

DISSERTATION
MODALITY SPECIFIC CONTRIBUTIONS TO TRUE AND FALSE RECOGNITION:
AN EVENT-RELATED POTENTIAL STUDY

Submitted by
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In partial fulfillment of the requirements
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WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY PAUL STEVEN MERRITT ENTITLED MODALITY SPECIFIC CONTRIBUTIONS TO TRUE AND FALSE RECOGNITION: AN EVENT-RELATED POTENTIAL STUDY BE ACCEPTED AS FULFILLING INPART REQUIREMENTS FOR THE DEGREEE OF DOCTOR OF PHILSOPHY.

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ABSTRACT OF DISSERTATION

MODALITY SPECIFIC CONTRIBUTIONS TO TRUE AND FALSE RECOGNITION: AN EVENT RELATED POTENTIAL STUDY

Retrieval in recognition memory is generally thought to operate based on two distinct processes, recollection and familiarity. The contribution of modality specific information to these processes is unclear, however. The Deese/Roediger and McDermott (D/RM) paradigm was used to create a situation in which test items differed according to perceptual experience, with old items associated with a previous sensory experience, but lure items not associated with such an experience. Additionally the modality of study lists was manipulated such that participants either saw or heard items at study, then were tested visually, such that there was a match or mismatch in study-test modality. Event-related potentials (ERPs) were used to provide a precise measurement of recognition memory processes as they unfolded. Significant differences were found for several ERP components. The P300 was larger for participants in the visual study condition and for false alarms to lure items. Analysis of the FN400 component revealed higher amplitudes for false alarms compared to hits in the visual study condition, but lower amplitudes for false alarms than hits in the auditory condition. A parietal old/new effect was found in the auditory but not the visual condition, with hits and false alarms producing ERPs consistent with recollection and familiarity processes, respectively. Finally, late frontal effects were found which indicated that participants in the visual condition were engaging in greater post-retrieval evaluation than those in the auditory condition. This effect was driven by a large late frontal positivity for false alarms in the visual study condition.

These results are interpreted as indicating a possible retrieval strategy difference between the study modality conditions, consistent with an explanation based on distinctiveness.

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Dedication

Dedicated to the loving memories of Virginia Tyler and Louis Digusto.

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Chapter 1 - Introduction

The search to understand the processes underlying recognition memory has been long and at times contentious. Even the earliest experimental psychologists struggled to understand the differences in the processes involved in free recall versus recognition (e.g. Hollingworth, 1913). The study of psychological illusions has an equally long and storied history, with a number of early psychologists acknowledging that understanding illusions can lead to a superior understanding of the mental processes involved in generating both accurate and illusory recollections (see Roediger, 1996 for review). The research presented here uses the well-studied Deese/Roediger-McDermott (D/RM) recognition memory illusion to investigate the contributions of modality specific information to recognition memory processes. These processes are examined using event-related potentials (ERPs). ERPs can potentially provide insight into recognition memory processes as they unfold, in that they provide an objective and precise measure that is temporally related to the underlying mental processes.

Recognition Memory Processes

A considerable amount of research and theory exists on the specific processes involved in recognition memory. Several models have been proposed that describe a single search process, generally referred to as global familiarity, in which a recognition judgment is based on the overall activation induced by a test item (e.g., Gillund & Shiffrin, 1984; also see Raaijmakers & Shiffrin, 2002 for a general review of memory models). The dual-process model proposed by Mandler (1980) is arguably the most influential, however. Dual-process accounts propose that recognition judgments result from two distinct processes: familiarity, which is described as a rapid, automatic process;

and recollection, which is a slower, deliberative process. Given the temporal precision of ERPs, it is possible to examine these processes separately, and indeed, recollection and familiarity appear to be associated with unique ERP signatures (e.g., Curran, 2000).

The more recent dual-process literature is split between using the terms “remember versus know” and “recollection versus familiarity” to describe the two processes described above. Generally speaking, the remember/know distinction is based on studies in which participants are asked to provide a subjective evaluation of the quality of memorial information (e.g., give a “remember” response if they specifically remember seeing an item during the study episode versus a “know” response if they believe an item was presented but do not have a specific memory for the study episode). The recollection/familiarity distinction is based on a more objective assessment of underlying cognitive processes in which recollection is said to occur when there is evidence for specific retrieval of a study episode. Correctly identifying the context associated with the study episode is considered recollection, whereas correctly identifying an item as having been studied but without recalling the specific study context is considered recognition based on familiarity. Both sets of terms seem to describe the same underlying processes (Rugg, Schloerscheidt, & Mark, 1998), so for simplicity, the terms recollection and familiarity will be used here to describe results from both bodies of research.

Familiarity-based recognition is generally described as arising from an automatic, unconscious process in which a participant is aware they have encountered a word on the study list, but do not remember the specific encoding episode (e.g., Knowlton & Squire, 1995; Jacoby, 1991). Familiarity is commonly thought to arise from an assessment of the global similarity between studied and test items (see Curran, 2000). This is believed to

be the dominant process that underlies subjective "know" responses, correct recognition of studied items with incorrect source attribution of those items (Mather, Henkel & Johnson, 1997), and false alarms to test items that differ from studied items in plurality (Curran, 2000; Hintzman & Curran, 1994).

Recollection is described as consciously controlled intentional use of memory in which the specific study episode is remembered (Jacoby, 1991; Knowlton & Squire, 1995). Recollection is believed to be the dominant process underlying subjective "remember" responses, recollection of specific episodic information such as the speaker's voice (Mather et al., 1997; Wilding & Rugg, 1997a) or whether an item was heard or spoken out loud (Wilding & Rugg, 1997b), and correct recognition of studied item plurality (Curran, 2000; Hintzman & Curran, 1994).

What is not entirely clear is the type of memorial information that is used during familiarity and recollection processes. What type of information is used as the basis for calling an item "old"? What information is retrieved initially? What, if any, post-retrieval evaluation takes place, and what type of information does this involve? A variety of paradigms have been used to investigate the differences between recollection and familiarity, most focusing on encoding manipulations and their effects on the two processes (see Yonelinas, 2002 for review). Some research suggests that familiarity is a more perceptually or feature-based process, such that matching modality at study and test increases familiarity but not recollection (Gregg & Gardiner, 1994; Jacoby & Dallas, 1981; except see Rajaram, 1993). Familiarity (but not recollection) is also boosted with maintenance rehearsal (Gardiner, Gawlik, & Richardson-Klavehn, 1994), feature-based processing (Jacoby & Dallas), for non-words relative to words (Gardiner & Java, 1990)

and for massed versus spaced repetition (Parkin & Russo, 1993). All of these effects suggest that familiarity is primarily a data-driven process. One would therefore expect modality specific information to be important to familiarity-based recognition.

Recollection, on the other hand, is most often affected by meaning-based manipulations. For example, deeper processing (Gardiner, 1988; Rajaram, 1993), intentional learning (Maken & Hampson, 1993), and elaborative rehearsal (Gardiner, et al., 1994) all result in increased recollection. In general, items that are more distinctive also show increased recollection, including generated items (Gardiner, 1988), low frequency items (Gardiner & Java), visually distinct items (Arndt & Reder, in press) and orthographically distinct items (Rajaram, 1998). It is also possible that modality specific information is important for recollection-based processes in some situations: If modality information is distinctive, it may contribute to recollection processes (see below for further discussion of this possibility).

Use of Perceptual Information in Recognition

As outlined above, there are a number of studies that show effects of perceptual manipulations at encoding on familiarity processes. This finding is not without controversy, however. Early in their dual-process work, Jacoby and colleagues argued that familiarity was mediated by perceptual fluency (Jacoby, 1991; Jacoby & Dallas, 1981; Johnston, Dark & Jacoby, 1985), with this relationship tied to perceptual priming effects (Jacoby & Dallas; Kelly, Jacoby & Hollingshead, 1989). Others have argued that perceptual priming and recognition reflect distinct cognitive processes (Tulving & Schacter, 1990; Wagner, Gabrieli, & Verfaellie, 1997), and a variety of recent work suggests that perceptual representations are not typically accessed during recognition

judgments (Challis et al., 1993; Hintzman & Caulton, 1997; Jones, Jacoby & Gellis, 2001; Snodgrass, Hirshman & Fan, 1996; Watkins & Gibson, 1988; for an exception, see Parkin et al., 2001).

Of particular interest here is the use of modality specific information in making recognition judgments. Early research indicated a significant contribution of modality information in recognition judgments, with memory performance best when modality is matched (Kirsner, 1974), when the speaker's voice is matched (Craig & Kirsner, 1974), and when visual information is matched (Kirsner, 1973) from study to test. Jacoby and Dallas (1981) were initial proponents of the idea that there is a direct relationship between perceptual fluency and recognition memory. They used both perceptual identification and recognition memory to investigate this relationship and found not only a tendency for perceptual identification to predict recognition memory, but also that switching modality from study to test substantially reduced priming in perceptual identification and substantially reduced recognition memory performance (Jacoby & Dallas, Experiment 6).

Kelley et al. (1989) also found that recognition performance was best when there was a match between study and test modality. Based on their data, however, they made the specific argument that perceptual fluency boosts familiarity, and that this is the basis for modality effects in recognition. In a subsequent study, Gregg & Gardiner (1994) found a small advantage for modality matched recognition performance that was associated with a small increase in "know" responses (i.e., familiarity) when participants engaged in shallow processing (Experiment 1) and a more substantial increase for a perceptually based orienting task (Experiment 2). These results suggest that modality

information has more influence on familiarity than recollection. Jacoby (1996) later used a modality specific manipulation and concluded that “effects of conceptually driven processing were modality free whereas effects of prior data-driven processing were fully modality specific (p.44).” This further argues that modality information is useful for recognition judgments when meaning-based contextual information is unavailable for recollection, driving increases in familiarity-based recognition.

Kelley et al. (1989) argued that modality information is not only used to support data-driven processes, it may also be used to support conceptually-driven processes, provided that the modality information is encoded in a meaningful way. Similarly, Johnston, Hawley, & Elliot (1991) argued that perceptual fluency is used as the basis for recognition memory judgments only in the absence of other, explicit memorial information. Likewise, Light and colleagues argued that visual information is only encoded when it is task relevant (Light & Berger, 1976; Light, Berger & Bardales, 1975) and is stored as distinct, propositional information. In addition, Mulligan and Hirshman (1995) examined the time course of the contribution of modality information to recognition memory and found that modality match significantly improved performance at early response intervals, but did not improve performance at later intervals. What is important here is that some lists were presented auditorally and others visually, making modality specific information relevant to the old/new decision.

Along similar lines, Snodgrass et al. (1996) proposed that sensory information does not contribute to recognition judgments by virtue of perceptual fluency, but is explicitly retrieved to support old/new decisions. Likewise, Hintzman & Caulton (1997) proposed that modality information is stored as part of the memory trace rather than as a

perceptual copy of the original experience, and that this information is used to support recollection rather than familiarity (also see Light & Berger, 1976). This stored sensory information, they argued, may only surface in experiments where modality information is useful in the old/new decision. Reder, Donavos, and Erickson (2002) also argued that perceptual matching effects in recognition memory are dependent on “a memory representation and retrieval mechanism (p. 321).”

Some studies do not, however, point to an important role of perceptual and modality specific information in recognition memory processes. Rajaram (1993), for example, found no evidence for a modality specific contribution to recognition memory in an experiment (Experiment 1) in which modality was varied across study items. Note, however, that the experiment also varied level of processing (rhyme vs. semantic associations) and this may have been the basis for old/new judgments rather than modality information. Also note that Rajaram does argue for a perceptual component to recognition memory in a subsequent experiment (Experiment 3) in which performance improved when items were perceptually primed. More recently, Jones et al. (2001) examined the use of modality information in which they concluded that the familiarity component of recognition memory is not modality specific and is different from the underlying process in perceptual fluency. Similarly, Watkins and Gibson (1988) varied the amount of perceptual information given to participants to assess the influence of this information on a subsequent recognition test. They found no effect of the perceptual salience of an item on its subsequent recognition and conclude that perceptual fluency does not contribute to recognition memory. Finally, there is evidence that familiarity is related to conceptual information about test items rather than perceptual information

(Wagner et al., 1997). Thus there is evidence that modality information may not influence recognition memory judgments based on familiarity. Clearly, this issue requires further investigation to resolve the discrepancies in the literature.

Although existing data is not conclusive, it appears that there are three general trends regarding the use of modality specific information in recognition. First, modality information tends to be used when it provides important or diagnostic information. Second, modality information and perceptual information are often used when encoding conditions encourage their use. Third, perceptual information may be used for retrieval if the perceptual representations are distinctive. The present study attempts to better elucidate the role of perceptual information, and modality specific information in particular, in recognition memory processes.

Perceptual Information and False Recognition

Although the contribution of perceptual information to accurate recognition is not entirely clear, the study of memory illusions provides a situation in which perceptual information may not be diagnostic in making recognition judgments, since the illusory events were not presented to begin with. Recent interest in false recognition has led to a veritable flood of research using the Deese/Roediger-McDermott (D/RM) paradigm. Based on research initially completed by Deese (1959), Roediger and McDermott (1995) presented lists of words such that all of the items in a given list were direct associates of a single “lure” item which was not presented at study. On a subsequent recognition test, results indicated that participants falsely recognized the lure items as often as they correctly recognized previously presented items. Since that study was published, a variety of researchers have attempted to determine whether different cognitive processes

underlie correct recognition of old items versus false recognition of lure items, with limited success. Some researchers found that lure items are associated with fewer “remember” judgments (Mather et al., 1997), but others reported that lure items are associated with remember judgments just as often as old items (Roediger & McDermott). Mather et al., on the other hand, found that old items were associated with memory for perceptual details, but lure items were not. Yet on a source judgment task in which participants judged whether items were presented in a male or female voice, lure items were reported to have been in the same voice as the voice used for the original list items. It seems then, that some perceptual information may be associated with lure items, even though the items were never presented. Thus, perceptual information may not be an adequate for distinguishing true from false recognition.

Although the exact nature of the differences between true and false recognition is unclear, the underlying cause of the false recognition effect is generally accepted as arising from associative processes that occur during encoding (Roediger, Balota, & Watson, 2001; Roediger, McDermott & Robinson, 1998). What is important for the present research is that this effect is semantic in nature: The false recognition effect occurs because of the direct semantic relationship between study items and the critical lures. Whether false recognition reflects source-monitoring errors, in which participants confuse associative processes at encoding with actual experiences (c.f. Mather et al.; also see Johnson, Hashtroudi, & Lindsay, 1993 for review of the source-monitoring framework) or it reflects gist rather than verbatim memories as posited by fuzzy-trace theory (Brainerd, Reyna & Kneer, 1995), the effect is one of semantic confusion that results from semantic processes. Moreover, the lure items that are falsely recognized do

not have a corresponding sensory trace, because these items were never presented. This provides a possible basis for dissociating the processes involved in true recollection from the processes involved in false recollection. Recognition judgments can be based on both sensory information and semantic information in the case of previously presented old items, but can only be based on semantic information in the case of non-presented items that do not have a sensory trace.

The present study attempts to capitalize on the above logic as a means for differentiating between true and false recognition. A modified Deese/Roediger-McDermott (D/RM) protocol was used with list items presented visually in one condition and auditorally in a second condition. The subsequent recognition test was always presented visually. In the visual study condition, participants can directly compare an item on the test to the original sensory trace and use modality specific sensory information as one possible basis for judging whether items are old or new. This may produce differences in ERP waveforms for old items (in which modality specific sensory information is accessed and retrieved) versus lure items (for which there is no sensory information). In the auditory presentation condition, participants can not use modality specific sensory information as the basis for their judgments because of the mismatch between study and test modality. Those differences in ERP waveforms in the visual presentation condition that reflect access to modality specific information would not be expected in the spoken condition. Also note that the retrieval processes that contribute to semantic confusion in false recognition experiments may be seen as reliable differences in ERP waveforms for false alarms to lure items versus unrelated new items, irrespective of the presentation condition.

On a more general note, there is also recent evidence to indicate that modality specific information plays a greater role in D/RM protocols than in standard tests of recognition memory. The general finding is that false alarms to lure items increase with auditory study lists combined with visual recognition tests relative to visual study and test paradigms (Smith & Hunt, 1998; Gallo, McDermott, Percer & Roediger, 2001; Cleary & Greene, 2002; but see Maylor & Mo, 1999). Schacter and his colleagues have described similar results using pictures for study items (Israel & Schacter, 1997; Schacter, Cendan, Dodson & Clifford, 2001; Schacter, Israel, & Racine, 1999). They suggest that the reduced false recognition rate in visual study-test paradigms reflect “participants’ metamemorial assessments of the kinds of information that they feel they should remember” (Schacter et al., 2001, p. 827; see also Dodson & Schacter, 2001). It is possible that for visually presented list items, participants expect that they will be able to generate the visual details of the studied items, and therefore make old-new judgments based on whether visual details come to mind at retrieval. There would be no such expectation for lists that are presented auditorally. This account fits well with the research described earlier showing that perceptual information is used for recognition memory judgments only when it provides a useful contribution to such judgments.

ERPs and Recognition Memory

As indicated above, the present study will use ERPs to examine true and false recognition as a function of study-test modality. A wide variety of research has been conducted examining ERPs during recognition memory tasks. Only recently, however, has the field begun to identify ERP characteristics that are associated with specific recognition memory processes. Curran (2000) used ERPs to investigate the

electrophysiological properties of recollection versus familiarity processes in recognition memory. Curran reports several ERP effects that are associated with these different processes. The first difference concerns the FN400, which appears over frontal regions from 300 to 500 ms post stimulus and seems to be associated with familiarity. The correct rejection of new items elicits a more negative FN400 than hits to old items (Curran 2000, 1999). Interestingly, Curran (2000) also found that false alarms to similar items produced an FN400 comparable to that obtained for hits to old items. Note, however, that Curran (2000) used a procedure in which studied items were singular or plural and the similar test items were simply studied items with the opposite plurality. For this particular protocol, then, both old and similar items may have involved access to specific perceptual information. It therefore remains to be seen whether there are FN400 differences between hits and false alarms in the traditional D/RM paradigm.

Curran (2000) also describes a “parietal old/new effect” in which ERPs for old items are more positive than ERPs for new items over parietal sites from 400 to 800 ms post-stimulus onset. Several studies have associated this effect with recollection (Duzel, Yonelinas, Mangun, Heinze, & Tulving, 1997; Rugg, Schloerscheidt, & Mark, 1998; Smith, 1993; Wilding & Rugg, 1996). Curran (2000) found that ERPs in the 400-800 ms range were more positive for hits to studied items than for false alarms to similar items (items with the opposite plurality as studied items). Curran argues that hits to studied items involve the specific recollection of the studied episode and that ERP differences reflect this recollection process. Consistent with these findings, Henson, Rugg, Shallice, Josephs, and Dolan (1999), using fMRI, found that activation in the left parietal and

anterior left prefrontal sites was greater for remember judgments than for know judgments.

There is also some limited evidence showing a late right frontal effect that may reflect post-retrieval evaluation. Curran (2000) found significant right frontal differences between correct rejections of new items and false alarms to similar items between 1,000 and 1,500 ms post-stimulus onset (see also Johnson, Kounios, & Nolde, 1996; Wilding & Rugg, 1996). Using event-related fMRI, Henson et al. (1999) found greater right posterior prefrontal activation for familiarity based recognition, which they argue indexes attempts at further information retrieval during source-monitoring decisions.

There are also several ERP studies that have specifically examined the phenomenon of false recognition in the D/RM paradigm, although these have produced somewhat conflicting results. This inconsistency may, however, stem from the different methods used in these studies. Johnson and colleagues (1997) published one of the first studies to use ERPs to investigate false recognition. Johnson et al. presented study lists auditorally and tested participants using a visual recognition test. In addition, the test was structured either according to a blocked design (in which all test items are presented in blocks according to item type) or a random design (in which all item types are presented in random order). Comparing the average ERP amplitude for 50 to 775 ms and 775 to 1500 ms, they found no differences between ERPs for old and lure items in the random design condition, but a significant difference in the blocked design condition. Johnson et al. argue that in the random test condition participants were basing recognition judgments largely on semantic familiarity. However, for the blocked design, it would be difficult to base judgments on semantic familiarity (i.e., items within a block would presumably

produce comparable levels of familiarity), so they argued that these judgments were based on a more effortful evaluation of perceptual and contextual properties. If this is the case, the ERP differences across conditions may reflect different strategy use. Note, however, that participants could not use modality specific information to help them with their recognition judgments because Johnson et al. presented study items auditorally but tested them visually. Thus, this study does not address the possibility that ERPs differ for old items versus lure items on the basis of differential access to modality specific information.

Walla et al. (2000) also examined ERP correlates of false recognition and found significant differences in the ERPs of true and false recognition. They found that ERPs for false alarms were significantly more negative than ERPs for hits over frontal and parietal locations. This effect was especially pronounced over frontal locations. They argue this is caused by a more intensive search for item representations, increased source-monitoring activity, and more effortful retrieval for falsely recognized items relative to old items. One key difference between this study and the others discussed here is that they did not use lists of related items as in the typical DR/M paradigm, rather they used a large number of items and examined ERPs associated with false alarms in a standard recognition memory test. As such, it is unlikely that the false alarms are based solely on semantic processes. Also important is the fact that they used visual presentation for both study and test lists. It is possible, then, that the differences may be attributed to a retrieval process in which participants search for stored sensory information as the basis for their recognition judgments.

Fabiani, Stadler and Wessels (2000) specifically investigated whether or not access to sensory information is important for differentiating old items from lures in the D/RM paradigm. Using a lateralized presentation method in which all of the items in a study list were presented in one visual field, ERP differences were observed for items tested in the same versus opposite hemisphere. Specifically, they found that ERPs were more positive over temporoparietal sites between 200 and 600 ms for the old items presented to the same hemisphere as the study presentation, relative to old items presented to the opposite hemisphere. However, ERP waveforms associated with the false recognition of lure items were not lateralized. Overall, ERP amplitudes for false targets were greater at frontal sites and for those lures associated with study lists presented to the left hemisphere. Fabiani et al. argue that the latter indicates that the semantic processing underlying the DR/M effect is carried out in the left hemisphere. What is important here is that there appears to be a sensory component underlying correct recognition, with meaning-based processes presumably driving false recognition.

Using high-density ERP recordings, Curran, Schacter, Johnson and Spinks (2001) investigated individual differences in the ERPs associated with true and false recognition using the D/RM paradigm. Specifically, they were interested in how the parietal old/new effect and right frontal old/new effects might be related to true and false recognition. Curran et al. suggest that the parietal old/new effect might index access to specific featural information that is characteristic of recollection, and that this could therefore be used to determine how recollective processes relate to false recognition. They also predicted that right frontal old/new effects would be related to false recognition, given that right frontal lesions have been associated with increases in the rate of false

recognition (Schacter, Curran et al., 1996). In addition, other neuroimaging studies and ERP studies suggest that right frontal effects may reflect post-retrieval evaluation processes (Schacter et al., 1997; Curran, 2000), so any differences between true and false recognition with regard to post-retrieval evaluation processes may be revealed as differences in right frontal old/new effects. Note that Curran et al. examined these ERP effects for both good performers (low false recognition rates) and poor performers (high false recognition rates).

Good performers showed a significant right frontal old/new effect for correct and false recognition, whereas poor performers showed no differences in responses to old, lure or new items at frontal sites. Curran et al. argue that this indicates that good performers are engaging in more post-retrieval evaluation of recognized items than are poor performers. This post-retrieval evaluation might be careful evaluation of retrieved information or attempts to retrieve additional information to make a recognition decision. Both good and poor performers demonstrated the standard parietal old/new effect. Only poor performers showed a difference between lure and old items, however. Curran et al. argue that this is because poor performers only differentiated items based on the initial retrieval attempt and did not engage in extensive post-retrieval evaluation. Thus, for poor performers, hits to old items would be based on recollection processes but false alarms to lure items would be based on familiarity processes. Good performers, on the other hand, engage in extensive post-retrieval evaluation such that their correct recognitions would include old items associated with both recollection and familiarity, eliminating possible differences between old items and lures based on differential use of recollection versus familiarity processes. What Curran et al. do not specify are the processes that underlie

these effects. For example, is the initial retrieval attempt or post-retrieval evaluation based on access to semantic information or attempts to match test items to the perceptual representations of study items?

Curran et al. also examined the FN400 and found no difference between old items and lure items. Curran et al. point out, however, that the FN400 may index perceptual familiarity or fluency, so this effect may not be particularly robust with the auditory study/visual test design that they used in their study.

Miller, Baratta, Wynveen and Rosenfeld (2001) specifically examined the P300 component for true versus false recognition. The P300 is generally associated with the amount of resources allocated to the processing of an event and the subjective probability of task relevant events (cf. Miller et al.). In addition, P300 amplitude is generally larger for classifying previously learned words as “old” than it is for correct rejection of new items (Miller et al.). Miller et al. found that false recognition of lure items was associated with shorter P300 latencies than correct recognition of old items. Although Miller et al. did not examine any other ERP components, visual inspection of their ERPs suggests that “old” responses to critical lure items may have elicited a more negative ERP over the same time window and electrode sites associated with the parietal old/new effect (Miller et al., p. 358, Figure 3).

Complementing ERP studies, cerebral blood flow measures have been used to study false recognition, and this data provides further support for underlying differences in true and false recognition memory processes. Using positron emission tomography (PET), Schacter, Reiman et al. (1996) studied regional cerebral blood flow (rCBF) differences for true and false recognition. Using the standard auditory study/visual test

D/RM paradigm, they found that recognition of both studied and lure items was associated with increased blood flow bilaterally to the medial temporal lobes and the left parahippocampal areas. Veridical recognition was associated with significant blood flow increases in the left temporoparietal cortex, but false recognition did not show this effect. Schacter, Reiman et al. contend that this reflects retrieval of auditory or phonological information about previously heard words. If this interpretation were correct, one would not expect this effect using a visual study/visual test design. Additionally, false recognition was associated with increased blood flow to the anterior prefrontal cortex, orbitofrontal cortex and cerebellum relative to true recognition. Schacter, Reiman et al. indicate that the frontal activation is likely related to effortful retrieval processes and attempts to reinstate the study context. They further argue that the cerebellum activation reflects processes involved in error detection. It is important to note that this study involved use of a blocked test design in which each type of item (old, new, and lure) was presented together, as required in PET research. There is some evidence that differences between true and false recognition are specific to this type of design (c.f. Johnson et al., 1997; Schacter, Buckner, Koutstaal, Dale, & Rosen, 1997).

To further investigate the hemodynamic response associated with false recognition, Schacter et al. (1997) conducted another study using event-related fMRI. Here, they had the advantage of using a standard mixed design for the test lists and could compare their results with the blocked design used in the Schacter, Reiman et al. (1996) PET study. Schacter et al. (1997) found significant blood flow increases for both true and false recognition in the anterior prefrontal cortex. Time course analysis showed that true and false recognition were characterized by nearly identical hemodynamic response

curves. False recognition was associated with increased blood flow to the prefrontal cortex relative to correct recognition, but only in the blocked condition. Schacter et al. (1997) conclude that this prefrontal activity is likely associated with post-retrieval evaluation processes.

Overview of Current Study

The current study further examines the role of perceptual fluency, and modality specific information in particular, in recognition memory processes. Using the standard D/RM paradigm, the presentation modality of study lists was manipulated between participants, such that some participants viewed study items and other participants heard study items. The recognition test was presented visually, and ERP data was collected from the time of stimulus onset during the recognition test. Based on past research (Gallo et al., 2001; Smith & Hunt, 1998), the overall rate of false recognition should be higher for the auditory study condition than for the visual condition. If perceptual fluency contributes to recognition judgments, then ERPs for hits versus false alarms should differ in the visual study condition but not the auditory study condition. This effect would presumably have an early manifestation, given evidence that modality effects occur early in time-course analyses of recognition memory (Mulligan & Hirshman, 1995), and the suggestion that the FN400 component indexes familiarity processes (Curran, 2000). In addition, if the parietal old/new effect indexes recollection, as suggested by the literature, then there should be no ERP differences as a function of modality, but differences between lure items and old items, such that old items yield a robust parietal old/new effect but lure items do not. Finally, if post-retrieval evaluation processes involve access to the initial perceptual representation of items, one would expect differences in late-

onset frontal activity associated with false alarms to lure items as a function of presentation modality, such that participants engage in a more effortful search for a perceptual representation in the visual presentation condition relative to the auditory presentation condition.

Chapter 2 - Methods

Participants

The participants were 36 volunteers from Colorado State University between the ages of 18 and 23 ($M = 18.76$), 26 of whom were male. All participants were non-smokers and were screened for right-handedness, normal or corrected vision, normal or corrected hearing, and no past history of brain injury or psychiatric conditions. All participated as partial fulfillment of a requirement for an introductory psychology course. Of the original 36 participants, 15 (9 males) were not included in the ERP analysis due to excessive artifacts as defined in the “Apparatus” section below. Only participants who contributed a total of 100 or more trials with at least 15 false alarms to lures were included to ensure each participant contributed sufficient data to the analysis (Picton et al, 2000).

Stimuli

For the study phase of the experiment, the 36 lists from the Stadler, Roediger, & McDermott (1999) norms were used. Three additional associates from each list were used as lure items to increase the number of lures to four per list. The list and lure items are presented in Appendix 1. Following the method used by Curran et al., (2001) and Duzel et al. (1997) this greatly increases the number of opportunities for false alarms. In most cases, the top three associates were selected as additional lures, but for some lists, items further down the list were used when judged to be more directly associated to the remaining list items (see Curran et al., 2001). The recognition test phase included the four lures from each list; the first, fourth, eighth and twelfth items from each list; and 144 new unrelated words, for a total of 432 test items. For the auditory presentation

condition, each study word was recorded using a microphone and the Windows '98 sound recorder utility. Each item was spoken clearly and digitized at a rate of 22,050 Hz in 8 bit mono sound and saved in the wav audio format. For the visual presentation condition, each item was presented in the center of the screen in 24-point Arial font in black letters on a white background.

Apparatus

All study and test stimuli were presented using a Dell Dimension XP personal computer using E-Prime 1.0. EEG data was recorded during the test phase using a 32 channel Neuroscan amplifier and a second Dell Dimension XP. All electrodes were left mastoid referenced and placed using an E-net 24 channel cap with the Hydrodot biogel electrodes. Using the international 10-20 system, EEGs were recorded from FP1, FP2, F3, F4, F7, F8, C3, C4, P3, P4, T3, T4, T5, T6, O1, O2, Fz, Pz, and Cz. Each ERP epoch was triggered 100 ms prior to the onset of a test stimulus on the screen and was recorded for 1500 ms post-stimulus onset. Analog EEG signals were band-pass filtered .01 to 250 Hz and digitized at a rate of 1000 Hz. Resulting epochs were base-line corrected with respect to the pre-stimulus recording interval. There was an equipment malfunction in the recording from T6, therefore the data from both T5 and T6 were dropped from further analysis. To remove the effect of eye movements or blinking, sites F7 and F8 were used for artifact rejection, with any trial exceeding 70 μ V rejected.

Procedure

Upon arrival, each participant signed an informed consent form and then filled out a standard questionnaire to ensure that they met the criteria for the study as outlined in the Participants section. The participants were then given a brief description of the

electrode application process. Electrode application then proceeded with each participant fitted with the appropriate E-net for their head circumference. Upon completion of electrode application, all sites were tested to ensure that the impedance was below 50 k . The participant was then seated in an EEG recording room. Participants sat approximately 1.5 m from the screen on which instructions and stimuli were presented. For the auditory condition, speakers were placed approximately 0.5 m on each side of the participant. Once the participant was seated, they were instructed via text on the screen and by the experimenter that they would be presented with a series of word lists and that they should try to remember as many items as possible for a later memory test. At the beginning of each list the participant saw (or heard, in the case of the auditory condition) a message stating, "Get ready for the next list." Then the lists were presented in random order for each participant, with the items within each list presented in order of strongest to weakest associate. For the visual condition each item was presented for 750 ms on the computer screen, which was the average presentation time for the auditory condition. For both conditions there was 1 s between study items.

At the end of the study phase, the participant was taken back to the control room to adjust any electrodes that no longer showed an impedance reading below 50 k . At this point, the EEG recording was started. The participants were then shown their on-line EEG recordings in order to educate them about the methodology involved as well as the importance of sitting still and refraining from blinking during recorded trials. The participant was asked to sit still and then blink to demonstrate this effect. The participants were then returned to the EEG recording room to begin the test phase of the experiment.

For the test phase, participants responded using a four-button response box, with one button labeled “old” and another labeled “new.” Each participant responded with their right hand using their middle and index fingers. The participants were then instructed by the experimenter and via text on the screen that they would be presented with a series of words, some of which appeared on the previous lists, some of which were new. They were told that when the item was presented they should try to remember if the item was old or new, but not to respond until cued to do so. They were also instructed to minimize any movement and to avoid blinking during this time, but that they would be given the opportunity to move and blink after each trial. Each test trial began with instructions to blink, then press any button when ready to continue. Then a fixation point was presented for 500 ms, followed by the test word for 2 s. Test items were presented in 24 point Arial font in the center of the screen. The participant was then cued to respond “old” or “new.” During the test phase, participants’ responses and EEG patterns were monitored to insure compliance with the instructions. Following the test phase, the E-net was removed and participants were debriefed.

Chapter 3 - Results and Discussion

Statistical Analyses

All analyses were conducted with an alpha level of .05. Average amplitudes were analyzed using analyses of variance (ANOVAs). All ANOVA results were corrected for non-sphericity using the Greenhouse-Geisser procedure.

Behavioral Results

The proportions of correct responses for each item type were submitted to a 2 x 3 (Modality x Item Type) mixed analysis of variance (ANOVA), with presentation modality a between-participants factor and item type a within-participants factor. Data from all participants was included in this analysis (but note that comparable results were found using the data from the 21 participants included in the ERP analysis). Although there was no main effect of presentation modality, $F(1,33) = 1.65$, $MSE = .017$, there was a significant effect of item type, $F(2,66) = 13.03$, $MSE = 0.17$, $p < .001$, such that performance was best for 'new' items ($M = 0.66$, $SD = 0.15$), followed by 'old' items ($M = 0.61$, $SD = 0.13$) then 'lure' items ($M = 0.50$, $SD = 0.14$). This main effect of item type was qualified by a significant interaction with modality, $F(2,66) = 5.22$, $p < .01$. Planned comparisons revealed a significant difference between modalities for lure items but not for the other item types. Figure 1 plots this data as it is typically presented in the false recognition literature, with the proportion of "old" responses plotted as a function of item type, and this figure reveals a higher rate of false recognition in the auditory condition than in the visual condition.

The overall pattern in which visual study produced lower levels of false recognition than auditory study is consistent with past findings. Past research has shown

that the rate of false recognition is highest with an auditory study and visual test combination (Cleary & Green, 2002; Gallo et al., 2001; Smith & Hunt, 1998; see also Maylor & Mo, 1999). It is also worth noting that veridical recognition did not improve by matching study and test modality: the hit rate was actually nominally better for the auditory-visual condition than the visual-visual condition. In the false recognition literature, however, the data is mixed on this issue: some studies have found a benefit of matching modality on hit rates (Cleary & Greene; Gallo et al.) but others have not (Maylor & Mo; Smith & Hunt).

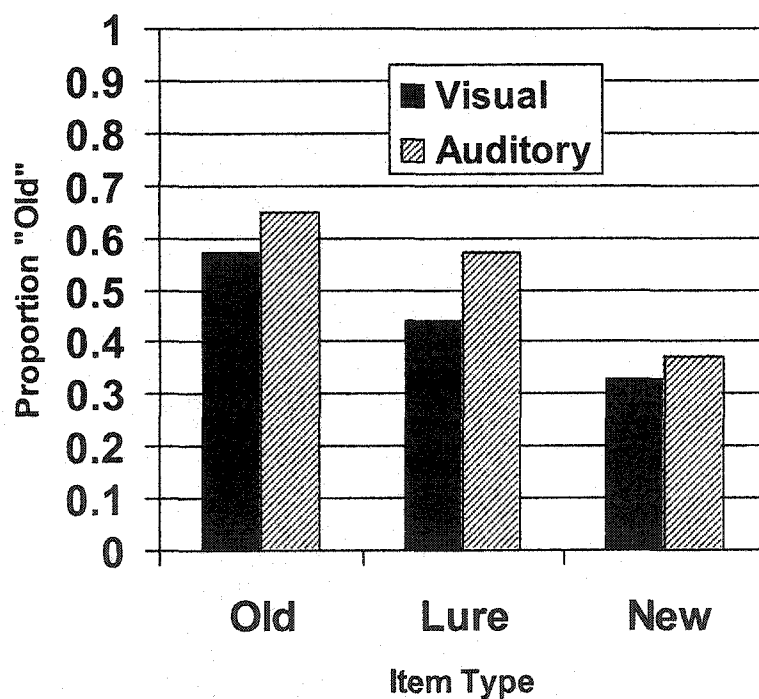


Figure 1: Proportion of "old" responses by for each modality and item type

ERP Component Analyses

Several specific ERP components/effects were examined as a function of study modality (auditory vs. visual) and item type (hits to old items vs. false alarms to lures): the P300, FN400, parietal old/new effect, and late frontal effect. As described in Chapter 1, the P300 component has been directly linked to false recognition (Miller et al., 2001). In addition, FN400, parietal old/new and late frontal differences have been associated with various recognition memory processes, as well as the phenomenon of false recognition (c.f. Curran et al., 2001). In order to visually examine ERP effects, ERPs are plotted for each condition. ERPs for hits versus false alarms to lure items are shown for the visual and auditory conditions in Figures 2 and 3, respectively. ERPs for hits as a function of modality are shown in Figure 4, with false alarms to lure items compared in Figure 5.

P300 Effects. Although there were no a priori hypotheses pertaining to P300 effects, this component was examined because it was the focus of a past study on false recognition (see Miller et al., 2001). Possible P300 amplitude differences were analyzed by computing the peak amplitude within the 200 to 300 ms time window for each participant, then submitting this data to a 2 x 2 x 15 (Modality x Item Type x Site) mixed ANOVA. The effect of electrode site was significant, $F(14, 285) = 11.76, p < .001$, but did not interact with the variables of interest ($ps > .10$). This analysis revealed main effects of modality, $F(1, 285) = 43.81, p < .001, MSE = 17.62$, and item type, $F(1, 285) = 46.02, p < .001, MSE = 7.31$. Mean peak amplitudes (μV) were greater for false alarms ($M = 7.61$) than for hits ($M = 6.13$) and were greater in the visual condition ($M = 8.03$) than the auditory condition ($M = 5.81$). In addition, there was a marginally significant

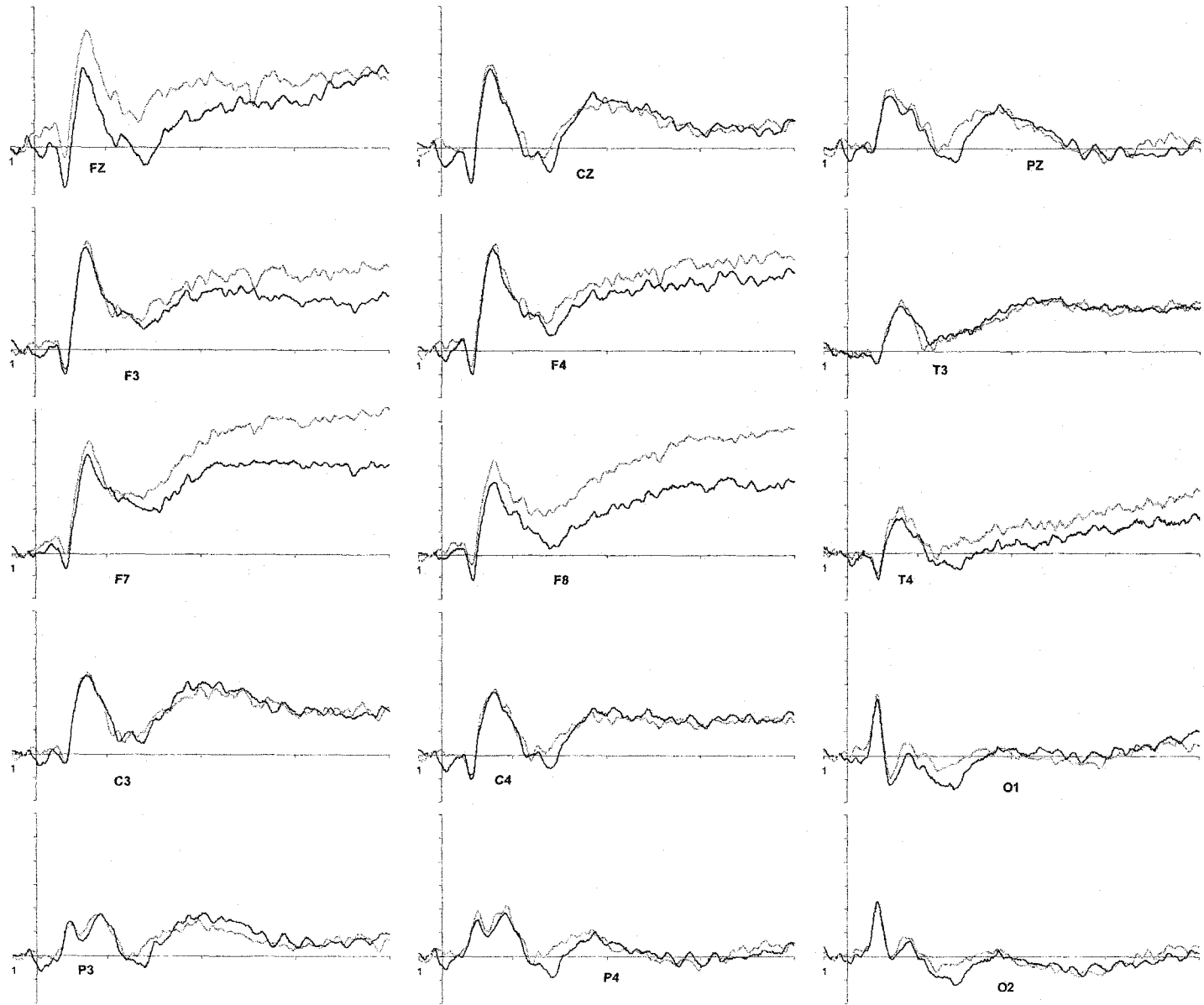


Figure 2: ERPs for Visual Condition; Darker lines – hits; Lighter – false alarms. For all ERP figures, each tic mark on the y axis represents 2 μ Volts and crosses at stimulus onset. For the x axis, each mark is 400 ms starting at -100 ms.

Figure 3: ERPs for
 Auditory Condition:
 Hits -darker lines;
 False alarms -
 lighter lines.

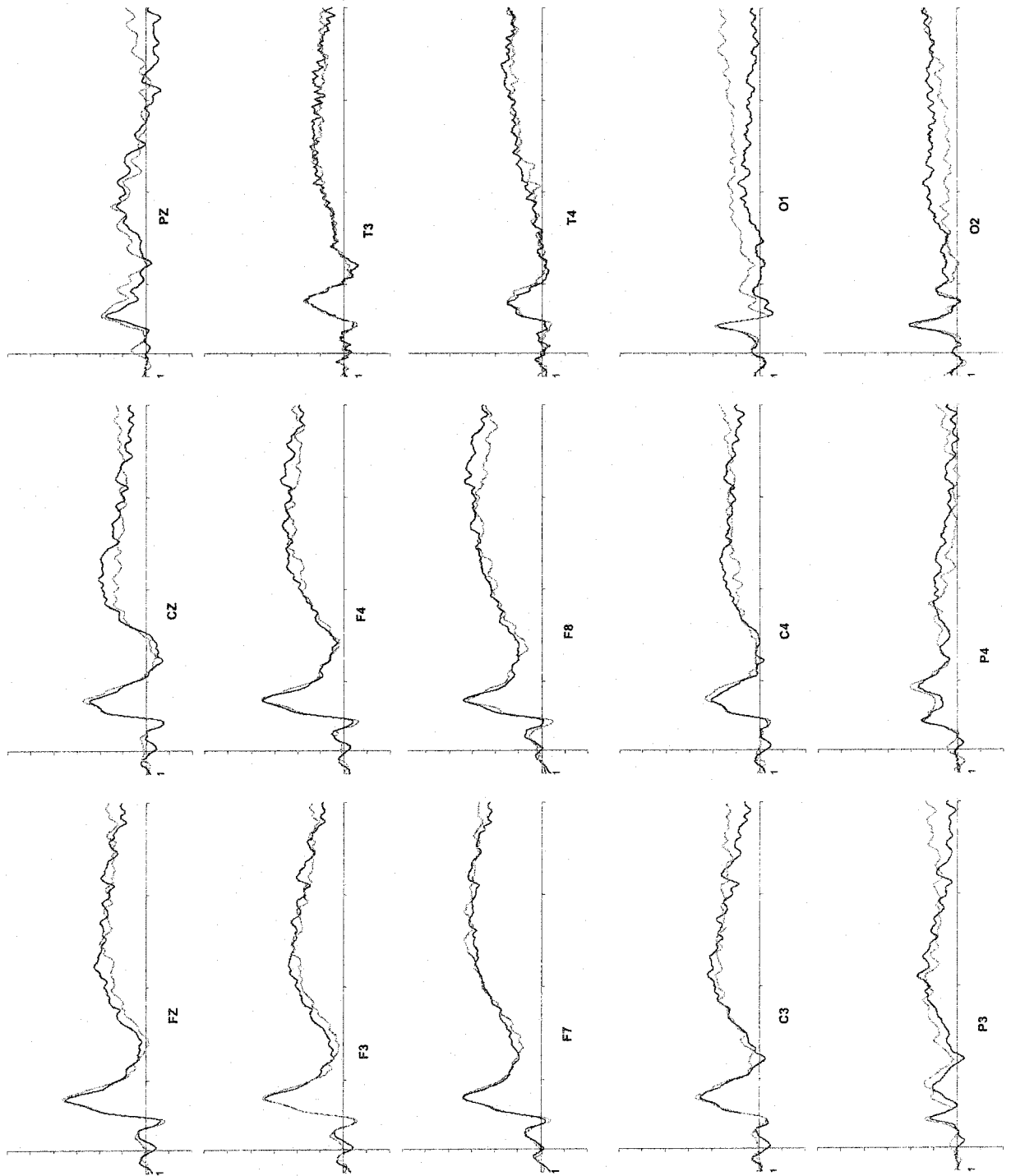


Figure 4: ERPs
for hits. Visual –
Darker Lines;
Auditory –
Lighter Lines.

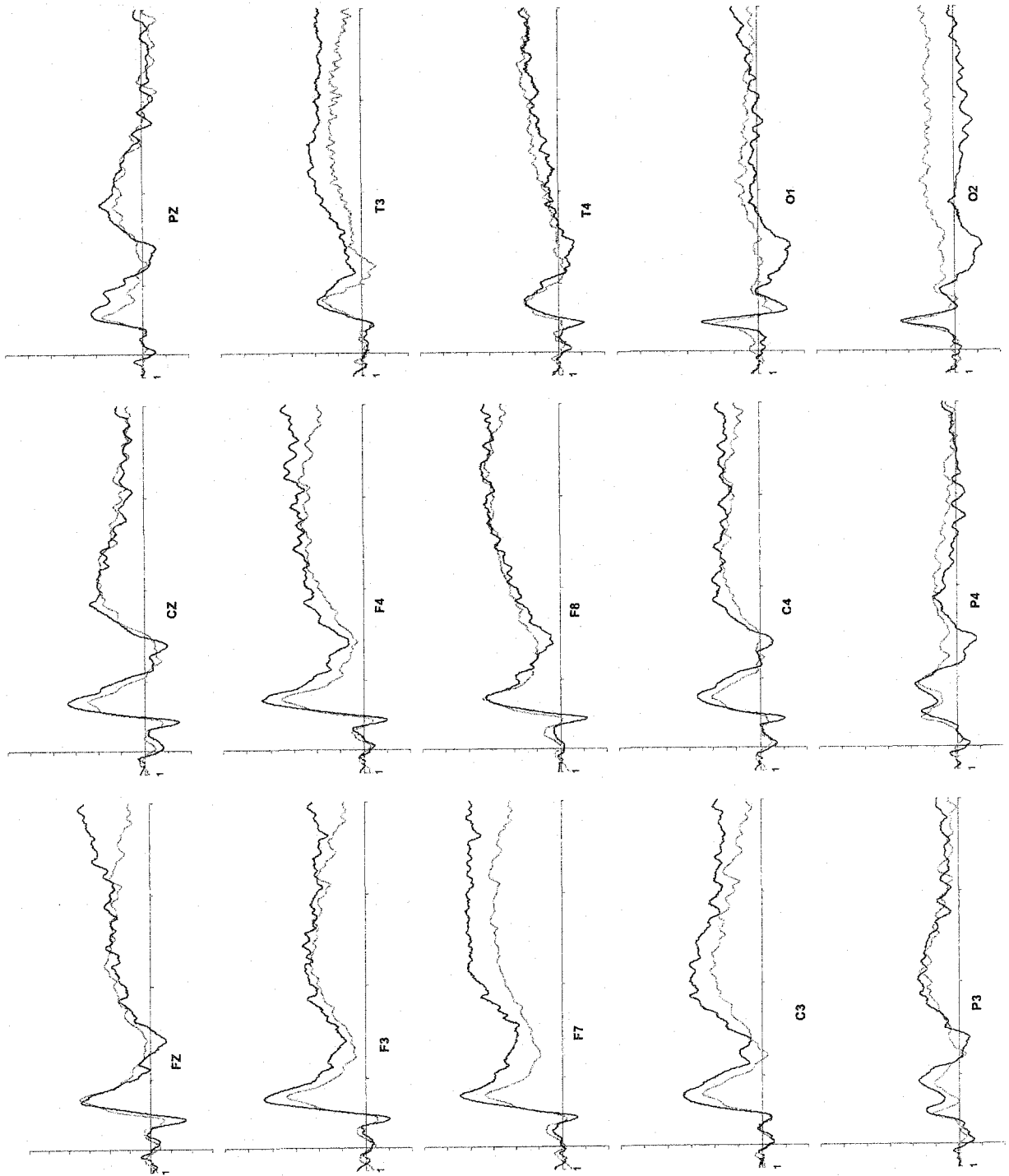
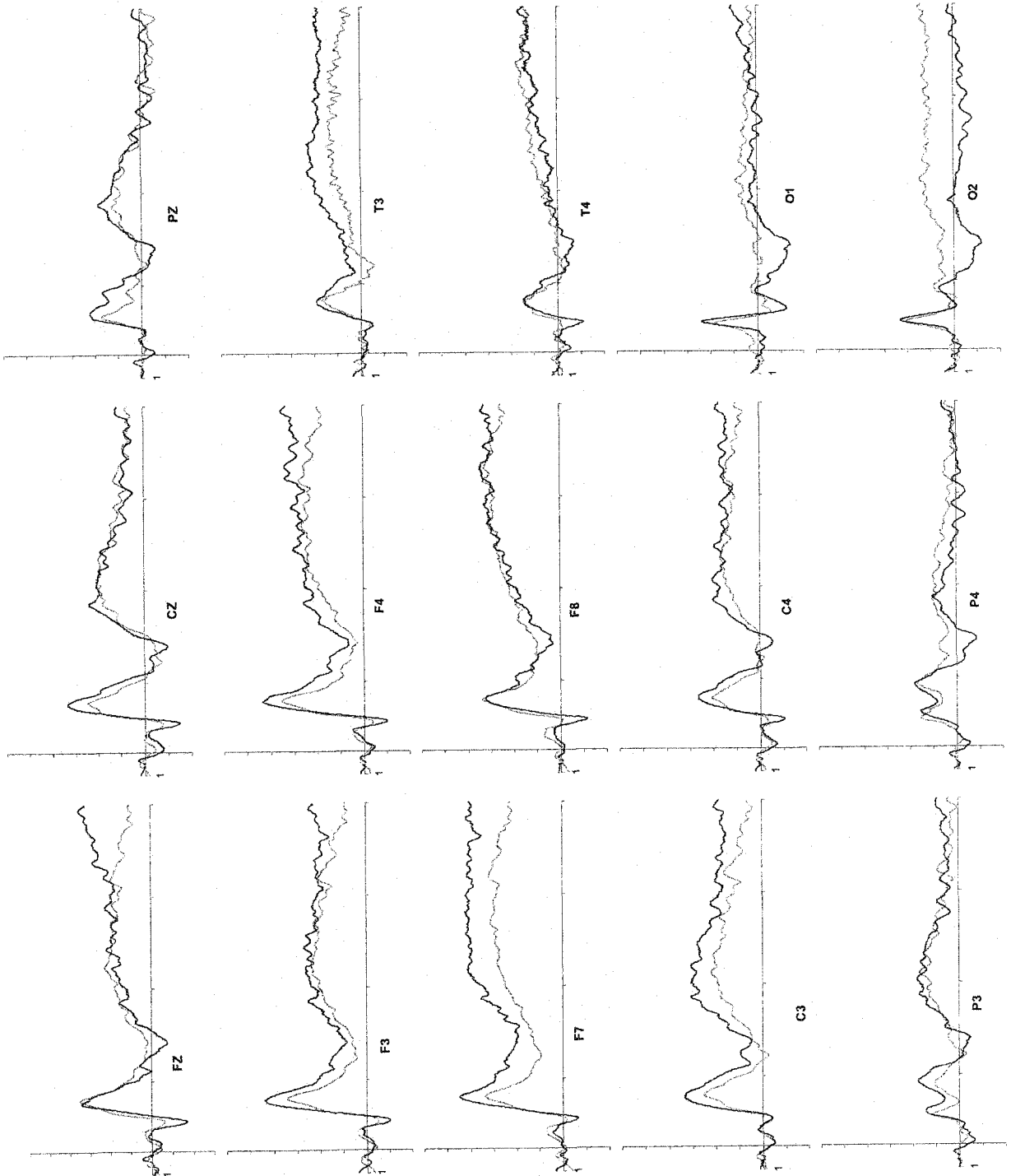


Figure 4: ERPs
for hits. Visual –
Darker Lines;
Auditory –
Lighter Lines.



interaction between modality and item type, $F(1,285) = 3.01, p = 0.08$, as shown in Figure 6.

Miller et al. (2001) specifically examined P300 amplitude and latency in the D/RM paradigm and found no difference in amplitudes between hits and false alarms using a visual study-visual test design. This is inconsistent with the data presented here, in which false alarms produced greater peak amplitudes than hits in both modality conditions. Note, however, that Miller et al. used a recognition test that was designed to elicit the traditional 'oddball' P300 by making old items and lures relatively rare within the context of the test list. Thus, the uniqueness of the items relative to new items may have produced P300 responses that obscured possible differences as a function of item type. In the present study, old, lure and new items occurred with the same probability, such that P300 effects were unlikely to be driven by item probability. Under these conditions, P300 amplitude differed as a function of item type.

Other research has found that the amplitude of the P300 is related to the processing resources demanded by a task (Fabiani, Gratton & Coles, 2000) as well as the mnemonic strategy employed by participants (Fabiani, Karis & Donchin, 1990). The P300 effects observed here fit well within this body of research. For the main effect of modality, participants may have used a strategy involving a search for visual representations for the visual study condition but not the auditory study condition. Regarding the main effect of item type, some have suggested that lure items attract more processing resources than old items (see Curran et al., 2001). If lure items are associated with allocation of additional processing resources, then following from Fabiani et al. (2000), one would expect larger P300 amplitudes for lure items than old items.

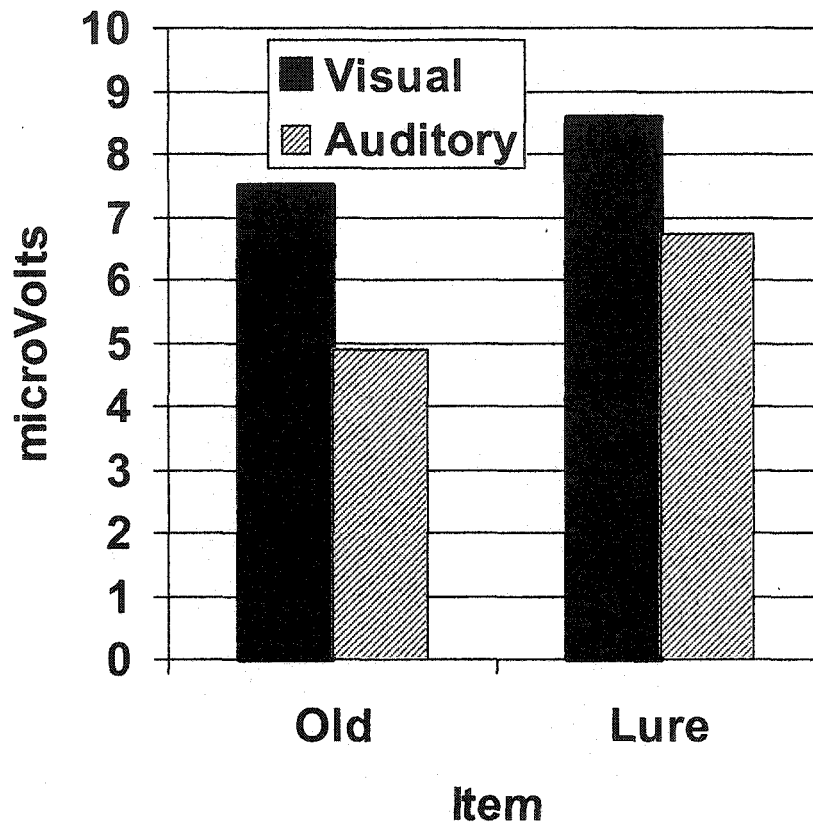


Figure 6: Mean peak amplitude for each modality and item type between 200 and 300 ms, showing higher P300 amplitudes for the visual condition and lure items.

FN400 Effects. To determine whether there were any effects related to the FN400 component, a 2 x 2 x 15 (Modality x Item x Site) ANOVA was conducted for the 300 to 499 ms time frame. Main effects of modality [$F(1,285) = 28.48, p < .001, MSE = 21.49$], item type [$F(1,285) = 12.50, p < .001, MSE = 9.90$], and site [$F(14,285) = 2.37, p < .01, MSE = 21.49$] were found. No factor interacted with site, indicating general trends for higher amplitudes (μV) in the visual condition ($M = 1.20$) than the auditory condition ($M = 0.25$), and for false alarms ($M = 0.81$) over hits ($M = 0.63$). However, these main effects were qualified by a significant Modality x Item Type interaction, $F(1, 285) = 69.32, p < .001$, such that in the visual study condition there were higher

amplitudes for false alarms ($M = 1.69$) than hits ($M = .69$), but in the auditory condition, higher amplitudes for hits ($M = .92$) than false alarms ($M = -.42$).

The results presented above are only partially consistent with the view that perceptual fluency contributes to the early familiarity processes indexed by the FN400. As outlined in Chapter 1, the perceptual fluency view predicts that there would be a significant difference in the FN400 for hits versus false alarms in the visual study condition, but no difference between hits and false alarms in the auditory study condition. The observed difference between hits and false alarms in the visual study condition is consistent with the predicted pattern. However, a difference between hits and false alarms was also observed in the auditory condition (but note that the pattern was opposite to that found in the visual condition). This difference in the auditory condition is not only inconsistent with the perceptual fluency view, it is also inconsistent with the results of Curran et al. (2001), which showed no FN400 difference for hits versus false alarms using an auditory study – visual test protocol.

Parietal Old/New Effect (400 to 800 ms). To compare the results here with those found by Curran et al. (2001) and Curran (2000), data from sites PZ, P3 and C3 were analyzed to measure left parietal effects. A $2 \times 2 \times 3$ (Modality x Item Type x Site) ANOVA was conducted using data from the 400 to 799 ms time window. No main effects of modality [$F(1,57) = 3.09, p = .08, MSE = 50.14$], item type [$F(1,57) = 2.85, p = .09, MSE = 10.05$], or site [$F(2,57) = 2.19, p = .12, MSE = 50.14$] were found. However, a significant Modality x Item Type interaction was obtained, $F(1,57) = 4.76, p < .05$. In the auditory condition, amplitudes (μV) associated with lures ($M = .97$) were lower than responses to hits ($M = 2.06$; note that Curran et al. found the opposite pattern,

but this is due to the use of a vertex reference, where here a mastoid reference was used). There was no difference between responses to hits and false alarms in the visual condition ($M = 2.55$ and 2.69 , respectively).

Curran (2000) identified parietal effects that were associated with recollective processes. He found that over the 400 to 800 ms time window, left parietal voltages were significantly higher for correctly recognized items (hits to items given in the same plurality as study, assumed to require recollective processes) than for incorrectly recognized items (false alarms to items in a different plurality from study, assumed to reflect familiarity based processes). Curran et al. (2001) also examined this parietal effect for good and poor performers in a D/RM false recognition paradigm and found significant differences between hits and false alarms to lures, but only for only poor performers. They argued that poor performers based their recognition judgments on the initial retrieval attempt, whereas good performers base their judgments on the results of post-retrieval evaluation processes. As such, the ERPs for poor performers are thought to be related to recollection processes in the case of hits but familiarity processes in the case of false alarms.

In the results found here, there was no parietal ERP effect for participants in the visual presentation condition. However, false alarms to lures yielded lower amplitudes than hits in the auditory condition. Following the logic of Curran et al. (2001), it may be the case that in the visual condition, participants based their recognition judgments on the results of a post-retrieval evaluation of the retrieved information (see Late Frontal Effects section below for further elaboration of this view). In the auditory condition, on the other hand, participants may have based their recognition judgments primarily on the initial

retrieval attempt, with hits reflecting recollective processes but false alarms reflecting familiarity processes. Note that this may also explain the consistent finding that the rate of false recognition is higher in studies using auditory study conditions.

Late Frontal Effects (1000 to 1500 ms). To assess late frontal effects that have been found elsewhere, data was analyzed for sites F3, F4, F7, and F8 using a 2 x 2 x 4 (Modality x Item Type x Site) ANOVA. There was no main effect of site, $F(1,76) = 1.45, p = .24, MSE = 291.88$, and no interactions with this variable ($ps > .60$). A main effect of study condition was found, $F(1,76) = 11.61, p = .001, MSE = 291.88$, with amplitudes significantly higher in the visual ($M = 7.73$) than auditory ($M = 3.70$) study condition. There was no main effect of item type, $F(1,76) = 1.58, p = .21, MSE = 100.39$. The main effect of modality was qualified by a significant interaction with item type, $F(1,76) = 11.35, p = .001$. Planned comparisons were conducted to assess the nature of this interaction and all pair-wise comparisons were significant. The mean amplitudes were ordered as follows: auditory-false alarms ($M = 2.97$) < auditory-hits ($M = 4.43$) < visual-hits ($M = 6.12$) < visual-false alarms ($M = 9.32$).

In previous ERP studies, late frontal effects have been associated with post-retrieval evaluative processes (Curran et al., 2001; Wilding & Rugg, 1997a, 1997b). Comparable results have been obtained in functional neuroimaging studies (Schacter, Reiman et al., 1996), including event-related fMRI studies (Henson et al., 1999; Schacter et al., 1997). Therefore, one possible interpretation of the results presented here are that participants are engaging in more post-retrieval evaluation in the visual study condition than in the auditory study condition. This may be due to participant's search for a matching perceptual representation in the visual condition. That is, when items are

presented visually at both study and test, participants may be attempting to match the perceptual information of the test stimulus with a stored perceptual representation. When there is a mismatch between study and test modality, participants would presumably be less likely to use modality-specific perceptual information as the basis for their judgments.

Note that Schacter and colleagues (Schacter et al., 2001; Dodson & Schacter, 2001) also proposed that lure items are subjected to more intense post-retrieval evaluation than old items. This evaluation might be especially intense for lure items in the visual condition because the lure items have a strong sense of semantic familiarity and because participants try to reconcile that sense of familiarity by actively searching for a visual representation as the basis for ascertaining whether the item was presented

Chapter 4 - General Discussion

The goal of this experiment was to investigate the role of modality specific information in recognition memory processes. Several key findings emerged from the results. First, study modality affected familiarity processes as indexed by the FN400, but the specific pattern of results offer only mixed support for the perceptual fluency view. Second, study modality also affected recollective processes as indexed by the parietal old/new effect, possibly due to different strategy use as a function of modality. Third, several ERP effects suggest that the modality of study is important for recognition memory processes, not because of perceptual contributions to familiarity, but instead because modality encourages different retrieval strategies. Finally, several ERP components differ for true versus false recognition, but these differences appear to be at least partially dependent on the retrieval strategy induced by study modality.

Modality Specific Information and Familiarity Processes

It is generally assumed that familiarity-based processes occur early in recognition. This assumption is based research suggesting that familiarity is a faster process than recollection (Jacoby, 1991), as well as speed-accuracy tradeoff studies which show participants are able to make familiarity-based recognition memory judgments very quickly, whereas recollection requires additional retrieval time (Hintzman & Curran, 1994). Familiarity effects tend to occur primarily in frontal areas, as shown in both ERP (Curran, 2001; Rugg, Mark et al, 1998) and event-related fMRI (Henson et al, 1999) studies. In ERP research, the FN400 component, in particular, has been associated with familiarity-based processes (Curran, 2000).

One of the key questions considered here is the role of modality specific information (or perceptual fluency) in familiarity-based recognition processes. If modality specific information is used to support familiarity processes, then there should be a difference in the FN400 for hits to old items versus false alarms to lure items in the visual study condition. The idea is that for the visual study condition, perceptual fluency (i.e., access to modality specific information) could potentially contribute to familiarity for hits (for which there is a sensory signature) but not false alarms (for which there is not a sensory signature). One can not use modality specific information as the basis for discriminating old versus lure items in the auditory study condition, on the other hand, so one would not expect an FN400 difference for hits versus false alarms in this condition.

The present results are only partially consistent with the perceptual fluency view. As predicted, a significant difference between hits to old items and false alarms to lure items was observed in the visual condition. However, a difference was also observed in the auditory condition, albeit in the opposite direction. In the auditory condition, neither old items nor lure items have a prior visual representation associated with them, so they should have equal status with regard to perceptual fluency. This finding suggests that there is more to familiarity than perceptual fluency, at least for auditory study – visual test protocols.

Modality Specific Information and Recollection

Whereas the FN400 appears to be associated with familiarity, a variety of studies indicate that the parietal old/new effect is associated with recollection processes. Curran (2000), for example, found that ERPs for old items were more positive than those for new items over parietal sites in the 400-800 ms time window. Curran argues that this

difference reflects the recollection of specific episodes in the case of old items but not similar items. Based on such findings, the prediction here was that parietal old/new effects would be observed for old versus lure items regardless of presentation modality. Although the parietal old/new effect was observed for the auditory study condition, no difference was obtained in the visual condition.

A post-hoc explanation of this pattern is that in the auditory study condition, participants made their old/new judgments based on the results of their initial retrieval attempt, whereas in the visual condition, judgments were based on post-retrieval evaluation processes. Recall that Curran et al. (2001) observed a parietal old/new effect for old items versus lures, but only for poor performers. They argued that poor performers differentiated the items based on the initial retrieval attempt, with old items associated with recollection, but lure items associated with familiarity. Good performers, on the other hand, were argued to have made their judgments based on extensive post-retrieval evaluation, such that correctly recognized old items were associated with both recollection and familiarity. Old items and lure items could not therefore be differentiated based on the use of recollection versus familiarity processes, respectively.

Applying this logic to the current study, participants in the auditory study condition may have based their judgments on the initial retrieval result, with hits to old items associated with recollection processes, but false alarms to lures associated with familiarity. Participants in the visual study condition may have instead based their judgments on the results of post-retrieval evaluation, such that recollection versus familiarity were not differentially associated with old items and lure items, respectively. In this latter case, the presence of distinctive visual information that could be used to

distinguish old items from lure items may have encouraged more extensive post-retrieval evaluation.

Presentation Modality and Strategy Use

Whereas the FN400 and parietal old/new effect have been associated with familiarity and recollection processes, respectively, late frontal ERP effects seem to be associated with post-retrieval evaluative processes (Curran et al., 2001; Johnson et al., 1996; Wilding & Rugg, 1997a, 1997b; Wilding, 1999). The present study revealed larger frontal ERP amplitudes in the 1000-1500 ms time window for the visual study condition than the auditory study condition, suggesting that participants are engaging in more post-retrieval evaluation in the visual condition. One possibility is that in the visual study – visual test condition, participants are engaging in an extensive search in which they try to match the perceptual information of the test stimulus with a stored perceptual representation. Given that the frontal ERP effect is larger for false alarms than hits in the visual condition, this search may be most extensive when lure items are presented at test. Participants may be attempting to reconcile the semantic familiarity of lure items by searching for a visual representation of the lure item from the study episode.

Other findings also suggest that presentation modality affected strategy use. As described in the preceding section, the pattern of parietal old/new effects may reflect greater reliance on post-retrieval evaluation processes in the visual condition than the auditory condition. The P300 results are also consistent with the idea that there is a difference in strategy use for the auditory versus visual study conditions. Past research shows that the P300 is related to the mnemonic strategy employed by participants

(Fabiani et al., 1990), and the present data reveal that the amplitude of the P300 was greater for the visual study condition than the auditory study condition.

Overall, then, it appears that presentation modality affects the retrieval strategy employed by participants in the D/RM paradigm. Participants in the visual study condition (for which there is a match between study and test modalities) appear to be engaging in effortful, post-retrieval evaluation in which they attempt to match the perceptual information of the test stimulus with stored perceptual representations. Participants in the auditory study condition, on the other hand, appear to base their recognition judgments on initial recollection and familiarity processes. Note that this may be related to the unexpected reversal in the FN400 effect in going from the visual to auditory study condition. The strategy differences across study conditions may encourage the use of different familiarity processes, although the nature of these different familiarity processes is unclear based on the present data.

Although the finding that participants seem to use different retrieval strategies depending on task conditions complicates the study of the underlying retrieval processes in false recognition, the present results are informative in evaluating extant accounts of false recognition. Explanations for the false recognition effect fall into two general frameworks—source monitoring theory and fuzzy-trace theory. The source-monitoring framework holds that participants confuse the source of memorial information at the time of retrieval (c.f. Johnson et al., 1993 for review). By this account, participants misattribute automatic processes at the time of study as reflecting the retrieval of a presented item. Fuzzy-trace theory posits that true recognition arises from access to verbatim traces, while false recognition arises from retrieval of only the semantic gist of

lure items (c.f. Brainerd et al., 1995). The present finding that participants engage in different retrieval strategies based on presentation modality fits best with the source-monitoring framework. Participants appear to have engaged in significant post-retrieval evaluation, as shown by the ERP results as well as the reduced rate of false recognition in the visual condition, indicating participants may be searching for the source of a memory trace. If false recognition arose solely from gist comparisons then there would be no reason to expect a difference between study modalities for ERPs associated with false recognition.

Distinctiveness in Recognition Memory

One way to interpret differences in strategy use as a function of modality is based on distinctiveness or diagnosticity. A variety of research points toward the use of modality specific information in recognition memory only when it is diagnostic (e.g. Kelley et al., 1989) or useful in making recognition judgments (Reder et al., 2002). It appears that modality specific information may be more diagnostic when items are studied visually than when they are studied auditorally. False recognition in the D/RM paradigm is generally thought to arise from an implicit associative response during study, such that participants internally generate the lure item as a response to list items. This associative response appears to be more robust in the case of heard items. Mather et al. (1997) found that participants associated lure items with the same voice used to present list items. In addition, Roediger and McDermott (1995) found that for heard lists, participants were equally confident in their recognition judgments for false alarms to lure items and hits to old items, and were just as likely to report false alarms and hits as being "remembered" rather than "known." If the implicit associative response is more robust

for heard items than seen items, then modality specific information would be less diagnostic in discriminating old items from lure items in auditory study conditions than in visual study conditions.

Dodson and Schacter (2002) have recently proposed that participants may use a distinctiveness heuristic when retrieving items in the D/RM paradigm. They suggest that a metacognitive process operates during retrieval such that participants expect to retrieve detailed information about previously presented items, and when such details are absent, they tend to label an item as being new. They argue, however, that this heuristic is used only when retrieved information is diagnostic of prior study.

The behavioral evidence seems to converge, then, on the idea that recognition processes vary depending on what information is useful in distinguishing new items from old items. In the present study, it appears the participants used different retrieval strategies in the auditory versus visual presentation conditions. Several ERP effects point to a difference in retrieval strategy across modalities. First, P300 amplitudes were larger in the visual condition than the auditory condition, which is consistent with previous research showing P300 differences with changes in retrieval strategy (Fabiani, Karis & Donchin, 1990). Second, a parietal old/new effect was observed in the visual but not auditory condition, suggesting participants may have based their recognition decisions on initially retrieved information in the auditory study condition, but used post-retrieval evaluative processes to make these decisions in the visual study condition. Finally, late frontal ERP amplitudes were larger for the visual condition than the auditory condition (and were largest for lure items presented visually). As discussed in previous sections, late frontal differences have been associated with post-retrieval evaluative processes

(Curran et al., 2001; Curran, 2000; Wilding & Rugg, 1997a, 1997b) as well as source-monitoring (Johnson, Kounios & Nolde, 1996; Wilding, Doyle & Rugg, 1995), therefore these results are consistent with the idea that participants are more likely to engage in an intensive search for an item's original perceptual representation in the visual condition than the auditory condition. These arguments fit well with the distinctiveness view, given that modality specific information is diagnostic to an item's old/new status in the visual condition but not the auditory condition. The interpretation offered here is that when modality specific information is diagnostic, participants engage a more effortful retrieval strategy, attempting to match the test item with the original perceptual representation that was formed at study.

ERP Signatures of False Recognition

As described above, there were several ERP differences that distinguished veridical recognition from false recognition. First, P300 amplitudes were larger for false alarms to lure items than for hits to old items regardless of study modality. Although past research did reveal a difference in P300 latency for true versus false recognition, this research did not show a difference in P300 amplitude (Miller et al., 2001). Note, however, that the Miller et al. protocol was designed to elicit the traditional 'oddball' P300 by making old items and lures relatively rare within the context of the test list. Thus, the uniqueness of the items relative to new items may have produced P300 responses that obscured differences as a function of item type, although additional research is needed to test this supposition. Should P300 amplitude differences prove to be reliable, it may be the case that lure items attract additional processing resources at the time of test, as suggested elsewhere (Curran et al., 2001; Fabiani et al., 2000). It is also

possible that old items are associated with lower amplitudes because they have been recently experienced by participants (see Fabiani et al., 2000 for review).

A second difference in the ERPs associated with true versus false recognition was observed with regard to the FN400 component. This component has previously been associated with familiarity-based recognition (Curran, 2000). In the present study, amplitudes associated with veridical recognition were similar for both the auditory and visual study protocols. If the FN400 indexes familiarity, this indicates that perceptual fluency is unlikely to be a predominant factor in familiarity-based, veridical recognition. In addition, the perceptual fluency view would predict a significant difference between veridical and false recognition in the visual study condition but not the auditory study condition. In the visual study condition amplitudes were, in fact, significantly greater for false recognition to lure items. In the auditory condition, amplitudes were lower for false alarms to lure items than for veridical recognition, inconsistent with the perceptual fluency view. Note, however, that a previous study that did not find differences in true and false recognition using auditory study lists (Curran et al., 2001). Further research on the FN400 is needed to resolve this discrepancy.

The ERPs associated with true versus false recognition also differed with regard to the parietal old/new effect. In the auditory study condition, false alarms to lures produced lower amplitudes than hits. There was no parietal effect detected in the visual study condition. Parietal old/new effects have previously been associated with recollection-based recognition memory judgments, with increased amplitudes observed for recollection-based judgments than familiarity-based judgments (Curran, 2000. Curran et al. (2001) examined this parietal effect in a D/RM false recognition paradigm

and found significant differences between hits and false alarms to lures, but only for only poor performers. They argued that poor performers based their recognition judgments on early retrieval attempts, whereas good performers base their judgments on the basis of post-retrieval evaluative processes. The parietal ERPs for poor performers are therefore thought to be related to recollection processes in the case of hits but familiarity processes in the case of false alarms.

In the results presented here, participants in the auditory study condition may have based their recognition judgments on initial retrieval attempts, with hits reflecting recollection but false alarms reflecting familiarity-based processes. In the visual study condition, participants may have based their judgments on post-retrieval evaluation, similar to the good participants in the Curran et al. (2001) study. This pattern of results may explain the consistent reduction in the rate of false recognition for visual study protocols.

Finally, the late frontal ERP component also differed for true versus false recognition. ERP amplitudes were greater for false recognition than true recognition in the visual study condition, but lower for false recognition than true recognition in the auditory study condition. This late frontal component has previously been associated with post-retrieval evaluative processes. (Curran et al., 2001; Wilding & Rugg, 1997a, 1997b). Based on the results presented here, it is possible that the reduced rate of false recognition for visual study protocols found in this and other studies is due participants engaging in greater post-retrieval evaluation of items. This is especially the case for lure items, as the participant may be attempting to reconcile the strong sense of familiarity for the lure item with a visual record from the study episode.

One of the central themes to emerge from the present study is that ERP differences for true versus false recognition may depend on the strategy used by participants. As described above, the current data suggest that different strategies were used depending on study modality (i.e., the match between study-test modality). It is argued that in visual study condition, participants were more likely to engage an effortful retrieval strategy based on extensive post-retrieval evaluation, in an attempt to match the presented test item with stored perceptual representations. Reflecting this difference in strategy use, ERPs for true versus false recognition differed as a function of modality. FN400, parietal old/new, and late frontal effects all interacted with study modality, in some cases showing a difference for one modality but not the other (parietal old/new effect) and in other cases showing a reverse effect in going from one modality to the other (FN400, late frontal effect).

Previous studies that manipulated variables other than study modality also suggest that ERP differences for true versus false recognition are dependent on strategy use. Johnson et al. (1997) used the D/RM paradigm and included both a random and blocked test design. They observed late ERP differences for true versus false recognition in their blocked condition, but not the random condition. They argued that the random versus blocked conditions encouraged participants to use different evaluative criteria and/or different processes when making their recognition judgments. Other studies have found differences in ERPs which are consistent with these results as well. Most notably, Curran and colleagues (2001) argued that the differences between good and poor performers in their study were the result of differences in retrieval strategy.

Concluding Remarks

The findings of the present study provide evidence that retrieval processes play a key role in the effects of presentation modality on true and false recognition. Although the current results are consistent with the view that modality effects reflect differences in retrieval strategy, additional study is needed to further examine this view. Future research might include speed/accuracy trade-off procedures combined with ERP methods, with the expectation that rapid responses would eliminate post-retrieval evaluation and therefore produce increased false recognition in a visual study condition. Another possibility would be to manipulate the visual distinctiveness of study items, with the prediction that enhanced visual distinctiveness would further reduce false recognition.

On a more general note, the present study illustrates the potential power of ERP procedures for elucidating the underlying processes involved in recognition memory. ERPs can be used to study the temporal dynamics of recognition memory processes with precision that is not possible using traditional behavioral methods. Further research on recognition memory using ERP methodology is clearly warranted.

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Appendix 1

Study lists were selected from the Stadler et al. (1999) norms and are shown below. The first four words in each list served as *critical lure* items that were not studied but were given on the test list. Bold words were studied and served as *old* items on the test list.

Following the study lists are the *new* items that appeared on the test list.

ANGER	ARMY	BLACK	BREAD
MAD	NAVY	WHITE	BUTTER
FEAR	SOLDIER	DARK	FOOD
HATE	MILITARY	DEATH	EAT
RAGE	RIFLE	CHARRED	SANDWICH
TEMPER	AIR FORCE	NIGHT	RYE
FURY	DRAFT	FUNERAL	JAM
IRE	UNITED STATES	COLOR	MILK
WRATH	MARINES	GRIEF	FLOUR
HAPPY	MARCH	BLUE	JELLY
FIGHT	INFANTRY	CAT	DOUGH
HATRED	CAPTAIN	INK	CRUST
MEAN	WAR	BOTTOM	SLICE
CALM	UNIFORM	COAL	WINE
EMOTION	PILOT	BROWN	LOAF
ENRAGE	COMBAT	GRAY	TOAST

CAR	CHAIR	CITY	COLD
TRUCK	TABLE	TOWN	HOT
BUS	SIT	CROWDED	SNOW
DRIVE	LEGS	URBAN	FREEZE
AUTOMOBILE	SEAT	CAPITAL	WINTER
VEHICLE	COUCH	STREETS	ICE
TRAIN	DESK	SUBWAY	WET
JEEP	RECLINER	COUNTRY	FRIGID
FORD	SOFA	NEW YORK	CHILLY
RACE	WOOD	VILLAGE	HEAT
KEYS	CUSHION	METROPOLIS	WEATHER
GARAGE	SWIVEL	BIG	WARM
HIGHWAY	STOOL	CHICAGO	AIR
SEDAN	SITTING	SUBURB	SHIVER
VAN	ROCKING	COUNTY	ARCTIC
TAXI	BENCH	STATE	FROST

<i>CUP</i>	<i>DOCTOR</i>	<i>FLAG</i>	<i>FOOT</i>
<i>MUG</i>	<i>NURSE</i>	<i>BANNER</i>	<i>SHOE</i>
<i>SAUCER</i>	<i>SICK</i>	<i>AMERICAN</i>	<i>HAND</i>
<i>TEA</i>	<i>LAWYER</i>	<i>SYMBOL</i>	<i>TOE</i>
MEASURING	MEDICINE	STARS	KICK
<i>COASTER</i>	<i>HEALTH</i>	<i>ANTHEM</i>	<i>SANDALS</i>
<i>LID</i>	<i>HOSPITAL</i>	<i>STRIPES</i>	<i>SOCCER</i>
HANDLE	DENTIST	POLE	YARD
<i>COFFEE</i>	<i>PHYSICIAN</i>	<i>WAVE</i>	<i>WALK</i>
<i>STRAW</i>	<i>ILL</i>	<i>RAISED</i>	<i>ANKLE</i>
<i>GOBLET</i>	<i>PATIENT</i>	<i>NATIONAL</i>	<i>ARM</i>
SOUP	OFFICE	CHECKERED	BOOT
<i>STEIN</i>	<i>STETHOSCOPE</i>	<i>EMBLEM</i>	<i>INCH</i>
<i>DRINK</i>	<i>SURGEON</i>	<i>SIGN</i>	<i>SOCK</i>
<i>PLASTIC</i>	<i>CLINIC</i>	<i>FREEDOM</i>	<i>KNEE</i>
SIP	CURE	PENDANT	MOUTH

<i>FRUIT</i>	<i>GIRL</i>	<i>HIGH</i>	<i>KING</i>
<i>APPLE</i>	<i>DRESS</i>	<i>LOW</i>	<i>QUEEN</i>
<i>VEGETABLE</i>	<i>DOLLS</i>	<i>CLOUDS</i>	<i>PRINCE</i>
<i>ORANGE</i>	<i>FEMALE</i>	<i>TOWER</i>	<i>CROWN</i>
KIWI	BOY	TALL	ENGLAND
<i>CITRUS</i>	<i>YOUNG</i>	<i>UP</i>	<i>GEORGE</i>
<i>RIPE</i>	<i>PRETTY</i>	<i>JUMP</i>	<i>DICTATOR</i>
PEAR	HAIR	ABOVE	PALACE
<i>BANANA</i>	<i>NIECE</i>	<i>BUILDING</i>	<i>THRONE</i>
<i>BERRY</i>	<i>DANCE</i>	<i>NOON</i>	<i>CHESS</i>
<i>CHERRY</i>	<i>BEAUTIFUL</i>	<i>CLIFF</i>	<i>RULE</i>
BASKET	CUTE	SKY	SUBJECTS
<i>JUICE</i>	<i>DATE</i>	<i>OVER</i>	<i>MONARCH</i>
<i>SALAD</i>	<i>AUNT</i>	<i>AIRPLANE</i>	<i>ROYAL</i>
<i>BOWL</i>	<i>DAUGHTER</i>	<i>DIVE</i>	<i>LEADER</i>
COCKTAIL	SISTER	ELEVATE	REIGN

LION	MAN	MOUNTAIN	MUSIC
TIGER	WOMAN	HILL	MELODY
CAGE	HUSBAND	VALLEY	SOUND
JUNGLE	UNCLE	CLIMB	PIANO
CIRCUS	LADY	SUMMIT	SING
TAMER	MOUSE	TOP	RADIO
DEN	MALE	MOLEHILL	BAND
CUB	FATHER	PEAK	NOTE
AFRICA	STRONG	PLAIN	HORN
MANE	FRIEND	GLACIER	CONCERT
FELINE	BEARD	GOAT	INSTRUMENT
ROAR	PERSON	BIKE	SYMPHONY
FIERCE	HANDSOME	CLIMBER	JAZZ
BEARS	MUSCLE	RANGE	ORCHESTRA
HUNT	SUIT	STEEP	ART
PRIDE	OLD	SKI	RHYTHM

NEEDLE	PEN	RIVER	ROUGH
THREAD	PENCIL	WATER	COARSE
PIN	WRITE	STREAM	BUMPY
EYE	MARKER	LAKE	ROAD
SEWING	LEAK	MISSISSIPPI	TOUGH
EYE	QUILL	BOAT	SANDPAPER
POINT	FELT	TIDE	JAGGED
PRICK	BIC	SWIM	READY
THIMBLE	SCRIBBLE	FLOW	COARSE
HAYSTACK	CRAYON	RUN	SMOOTH
THORN	CROSS	BARGE	RIDERS
HURT	TIP	CREEK	RUGGED
INJECTION	FOUNTAIN	BROOK	UNEVEN
SYRINGE	RED	FISH	BOARDS
CLOTH	CAP	BRIDGE	GROUND
KNITTING	LETTER	WINDING	GRAVEL

<i>RUBBER</i>	<i>SHIRT</i>	<i>SLEEP</i>	<i>SLOW</i>
<i>ELASTIC</i>	<i>BLOUSE</i>	<i>BED</i>	<i>FAST</i>
<i>BOUNCE</i>	<i>SLEEVES</i>	<i>REST</i>	<i>LETHARGIC</i>
<i>FLEXIBLE</i>	<i>PANTS</i>	<i>AWAKE</i>	<i>STOP</i>
TIRE	TIE	TIRED	LISTLESS
GLOVES	BUTTON	DREAM	SNAIL
BALL	SHORTS	WAKE	CAUTIOUS
SPRINGY	IRON	SNOOZE	DELAY
ERASER	POLO	BLANKET	TRAFFIC
FOAM	COLLAR	DOZE	TURTLE
GALOSHES	VEST	SLUMBER	HESITANT
LATEX	POCKET	SNORE	SPEED
SOLES	JERSEY	NAP	QUICK
GLUE	BELT	PEACE	SLUGGISH
RESILIENT	LINEN	YAWN	WAIT
STRETCH	CUFFS	DROWSY	MOLASSES

<i>SMELL</i>	<i>SMOKE</i>	<i>SOFT</i>	<i>SPIDER</i>
<i>NOSE</i>	<i>CIGARETTE</i>	<i>FLUFFY</i>	<i>CRAWL</i>
<i>BREATHE</i>	<i>PUFF</i>	<i>LIGHT</i>	<i>INSECT</i>
<i>SMELL</i>	<i>BLAZE</i>	<i>PILLOW</i>	<i>BUG</i>
AROMA	BILLOWS	HARD	FRIGHT
HEAR	POLLUTION	PLUSH	FLY
SEE	ASHES	LOUD	ARACHNID
NOSTRIL	CIGAR	COTTON	WEB
WHIFF	CHIMNEY	FUR	TARANTULA
SCENT	FIRE	TOUCH	POISON
REEK	TOBACCO	FEATHER	BITE
STENCH	STINK	FURRY	CREEPY
FRAGRANCE	PIPE	DOWNY	ANIMAL
PERFUME	LUNGS	KITTEN	UGLY
SALTS	FLAMES	SKIN	FEELERS
ROSE	STAIN	TENDER	SMALL

SWEET	THIEF	TRASH	WINDOW
SOUR	STEAL	GARBAGE	DOOR
CANDY	ROBBER	WASTE	GLASS
SUGAR	CROOK	JUNK	PANE
BITTER	BURGLAR	REFUSE	SHADE
GOOD	MONEY	SEWAGE	LEDGE
TASTE	COP	BAG	SILL
TOOTH	BAD	CAN	HOUSE
NICE	ROB	RUBBISH	OPEN
HONEY	JAIL	SWEEP	CURTAIN
SODA	GUN	SCRAPS	FRAME
CHOCOLATE	VILLAIN	PILE	VIEW
HEART	CRIME	DUMP	BREEZE
CAKE	BANK	LANDFILL	SASH
TART	BANDIT	DEBRIS	SCREEN
PIE	CRIMINAL	LITTER	SHUTTER

New Items

ACCOUNT	CORNER	GROUP
ACTION	COST	HALF
AGREEMENT	COUNCIL	HELP
ANSWER	DECISION	HISTORY
AREA	DEGREE	HIT
ATTENTION	DEPARTMENT	HOOR
BEGINNING	DESIGN	INCOME
BILL	DIFFERENCE	INDIVIDUAL
BIT	DISTRICT	INDUSTRY
CASE	EARTH	INSIDE
CENT	EFFORT	JOB
CENTURY	EIGHT	JUSTICE
CHARGE	END	KIND
CHILDREN	ENERGY	KNOW
CHOICE	EVIDENCE	LANGUAGE
CHRISTIAN	EXAMPLE	LAST
CHURCH	EXISTENCE	LEAD
CLOSE	FEET	LEAST
COMMITTEE	FIGURE	LEAVE
COMMON	FORMER	LEFT
COMMUNITY	FORWARD	LEVEL
COMPANY	FUTURE	LOCAL
CONGRESS	GOVERNMENT	LOVE

MAJOR
MASS
MEANS
MIDDLE
MIGHT
MILLION
MIND
MOMENT
MORAL
MORNING
MOTHER
MOVE
NATURE
NEWS
NONE
NOTE
ORIGINAL
PART
PARTICULAR
PAY
PLANE
POINT
POLICE
POOL
POPULATION

PRESENT
PRESIDENT
PRINCIPLE
PROCESS
PRODUCTION
PROGRAM
PROGRESS
PROPERTY
PUBLIC
PUT
QUALITY
QUESTION
RATE
REACH
RECORD
RESEARCH
REST
RESULT
ROLE
SCHOOL
SEASON
SERVICE
SEVEN
SHORT
SHOT

SHOW
SIDE
SOUTH
SOVIET
SPIRIT
SQUARE
STATEMENT
STUDENT
SUPPORT
TEN
THING
THOUGHT
THREE
TREATMENT
TRIAL
TRUTH
TURN
UNIVERSITY
USE
VALUE
VOICE
WATER
WHILE
WORD
WRONG

Appendix 2

General ERP Results

For completeness and purposes of future reference, the entire 1500 ms epoch was examined in detail. ERP amplitudes were averaged over 100 ms intervals, then the entire data set was analyzed using a multivariate ANOVA with all 15 times set as multivariates, and modality, item and site as factors. This analysis was conducted to provide an initial assessment of the data that would be free from family-wise error rates associated with multiple comparisons. This analysis showed significant effects of modality [*Wilks' Lambda* (15, 271) = .752, *Roa's R* = 5.94, $p < .001$], item [*Wilks' Lambda* (15, 271) = .844, *Roa's R* = 3.32 $p < .001$], site [*Wilks' Lambda* (210, 2819) = .096, *Roa's R* = 3.42, $p < .001$], and a significant Modality x Item interaction [*Wilks' Lambda* (15, 271) = .593, *Roa's R* = 12.38, $p < .001$]. Overall, amplitudes were higher for responses in the visual study condition than the auditory study condition, and higher for false alarms than for hits, with false alarms in the visual condition associated with larger amplitudes than false alarms in the auditory condition.

The data was then analyzed over five 300 ms time windows. For each of these windows, a 2 x 2 (Modality x Item) ANOVA was conducted for each electrode site, with the average for each time window treated as a repeated measure. The results of these analyses are given in Table 1.

Early effects (0 to 299 ms). Visual inspection of the ERPs suggests that participants in the visual condition had a larger P300 than those in the auditory condition, particularly at frontal and parietal electrode sites. A statistical analysis of the early time window showed that amplitudes in this time frame were significantly larger in the visual

condition than the auditory condition at several frontal sites (F4, F7, F8) as well as C3. The main effects at the frontal sites were qualified by significant Modality x Item Type interactions such that the amplitudes for false alarms were higher than the amplitudes for hits in the visual condition, but not the auditory condition (see Figures 2 and 3). There were also significant Modality x Item Type interactions at C4, P3 and O1, although the ERP graphs do not reveal a clear pattern of amplitude differences at these sites.

300 to 599 ms. In the 300 to 599 ms time frame, there was a continued tendency for amplitudes to be larger in the visual condition than the auditory condition at frontal sites (F3, F4, F7). These effects were once again qualified by interactions between modality and item type such that amplitudes were higher for false alarms than hits in the visual condition but not the auditory condition (sites F3, F7 and F8). Additional Modality x Item Type interactions occurred over sites P3, PZ, T4 and O1. While there is no discernable pattern for sites P3, PZ and O1, at site T4 there are larger amplitudes for false alarms than for hits in the visual condition, but not the auditory condition.

600 to 899 ms. Within the 600 to 899 ms time window, ERP amplitudes for the visual condition were again larger than amplitudes for the auditory condition over left inferior frontal areas (F7). There was also, once again, a trend for false alarms to elicit higher amplitudes than hits in the visual study condition but not the auditory study condition at inferior frontal sites (F7, F8).

900 to 1499 ms. In the 900 to 1199 ms time window, one significant effect was obtained, a significant Modality x Item Type interaction at site F7 such that amplitudes were higher for false alarms than for hits in the visual but not auditory condition. No significant effects were observed for the 1200 to 1499 ms time window.

Table 1

0 to 299 ms	Site	Modality*	Item*	Modality x Item**
	F3	3.12 (20.42)	1.46 (9.77)	3.79
	F4	4.89 (22.60) +	2.69 (10.43)	6.71 ++
	F7	8.11 (34.77) ++	3.92 (14.96)	12.04 ++
	F8	5.71 (19.40) +	1.82 (14.17)	10.37 ++
	FZ	1.66 (25.57)	<1 (19.48)	6.82 +
	C3	4.58 (16.01) +	1.74 (9.71)	3.35
	C4	1.61 (20.63)	2.29 (6.16)	5.82 +
	CZ	1.62 (32.80)	1.31 (16.61)	3.90
	P3	1.55 (22.05)	3.26 (6.22)	7.35 +
	P4	<1 (20.76)	<1 (7.44)	3.35
	PZ	1.26 (19.16)	<1 (7.05)	3.43
	T3	<1 (11.94)	<1 (11.41)	<1
	T4	<1 (10.29)	<1 (6.01)	4.05
	O1	<1 (19.48)	<1 (3.50)	5.44 +
	O2	<1 (24.41)	<1 (6.67)	1.55
300 to 599 ms	Site			
	F3	5.45 (26.90) +	<1 (19.88)	4.11 +
	F4	7.90 (28.62) +	<1 (24.26)	1.94
	F7	8.74 (60.99) ++	<1 (15.81)	6.95 +
	F8	3.53 (39.24)	<1 (28.89)	6.02 +
	FZ	<1 (70.12)	1.97 (45.16)	2.54
	C3	3.64 (23.95)	<1 (12.62)	1.11
	C4	1.64 (21.13)	<1 (9.86)	3.68
	CZ	2.22 (27.57)	<1 (18.15)	2.83
	P3	<1 (24.93)	1.67 (8.62)	5.16 +
	P4	<1 (36.80)	<1 (15.13)	2.93
	PZ	<1 (26.06)	<1 (8.43)	5.97 +
	T3	2.54 (12.84)	<1 (20.98)	<1
	T4	<1 (21.75)	<1 (8.60)	4.67 +
	O1	2.71 (26.65)	<1 (13.22)	5.52 +
	O2	<1 (34.93)	<1 (12.73)	1.85
600 to 899 ms	Site			
	F3	2.34 (64.99)	<1 (11.96)	2.78
	F4	2.95 (74.93)	<1 (12.49)	4.15
	F7	5.75 (150.84) +	<1 (25.92)	11.13 ++
	F8	2.69 (91.05)	<1 (39.60)	6.36 +
	FZ	<1 (79.77)	2.02 (16.88)	3.44
	C3	3.80 (46.92)	1.98 (7.06)	<1
	C4	2.40 (32.70)	<1 (8.16)	<1
	CZ	1.12 (61.97)	<1 (12.91)	<1
	P3	<1 (29.79)	2.62 (7.64)	<1
	P4	<1 (44.92)	<1 (12.24)	<1
	PZ	<1 (47.86)	<1 (12.91)	<1

	T3	4.34 (26.06)	<1 (39.03)	<1
	T4	<1 (29.18)	<1 (11.36)	2.31
	O1	1.74 (38.50)	1.37 (17.37)	<1
	O2	1.18 (44.70)	<1 (15.49)	<1
900 to 1199 ms	Site			
	F3	1.73 (90.82)	<1 (20.45)	2.96
	F4	2.15 (96.48)	<1 (14.89)	3.95
	F7	3.54 (252.61)	<1 (69.56)	5.11 +
	F8	3.32 (124.55)	<1 (69.16)	3.76
	FZ	<1 (103.30)	<1 (22.15)	1.73
	C3	1.75 (44.24)	1.49 (9.29)	1.17
	C4	<1 (26.26)	<1 (12.96)	<1
	CZ	<1 (59.51)	1.38 (13.35)	<1
	P3	<1 (31.05)	1.85 (14.83)	<1
	P4	<1 (38.78)	<1 (21.26)	<1
	PZ	<1 (45.69)	<1 (23.37)	<1
	T3	2.96 (28.90)	<1 (71.76)	<1
	T4	<1 (35.97)	<1 (22.15)	1.27
	O1	2.02 (43.56)	1.74 (25.88)	<1
	O2	2.75 (47.56)	<1 (24.97)	<1
1200 to 1499 ms	Site			
	F3	3.01 (108.83)	<1 (29.23)	3.29
	F4	3.44 (118.87)	<1 (19.09)	2.81
	F7	3.01 (374.95)	<1 (115.49)	3.56
	F8	3.82 (165.72)	<1 (104.51)	2.26
	FZ	2.64 (144.46)	<1 (44.40)	<1
	C3	2.10 (47.04)	1.29 (16.40)	2.01
	C4	1.09 (25.84)	<1 (21.18)	<1
	CZ	<1 (53.89)	1.15 (23.67)	164
	P3	<1 (41.37)	2.08 (23.85)	2.14
	P4	<1 (43.61)	<1 (25.10)	<1
	PZ	<1 (52.17)	<1 (31.93)	1.67
	T3	3.18 (37.87)	<1 (114.83)	<1
	T4	<1 (48.04)	<1 (37.54)	<1
	O1	<1 (55.89)	2.40 (30.57)	1.39
	O2	1.67 (51.17)	<1 (35.90)	<1

* Greenhouse-Geisser corrected F values on 1,19 degrees of freedom, with the MSE given in parentheses.

** Greenhouse-Geisser corrected F values on 2,38 degrees of freedom, with the MSE given in parentheses.

+ $p < .05$

++ $p < .01$