	16.75	1.34	15.75	3.09
Laterality quotient ^a	61.38	60.95	73.69	24.19
SES ^b	49.50	4.32	51.69	15.89
Modified MMS ^c	55.81	1.17	54.63	1.75
Digits Forward ^d	7.25	1.39	7.36	1.26
Digits Backward ^d	6.06	1.39	5.63	1.31
Vocabulary Scaled Score ^d	12.88	2.25	14.13	2.13
Block Design Scaled Score ^d	10.25	1.98	8.75	2.21
Vocabulary Age Score ^e	13.25	2.54	14.88	2.13
Block Design Age Score ^{e+}	10.13	1.86	12.63	2.92
WAIS-R Verbal IQ Estimate ^f	114.38	11.24	122.38	11.09
WAIS-R Performance IQ Estimate ^{f+}	101.25	9.92	111.75	11.41
WAIS-R Full Scale IQ Estimate ^{f+}	108.56	8.03	119.25	11.29
Depression (Short CARE) ^g	NA	NA	2.56	1.50
Dementia (Short CARE) ^g	NA	NA	0.13	0.34

^aEdinburgh Handedness Inventory (Oldfield, 1971). ^bSocio-economic status (Watt, 1976) - higher score = lower status. ^cModified Mini-Mental Status Exam (Mayeux, Stern, Rosen & Leventhal, 1981) - maximum score possible is 57. ^dWechsler Adult Intelligence Scale-Revised (Wechsler, 1981). ^eBased on Wechsler Adult Intelligence Scale-Revised (Wechsler, 1981) for subjects through age 74, and MOANS scores (Ivnik et al., 1992) for subjects over age 74. ^fBased on WAIS-R Vocabulary, BD, and Vocabulary and BD scaled scores respectively for young subjects, and a short form of the WAIS-R for older subjects (Adams, Smigielski & Jenkins, 1984). ^gSHORT-CARE (Gurland, Golden, Teresi & Challop, 1984); Cutoff is 6 for depression and 7 for dementia scores. NA, not applicable. *Significant difference between group means, two-tailed t-test, $p < .05$. + Significant difference between group means, two-tailed t-test, $p < .01$.

All older controls were normal on a medical and neurological

examination administered by a board-certified neurologist assessing prospective subjects for neurodegenerative disorders (e.g., Parkinsonism, cerebellar disease, multiple sclerosis), clinically detectable neurovascular disease (embolic CVA, thrombotic CVA, lacunar CVA), visual acuity, visual field defects, and the presence of any tremor or rheumatological disorders that would interfere with manipulation of the response buttons.

General Procedures:

Young subjects were first screened with the mMMS and then performed the study-test recognition task during which ERPs were recorded. Following this, the electrocap was removed and subjects were questioned about their task strategies. Finally, the neuropsychological tests were administered. These included IQ tests as described above, the Edinburgh Handedness Inventory (Oldfield, 1971), the Boston Naming Test (Kaplan, Goodglass, Weintraub & Segal, 1983), the Wisconsin Card Sorting Test (Heaton, 1981) and the Controlled Oral Word Association Test (Benton & Hamsher, 1976).

The majority of the neuropsychological tests were administered to older subjects in a session prior to the ERP testing. On a later day, they performed the study-test recognition task during which ERPs were

recorded. At the end of this recording session, they were administered the Wisconsin Card Sorting Test and the Controlled Oral Word Association Test. All subjects were given a lunch break halfway through the recording session and other breaks every two to three blocks as needed. The recording session lasted approximately 4 hours. Subsequent neuropsychological testing required an additional hour for young and 30 minutes for older subjects.

Study Procedures:

During study, sentences were presented in two lists separated by a short interval (approximately 1 minute). The label LIST 1 or LIST 2 preceded each list. Sentences were presented on the computer screen one word at a time to facilitate ERP recording. Subjects were seated in a comfortable chair, 100 cm from the screen. At that distance, each letter subtended a vertical visual angle of 0.86° . Horizontal visual angles ranged from 0.86° to 5.56° . The range for nouns was 0.86° to 4.07° . The first word in each sentence was a function word (e.g., the, her, an); the second word was Noun1; the third word the Verb; the fourth word another function word; and the last word was Noun2. A large dot followed the last word of each sentence and signaled the end of the

sentence. Presentation time for each word and period was 300 msec with an interstimulus interval (ISI) of 1200 msec. See Table 4 for sentence examples.

Test Procedures:

All of the nouns from the experimental sentences studied in the previous two lists, along with an equal number of new, foil nouns, were used in a recognition block. Nouns were presented one at a time in sequential pairs. Stimulus presentation time was 300 msec with an ISI of 2000 msec. Subjects were asked to make speeded, but accurate old/new judgments for each noun via a button press. RT and accuracy were recorded. After a two noun sequence was presented, a noun that had been judged old was re-presented on the computer screen. At this point, subjects were asked to make an R/K judgment followed by a source judgment (on which list did you see it?). These two judgments were made via non-speeded button presses and ERPs were not averaged during these judgment periods. The R/K judgments were signaled by the word "REMEMBER" appearing in one bottom corner of the computer screen and "KNOW" in the other. Likewise, the list judgment was cued by the word "LIST 1" appearing in one bottom corner and "LIST 2" in the other

bottom corner. Subjects pressed a button with one hand for old and the other hand for new, one hand for remember and the other hand for know, and one hand for list 1 and the other hand for list 2. The 8 combinations of type of response and hand of response were counterbalanced across subjects. For any one subject, hands assigned to given decisions were the same for all blocks (e.g., Subject 1 used the left hand for old, remember, and list 1). Placement of the cue on the computer screen for remember/know and list1/list2 was on the same side as the hand assigned to that response.

Instructions:

Prior to the first study/test block, subjects were given verbal instructions and administered a practice block. They were encouraged to ask questions to clarify the instructions. Following the practice study/test block they were asked to explain how they made their R/K judgments. If necessary they were *reinstucted and/or administered* the practice block a second time. No subject required more than two administrations of the practice block to understand and execute the task. In the verbal instructions they were asked to read the sentences and to try to memorize the nouns and the list in which they were presented for a later memory

test. They were told that the sentences were provided to help them remember the nouns. Complete verbatim instructions can be found in the appendix.

Stimuli:

There were 8 study/test blocks. Each study phase contained two lists of sentences presented sequentially. There were 8 target sentences in each list and 16 sentences per study phase. Each test phase contained the 32 target nouns from the previous two lists of study sentences, plus 32 foil nouns for a total of 64 nouns per test phase. Over the 8 study/test blocks subjects studied 128 target sentences each containing 2 nouns. A total of 256 sentences were divided into two pools that served as targets or foils (counterbalanced across subjects). An additional filler sentence was inserted at the beginning and end of each list to control for primacy and recency effects. These 32 filler sentences were the same for every subject and the nouns in these sentences were not tested. The practice study/test block differed from experimental blocks only in that there were no filler sentences during the study phase. Nouns were of low to medium frequency (count of less than 20 words per million in the printed language) according to the Kucera & Francis (1967) frequency norms,

with a length of 3 to 9 letters. The two nouns in each of the experimental sentences were found to be unrelated in a normative study using the following operational criteria. The degree of relationship between the nouns was assessed by asking 20 young adults to rate the degree of relationship of 340 pairs of nouns on a 5 point scale (1 = least associated; 5 = highly associated). Noun pairs were used in the experimental study only if 75% of the raters gave them a mean rating of 3 or less, resulting in a total of 256 noun pairs (Table 2). The length (i.e., number of letters) and frequency of the first and second nouns were compared using two-tailed t-tests. The first and second nouns did not differ significantly in frequency or length ($p > .05$). Nouns in the two pools were similarly balanced ($t(254) = 0.27, p > .05$). See Table 3 for mean frequencies and lengths.

Table 2. Relatedness ratings of noun pairs.

POOL	Mean	SD	RANGE
A	1.7	0.43	1-2.8
B	1.7	1.4	1-2.7

Table 3. Noun frequency and length.

POOL	NOUN	FREQUENCY		LENGTH	
		MEAN	RANGE	MEAN	RANGE
A	N1	10.6	6-19	5.8	3-8
A	N2	9.7	1-19	5.9	3-8
B	N1	10.3	1-19	5.8	3-8
B	N2	9.3	1-19	5.9	3-8

Note: Frequency is per million (Kucera & Francis, 1967). Length is number of letters in a noun.

Counterbalancing of Stimuli:

As part of a larger study, the recognition test was designed to investigate the priming of a studied Noun2 when preceded by a studied noun from the same sentence or a studied noun from a different sentence.

During the test phase, words from both sets of sentences (seen and not seen) were presented in pairs. The first noun of the pair was always the first noun from a sentence (Noun1) and the second noun of the pair was the second noun from a sentence (Noun2). This resulted in four possible conditions that were equiprobable: (1) old N1, old N2; (2) old N1, new N2; (3) new N1, old N2; (4) new N1, new N2 (See Table 4). In one half of the instances of condition 1 (old, old), both N1 and N2 were from the

same sentence; in the other half they were from different sentences.

Conditions 2 - 4 were split in half to form, with the two halves of condition 1, eight rows of a Latin Square Table. Eight test orders of conditions were created by randomizing the eight rows of the Latin Square Table so that each noun served equally often in each of the four possible pair conditions. The test orders were yoked such that four subjects (two young and two elderly) received each test order

Table 4. Examples of study and foil sentences and their subsequent assignment to conditions in the recognition test

SENTENCES

	POOL A STUDIED		POOL B FOIL
1.	The plow created the delay.	5.	Her nephew joined the cult.
2.	The lyrics reflected his wit.	6.	His singing filled their dwelling.
3.	The monkey ate the cereal.	7.	The elevator became a tomb.
4.	The deputy read the script.	8.	The candy eased her sorrow.

RECOGNITION TEST

CONDITION		DESCRIPTION	NOUN1, NOUN2
A	Old, Old— Same	Both words from the same, studied (old) sentence	(1.plow, 1.delay)
B	Old, Old— Different	Both words from studied, but different sentences	(2.lyrics, 3.cereal)
C	Old, New— Mixed	An old, studied word and a foil from a never seen, foil sentence	(3.monkey, 6.dwelling)
D	Old, New— Mixed	An old, studied word and a foil from a never seen, foil sentence	(4.deputy, 8.sorrow)
E	New, New— Same	Two new, foil words from the same sentence	(5.nephew, 5.cult)
F	New, New— Different	Two new, foil words from different sentences	(6.singing, 7.tomb)
G	New, Old— Mixed	A new, foil word and an old studied word	(7.elevator, 2.wit)
H	New, Old— Mixed	A new, foil word and an old studied word	(8.candy, 4.script)

Same Context trials (Condition A) are those in which the second old noun (Noun2) is from the same sentence as the first old noun (Noun1) (e.g. **delay** tested immediately after **plow**). Different Context trials (Conditions B) are those in which the Noun2 is from a different sentence

than Noun1 (e.g. **cereal** tested immediately after **lyrics**). The first noun of a recognition pair was always a Noun1 and the second noun of a pair a Noun2. In the Same Context condition, Noun2 of a sentence was always seen after Noun1 from the same sentence. In all other conditions either Noun1 or Noun2 from a sentence may have been presented for recognition earlier in the test.

EEG Recording Procedures:

EEG was recorded from 32 sites using an Electro cap (Electrocap International, Inc.) for scalp placements and disposable Ag/AgCl electrodes for the face and mastoids. All electrodes were referred to the nosetip. See Figure 1 for the spherical coordinates of the electrode placements. Horizontal and vertical electrooculogram (EOG) was recorded bipolarly with electrodes placed, respectively, at the outer canthi of both eyes and above and below the right eye. EOG and EEG were recorded continuously with a bandpass of 0.01-30 Hz (5.3 s time constant) and digitized at 100 Hz. Data were epoched off-line with a 100 ms prestimulus baseline and an 1100 ms poststimulus interval for the study phase and a 1900 ms poststimulus interval for the test phase. Eye movement artifacts were corrected off-line with a procedure developed by

Gratton, Coles and Donchin (1983). ERP waveforms were digitally re-referenced to an averaged mastoid reference to facilitate observation of frontal scalp activity that would have been reduced with a nose reference. This resulted in 28 active scalp sites.

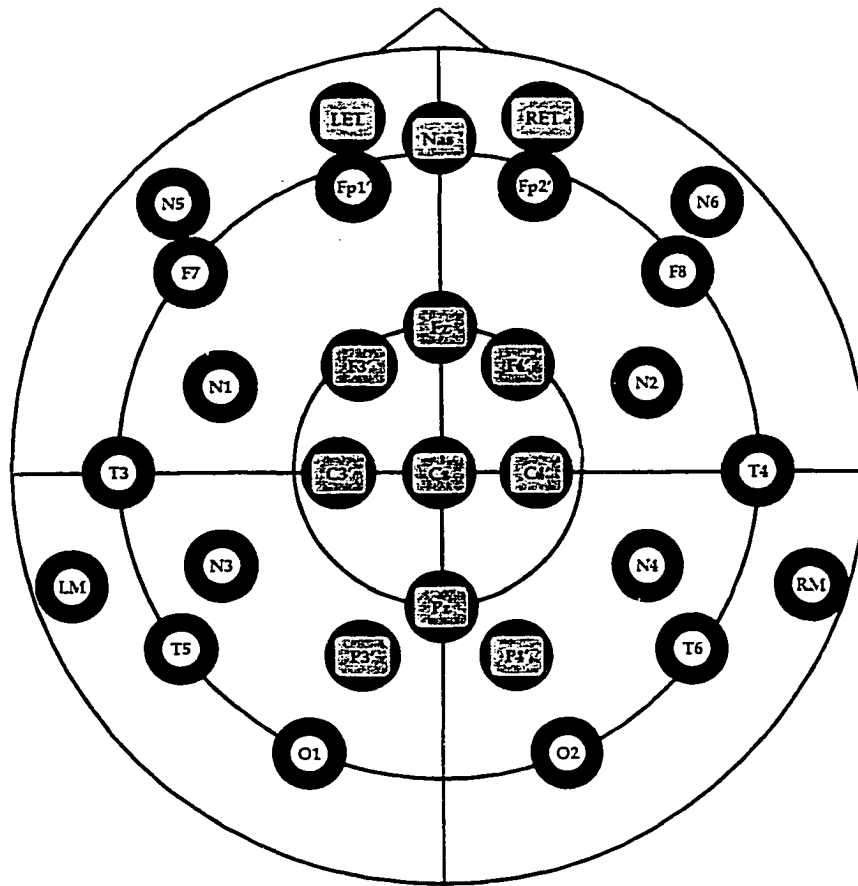


Figure 1. Electrode Montage.

Standard placements (International 10-20 system, Jasper, 1958) included: Fz, Cz, Pz, Oz, F7, F8, T3, T4, T5, T6, O1, O2 and mastoids. Non-standard placements were as follows: (Fp1' 16% of the distance on the midline from the back to the front of the cap in front of Fz and laterally on the left hemisphere 10% of the distance from ear to ear), Fp2' (homologous of Fp1' on the right hemisphere), F3' (33% of the distance on a line between Cz and F3 on the left hemisphere, closer to F3), F4' (homologous of F3' on the right hemisphere), C3' (60% of the distance on a line between Cz and C3 on the left hemisphere, closer to C3), C4' (homologous of C3' on the right hemisphere), P3' (65% of the distance on a line between Pz and P3 on the left hemisphere, closer to P3), P4' (homologous of P3' on the right hemisphere), N1 (50% of the distance on a line between F3 and T3 on the left hemisphere), N2 (homologous of N1 on the right hemisphere), N3 (50% of the distance on a line between P3 and T3 on the left hemisphere), N4 (homologous of N3 on the right hemisphere), N5 (midway on a line between the left preauricular depression and the left eye canthus), N6 (homologous of N5 on the right hemisphere). Electrodes used in analyses are shaded.

Data Analyses:

Behavioral: Accuracy data, collapsed across nouns 1 and 2, were averaged according to the conjunction of correct recognition (hits) and subsequent remember/know or temporal source judgments (list correct/incorrect) as well as to correctly identified new items (correct rejections). Planned comparisons between groups were evaluated using independent sample, 1-tailed t-tests. These included accuracy differences between age groups on measures of item and source memory, remember judgments, and old/new discrimination. Indices of discrimination (Pr , d_L) and response bias (Br , C_L) were computed using the methods described by Snodgrass and Corwin (1988). To ascertain whether subjects were better able to remember items and/or sources from either list 1 or list 2, between list tests of item and source accuracy measures were computed for each age group. Since there was no reason to believe that memory would be better for one list over the other, 2-tailed t-tests were employed.

Because reaction time data sometimes produce a skewed distribution, the normality of the distributions was assessed using the Kolmogorov-Smirnov two-tailed test of normality. Since the analysis of variance test by which these data were to be analyzed is relatively robust with regard to the normality of a distribution, the significance level for

rejection of the hypothesis of normality was set at $p < .01$. Reaction time data were analyzed using the BMDP-4V program for mixed-design ANOVAs (Dixon, 1987). Degrees of freedom were adjusted using the Greenhouse Geisser procedure where appropriate (Jennings & Wood, 1976). Uncorrected degrees of freedom with the corresponding epsilon (ϵ) values, and p values reflecting the epsilon correction are reported below. Significant interactions were followed up using simple effects and/or Tukey HSD tests (calculated using Geisser-Greenhouse adjusted df).

ERPs recorded during the old/new recognition phase were averaged on the basis of old/new accuracy (hit, miss, correct rejection & false alarm), collapsed across nouns 1 and 2. Additional averages were computed based on the conjunction of a correct old recognition judgment and the remember/know or temporal source judgments (list correct/incorrect). Averaged voltages were measured for three latency windows that revealed differences between conditions and age groups. For the young these windows were: early – 260-480 ms; middle – 490-800 ms; and late – 830-1450 ms. For the old the windows were slightly later: early 280-490 ms; middle 500-860 ms; and late 870-1490 ms. All voltages were measured from the 100 ms pre-stimulus baseline.

Data were analyzed using the BMDP-4V program for mixed-design ANOVAs (Dixon, 1987) as described above for analysis of reaction time data.

Because ERP amplitude can vary with age and condition, the data were normalized to remove amplitude differences (McCarthy & Wood, 1985) before topographic analyses. This allowed an unambiguous comparison of the shape of the distribution across the scalp between age groups and/or conditions. An interaction between age group (or condition) and electrode location indicates a significant difference in scalp distribution (e.g., a significant electrode by remember/know interaction).

BEHAVIORAL RESULTS

Accuracy:

Overall: Overall, younger subjects were more accurate and better able to discriminate old from new items than were older subjects (hits - false alarms $p=.02$, d_L $p=.04$). (Table 5). However, there were no significant differences between groups in the percentage of hits, correct rejections, or response bias.

Table 5. Significance of overall accuracy data for young and old age groups.

	PERCENT				SIGNIFICANCE	
	YOUNG		OLD			
	MEAN	SD	MEAN	SD	t	p
Correct	81.71	8.30	76.62	5.53	2.04	.025 ⁻
Hits	71.75	17.30	65.67	12.24	1.15	.13 ⁻
Correct Rejections	91.69	7.34	87.51	2.62	1.31	.10 ⁺
Hits - False Alarms (Pr)	63.44	16.50	53.18	11.09	2.06	.02 ⁻
Br	.25	.20	.26	.20	-.12	.91 [*]
d_L	3.78	1.13	3.06	1.12	1.80	.04 ⁻
C_L	.82	.71	.84	.78	-.06	.95 [*]

Note: Percents are based on all old for hits and all new for correct rejections. ⁺1-tailed t-test; ^{*}2-tailed t-test.

Remember/Know and List Correct/Incorrect: Young and old subjects did not differ in the proportion of hits associated with remember judgments (Table 6). However, the age groups did differ significantly in correct source attribution with the young performing better than the old. The proportion of hits associated with correct list judgment was significantly greater than chance (i.e., 50%) for both young ($t(15) = 8.11$, $p < .0001$) and old subjects ($t(15) = 2.87$, $p < .01$). However, when the proportion of hits with correct temporal source judgments was corrected for guessing by subtracting the proportion of hits accompanied by an incorrect source judgment, only small proportions of the source

judgments were associated with true memory for the list (young = 0.34; old = 0.10). Because of the prediction that the old would be relatively more impaired on source compared to item memory, effect sizes (Cohen's d) were calculated for age related differences in the corrected hit rate (hits – false alarms) and corrected source hit rate (hits+list correct – FAs+list) (Rosenthal, 1991). The effect size for the age-related source memory difference (1.50) was twice that of the age-related item memory difference corrected hit rate (0.72).

Table 6. Significance of accuracy data for hits plus remember/know and list judgments

	PERCENT				SIGNIFICANCE	
	YOUNG		OLD		t	1-tailed p
	MEAN	SD	MEAN	SD		
Hits+Remember	68.28	15.67	63.85	27.39	.56	.29
Hits+List Correct	66.92	8.35	55.25	7.31	4.21	.0001

Note: Percents are based on total hits.

As seen in Table 7, there was no difference between the percentage of hits in list 1 vs. list 2 for either the young or the old groups. Similarly, there was no difference in the percentage of remember judgments associated with the two lists for either group. However, there

was a significant difference between lists for correct list attribution for both young and old subjects. Both groups identified the correct list more often for items from list 1 than from list 2.

Table 7. Between list significance of accuracy data for hits, remember judgments & list correct for both age groups.

	PERCENT				SIGNIFICANCE	
YOUNG						
	LIST 1		LIST 2			2-tailed
	MEAN	SD	MEAN	SD	t	p
Hits	73.88	15.57	69.61	19.61	.68	.50
Hits+R	68.12	14.36	67.64	20.07	.08	.93
Hits+List Correct	75.12	13.26	57.74	12.98	3.75	.0008
OLD						
Hits	64.35	13.53	66.94	12.04	-.57	.57
Hits+R	63.48	28.05	64.13	26.92	-0.07	.95
Hits+List Correct	68.42	15.88	43.46	18.95	4.04	.0003

Note: Percents are based on all old for hits and on all hits for Hits+R and Hits+List Correct.

When hits were separated according to the conjunction of remember/know with list correct/incorrect, both age groups showed the same pattern (Table 8). The greatest proportion of hits were those associated with both a remember and a correct list judgment followed by those associated with a remember plus an incorrect list judgment, a know

plus a correct list judgment, and a know plus an incorrect list judgment. Relative to older subjects, younger subjects had significantly more hits with remember plus list correct judgments and significantly fewer remember plus list incorrect judgments. This reflects the large difference between these two categories in the young group and the smaller difference in the old.

Table 8. Accuracy data for hits plus the conjunction of remember/know and list judgments.

	PERCENT				SIGNIFICANCE	
	YOUNG		OLD		t	1-tailed
	MEAN	SD	MEAN	SD		p
Hits+R+LC	49.81	13.73	34.70	14.21	3.06	.002
Hits+R+LI	18.47	7.72	29.15	15.47	-2.47	.01
Hits+K+LC	17.11	9.44	20.56	16.14	-.74	.23
Hits+K+LI	14.61	6.86	15.60	11.78	-.29	.39

Note: Hits+R+LC=correctly identified old nouns with subsequent judgments of remember and correct list. Hits+R+LI=correctly identified old nouns with subsequent judgments of remember and incorrect list. Hits+K+LC=correctly identified old nouns with subsequent judgments of know and correct list. Hits+K+LI=correctly identified old nouns with subsequent judgments of know and incorrect list. All percents are based on total hits.

Reaction Times:

Reaction times were normally distributed in each age group for hits, correct rejections, hits +remember, hits+know and hits+list correct (Kolmogorov-Smirnov test of normality $p > .1$), and for hits+list incorrect judgments ($p > .02$).

Old/new reaction times, collapsed across nouns 1 and 2, were analyzed in separate Age Group by Condition (e.g., hits, correct rejections) ANOVAs for trials associated with the conjunction of correct old recognition with each subsequent judgment (e.g., hits+remember; see Table 9). Reaction times were significantly faster in the young group for all analyses and both groups responded similarly to all conditions. (See Table 10). The relatively larger standard deviation in the old age group for correct rejections was the result of one subject who was 200 ms slower than the others. There was a significant condition effect for hits+remember by hits+know by correct rejections ($F[2.60]=17.34$, $p<01$). Subsequent simple analyses indicated that reaction times to hits associated with remember judgments were significantly faster than to hits associated with know judgments ($F[1,31]=60.03$, $p<0.01$). Likewise, reaction times to correctly identified new items (correct rejections) were faster than to hits associated with know judgments ($F[1,31]=18.08$,

$p < .01$). Reaction times did not differ between hits and correct rejections ($p > .5$) nor between hits with correct and incorrect list judgments ($p > .2$).

Table 9. ANOVA results for reaction times to correctly identified old and new nouns and to correctly identified old nouns in conjunction with subsequent remember/know and list correct/incorrect judgments.

ANALYSIS	FACTORS	F	df	ϵ	p
Condition (Hit, CR)	Group	14.46	1,30	--	0.0007
	Condition	0.36	1,30	--	0.55
	Group x Cdn	0.10	2,60	--	0.76
Condition (Hits+R, Hits+K, CR)	Group	14.00	1,30	--	0.0008
	Condition	17.34	2,60	0.68	0.00001
	Group x Cdn	0.23	2,60	0.68	0.75
Condition (Hits+LC, Hits+LI, CR)	Group	15.87	1,30	--	0.0004
	Condition	1.30	2,60	0.97	0.27
	Group x Cdn	0.32	2,60	0.97	0.60

Note: Hits+R = Hits associated with Remember judgments; Hits+K = Hits associated with Know judgments; Hits+LC = Hits associated with correct list judgments; Hits+LI = Hits associated with incorrect list judgments; CR = correct identification of new items.

Table 10. Reaction times and standard deviations (msec) for each age group for correctly identified new and old items and for correctly identified old items in conjunction with subsequent remember/know and list correct/incorrect judgments.

REACTION TIMES				
	YOUNG		OLD	
CONDITIONS	MEAN	SD	MEAN	SD
Correct Rejections	898	130	1063	187
Hits	921	115	1070	100
Hits+R	880	110	1029	107
Hits+K	1018	151	1152	116
Hits+List Correct	907	110	1067	104
Hits+List Incorrect	947	125	1080	100

Correlations:

To assess the relationship of accuracy with frontal lobe measures, five accuracy indices were correlated with four putative measures of frontal lobe functioning, and five measures not specifically related to frontal lobe functioning across all 32 subjects. (The four putative measures of frontal lobe functioning were the score on the verbal fluency test and three scores from the Wisconsin Card Sorting Test: number of perseverative errors, number of trials to criterion and percent of conceptual level responses. The five measures less specifically related to frontal lobe functioning

were the score on the modified Mini-Mental Status, the number of digits forward and backward, full scale IQ and the number correct on the Boston Naming Test.) For 45 correlations, the .05 significance level with the Bonferroni correction is $p < .001$. None of the correlations reached this level of significance indicating no significant relationship between these measures of accuracy and any of the putative frontal or non-frontal measures. Several correlations approached significance. See Table 11 for these correlations and p values. However, when the underlying distributions of these correlations were examined, the linear relationships appeared weak at best as most subjects performed quite well on both the WCST and the CFL. See appendix for complete tables of correlations (Tables A1-A3) and scores on the Boston Naming Test, the WCST, and the CFL (Table A4).

Table 11. Correlation of accuracy data for all subjects with measures of intellectual and frontal lobe functioning that approach significance.

PEARSON'S R CORRELATIONS				
	%Hits-FAs	p	%HLC	p
WCST Number of Trials	-.34	.03	-.43	.008
WCST % Conceptual Level Responses	.42	.009	.42	.008
mMMS Score	.29	.05	.46	.004

Note: WCST = Wisconsin Card Sorting Test (Heaton, 1981); mMMS Score = Modified Mini-Mental Status Exam (Mayeux, Stern, Rosen & Leventhal, 1981); %Hits-FAs = percent of hits minus percent of false alarms; %HLC = percent of hits with list correct.

When the same correlations were computed for each age group separately, no correlations reached or approached significance in the young group. For old subjects, better item discrimination (hits-FAs) was significantly correlated with greater verbal fluency ($r = .75$, $p < .000$), and approached significance when correlated with higher full scale IQ ($r = .58$, $p < .009$). No other correlations approached significance. Examination of the underlying distributions of these two correlations revealed that in both cases the majority of subjects' scores fell in the middle range of each variable. The significance of the correlations depended on one subject each at the high and low ends of the distributions.

Summary of Behavioral Results:

These behavioral data indicate that, compared with young subjects, old subjects performed more poorly in both item and source recognition. However, as predicted, older subjects were significantly more impaired in source than in item retrieval. This cannot be accounted for by a difference in response bias as neither index (B_r or C_L) differed reliably between groups. In contrast, the age groups did not differ in their proportion of remember and know judgments. Young subjects had a greater proportion of hits with remember judgments and list correct than did old subjects suggesting the possibility that old subjects more often based their remember judgments on memory for contextual aspects other than list. Item discrimination (hits-FAs) was significantly correlated with verbal fluency in old subjects. However, the actual distribution of scores revealed that the relationship depended primarily on one subject at each extreme end of the distributions. No other correlations of accuracy measures with putative frontal or non-frontal scores were significant.

ERP RESULTS

Overview:

Figures 2 and 3 show grand mean ERPs averaged across young and

old subjects, respectively. Waveforms were averaged on the basis of whether a correctly recognized old noun was subsequently associated with a remember or a know judgment. Waveforms associated with correct rejections (CRs) of foil nouns are also depicted. At posterior sites, the brain potential responses of both young and old appear quite similar for the three conditions. Waveforms associated with remember judgments are more positive than those associated with know judgments or those associated with correct rejection of foil nouns. Both of these effects begin earlier and continue longer in the waveforms of the young subjects. In the early portion of the posterior old/new effect, waveforms associated with know judgments are also more positive than waveforms associated with correct rejections, whereas later in this old/new effect, they no longer seem to differ from new items. However, waveforms associated with remember judgments continue to appear more positive than those associated with know judgments or with correct rejections. At prefrontal scalp locations there are clear differences between the waveforms of the young and old subjects. The young show a large slow wave in the ERPs associated with both remember and know judgments that is larger than that associated with correct rejections. This effect is not evident in the waveforms of the older subjects.

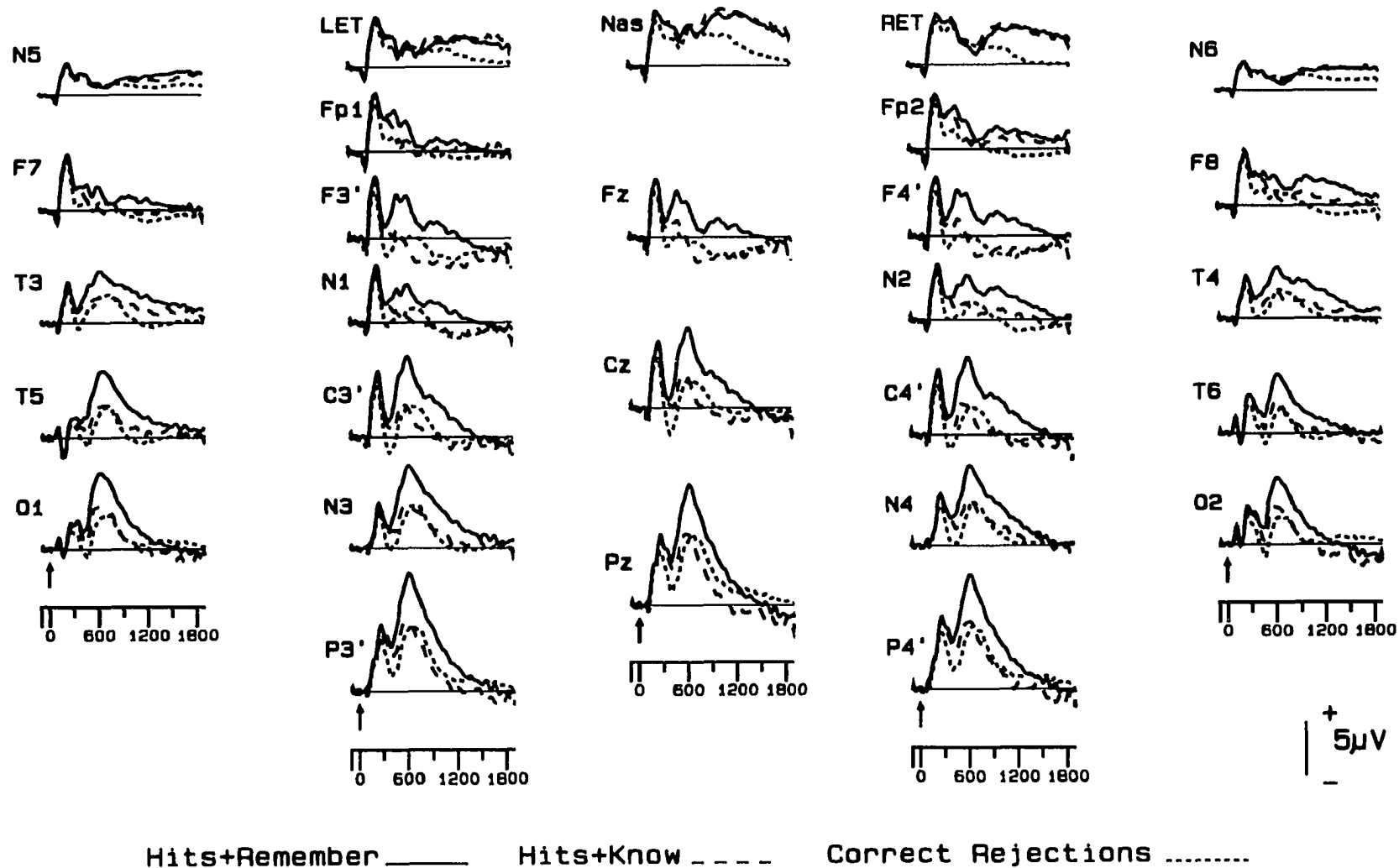


Figure 2. Grand mean ERPs averaged across subjects with the young age group according to whether the correctly recognized old item was associated with a remember or know judgment. Arrow marks stimulus onset.

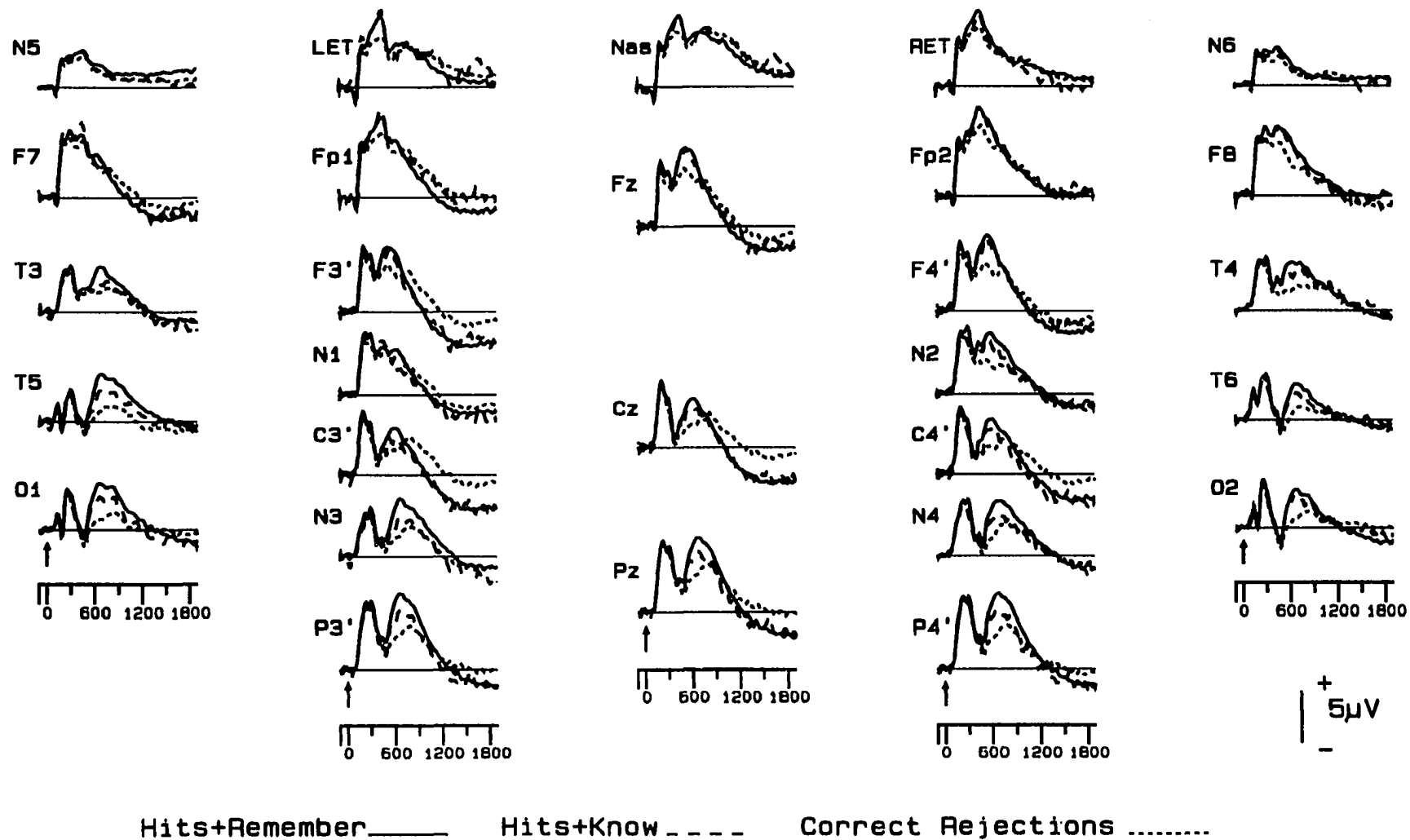


Figure 3. Grand mean ERPs averaged across subjects with the old age group according to whether the correctly recognized old item was associated with a remember or know judgment. Arrow marks stimulus onset.

Figures 4 and 5 show the waveforms for both age groups averaged according to whether a correctly identified old noun was subsequently associated with a correct or incorrect source (i.e., list) judgment. For both age groups, posterior and prefrontal effects similar to those described above for the remember/know waveforms are evident in these ERPs. At posterior sites, waveforms associated with a correct list judgment are more positive than those associated with an incorrect list judgment. Both show an old/new effect in that they are more positive than the waveform associated with correct rejections. Again these effects are more extensive for the young group. For the young group at prefrontal sites, slow waves associated with correct and incorrect list judgments are more positive than the waveform associated with correct rejections. In contrast to the posterior effect, at prefrontal sites ERPs associated with an incorrect list judgment are more positive than those associated with a correct list judgment. Old subjects do not show the prefrontal effect.

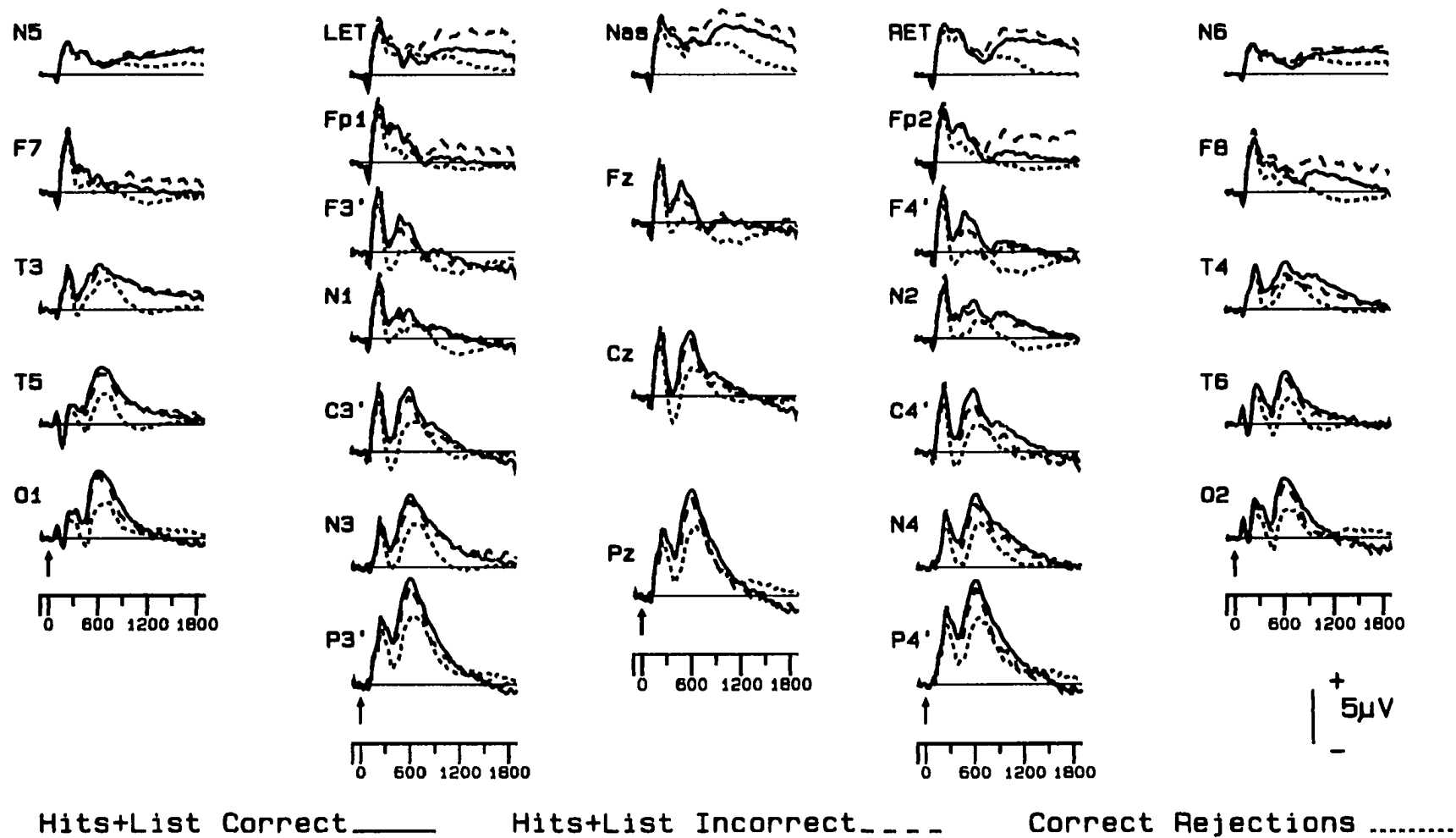


Figure 4. Grand mean ERPs averaged across subjects with the young age group according to whether the correctly recognized old item was associated with a correct or incorrect temporal source (list) judgment. Arrow marks stimulus onset.

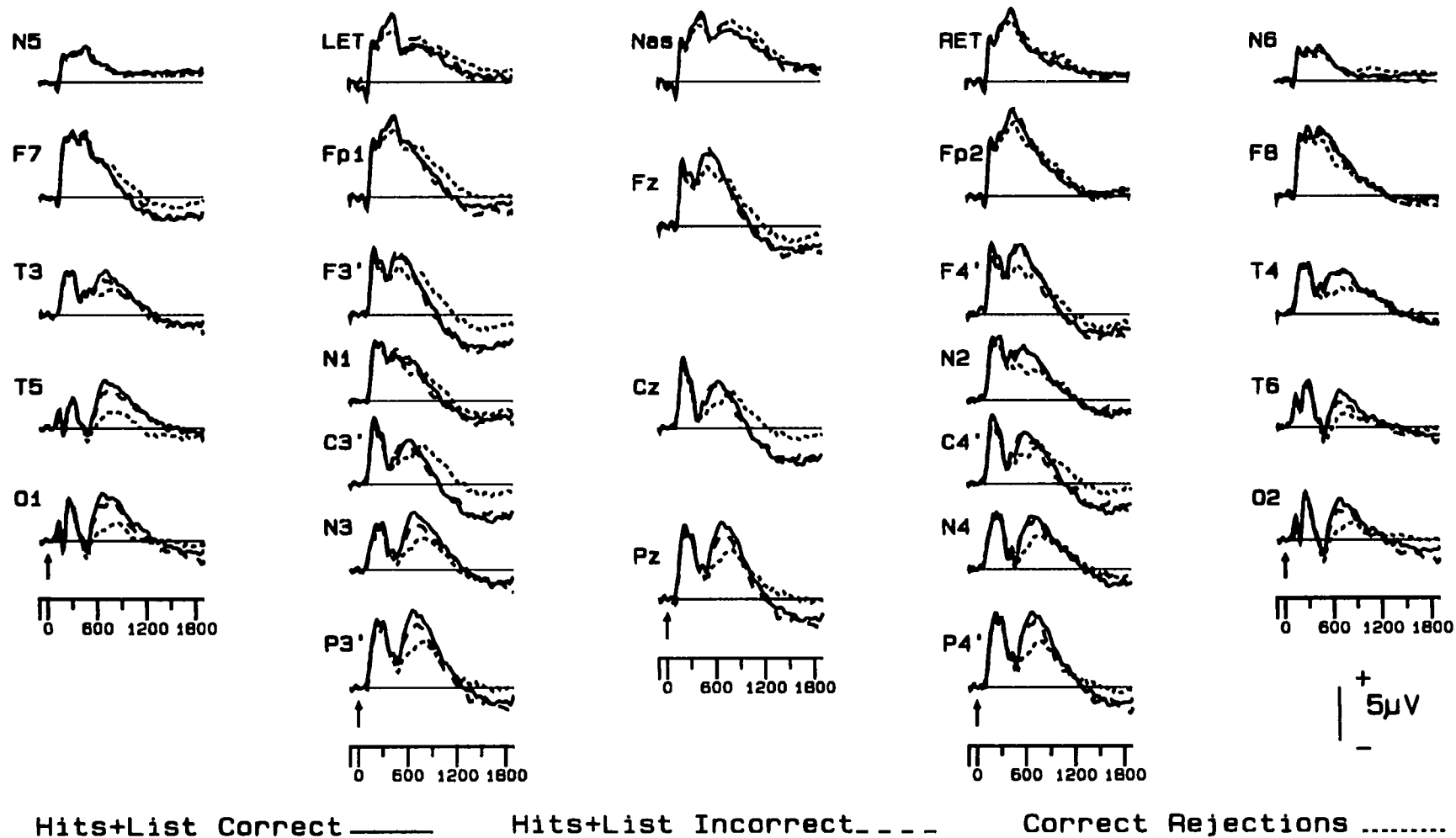


Figure 5. Grand mean ERPs averaged across subjects with the old age group according to whether the correctly recognized old item was associated with a correct or incorrect temporal source (list) judgment. Arrow marks stimulus onset.

Averaged Voltage Analyses:

To analyze the posterior and prefrontal effects described above, two sets of ANOVAs were performed, one on the remember/know and one on the source (list) data. These were performed separately in order to compare the results with previous studies using only remember/know (Smith, 1993) or source (Wilding & Rugg, 1996) judgments following the old/new discrimination. In these analyses, a subset of electrode sites in which the age and condition effects were the largest was used. Figures 6, 7, 9 and 10 show these sites for each age group and condition.

Remember/Know. (See Figures 6 & 7.) In these analyses, the data of two elderly subjects were removed due to insufficient N. The mean number of trials entering into the young subjects' averages were 93.4, 37.8 and 165.7 for the remember, know and correct rejections, respectively. For the elderly, these values were 69.2, 38.5 and 142.8. For each time window, the analysis included the factors of Age (young/old), Condition (remember/know/correct rejections), sagittal Chain (*Left*--LET, F3', C3', P3' /*Middle*--Nasion, Fz, Cz, Pz /*Right*--RET, F4', C4', P4') and Anterior/Posterior chain (*Prefrontal*--LET, Nasion, RET /*Frontal*--F3', Fz, F4' /*Central*--C3' Cz, C4' /*Posterior*--P3', Pz, P4'). Effects involving sagittal and anterior/posterior chains will not be

discussed unless they interact with Condition because they do not relate to the hypotheses of this study. (See Tables 5-7 in the appendix for complete results.)

Early Latency Window (young 260-480 ms.; old 280-490 ms.).

There was a main effect of Condition ($F(2,56) = 18.04, p < .00001, \epsilon = 0.97$) that was modified by the Condition by Anterior/Posterior by Group interaction ($F(6,168) = 4.02, p < .02, \hat{\eta}^2 = 0.39$). Tests for simple effects indicated that the main effect of Condition was significant for both the young ($F(2, 56) = 16.73, p < .00001, \epsilon = .097$) and the old ($F(2,56) = 4.53, p < .02, \epsilon = 0.97$). However, the Condition by Anterior/Posterior interaction was significant for the young ($F(2,56) = 16.73, p < .00001, \epsilon = .097$), but not for the old ($F = 1.04$). Post hoc testing revealed that the old subjects had an old/new effect associated with remember but not know judgments (waveforms of both were more positive than the waveform for correct rejections). ERPs associated with remember and know judgments did not differ. For young subjects, post hoc testing revealed an old/new effect for remember and for know judgments at the frontal, central and parietal sites, but not at prefrontal locations. In addition, waveforms for remember judgments were more positive than those for know judgments at frontal and central locations.

Middle Latency Window (young 490-800 ms.; old 500-860 ms.).

Again there was a main effect of Condition ($F(2,56) = 14.52, p < .00001, \epsilon = 0.84$). It was modified by the Condition by Anterior/Posterior ($F(6, 168) = 7.97, p < .0002, \epsilon = 0.46$) and the Condition by Anterior/Posterior by Group ($F(6,168) = 3.48, p < .02, \epsilon = 0.46$) interactions. Tests for simple effects indicated that the main effect of Condition was significant for the young ($F(2,56) = 14.37, p < .00001, \epsilon = 0.84$), but only marginally significant for the old ($F(2,56) = 2.90, p < .07, \epsilon = 0.84$). The Condition by Anterior/Posterior interaction was significant for the young ($F(6,168) = 10.14, p < .00001, \epsilon = 0.46$), but not the old ($F=1.87$). Post hoc testing of the Condition main effect for the old revealed a significant old/new effect for remember, but not know judgments, and a significant difference between remember and know judgments. Post hoc testing of the Condition by Anterior/Posterior interaction for the young revealed the same effects as for the old. These effects were reliable at frontal, central and posterior, but not at prefrontal locations.

Late Latency Window (young 830-1450 ms.; old 870-1490 ms.).

The main effect of Condition was again significant ($F(2,56) = 4.27, p < .02, \epsilon = 0.95$). It was modified by the Condition by Group ($F(2,56) = 6.27, p < .004, \epsilon = 0.95$), Condition by Chain ($F(4,112) = 3.68, p < .02, \epsilon$

= 0.62), Condition by Anterior/Posterior ($F(6,168) = 3.55, p < .02, \epsilon = 0.46$), and Condition by Chain X Anterior/Posterior ($F(12,336) = 2.58, p < .03, \epsilon = 0.38$) interactions. The important interaction of Condition by Anterior/Posterior by Group approached significance ($F(6,168) = 2.21, p < .09, \epsilon = 0.46$). Because of the age-related predictions made with respect to this region of the waveform, tests for simple effects were performed. These revealed a significant Condition by Anterior/Posterior interaction for the young ($F(6,168) = 4.48, p < .007, \epsilon = 0.46$), but not for the old ($F = 1.48$). Post hoc testing of this interaction for the young revealed a significant old/new effect for waveforms associated with remember judgments at all anterior/posterior locations. By contrast, waveforms associated with know judgments showed an old/new effect only at prefrontal sites. The waveforms associated with remember judgments were significantly more positive than those associated with know judgments at frontal, central and posterior, but not at prefrontal sites. Figure 8 presents the difference waveforms (remember minus correct rejections and know minus correct rejections) for young and old subjects for the above analyses.

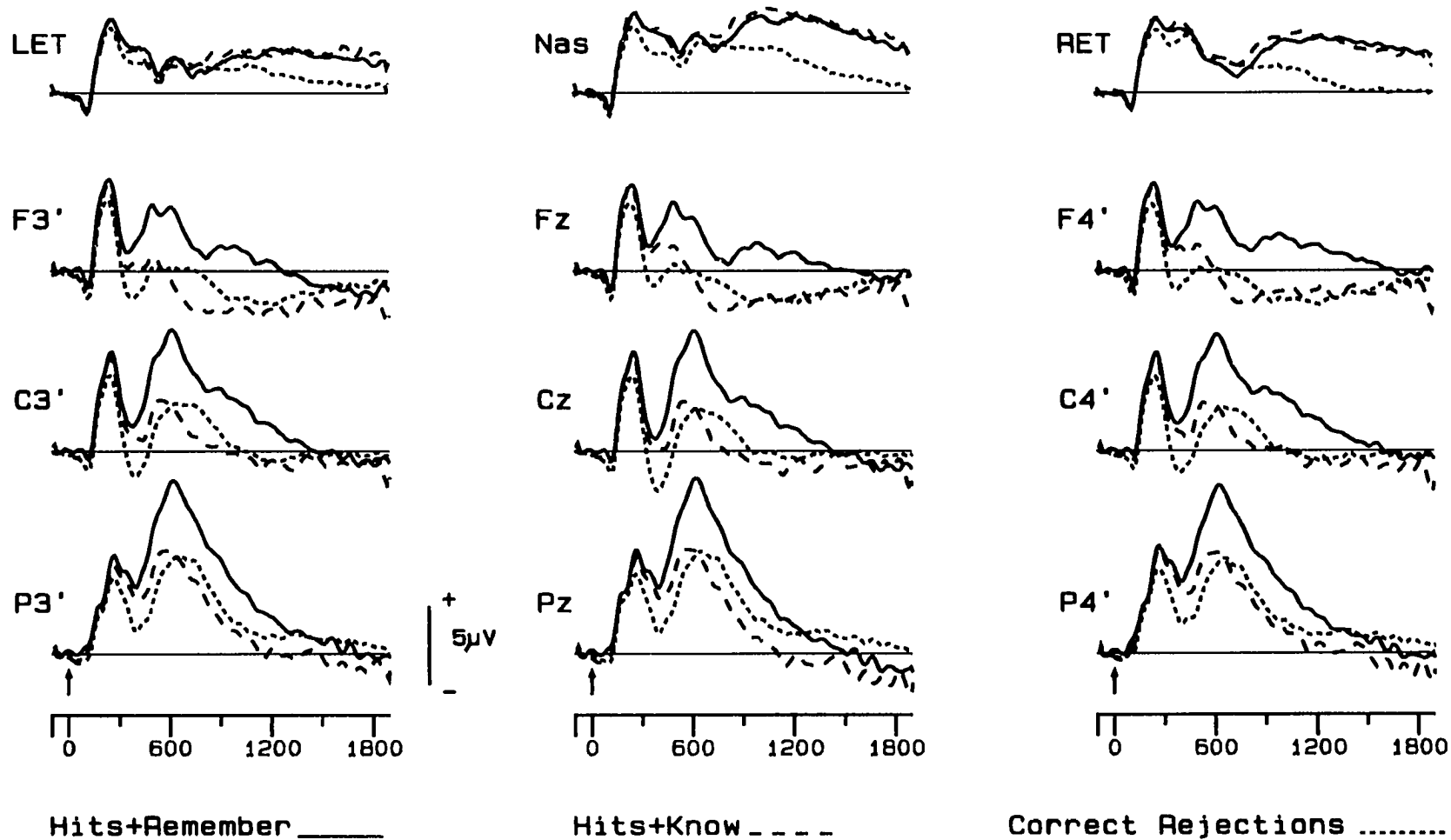


Figure 6. Grand mean ERPs averaged across subjects with the young age group according to whether the correctly recognized old item was associated with a remember or know judgment. Waveforms are depicted at the 12 scalp sites used in the analyses. Arrow marks stimulus onset.

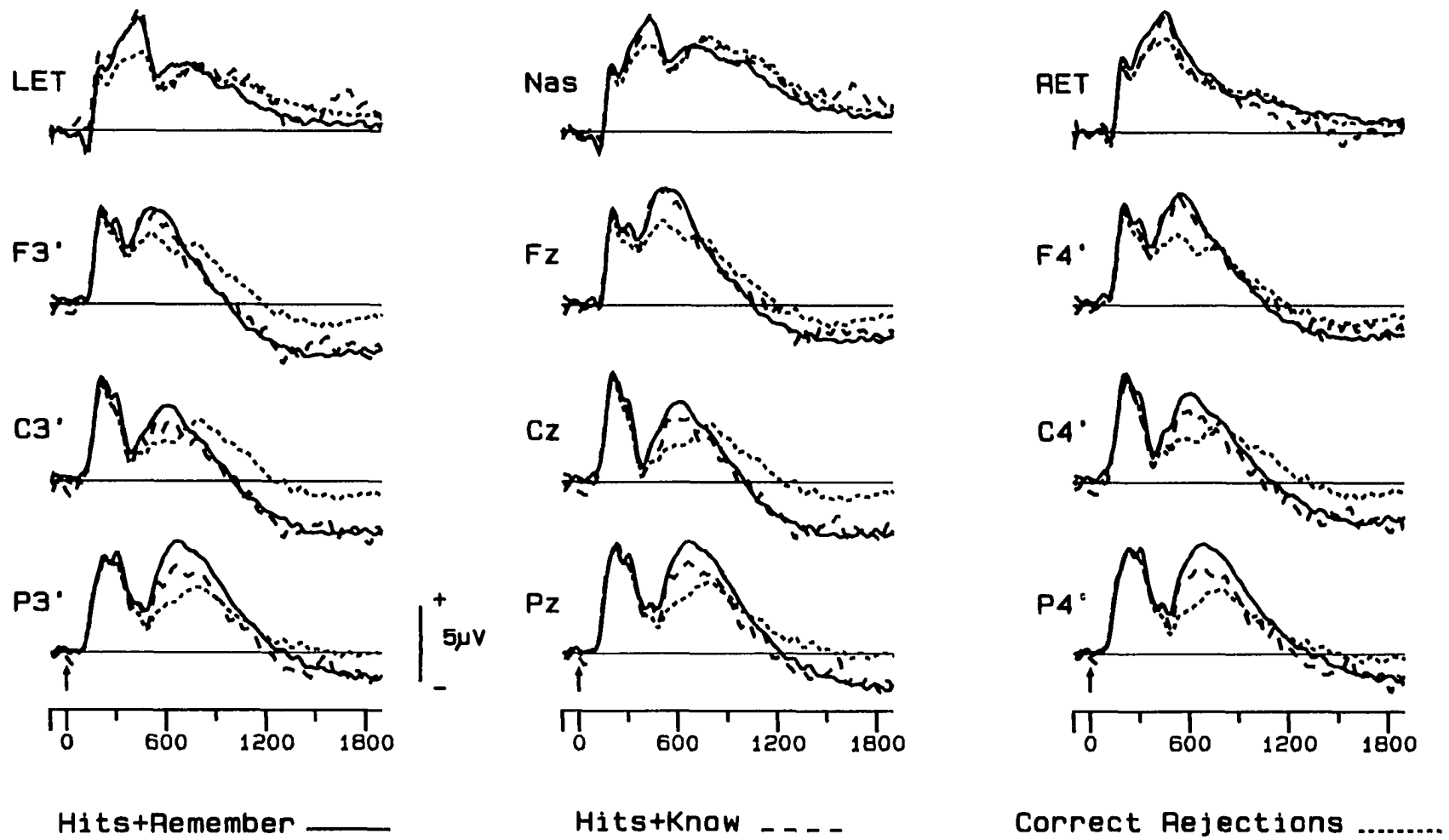


Figure 7. Grand mean ERPs averaged across subjects with the old age group according to whether the correctly recognized old item was associated with a remember or know judgment. Waveforms are depicted at the 12 scalp sites used in the analyses. Arrow marks stimulus onset.

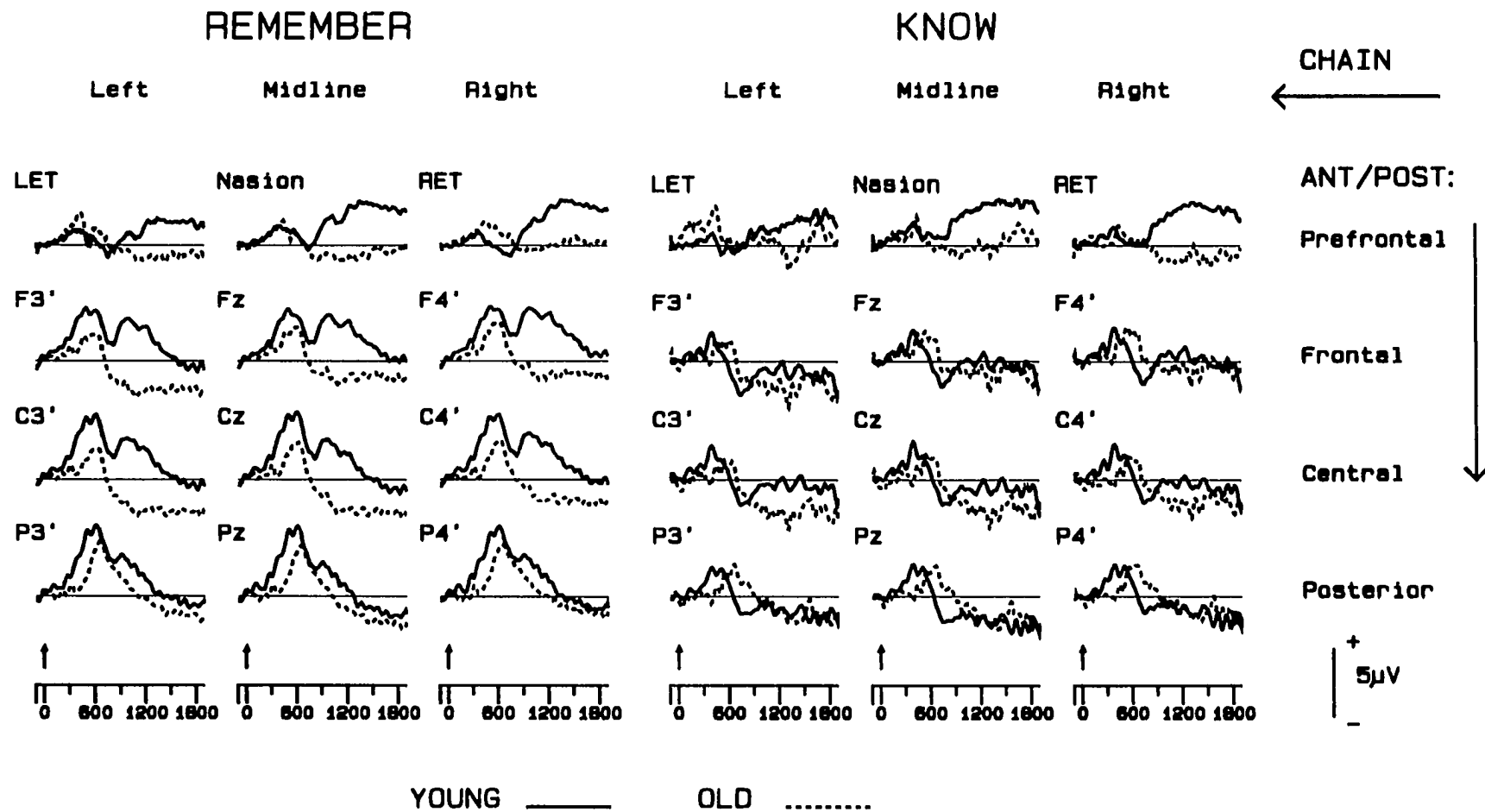


Figure 8. Grand mean difference waveforms derived by subtracting the ERPs to correctly rejected new items from those of correctly recognized old items with subsequent remember (left panel) or know (right panel) judgments. The ERPs of the young and old are superimposed. Waveforms are depicted at the 12 scalp sites used in the analyses. Arrow marks stimulus onset.

Temporal Source (Hits+List Correct/Incorrect). (See Figures 9 & 10.) The mean number of trials entering into the young subjects' averages were 88.9, 42.4 and 165.7 for the hits+list correct, hits+list incorrect and correct rejections, respectively. For the elderly, these values were 58.8, 47.1 and 139.7. For each time window, the analysis included the factors of Age (young/old), Condition (hits+list correct/list incorrect/correct rejections), sagittal Chain (*Left--LET, F3', C3', P3' /Middle--Nasion, Fz, Cz, Pz /Right--RET, F4', C4', P4'*) and Anterior/Posterior chain (*Prefrontal--LET, Nasion, RET /Frontal--F3', Fz, F4' /Central--C3' Cz, C4' /Posterior--P3', Pz, P4'*). Again, effects involving sagittal and anterior/posterior chains will not be discussed unless they interact with Condition because they do not relate to the hypotheses of this study. (See Tables 5-7 in the Appendix for complete results.)

Early Latency Window (young 260-480 ms.; old 280-490 ms.).

There was a main effect of Condition ($F(2,60) = 19.29, p < .00001, \epsilon = 0.96$) which was modified by the Condition by Group ($F(2,60) = 4.99, p < .01, \epsilon = 0.96$) and Condition by Anterior/Posterior by Group ($F(6,180) = 2.71, p < .05, \epsilon = 0.50$) interactions. Tests for simple effects revealed that the Condition main effect ($F(2,60) = 21.87, p < .05, \epsilon = 0.50$) and

the Condition by Anterior/Posterior interaction ($F(6,180) = 3.33, p < .02, \epsilon = 0.50$) were significant for the young, but not for the old ($F_s < 2.41, p_s > .10$). Post hoc testing of the interaction in the young revealed significant old/new effects for hits+list correct and hits+list incorrect. Waveforms for both were more positive than waveforms for correct rejections at frontal, central and posterior, but not at prefrontal locations. There were no significant differences between ERPs associated with hits+list correct and those associated with hits+list incorrect at any anterior/posterior location.

Middle Latency Window (young 490-800 ms.; old 500-860 ms.).

There was a main effect of Condition ($F(2,60) = 6.12, p < .006, \epsilon = 0.85$) which was modified by the Condition by Anterior/Posterior interaction ($F(6, 180) = 8.48, p < .0002, \epsilon = 0.39$). Tests for simple effects revealed that the greatest differentiation among the three conditions occurred at the posterior sites ($p < .00001$). Post hoc tests of the interaction indicated a significant old/new effect for waveforms associated with hits+list correct at frontal, central and posterior locations and for those associated with hits+list incorrect at central and posterior sites. The waveforms associated with hits+list correct were more positive than those associated with hits+list incorrect only at posterior locations.

Late Latency Window (young 830-1450 ms.; old 870-1490 ms.).

Significant interactions included Condition by Group ($F(2,60) = 7.64$, $p < .002$, $\epsilon = 0.81$), Condition by Chain ($F(4,120) = 4.52$, $p < .01$, $\epsilon = 0.55$), Condition by Anterior/Posterior ($F(6,180) = 3.19$, $p < .04$, $\epsilon = 0.40$) and Condition by Chain by Anterior/Posterior ($F(12,360) = 2.86$, $p < .02$, $\epsilon = 0.37$). The Condition by Anterior/Posterior by Group interaction approached significance ($F(6,180) = 2.37$, $P < .09$, $\epsilon = 0.40$). Because of the *a priori* age-related predictions made with respect to this region of the waveform, it was assessed further by performing tests for simple effects. These tests indicated that the Condition by Anterior/Posterior interaction was significant only for the young ($p < .01$) and only at prefrontal and frontal sites ($ps < .007$). Post hoc testing at these sites revealed an old/new effect for waveforms associated with hits+list correct and those associated with hits+list incorrect at both prefrontal and frontal locations. In addition, waveforms associated with hits+list incorrect were significantly more positive than those associated with hits+list correct at prefrontal locations. Figure 11 presents the difference waveforms (hits+list correct minus correct rejections and hits+list incorrect minus correct rejections) for young and old subjects.

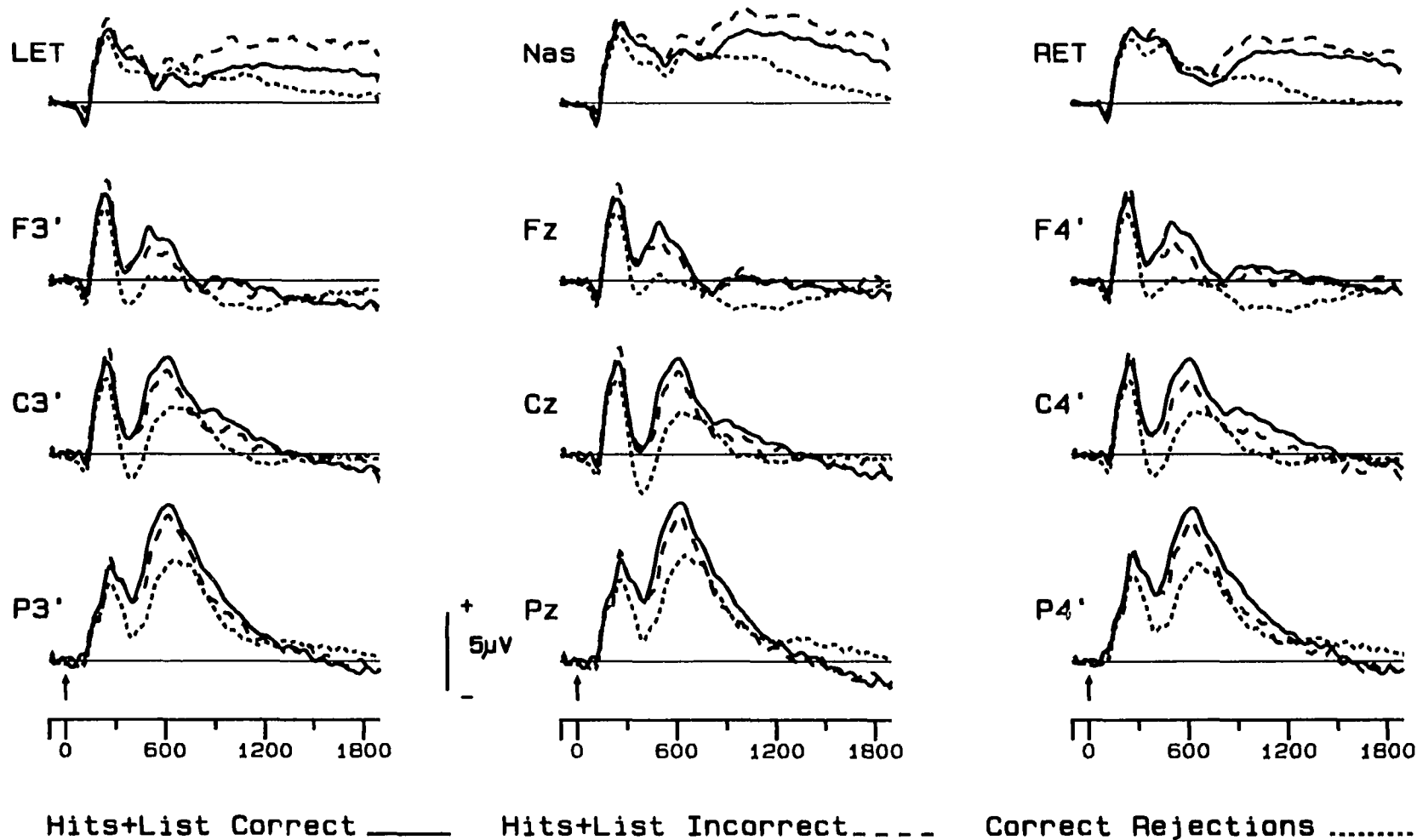


Figure 9. Grand mean ERPs averaged across subjects with the young age group according to whether the correctly recognized old item was associated with a correct or incorrect temporal source (list) judgment. Waveforms are depicted at the 12 scalp sites used in the analyses. Arrow marks stimulus onset.

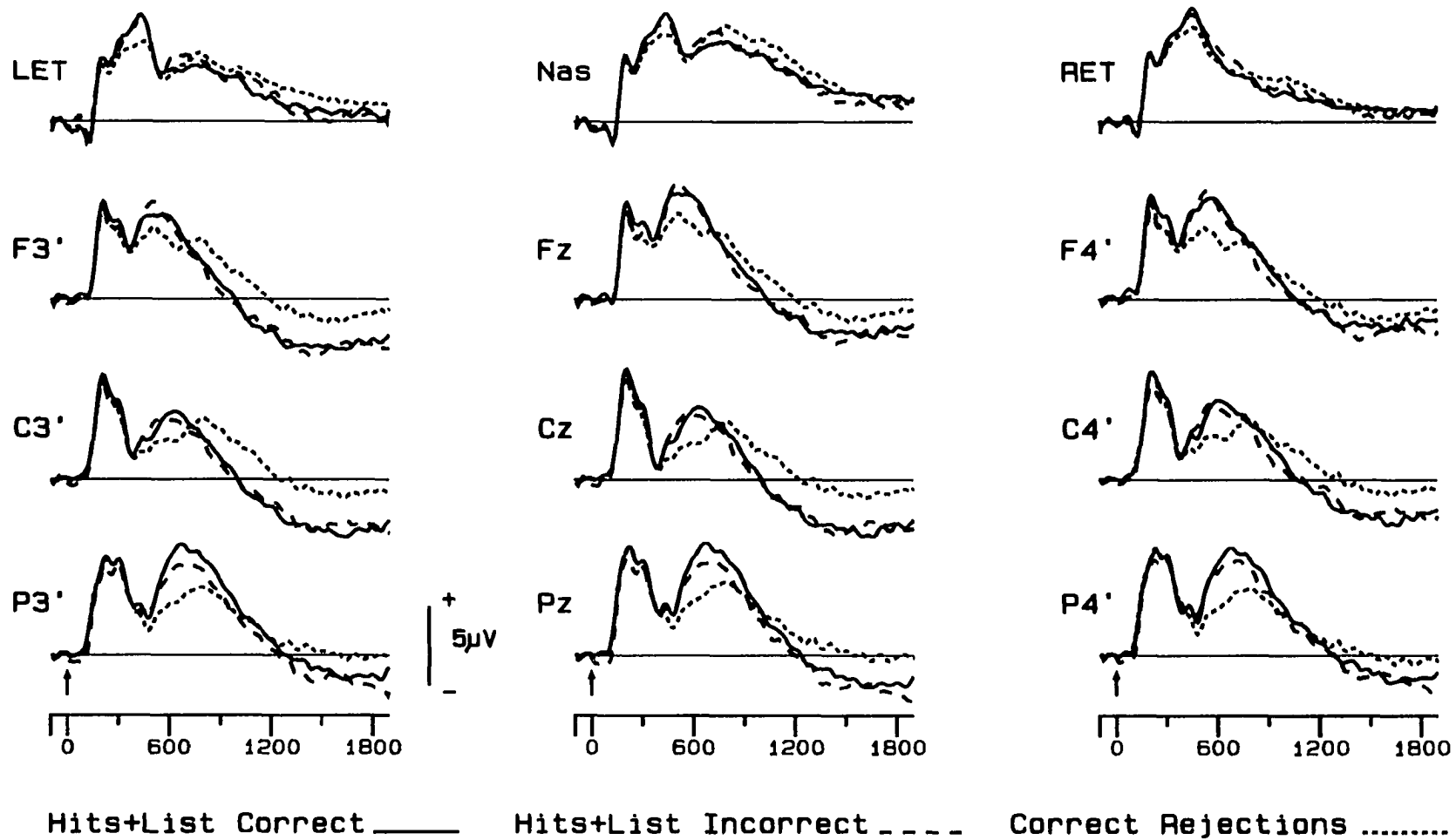


Figure 10. Grand mean ERPs averaged across subjects with the old age group according to whether the correctly recognized old item was associated with a correct or incorrect temporal source (list) judgment. Waveforms are depicted at the 12 scalp sites used in the analyses. Arrow marks stimulus onset.

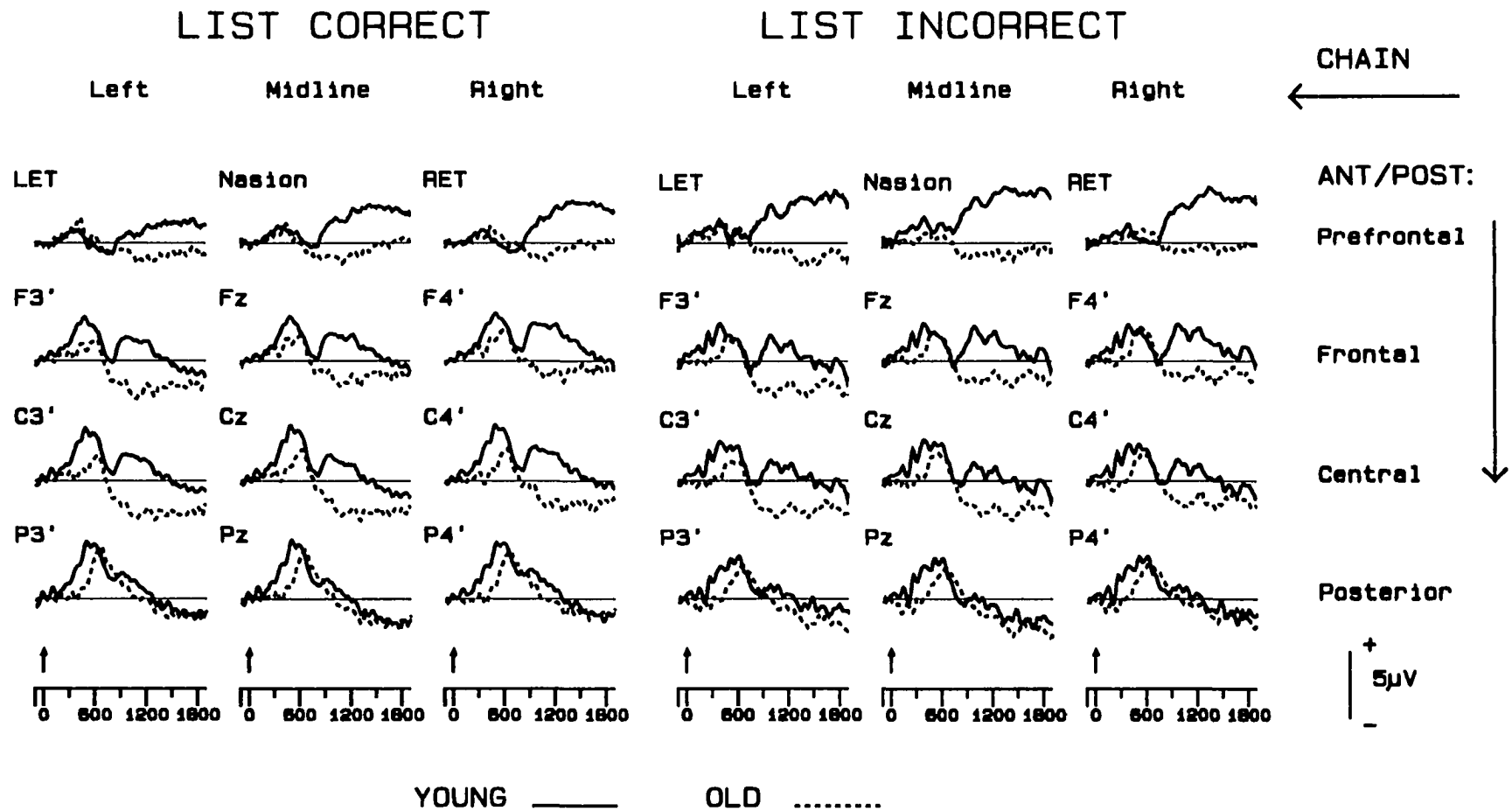


Figure 11. Grand mean difference waveforms derived by subtracting the ERPs to correct rejection new items from those of correctly recognized old items with subsequent correct (left panel) or incorrect (right panel) list judgments. The ERPs of the young and old are superimposed. Waveforms are depicted at the 12 scalp sites used in the analyses. Arrow marks stimulus onset.

Post hoc testing of the Condition by Chain by Anterior/Posterior interaction indicated that it occurred because at prefrontal sites waveforms associated with hits+list incorrect were more positive than those associated with hits+list correct while the opposite was true at posterior sites. However, the old subjects did not show the prefrontal effect. Therefore, because this interaction is the result of differences only in the young group, it will not be interpreted further.

Figure 12 is a summary of the major effects revealed by the above analyses. Two electrode sites where the posterior and prefrontal effects are largest are shown for each condition and age group. These sites are P3' (left posterior) and RET (right prefrontal). As can be seen, the posterior old/new effects are very similar in the two age groups for both remember/know and hits+list correct/incorrect judgments. The only difference between groups in this posterior effect is in the early latency window where only the young show old/new effects for remember, know, hits+list correct and hits+list incorrect judgments. With the exception of remember judgments, these posterior old/new effects do not occur in the older group until the middle latency window, perhaps reflecting an age-related latency difference in the timing of the old/new effect. A major age-related difference occurs during the late latency region at prefrontal

locations where only the young show old/new effects for remember,
know, hits+list correct and hits+list incorrect judgments.

Scalp Topography:

Figure 13 (top 2 rows) shows the surface potential topography for the remember/know difference waveforms (remember minus correct rejections; know minus correct rejections). The maps were computed using the middle and late latency windows. The similarity between age groups can be seen for the posterior old/new effect in the middle latency window, whereas the difference between age groups can be seen clearly for the anterior old/new effect in the late latency window.

Figure 13 (bottom 2 rows) shows the surface potential topography for the temporal source difference waveforms (hits+list correct minus correct rejections; hits+list incorrect minus correct rejections). The same posterior and anterior age-related differences seen in the remember/know maps can be seen in these.

To analyze the effects described above, three sets of analyses were performed on the normalized difference waveforms (McCarthy & Wood, 1985) using averaged voltages corresponding to the early, middle and late latency windows. The scalp locations utilized in the analyses were those at which both age-related differences and the anterior/posterior old/new effects were best differentiated. These were the three prefrontal (LET, Nasion, RET) and three posterior (P3', Pz, P4') scalp locations.

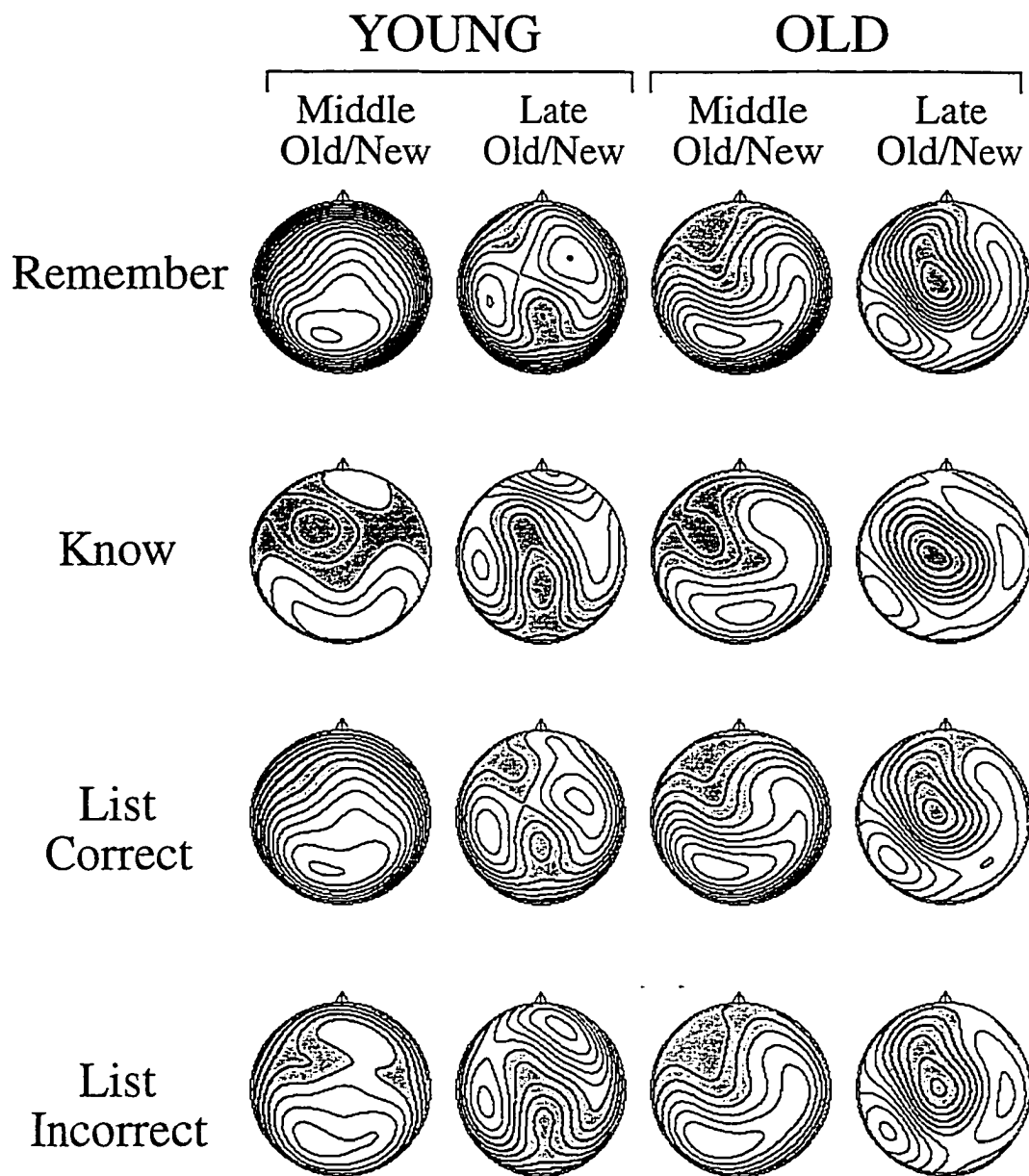


Figure 13. Surface potential scalp maps of the posterior and anterior old/new effects associated with remember and know (top) and correct and incorrect temporal source judgments (bottom) in young and old subjects. For both top and bottom portions, isopotential lines are separated by $0.35 \mu\text{V}$. Shaded areas represent negativity; unshaded areas reflect positivity.

Within-Age Group Analyses: There were no significant Condition (remember/know or hits+list correct/incorrect) by Electrode Site interactions for either the young or old age groups ($F_s < 3.50$, $p_s > .05$). This suggests that, for each age group, the topography of the old/new effect was similar for remember compared with know judgments and for hits+list correct compared with hits+list incorrect judgments.

Between-Group Analyses: Age-related differences in the posterior old/new effect were assessed at the middle latency windows where it was present in both age groups. None of the Age Group by Electrode Site interactions was significant ($F_s < 3.50$, $p_s > .05$), indicating that the topography of the posterior old/new effect was similar across age groups.

Young Only - Early vs Middle Time Periods: Since old subjects did not show a robust old/new effect in the early time window, these analyses were performed only on the data for the young. The topography of the old/new effect was similar in both time periods for hits+list correct ($F(5, 75) = 2.00$, $p > .10$, $\epsilon = 0.23$), and hits+list incorrect ($F < 1$). It was also similar for remember ($F(5,75) = 2.07$, $p > .1$, $\epsilon = 0.22$) and know ($F < 1$) judgments.

Young Only - Middle vs Late Time Periods: These analyses were performed only on the young since old subjects did not show a late

old/new effect. There were significant Time Period by Electrode Site interactions for hits+list correct ($F(5,75) = 14.51, p < .0004, \epsilon = 0.27$), hits+list incorrect ($F(5,75) = 30.00, p < .00001, \epsilon = 0.28$) and remember judgments ($F(5,75) = 14.50, p < .0004, \epsilon = 0.27$) indicating differences in scalp topography for the old/new effect between the middle and late time periods. The Time Period by Electrode Site interaction was not significant for the old/new effect associated with know judgments ($F < 1$), although the old/new differences between the two time periods were similar to those in the other three conditions.

Correlations:

To assess the relationship of ERP activity to frontal lobe measures, correlations were computed for young and old age groups separately (Tables 12 & 13). Averaged voltages from the early, middle and late time windows at two electrode sites (P3' and RET) in the hits+list correct condition were correlated with four putative measures of frontal lobe functioning and one measure not specifically related to frontal lobe functioning. The four putative measures of frontal lobe functioning were the score on the verbal fluency test and three scores from the Wisconsin Card Sorting Test (WCST): number of perseverative errors, number of

trials to criterion and percent of conceptual level responses. The non-frontal measure was the score on the modified Mini-Mental Status (mMMS). Only correlations reaching the .001 level of significance were considered reliable (.05 level of significance with Bonferonni correction for 30 correlations). None of the correlations in the old age group were significant. For the young, averaged voltages at the RET were significantly negatively correlated with number of perseverative errors in the middle time window and positively correlated with percent of conceptual level responses in the late time window. No correlations with Modified Mini-Mental Status scores were significant.

Table 12. Correlation of ERP data for young subjects with the modified Mini Mental Status and measures of frontal lobe functioning.

	PEARSON'S R CORRELATIONS					
	Early		Middle		Late	
	P3'	RET	P3'	RET	P3'	RET
Verbal Fluency (CFL)	0.45	0.06	0.35	-0.02	0.30	-0.05
WCST Number of Perseverative Errors	0.38	-0.38	0.57	-0.71(**)	0.19	-0.64
WCST Number of Trials	0.23	0.14	0.32	0.51	-0.04	0.52
WCST %Conceptual Level Responses	-0.27	-0.12	-0.42	0.65	-0.08	0.71(**)
mMMS Score	-0.28	0.43	-0.24	0.00	-0.26	-0.22

Note: One-tailed significance ** $p < .001$. Verbal Fluency Test = the Controlled Oral Word Association Test (Benton & Hamsher, 1976); WCST = Wisconsin Card Sorting Test (Heaton, 1981); mMMS Score = Modified Mini-Mental Status Exam (Mayeux, Stern, Rosen & Leventhal, 1981).

Table 13. Correlation of ERP data for old subjects with the modified Mini Mental Status and measures of frontal lobe functioning.

	PEARSON'S R CORRELATIONS					
	Early		Middle		Late	
	P3'	RET	P3'	RET	P3'	RET
Verbal Fluency (CFL)	-0.23	-0.35	-0.31	0.09	-0.08	0.09
WCST Number of Perseverative Errors	0.06	-0.11	0.17	-0.01	0.27	0.05
WCST Number of Trials	-0.37	-0.08	-0.32	-0.00	-0.11	-0.16
WCST %Conceptual Level Responses	0.09	0.17	0.02	-0.15	-0.16	0.01
mMMS Score	0.27	0.25	0.36	0.32	0.36	0.08

Note: Verbal Fluency Test = the Controlled Oral Word Association Test (Benton & Hamsher, 1976); WCST = Wisconsin Card Sorting Test (Heaton, 1981); mMMS Score = Modified Mini-Mental Status Exam (Mayeux, Stern, Rosen & Leventhal, 1981).

Summary of ERP Results:

The ERP data reveal two old/new effects that can be dissociated on the basis of latency scalp distribution, and age. The early, posterior old/new effect extended from ~250 to 800 ms in the waveforms of the young with a peak at ~600 ms and a parietal maximum. It encompassed the early and middle time windows which were topographically indistinguishable. This suggests a unitary old/new effect across this time period. It was present in the waveforms associated with remember, list correct and list incorrect judgments in both time windows. In the waveforms of the young the posterior old/new effect also was significant for waveforms associated with know judgments in the early time window. In the waveforms of the old, the effect was present in the in the early time window only for remember judgments. It did not reach significance for the waveforms associated with list correct or list incorrect judgments until the middle time window where it peaked at ~ 750 ms. There was no difference between age groups in the scalp distribution of this effect in the middle time window where it was robust for both young and old. This suggests that it reflects similar memory processes in the two age groups.

The later, anterior effect began at ~ 800 ms and extended until the end of the recording epoch (1900 ms). It took the form of a positive slow

wave present at prefrontal sites in the waveforms of the young. It was present for waveforms associated with remember, know, list correct and list incorrect judgments, and was larger on the right than on the left. The waveforms associated with incorrect list judgments were more positive than those associated with correct list judgments. The topography of the old/new effect in this late time window differed from that of the old/new effect in the middle time window suggesting that the two effects reflect different mnemonic processes. This late old/new effect was not present in the waveforms of the old subjects.

Within age groups, scalp topographies of the old/new effects did not differ for waveforms associated with remember vs. know, or for list correct vs. list incorrect judgments. This suggests that remember and know judgments indexed similar memory processes as did correct and incorrect list judgments.

For young subjects, positive voltage at the RET in the middle latency window was correlated with fewer perseverative errors on the WCST. In the late time window, averaged voltage at the RET was positively correlated with the percent of conceptual level responses on the WCST. There were no significant correlations for old subjects.

DISCUSSION

The main findings of this study are: 1) the presence of two old/new effects that are dissociable on the basis of latency, scalp distribution and age; and 2) the similarity, within each age group, of the scalp distribution of these effects associated with subsequent remember vs. know, and list correct vs. list incorrect judgments. The early, posterior old/new effect was present in the waveforms of both young and old. The scalp distribution of this effect was similar in both age groups. The later, prefrontal old/new effect was present only in the waveforms of the young. It differed topographically from the early old/new effect. These two effects were associated behaviorally with a small age-related difference in item memory, and a relatively larger difference in temporal source memory. There was no age difference in the proportion of correctly recognized items that received a remember judgment.

The finding of these two dissociable old/new effects in the waveforms of the young is similar to what was found by Wilding & Rugg (1996) in a recognition test with subsequent memory for gender of voice (i.e., source) at study. They interpreted the early effect as a reflection of item retrieval. It is likely that the early, posterior effect found here also reflects item retrieval in both the young and old subjects. It occurred

early enough in each age group to have affected the old/new decision. For example, in young subjects, the reaction times to correctly recognized old (907 ms) and new (897 ms) items followed the peak amplitude (600 ms) of the old/new effect. This was true also of old subjects where the reaction times were 1066 and 1063 ms for old and new items and the peak of the old/new effect was 750 ms.

According to dual process theories of recognition memory, it is possible for an item to be judged old on the basis of familiarity- or episodic-based memory processes. If a subject correctly identifies an item as old and also identifies the correct source (here, correct list), it is likely that the item was retrieved on the basis of an episodically-based memory process. The lack of a scalp distribution difference in the old/new effect associated with subsequent correct and incorrect list judgments suggests that, in both instances, this early effect reflects an episodically-based retrieval process. This was true for both young and old subjects. Wilding & Rugg (1996) reported similar results. They found similar topography for waveforms associated with correct and incorrect source judgments. The old/new effect associated with remember and know judgments is similar to that for list judgments. There is no evidence in the present study that the early old/new effect reflects a

familiarity-based memory process. The smaller amplitude of waveforms associated with know vs remember and list incorrect vs list correct judgments argues for the presence of a graded episodic memory process (Moscovitch, 1992). The amplitude of the old/new effect may reflect the quality or amount of information retrieved and used in making an old/new decision (Rugg, Cox, Doyle & Wells, 1995).

Item memory is thought to depend on medial/temporal and/or diencephalic structures (Janowsky, Shimamura & Squire, 1989; Milner, Corsi & Leonard, 1991). Evidence for this comes from amnesic patients who have damage in these areas (Smith & Halgren, 1989; Rugg, et al., 1991; Johnson, 1995) and from a recent PET study (Schacter et al., 1996). Schacter et al. (1996) observed equal hippocampal activation in both young and old subjects and interpreted it as reflective of item retrieval. The lack of age-related amplitude and scalp distribution differences in the posterior old/new effect is consistent with this finding. It suggests that item retrieval is subserved by the same episodic-based memory process in the young and the old. This process is likely dependent on the medial/temporal and diencephalic structures and may reflect an awareness of prior occurrence (Moscovitch, 1994; Wilding & Rugg, 1996).

The late, anterior old/new effect was somewhat asymmetric, being larger on the right than the left. Waveforms associated with incorrect list judgments were more positive than those associated with correct list judgments. Scalp distributions of the old/new effect associated with these two judgments did not differ. These findings are similar to those reported by Wilding & Rugg (1996) with one exception. They found that waveforms associated with correct source judgment (gender of voice at study) were more positive than those associated with incorrect source judgment. Accordingly, they interpreted this anterior effect as reflecting the success of source retrieval. The finding in the present study of more positive waveforms associated with incorrect compared with correct source, and the lack of scalp distribution difference between these waveforms argues against such an interpretation. The data in the present study are more consistent with the suggestion that this old/new effect is related to the search for contextual information. Related studies provide additional support for this view. In a PET study, Schacter et al. (1996) found right frontal activation that was associated with efforts to retrieve studied words. Johnson et al. (1997), in an ERP study, found that items associated with an old judgment elicited a right frontal old/new effect whether they were truly old items or semantically associated lures, i.e.,

false alarms to newly presented items. In an event-related fMRI study, Schacter et al. (1997) obtained similar results. They observed late onset prefrontal activity associated with old judgments for both true old items and lures. Activity associated with false recognition (lures) tended to be larger over the right anterior scalp than that associated with true recognition (old items). Since new items (lures) cannot be successfully retrieved because they have no prior representation as studied items, these findings suggest that the right anterior activation is more likely to reflect something other than successful retrieval. This late anterior old/new effect has been interpreted as reflecting retrieval mode, i.e. thinking back in subjective time (Nyberg et al., 1995), retrieval effort (Buckner & Tulving, 1995), and source search (Senkfor & Van Petten, 1996). While each of these terms emphasizes a slightly different aspect of the retrieval search process, they can all be contrasted with the actual successful retrieval of stored information. The findings of the current study are most consistent with the interpretation of this late anterior old/new effect as reflecting some aspect of the search for, rather than only the successful retrieval of stored information.

The absence of the late, anterior old/new effect in the waveforms of old subjects is consistent with the decrease in amplitude observed by

Senkfor & Van Petten (1996) and Swick & Knight (1997). However, Mark & Rugg (in press) found no difference in the amplitude or scalp distribution of this effect between their young and old subjects. One possible explanation for the discrepancy might be that the waveforms of old subjects in the present study included relatively more items called old on the basis of guessing than did the waveforms of Mark & Rugg (in press). (This is the explanation they gave for the discrepancy between their data and that of Senkfor & Van Petten, 1996.) However, that does not seem likely. When corrected for guessing, the proportion of hits with correct source judgments in the Mark & Rugg (in press) study was .43. In the present study, that proportion was .34 for young subjects and .10 for old. Both of those proportions are lower than that seen by Mark & Rugg (in press), and yet the young in the present study showed a robust old/new effect which was larger when they were incorrect with regard to source. A related possibility might be the difference within the present study between the proportions for young and old. However, the top four performing old subjects obtained a corrected source detection rate of .30 which is similar to that of the young (.34), and yet their waveforms showed no evidence of the late, anterior old/new effect.

Another possible explanation is that temporal source is not as

contextually rich or salient as is the gender of voice, making it relatively more difficult for older subjects to remember. Support for this idea comes from recent behavioral studies (Daum et al., 1996; Fabiani & Friedman, 1997) which have shown that, relative to young adults, older subjects are more deficient in temporal order (recency) than in recognition memory judgments. However, the absence in the old age group of the late, anterior old/new effect for waveforms associated with remember responses argues against this explanation. If items were recollected as old on the basis of some other, more easily remembered aspect of context, one would expect an anterior old/new effect for the waveforms associated with remember judgments. In addition, in the Senkfor & Van Petten (1996) study, source judgments were made about gender of voice just as they were in the Mark & Rugg (in press) study. Even so, Senkfor & Van Petten (1996) found a decrease in the amplitude of this late, anterior old new effect in their old compared with their young subjects.

Both of the above explanations are based on the hypothesis that the anterior old/new effect reflects retrieval success. Differences between studies in the rate of guessing would be more likely to affect retrieval success than retrieval search. Likewise, the difficulty of remembering temporal source compared to gender of voice would affect retrieval

success more than the retrieval effort or search. A more likely explanation for the different results in the three studies is that this old/new effect reflects the search for stored information rather than the success of that search. There were numerous differences among the studies discussed here including encoding and retrieval tasks. Encoding tasks ranged from the most constrained in the Mark & Rugg (in press) study to the least constrained in the present study. In the Mark & Rugg (in press) study, encoding was structured and encouraged deep, as opposed to shallow, processing. Subjects were instructed to listen to each word, repeat it aloud, state the gender of the voice speaking the word and either rate the word as pleasant/unpleasant or as active/passive. The rating task was mapped onto gender of voice so that the same task was associated with the same voice for any particular subject. This mapping was counterbalanced across subjects. Thus, subjects were given the encoding strategy and helped to remember the source by performing a particular task associated with each voice. In the Senkfor & Van Petten (1996) study, subjects were given an encoding strategy that was designed to promote deep encoding. They were to visualize each concrete noun and push one button if it was larger than a 10 inch by 10 inch square and another button if it was smaller. In the current study, subjects were

simply told to read the sentences and memorize the nouns and the lists they were in. They performed no behavioral task during the encoding. This left the choice of strategy up to the subject. Craik & Jennings (1992) suggested that older subjects are less likely than young subjects to use optimal encoding strategies spontaneously. Stuss et al. (1996) found that older subjects were most impaired in list learning when the lists were unstructured. It is possible that the combination of the difficulty of the task and the unconstrained encoding task resulted in older subjects adopting less efficient encoding and/or retrieval strategies, and that these retrieval strategies were not indexed by the anterior old/new effect. In the present study, the significantly lower level of accuracy in the old group for correct temporal source retrieval is consistent with the use of less efficient processes.

There is considerable evidence that memory for context involves activity of the frontal lobes, both at encoding and retrieval. Evidence for this comes from patients with frontal lobe damage (Schacter, 1987; Shimamura, 1995; Squire, 1994), non-human primates (Fuster, 1985; Schacter, 1987), and neuroimaging studies (Buckner & Tulving, 1995; Cabeza et al., 1997; Nyberg et al., 1996; Schacter, et al., 1996; 1997; Tulving et al., 1994). The neuroimaging studies have generally found

increased activity in the right compared with the left prefrontal/frontal areas during retrieval. Although one must be cautious in making assumptions about the location of generators of ERP activity recorded from the scalp, the late, right, prefrontal maximum old/new effect found in the present study is consistent with a prefrontal locus of activity in the search for contextual information. The absence of this effect in the waveforms of old subjects is consistent with a decrease in frontal lobe functioning in the elderly. Supporting this idea is the study of Schacter et al., (1996) in which efforts to retrieve studied words were associated with activation of more posterior frontal areas in old compared with young subjects. Cabeza et al. (1997) also found differences between young and old subjects in prefrontal activation during both encoding and retrieval tasks. During recognition, old subjects had reduced activation in the prefrontal cortex and increased activation in the cuneus/precuneus region. The increased activation could reflect either beneficial compensatory activity or result from the adoption of less efficient memory strategies (Cabeza et al., 1997). Similarly, in the present study, the absence of the late, anterior old/new effect in the waveforms of old subjects could reflect a decrease in frontal lobe functioning or the adoption of less efficient retrieval strategies. These two possibilities are not mutually exclusive.

The question is, rather, which is causal. The present study is consistent with either interpretation. A decrease or alteration in the functioning of the frontal lobes during aging could lead to the adoption of compensatory memory strategies that are less efficient. This may be particularly evident in difficult tasks that require more from the frontal lobe system than it is able to deliver.

Contrary to expectations, neither the proportion of old subjects' remember/know nor the accuracy of their list judgments correlated significantly with any of the neuropsychological measures thought to be sensitive to frontal lobe functioning. As mentioned in the introduction, frontal pathology is not always associated with impaired performance on the WCST (Heck & Bryer, 1986; Anderson et al., 1991). The correlations found by Parkin & Walter (1992) between proportion of remember judgments and performance on a modified WCST were only for their oldest subjects (mean age 81.6 yrs.). They found no correlations between remember judgments and the CFL. Only two subjects in the current study were over 80 years old. Additionally, there was no difference between young and old subjects in the proportion of remember or know judgments as there was in the Parkin & Walter (1992) study. Parkin, Walter & Hunkin (1995) found that memory for temporal order

(i.e., list) was not correlated with deficits on the WCST or the FAS, but was correlated with more difficult tests of spontaneous flexibility (food, animal and country alternation, & design fluency). Because there were only 16 subjects entering into the correlations in the current study, the relationship between test performance and accuracy measures would need to be very robust to be significant. Although there were trends in the expected directions, there usually was not enough variability among subjects on one or both of the variables for the correlation to be significant or predictive.

One goal of this study was to investigate the validity of remember/know judgments for dissociating the hypothesized episodic- and familiarity-based processes of recognition memory. Contrary to expectations, there was no age related difference in the proportion of remember responses associated with correctly identified old items. However, there was a clear age-related decline in the proportion of correctly identified old items associated with correct list judgments. Mark & Rugg (in press) reported the same pattern of results. Since both remember and correct list judgments are thought to be measures of episodic-based processing, this discrepancy must be explained. Mark & Rugg (in press) suggested two possible explanations: 1) older subjects

adopted a more liberal criterion for making a remember judgment, i.e. the judgment was based on a weaker episodic representation; 2) both groups experienced equally strong "recollective experiences," but in old subjects, retrieval was based on less differentiated information, i.e. enough to identify an item as old, but not enough to identify the source. A third explanation is possible, namely, that remember judgments by old subjects were based more often on contextual information other than study list. This interpretation is supported by the finding that old subjects had a smaller proportion of correctly identified old items associated with the conjunction of remember and correct list judgments (.23) than did young subjects (.37). However, since remember judgments can, by definition, be based on memory for any aspect of context, it is clear, as Mark & Rugg (in press) point out, that equal proportions of remember judgments cannot predict equal proportions of correct source retrieval for any one objective aspect of context.

Although the evidence suggests that remember judgments reflect episodic-based processes, there is no evidence in this study that know judgments reflect familiarity-based processing. In fact, as discussed above, the lack of scalp distribution differences between waveforms associated with remember and know judgments suggest that both reflect

similar memory processes. This study, therefore, provides no support for the dual-process theory of recognition memory (Jacoby & Dallas, 1981). The data are more consistent with the proposal that episodic retrieval is a graded process (Moscovitch, 1992).

In summary, the data from this study provide evidence of two old/new effects that are dissociable on the basis of latency, scalp distribution and age. They suggest that the early, posterior old/new effect reflects similar episodic-based processes in both age groups and indexes item retrieval. The later, anterior old/new effect, present only in the young, most likely reflects the search for contextual information. The absence of this effect in the waveforms of old subjects is consistent with the hypothesis of an age-related decrease in frontal lobe functioning, and/or the adoption of less efficient retrieval strategies. The lack of scalp distribution differences in the waveforms associated with remember vs. know, and correct vs. incorrect list judgments provides no evidence for dual process theories of recognition memory. Instead, the data are consistent with the theory of graded episodic memory processing.

APPENDIX

INSTRUCTIONS

In this experiment we are interested in understanding two types of memory. Often when remembering a previous event, we consciously remember and become aware of other aspects of that experience. For example, if I were to ask you the name of the movie you last saw, you probably could tell me. In remembering that information, you might also remember who was in it, where you saw it, who you were with, whether you liked it or not, and so on. We call this type of memory Remembering. On the other hand, sometimes we simply know something without consciously recalling any events, thoughts or feelings connected with it. For example, you might hear a piece of music and say, "I know that music; I've heard that before," but not remember the name of it, where you heard it, or anything else connected to that memory. You simply know that you have heard that music before. We call this type of memory Knowing.

In the experiment to follow you will see two lists of sentences presented during a study phase. Then, in the memory test phase, you

will see the nouns from those sentences along with an equal number of new nouns. For each noun you will be asked, "Is the noun Old or New, i.e. was it in a sentence from one of the previous 2 study lists or not?" For those nouns you think are Old, you will be asked three more questions: 1. "Do you Remember the noun,(that is, do you have an association to the noun from the study phase), or do you Know it, (that is, you know it was on one of the previous two lists, but have no association to it from the study phase)?" 2. The second question is: "Was the noun in List 1 or List 2?"; 3. and the third question is: "What was the other noun in the same sentence with that noun?" You will be asked these questions only for the nouns that you say are Old. Do you understand?

In a few minutes we'll try a practice block, but first let me go over the instructions with you so that you know what to do.

STUDY

During the study phase you'll see a list of sentences presented on the computer screen. Each sentence will consist of 5 words presented one word at a time. A large period will follow each sentence. After you read the first list of sentences, a second list of different sentences will be

presented in the same way. You are to read all of the sentences in each list and try to memorize the nouns because you will be asked questions about the two nouns in those sentences, as I mentioned before. The sentences are provided to help you remember the nouns. Do you have any questions?

RECOGNITION

After reading the two lists of study sentences, a test phase will follow in which you will see a list of nouns presented sequentially two at a time. Half of these nouns will have occurred in the sentences you just read during study, and half will be new. This is your response box. Hold it in both hands, with your thumbs over these two buttons. When you see the first noun, press this button with your L/R hand if it is Old, meaning, that it was in one of the two previous lists of sentences. Press this button with your L/R hand if it is New, i.e. it was not in one of the two previous lists of sentences. Then you will see the next noun and do the same thing. For each Old/New judgment, press the button as quickly and as accurately as possible.

After you have responded to two nouns, you will be asked the three questions for the noun or nouns you said were Old. You'll see the

noun you said was old in the middle of the screen with the word "Remember" in this corner, and the word "Know" in this corner. If, when you pressed the button to say that the noun was old, you remembered something associated with having seen that noun in the study list, you would press this button that's on the same side as the word "Remember." If you know that the noun was on one of those lists, but you do not remember anything else associated with it, you would press this button that's on the same side as the word "Know." Do you understand?

Next you will see the noun in the center of the screen with the words, "List 1" in this corner and "List 2" in this corner. If you think the noun was in List 1, you would push this button on the same side as List 1. If you think it was in List 2, you would push this button on the same side as List 2.

Finally, underneath the old noun you will see "other noun," question mark. You are to say, out loud, the other noun that was in the same sentence with the noun on the screen. If you don't know what the other noun was, just say, "Don't Know." I'll be outside and will have to listen to you through the intercom, so speak as clearly as possible. Do you understand?

O.K. so let's go through the sequence again.

You see a noun and press one of these buttons to indicate if the noun was old or new. Then you see a second noun and do the same thing. If you responded old to either of those nouns, it will be presented again on the screen and you will answer the three questions. If you responded old to both of those nouns, then the second one will be presented again along with the three questions. Then you will go on to make old/new judgments about two other nouns. If you respond new to both nouns, then you'll simply go on to make old/new judgments for another set of nouns. Do you have any questions?

Make the old/new judgments as quickly as you can, and also be as accurate as possible. The answers to the other questions don't have a time limit, but don't spend too much time thinking about them. You may not be sure of the answer to every question. That's o.k. Just answer as accurately, and as quickly as you can. Except for the old/new judgments, you have to respond to the question before the computer will go on to the next question or noun. Do you understand? Do you have any questions?

O.K. Let's go on to the practice block.

Before each part of the experiment you will see a message that says, "Please Wait." You will have to wait until I begin the sequence. Then you will see a message that says, "Press When Ready." When you are ready to begin, press either of these buttons and the sequence will begin.

Remember, in the study section you'll see one list of sentences labeled, "List 1." The sentences will be presented one word at a time. After a short interval, a second list of sentences will be presented in the same way. This second list will be labeled, "List 2." You are to memorize the nouns in each of the sentences so you can answer the questions about them during the test phase. Are you ready?

RUN PRACTICE STUDY BLOCK

Now you'll see a list of nouns. Half of these nouns occurred in the sentences you just read, and half did not. Get your box positioned properly with your thumbs over the two buttons. When you see a noun, press this button with your L/R hand if you saw it in one of the sentences just presented, and this button with your L/R hand if you did not see it in one of those sentences. Please respond as quickly and accurately as

possible. After you respond to two nouns, the other questions will appear on the screen for the nouns you indicated you saw on one of the two previous lists. Please also answer those questions as quickly and accurately as possible. Do you have any questions?

RUN PRACTICE RECOGNITION

CORRELATIONS OF HITS PLUS REMEMBER/KNOW AND LIST CORRECT/INCORRECT

Table A1. Correlation of accuracy data for all subjects with measures of intellectual and frontal lobe functioning

MEASURE	%Hits-FAs	%HR	%HLC	%HRLC	%HKLC
Verbal Fluency (CFL)	0.01	0.06	-0.31	-0.15	-0.05
WCST Number of Perseverative Errors	-0.32	-0.25	-0.39	-0.04	-0.24
WCST Number of Trials	-0.34	0.22	-0.43(*)	-0.08	-0.22
WCST %Conceptual Level Responses	0.42(*)	-0.24	0.42(*)	0.06	0.24
mMMS Score	0.29	-0.18	0.46(*)	0.13	0.18
Number of Digits Forward	-0.03	-0.03	-0.05	-0.02	-0.02
Number of Digits Backward	-0.04	-0.12	0.02	-0.06	0.09
WAIS-R Full Scale IQ	0.16	-0.01	-0.07	-0.08	0.04
BNT Number Correct	0.38	-0.05	0.05	-0.01	0.05

Note: Pearson's r correlations. One-tailed significance * $p < .001$.
 Verbal Fluency Test = the Controlled Oral Word Association Test (Benton & Hamsher, 1976);
 WCST = Wisconsin Card Sorting Test (Heaton, 1981); mMMS Score = Modified Mini-Mental Status Exam (Mayeux, Stern, Rosen & Leventhal, 1981); WAIS-R = Wechsler Adult Intelligence Scale-Revised (Wechsler, 1981); BNT = Boston Naming Test (Kaplan et al., 1983); %Hits-FAs = percent of hits minus percent of false alarms; %HR = percent of hits with Remember judgments; %HLC = percent of hits with List correct; %HRLC = percent of hits with Remember judgments and List correct; %HKLC = percent of hits with Know judgments and List correct.

Table A2. Correlation of accuracy data for young subjects with measures of intellectual and frontal lobe functioning

MEASURE	%Hits-FAs	%HR	%HLC	%HRLC	%HKLC
Verbal Fluency (CFL)	-0.28	-0.03	-0.08	-0.08	-0.05
WCST Number of Perseverative Errors	-0.48	-0.23	-0.26	-0.36	-0.29
WCST Number of Trials	-0.34	-0.20	-0.20	-0.28	0.23
WCST %Conceptual Level Responses	0.40	0.09	0.29	0.22	-0.07
mMMS Score	0.14	-0.35	0.01	-0.19	0.28
Number of Digits Forward	-0.06	-0.22	-0.19	-0.18	0.09
Number of Digits Backward	-0.34	-0.12	-0.38	-0.27	0.06
WAIS-R Full Scale IQ	0.27	0.20	0.32	0.34	-0.20
BNT Number Correct	0.55	0.12	0.17	0.21	-0.16

Note: Pearson's *r* correlations. Verbal Fluency Test = the Controlled Oral Word Association Test (Benton & Hamsher, 1976); WCST = Wisconsin Card Sorting Test (Heaton, 1981); mMMS Score = Modified Mini-Mental Status Exam (Mayeux, Stern, Rosen & Leventhal, 1981); WAIS-R = Wechsler Adult Intelligence Scale-Revised (Wechsler, 1981); BNT = Boston Naming Test (Kaplan et al., 1983); %Hits-FAs = percent of hits minus percent of false alarms; %HR = percent of hits with Remember judgments; %HLC = percent of hits with List correct; %HRLC = percent of hits with Remember judgments and List correct; %HKLC = percent of hits with Know judgments and List correct.

Table A3. Correlation of accuracy data for old subjects with measures of intellectual and frontal lobe functioning.

MEASURE	%Hits-FAs	%HR	%HLC	%HRLC	%HKLC
Verbal Fluency (CFL)	0.75(*)	0.19	-0.25	0.10	-0.20
WCST Number of Perseverative Errors	-0.80	-0.37	-0.37	-0.24	-0.38
WCST Number of Trials	-0.28	0.45	-0.58	0.26	-0.49
WCST %Conceptual Level Responses	0.38	-0.41	0.36	-0.30	0.43
mMMS Score	0.25	-0.19	0.55	0.01	0.24
Number of Digits Forward	0.06	0.09	0.20	0.19	-0.08
Number of Digits Backward	0.24	-0.16	0.23	-0.05	0.15
WAIS-R Full Scale IQ	0.58	-0.023	0.32	0.10	0.06
BNT Number Correct	0.31	-0.18	0.28	-0.07	0.19

Note: Pearson's r correlations. One-tailed significance * $p < .001$. Verbal Fluency Test = the Controlled Oral Word Association Test (Benton & Hamsher, 1976); WCST = Wisconsin Card Sorting Test (Heaton, 1981); mMMS Score = Modified Mini-Mental Status Exam (Mayeux, Stern, Rosen & Leventhal, 1981); WAIS-R = Wechsler Adult Intelligence Scale-Revised (Wechsler, 1981); BNT = Boston Naming Test (Kaplan et al., 1983); %Hits-FAs = percent of hits minus percent of false alarms; %HR = percent of hits with Remember judgments; %HLC = percent of hits with List correct; %HRLC = percent of hits with Remember judgments and List correct; %HKLC = percent of hits with Know judgments and List correct.

ADDITIONAL NEUROPSYCHOLOGICAL TEST SCORES

Table A4. Performance scores on the Boston Naming, Wisconsin Card Sort, and Verbal Fluency Tests for young and old subjects.

MEASURE	YOUNG		OLD	
	Mean	SD	Mean	SD
BN Raw Score	54.44	4.49	55.81	2.81
BN Age Corrected Percentile	43.39	34.73	59.25	17.22
WCST Number of Categories	5.50	1.41	4.81	2.14
WCST Number of Trials	90.38	19.63	99.13	24.25
WCST Number Correct Responses	71.38	7.65	65.31	14.67
WCST Number Errors	19.00	15.34	33.81	29.86
WCST Number Perseverative Responses	9.94	6.58	22.19	27.96
WCST Number Perseverative Errors	9.31	6.05	19.25	21.86
WCST Number Non-Perseverative Errors	9.69	10.66	14.56	15.28
WCST Percent Perseverative Errors	9.69	4.19	16.86	16.14
WCST Number Trials to First Category	11.88	2.13	17.81	26.70
WCST Percent Conceptual Level Responses	77.13	15.91	62.56	28.30
WCST Failure to Maintain Set	0.81	1.11	0.44	1.26
WCST Learning to Learn	-0.99	2.99	-0.58	2.68
Verbal Fluency Total Raw Score	45.50	12.61	53.19	11.46

Note: BN = Boston Naming Test (Benton & Hamsher, 1976); WCST = Wisconsin Card Sorting Test (Heaton, 1981); Verbal Fluency = Controlled Oral Word Association Test - CFL (Benton & Hamsher, 1976). SD = standard deviation.

ERP ANALYSIS OF VARIANCE RESULTS

Table A5. ANOVA Results: Age Group (Young/Old) by Condition (Remember/Know/Correct Rejections) by Chain (Left/Middle/Right) by Anterior/Posterior (Prefrontal/Frontal/Central/Posterior). Early Latency Window.

FACTORS	F	df	ϵ	p
Group	1.52	1, 28	---	0.23
Condition (remember/know/correct rejections)	18.04	2, 56	0.97	0.0000
Condition x Group	2.42	2, 56	0.97	0.10
Chain	5.58	2, 56	0.88	0.009
Chain x Group	0.63	2, 56	0.88	0.52
Anterior/Posterior	9.16	3, 84	0.65	0.0004
Anterior/Posterior x Group	4.70	3, 84	0.65	0.01
Condition x Chain	1.97	4, 112	0.71	0.13
Condition x Chain x Group	1.73	4, 112	0.71	0.17
Condition x Anterior/Posterior	0.93	6, 168	0.39	0.41
Condition x Anterior/Posterior x Group	4.02	6, 168	0.39	0.02
Chain x Anterior/Posterior	3.87	6, 168	0.47	0.01
Chain x Anterior/Posterior x Group	0.95	6, 168	0.47	0.42
Condition x Chain x Anterior/Posterior	1.19	12, 336	0.41	0.32
Condition x Chain x Anterior/Posterior x Group	1.82	12, 336	0.41	0.11

Table A6. ANOVA Results: Age Group (Young/Old) by Condition (Remember/Know/Correct Rejections) by Chain (Left/Middle/Right) by Anterior/Posterior (Prefrontal/Frontal/Central/Posterior). Middle Latency Window.

FACTORS	F	df	ε	p
Group	0.65	1, 28	---	0.43
Condition (remember/know/correct rejections)	14.52	2, 56	0.84	0.0000
Condition x Group	1.98	2, 56	0.84	0.16
Chain	4.43	2, 56	0.90	0.02
Chain x Group	1.30	2, 56	0.90	0.28
Anterior/Posterior	11.17	3, 84	0.49	0.0005
Anterior/Posterior x Group	7.63	3, 84	0.49	0.004
Condition x Chain	1.68	4, 112	0.54	0.19
Condition x Chain x Group	0.76	4, 112	0.54	0.48
Condition x Anterior/Posterior	7.97	6, 168	0.46	0.0002
Condition x Anterior/Posterior x Group	3.48	6, 168	0.46	0.02
Chain x Anterior/Posterior	6.05	6, 168	0.49	0.001
Chain x Anterior/Posterior x Group	1.30	6, 168	0.49	0.28
Condition x Chain x Anterior/Posterior	1.47	12, 336	0.47	0.20
Condition x Chain x Anterior/Posterior x Group	1.38	12, 336	0.47	0.23

Table A7. ANOVA Results: Age Group (Young/Old) by Condition (Remember/Know/Correct Rejections) by Chain (Left/Middle/Right) by Anterior/Posterior (Prefrontal/Frontal/Central/Posterior). Late Latency Window.

FACTORS	F	df	ε	p
Group	1.59	1, 28	---	0.22
Condition (remember/know/correct rejections)	4.27	2, 56	0.95	0.02
Condition x Group	6.27	2, 56	0.95	0.004
Chain	6.63	2, 56	0.94	0.003
Chain x Group	0.06	2, 56	0.94	0.93
Anterior/Posterior	18.17	3, 84	0.57	0.0000
Anterior/Posterior x Group	0.84	3, 84	0.57	0.42
Condition x Chain	3.68	4, 112	0.62	0.02
Condition x Chain x Group	0.83	4, 112	0.62	0.46
Condition x Anterior/Posterior	3.55	6, 168	0.46	0.02
Condition x Anterior/Posterior x Group	2.21	6, 168	0.46	0.1
Chain x Anterior/Posterior	13.03	6, 168	0.42	0.0000
Chain x Anterior/Posterior x Group	1.07	6, 168	0.42	0.36
Condition x Chain x Anterior/Posterior	2.58	12, 336	0.38	0.03
Condition x Chain x Anterior/Posterior x Group	1.06	12, 336	0.38	0.38

Table A8. ANOVA Results: Age Group (Young/Old) by Condition (List Correct/List Incorrect/Correct Rejections) by Chain (Left/Middle/Right) by Anterior/Posterior (Prefrontal/Frontal/Central/Posterior). Early Latency Window.

FACTORS	F	df	ε	p
Group	1.66	1, 30	---	0.20
Condition (List Correct/List Incorrect/CR)	19.29	2, 60	0.96	0.0000
Condition x Group	4.99	2, 60	0.96	0.01
Chain	4.57	2, 60	0.85	0.02
Chain x Group	0.50	2, 60	0.85	0.58
Anterior/Posterior	8.60	3, 90	0.66	0.0005
Anterior/Posterior x Group	3.86	3, 90	0.66	3.86
Condition x Chain	0.84	4, 120	0.67	0.46
Condition x Chain x Group	0.81	4, 120	0.67	0.48
Condition x Anterior/Posterior	1.24	6, 180	0.50	0.30
Condition x Anterior/Posterior x Group	2.71	6, 180	0.50	0.05
Chain x Anterior/Posterior	3.78	6, 180	0.45	0.02
Chain x Anterior/Posterior x Group	0.36	6, 180	0.45	0.76
Condition x Chain x Anterior/Posterior	2.07	12, 360	0.41	0.07
Condition x Chain x Anterior/Posterior x Group	1.14	12, 360	0.41	0.34

Table A9. ANOVA Results: Age Group (Young/Old) by Condition (List Correct/List Incorrect/Correct Rejections) by Chain (Left/Middle/Right) by Anterior/Posterior (Prefrontal/Frontal/Central/Posterior). Middle Latency Window.

FACTORS	F	df	ε	p
Group	0.77	1, 30	---	0.39
Condition (List Correct/List Incorrect/CR)	6.12	2, 60	0.85	0.006
Condition x Group	0.62	2, 60	0.85	0.52
Chain	4.19	2, 60	0.92	0.02
Chain x Group	1.49	2, 60	0.92	0.23
Anterior/Posterior	12.41	3, 90	0.50	0.0002
Anterior/Posterior x Group	8.92	3, 90	0.50	0.002
Condition x Chain	1.69	4, 120	0.52	0.19
Condition x Chain x Group	1.29	4, 120	0.52	0.28
Condition x Anterior/Posterior	8.48	6, 180	0.39	0.0002
Condition x Anterior/Posterior x Group	0.87	6, 180	0.39	0.44
Chain x Anterior/Posterior	5.40	6, 180	0.50	0.002
Chain x Anterior/Posterior x Group	1.05	6, 180	0.50	0.38
Condition x Chain x Anterior/Posterior	1.89	12, 360	0.36	0.11
Condition x Chain x Anterior/Posterior x Group	1.20	12, 360	0.36	0.31

Table A10. ANOVA Results: Age Group (Young/Old) by Condition (List Correct/List Incorrect/Correct Rejections) by Chain (Left/Middle/Right) by Anterior/Posterior (Prefrontal/Frontal/Central/Posterior). Late Latency Window.

FACTORS	F	df	ε	p
Group	0.72	1, 30	---	0.40
Condition (List Correct/List Incorrect/CR)	0.05	2, 60	0.81	0.92
Condition x Group	7.64	2, 60	0.81	0.003
Chain	4.75	2, 60	0.97	0.01
Chain x Group	0.02	2, 60	0.97	0.98
Anterior/Posterior	19.12	3, 90	0.56	0.0000
Anterior/Posterior x Group	0.56	3, 90	0.56	0.55
Condition x Chain	4.52	4, 120	0.55	0.01
Condition x Chain x Group	0.51	4, 120	0.55	0.62
Condition x Anterior/Posterior	3.19	6, 180	0.40	0.04
Condition x Anterior/Posterior x Group	2.37	6, 180	0.40	0.09
Chain x Anterior/Posterior	11.37	6, 180	0.45	0.0000
Chain x Anterior/Posterior x Group	0.71	6, 180	0.45	0.53
Condition x Chain x Anterior/Posterior	2.84	12, 360	0.36	0.02
Condition x Chain x Anterior/Posterior x Group	0.76	12, 360	0.36	0.56

SENTENCES**SOURCE 1**

Her mate opened the cage.
The killing stunned the parish.
The chef created a spread.
The catcher sold the revolver.
Her lover anticipated her refusal.
The cream relieved his misery.
The commuter heard the roar.
The quest consumed the dentist.
The shelf held her slip.
His uncle cast a spell.
The doll provided a clue.
The dean brandished his cane.
An anchor decorated the saloon.
The bolt secured the tower.
Her client earned the reward.
The seal demonstrated his vigor.
The bull destroyed his trailer.
The wound destroyed his lung.
The boredom discouraged the singer.
The tourist recognized the frieze.
The colt circled the fringe.
The deputy read the script.
The flag frightened the sheep.
The militia stormed the palace.
The pioneer built a chapel.
A civilian initiated the broadcast.
The martyr carried a rose.
The elevator became a tomb.
The rookie investigated the theft.
His buddy bought the couch.
The moisture spoiled the straw.
An amateur chiseled the statue.
A curtain decorated the flat.
The bee began its dancing.
A fabric concealed the crystal.

The lever released the swing.
The foil decorated his crown.
His opponent took an airplane.
Their romance lasted a lifetime.
The rancher hosted a picnic.
The shower drenched the suburb.
The waiter recommended the liver.
The trio required some privacy.
The blockade precipitated the chaos.
The taxpayer supported the museum.
The raid enriched his kingdom.
The mayor received a discount.
The plow caused a delay.
That clause benefited the charity.
The scholar published a summary.
The monk refused the bacon.
The cyclist needed a permit.
The rider wore a sweater.
The bat frightened the soloist.
The basket held a potato.
The visitor admired the fountain.
The pianist hailed a taxi.
The sunlight penetrated the interior.
The merchant imported the whiskey.
The rent emptied his purse.
The sunset illuminated the summit.
The cave had an odor.
The opium ruined the elite.
The turtle entered the tunnel.
The carriage crossed the border.
The epidemic reached its climax.
The spy understood their logic.
The educator revealed his bias.
His lecture needed a revision.
The preacher drew an analogy.
The rescue drew their praise.
His niece twisted her ankle.
The diamond repaid the debt.
That ballot broke the deadlock.

The sheriff investigated the suicide.
The paradox puzzled the linguist.
The mouse startled the newt.
The stag surveyed the ridge.
The squad greeted the sunrise.
His pack contained the cheese.
The assault injured the resident.
The portrait elicited his satire.
The bulb illuminated the bathroom.
The steer trampled his luggage.
Her gaze followed the rocket.
The patrol located the uranium.
The suspect missed his workout.
The resort buried the garbage.
The lamb needed a washing.
The sunshine bathed the slope.
The haze obscured the dock.
The patriot curbed his ambition.
The garment expressed his defiance.
The beatnik rode the subway.
The brick broke the planter.
Her chatter relieved his sadness.
His helper obtained the lease.
The blond returned the volley.
The excerpt described his serenity.
The bailiff obtained a passport.
The jet brought his sax.
The goat ate his dessert.
The redhead stubbed her toe.
The porter blew the trumpet.
The referral generated a frenzy.
The lie was a trap.
The mainland exported their hay.
The theater became his refuge.
His zeal initiated the renewal.
The journal published his slogan.
The peasant killed the boa.
The knight hummed a tune.
The hunter built an oven.

The buffalo trampled the refugee.
The coach had a stroke.
Her laugh spoiled his throw.
The examiner requested a cushion.
The rat bit the murderer.
The thinker missed the deadline.
Her essay described the relic.
The rector enjoyed the operetta.
The blizzard obscured the mansion.
The banner advertised the recital.
The trustee called his bluff.
Her roast deserved a cheer.
The rabbi injured his spine.
The lad solved the puzzle.
The strife distracted the sculptor.

SOURCE 2

The python swallowed the battery.
The colonel swam the lake.
The embassy issued a warning.
The creek flooded the dairy.
The brief described the monopoly.
His kick broke a dish.
The novelist endured their scrutiny.
The rope secured his trunk.
The lion drank the alcohol.
The willow shaded the attic.
The spray created a chill.
The nurse preached a sermon.
The vapor covered the meadow.
The irony escaped the listener.
His ally spoke the dialect.
The pastor drove a pickup.
The terrain took its toll.
The umbrella fascinated the infant.
The priest reported the abuse.
The monkey ate the cereal.

The trick involved a balloon.
The aide took her leave.
The freshman made the jump.
The troop bridged the channel.
His cigar polluted the airport.
The liberal loosened his collar.
The jail provided the manpower.
The wax splashed the observer.
The rabbit had a cavity.
The arrow pierced his breast.
The candy eased her sorrow.
The landlord confiscated his stereo.
The posse beat a retreat.
Her cousin made the arrest.
His whisper traveled the corridor.
Her nephew joined the cult.
Her aunt was an angel.
The slug caused her distress.
The creature was a menace.
Her neglect destroyed the veranda.
The producer entered a plea.
The episode sparked a revival.
The restraint injured the calf.
Her parent circulated a petition.
The café guarded its recipe.
The thief stole the ivory.
The clergy sponsored the festival.
The flame consumed the pine.
The mare lost a shoe.
The sauce required a lemon.
The saint played the violin.
The bear uncovered an insect.
The foliage obscured the driveway.
The military filled the void.
Her singing filled their dwelling.
The claimant broke his wrist.
The acid burned his thigh.
The pump was an antique.
The shooting reduced his mobility.

The ribbon decorated the skiff.
Their protest closed the exhibit.
The empire devalued the currency.
The mineral enriched the lawn.
The reunion was a miracle.
The remedy was an apple.
The filly whinnied a welcome.
His employer conveyed his optimism.
The topic was her voyage.
The lantern illuminated the stable.
The organ pierced the quiet.
The vessel carried the wheat.
Their dialogue clarified her intent.
The founder gave his blessing.
The glare obscured the canvas.
The manure soiled her skirt.
Her pupil played the recorder.
The dividend was an error.
The supplier sent a postcard.
The robbery spoiled the ceremony.
The trader demonstrated his poise.
The player lost a filling.
The bayonet pierced the coconut.
The veteran held a grudge.
The antelope ate the peanut.
The junk littered his bunk.
Her hunch unmasked the pretense.
The rag covered her abdomen.
The robe was a bargain.
The mulch increased his yield.
The stake pierced the membrane.
The seller explained his plight.
The reporter surveyed the lobby.
The precinct held a banquet.
The laborer swallowed an oyster.
The fever delayed his escape.
The maze trapped his attacker.
The radical grabbed an axe.
The ant entered the castle.

The tangle became a nest.
 The newcomer offered his workshop.
 The elephant dropped the can.
 Their boss promoted the concerto.
 The corps endured the betrayal.
 The prisoner requested a comb.
 The adjunct took the bet.
 The marksman remembered his oath.
 His ancestor loved his brandy.
 The mandate upset the norm.
 The accord restored the calm.
 The beast destroyed the china.
 The deed marked his manhood.
 The rust weakened the sword.
 The glue fixed the lid.
 The bucket held the barley.
 The fort overlooked the bay.
 The lamp illuminated the dugout.
 The web covered the ladder.
 The assassin wore an apron.
 The soprano took her revenge.
 The pile blocked the stairway.
 The pony ate the pear.
 The academy accepted her twin.
 The hammer tore her lace.
 His servant composed a hymn.
 The hawk stole his snack.
 The boulder smashed the coffin.
 The tenor joined the boycott.
 The giant practiced his diction.

FILLER SENTENCES

The painter cooked his supper.
 The dancer shaved his beard.
 The booking was a mistake.
 The tea filled the boxcar.
 The killer planned his wedding.

His ugliness was his excuse.
Her accuracy earned his trust.
The incident ended her reign.
The reactor cost a fortune.
The cancer killed the pitcher.
His inaction delayed the mail.
The clerk examined her motive.
The corpse increased her terror.
The scratch disfigured her cheek.
The general drove the tractor.
His treason caused his poverty.
The turnpike was a disaster.
The blow struck her brow.
The attorney tried the diet.
Her clothing held the scent.
The zoo anticipated his arrival.
The cylinder contained a liquid.
His sister concealed her hatred.
Her partner made the deposit.
The gang climbed the mountain.
The tire toppled the stack.
Her humanity aroused his sympathy.
His gesture invited a reply.
The net caught the plaster.
The farmer needed a bath.
The disorder tried her patience.
His feat became a legend.

PRACTICE SENTENCES

The pepper spoiled his appetite.
The voltage damaged the computer.
The drill penetrated the pavement.
Their cruelty sparked a revolt.
The star sang the chorus.
The quarrel created a barrier.
His posture created the fatigue.
The bomber began its descent.

The cavalry patrolled the boundary.
The telegram announced his coming.
The adoption required her consent.
The juice sweetened the cake.
The puppet joined the circus.
The locust fulfilled the curse.
The chore relieved the monotony.
Her solo preceded the finale.

PRACTICE FOIL WORDS

thunder	alarm
rebel	wardrobe
surgeon	chart
athlete	doorway
pill	blame
document	applause
arch	razor
sergeant	morale
criminal	tumor
drunk	ideology
closet	anguish
diversity	friction
therapy	cabinet
outfit	temper
designer	boating
scream	wreck

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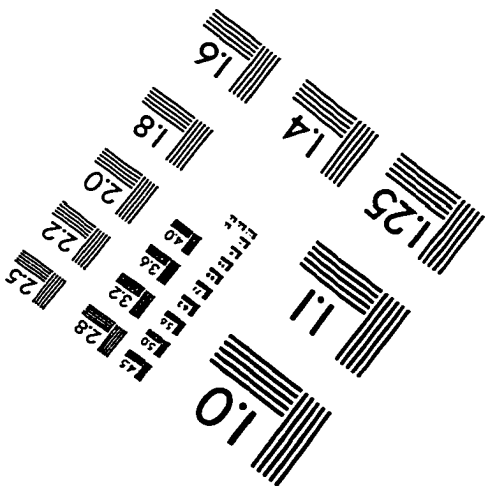
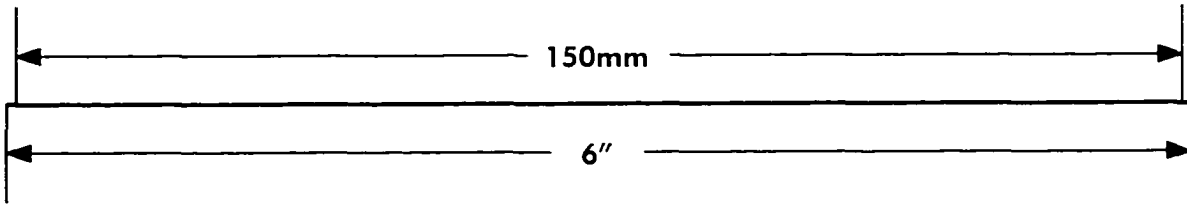
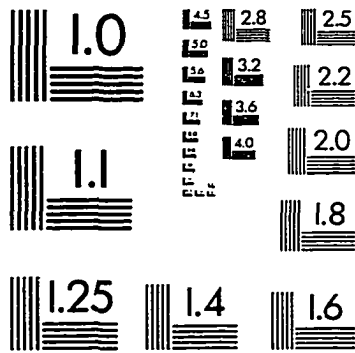
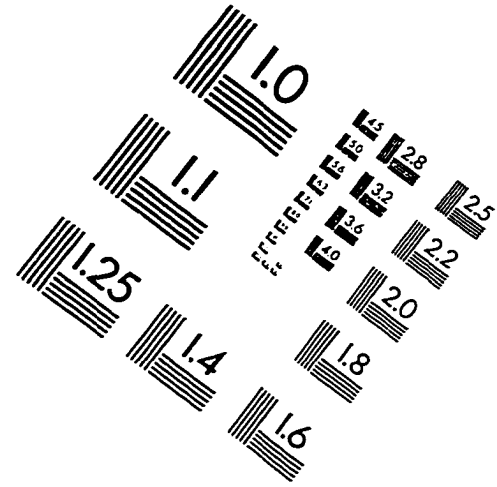
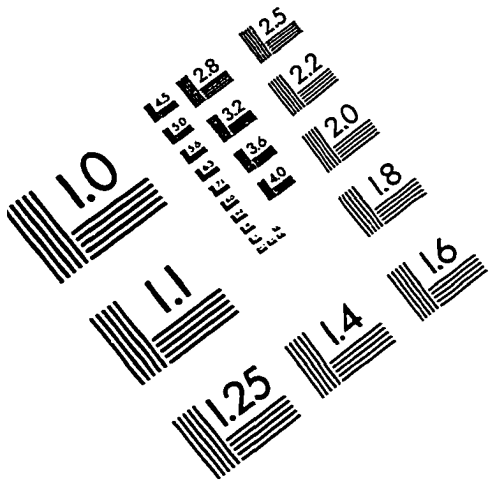
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IMAGE EVALUATION TEST TARGET (QA-3)



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