AN INVESTIGATION OF THE COGNITIVE BASIS FOR THE SELECTIVITY OF AGE-RELATED MEMORY IMPAIRMENT

by

Amy A. Overman

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M.S., University of Pittsburgh, 2002

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This dissertation was presented

by

Amy A. Overman

It was defended on

April 14th, 2006

and approved by

Erik D. Reichle, Ph.D., Assistant Professor, Department of Psychology

Greg Siegle, Ph.D., Assistant Professor, Departments of Psychology and Psychiatry

Robert D. Nebes, Ph.D., Professor, Department of Psychiatry

Dissertation Advisor: James T. Becker, Ph.D., Professor, Departments of Psychiatry and Psychology

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Amy A. Overman, Ph.D.

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Older adults have been found to have a selective impairment in certain types of episodic memory, although other types of memory are generally preserved. The goal of this research is to determine whether the selective age-related memory deficit is best explained by an impairment in perceptual processing, an impairment in the formation of associations between items and their contexts, or an impairment in controlled processing, which is presumed to be required for recollection. Three behavioral experiments were conducted which attempted to evaluate the relative merits of each of these three accounts of age-related memory impairment. To allow for a more meaningful comparison of the data from each experiment, the same participants completed all three behavioral experiments. In addition to the behavioral experiments, an event-related potential (ERP) experiment was conducted to provide further information regarding perceptual processing differences between older and younger adults. When relying solely on perceptual information, rather than semantic and perceptual information, older adults' memory performance was especially poor for perceptually impoverished stimuli (words), but less so for perceptually rich stimuli (pictures). Unlike young adults, older adults did not benefit from repeated presentations of pair information, suggesting that older adults do not form associative links between to-be-remembered stimuli. However, older adults did not show a recollection-specific impairment as the controlled processing hypothesis would have predicted. Older adults were equivalently impaired for both recollection and familiarity measures, suggesting that controlled processing is not specifically impaired in older adults. ERPs for older adults had much more individual variability than for young adults and the differences in ERP waveforms between age groups were observed more consistently in word conditions than in picture conditions, which is consistent with the behavioral results. Additionally, older adult ERPs to pictures were most similar to young adults, in accordance with the behavioral results. The behavioral data support the hypothesis that there is a deficit in perceptual processing which may help explain age-related memory impairments. The ERP data, though limited, lends some support to this explanation as it

reveals perceptual and semantic processing differences between young and older adults. An associative deficit may be an additional source of memory impairment.

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ACKNOWLEDGEMENTS

"I have learned that success is to be measured not so much by the position that one has reached in life as by the obstacles which one has overcome while trying to succeed."

-- Booker Taliaferro Washington

The path to this degree has been long and often arduous, not only because of the usual difficulties of graduate school, and the fact that I am both a first-generation college student and a first-generation graduate student, but also because of many tragedies that have affected my life over the last 6 years. I would never have had the strength to endure if it had not been for the sustaining power of God . In addition to her love, my mom, Nancy, has given wise advice throughout my educational training and been a tireless cheerleader when I doubted. My brother, Timothy, has offered love and a grounding perspective on what is important in life. Many other family members and friends have encouraged me throughout my training and I am grateful for them. Finally, my husband, Beau, has truly been one with me in pursuit of this goal. His love, strength, prayer, and unflagging support have been a constant source of emotional and spiritual help to me.

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1.0 INTRODUCTION

Researchers frequently describe impairments in episodic memory that are associated with aging (e.g., Johnson, Hashtroudi & Lindsay, 1993), despite the preservation of other types of memory in older adults (e.g., Laver & Burke, 1993). Episodic memory can be roughly divided into two common types of subjective memory phenomena (Rugg & Yonelinas, 2003; Knowlton, 1998; Hintzman, *et al*., 1998; Hintzman & Curran, 1994; Yonelinas, 1994; Jacoby, 1991; Gardiner & Parkin, 1990; Humphreys, *et al.*, 1989; Jacoby & Dallas, 1981, Mandler, 1980; Atkinson & Juola, 1974). Perhaps the more stereotypical of the two types is the recollective experience: one remembers having encountered an object, person, etc., and can specifically recall many of the particular details of that experience. These details might typically include the appearance of the object in question, the surrounding environment, the context of the experience in place and time, and perhaps even the thoughts or emotions being experienced during the encounter (Tulving, 1984). Another common memory experience is the experience of familiarity: one has a sense of knowing that something has been encountered before, but cannot recall the particular context in which the encounter took place. The familiarity-recollection division of episodic memory is a valuable framework for examining the age-related changes in episodic memory because the deficits repeatedly found in episodic memory among older adults can be conveniently described as a selective impairment of recollective memory (Light & Singh, 1987; Perfect, *et al.*, 1995; Perfect & Dasgupta, 1997; Balota, *et al.*, 2000; Clarys, *et al.*, 2002). Recollection and familiarity, however, are often poorly defined terms in research of older adult memory and there is little explanation of the underlying cognitive processes. As a result, the cognitive basis of the selectivity in age-related memory impairment is not well understood.

The goal of this research is to determine whether the cognitive underpinnings of the selective age-related memory deficit are best accounted for by an impairment in perceptual processing, an impairment in the formation of associations between items and their contexts, or an impairment in controlled processing. In pursuit of this goal, three behavioral experiments were conducted which attempted to capture each of the three hypothetical impairments listed above. To allow for a more meaningful comparison of the data from each experiment, the same participants completed all three behavioral experiments. In addition to the behavioral experiments, an event-related potential (ERP) experiment was conducted to provide further information regarding perceptual processing differences between older and younger adults. Each experiment is informed by a particular theory of age-related memory impairment. These three theories are described below.

1.1 THEORIES OF AGE-RELATED MEMORY IMPAIRMENT

1.1.1 Perceptual proccesing impairment

One way of characterizing the selective age deficit in memory is as a specific impairment of perceptual processing, whereas conceptual processing is preserved. According to this view, recollection and familiarity differ primarily in the use of perceptual information. Specifically, recollection depends on the use of perceptual information for the specific details of an item and familiarity depends on the use of conceptual information, such as semantic or relational features

(Brainerd, *et al.*, 1999; Brainerd, *et al.*, 1995). In this framework, separate perceptual and conceptual representations are formed at the encoding stage of memory. The process of perceptual retrieval is an all-or-none process that corresponds to recollection. The process of conceptual retrieval is a graded process that corresponds to familiarity. Thus, according to this type of memory theory, familiarity and recollection are characterized in terms of the type of information they use.

A perceptual/conceptual processing model can account for the selectivity of the age-related memory deficit by proposing that perceptual memory processing is specifically impaired in older adults (Koutstaal *et al.*, 2001; Koutstaal, *et al.*, 1999; Koutstaal & Schacter, 1997). Thus the tendency for older adults to rely on familiarity is the result of preserved conceptual-based processing. A perceptual-processing deficit impairs the ability to distinguish between items studied in different contexts.

1.1.2 Associative encoding impairment

Some theories of age-related memory impairment argue that older adults are impaired in memory for context but not for item (Naveh-Benjamin, 2000; Glisky, *et al.*, 2001; Smith *et al.*, 1998; Naveh-Benjamin & Craik, 1995; Park *et al.*, 1990; McIntyre & Craik, 1987). Some research in young adults has supported the idea that recollection is characterized by memory for the context in which an item was first experienced (Perfect, *et al.*, 1996; Johnson, 1997; Johnson, *et al.*, 1993). However, results have been mixed regarding the ability of older adults to utilize context. In fact, the problem for older adults may not be with processing context *per se* but in *binding* an item to its context. Several studies highlight a context-item binding difficulty for older adults (Chalfonte & Johnson, 1996; Mitchell, *et al.*, 2000; Naveh-Benjamin, 2000). Interestingly, Naveh-Benjamin's associative encoding hypothesis (AEH) for older adults is quite similar to a model of healthy episodic memory, the ICE model (item-context-ensemble; Murnane, *et al.*, 1999), although both were developed independently. ICE makes the claim that accurate recollection depends not only on memory for item and context information individually, but, crucially, on the integration of these two types of information into unique memory representation called an ensemble (Murnane, *et al.*, 1999). The ensemble enables the individual to have accurate memory for an item embedded within a specific context, rather than mere familiarity with both the item and context but not their relationship. The distinction between recollection and familiarity is defined at the encoding stage, based on whether an ensemble is formed that will enable future recollection. Formation of an ensemble requires the creation of associative features based on conjunctive information about item and context derived through elaborate processing.

The associative encoding model explains age-related deficits in memory as a specific impairment in the memory for components (items and context) of an episode *and* the relationship of the components to each other (Naveh-Benjamin, 2004). This explanation is the same as the ICE model explanation. It is the failure to properly associate the item and context at encoding, rather than a deficit in the processing of either item or context information individually, that is difficult for older adults. If associative links are not properly formed between items and their contexts at the encoding stage, the circumstantial details related to items cannot be effectively used in determining whether a cue matches an item in memory. For example, impaired ensemble formation would decrease the ability to discriminate between study lists. The process-dissociation procedure (Jacoby, 1991), explains inability to discriminate between study lists as a failure of recollection to oppose familiarity but impaired ensemble formation could explain it due to difficulty remembering in which experimental context an item was originally embedded. If normal memory processes involve the encoding of associative features between items and context, then it should be expected that associative features should be encoded when the context is actually another item in a pair.

1.1.3 Controlled processing impairment

Another common characterization of the selective age deficit in memory is as a specific impairment of controlled processing. According to such an account, the distinction between recollection and familiarity can primarily be defined by differences in attentional resources required to carry out the component processes. Specifically, recollection is supported by controlled processes and familiarity is supported by automatic processes (see Yonelinas, 2002, for review). The cognitive processes underlying both recollection and familiarity may operate on the same informational content from the environment, including perceptual and conceptual features of external stimuli and memory traces. Controlled processes are assumed to require attentional resources and occur at a relatively slow rate. Automatic processes are assumed to occur at a relatively fast rate, without the use of attentional resources.

The selectivity of the age-related deficit in memory can be accounted for, in this theoretical framework, as a specific impairment of controlled processing. If controlled processing is damaged, then the necessary cognitive operations underlying recollective memory will not effectively be carried out. Processes underlying familiarity are thought to be spared in old age because they can be executed without the need for controlled processing.

1.2 SUMMARY

Older adults experience a deficit in the type of memory referred to as recollection which requires remembering details of a past experience, such as perceptual features or the context in which the experience took place. The perceptual processing impairment theory posits that older adults have difficulty extracting and/or manipulating perceptual features when processing information. The associative encoding impairment posits that older adults cannot bind information about contexts and the items in the context. The controlled processing impairment posits that older adults have difficulty allocating attention to details of an experience. Since the goal of this study is to determine the best characterization of the age-related memory impairment, the three theories, perceptual processing impairment, associative encoding impairment, and controlled processing impairment, are necessarily framed as competitors. However, it is possible that the explanations are not mutually exclusive, as there may be more than one cognitive impairment in older adults that contributes to age-related memory impairment. Perceptual processing deficits could be the source of the associative encoding impairment and associative encoding could be a type of controlled process. Based on the data reported below I will argue that the age-related memory deficit is best accounted for by a perceptual processing impairment but that associative encoding may also play a role when context-item relationships are specifically tested. The data do not support the controlled processing impairment as an explanation of age-related memory deficits.

2.0 EXPERIMENT 1

2.1 RATIONALE

Two competing hypotheses for the selectivity of the age deficit are that it results from an impairment of representations for perceptual details, and that it results from an impairment of controlled processing. Experiment 1 tested both of these hypotheses simultaneously.

If the encoding of perceptual details is specifically impaired in older adults, then older adults should exhibit preferential processing of semantic information as opposed to perceptual information. Three previous studies have specifically tested the encoding of perceptual versus conceptual information in older adults. One study found that older adults had more false alarms for concrete pictures, than for abstract pictures (Koutstaal, *et al.*, 2003). Concrete pictures were picture representations of objects in the world. Abstract pictures were line drawings that were not representative of any object or concept in the world. The concrete pictures carried more semantic (conceptual) information than the abstract pictures, which lacked semantic information since they did not correspond to any object or concept. The fact that older adults had more false alarms to concrete pictures than to abstract pictures can be interpreted as a tendency for older adults to disregard perceptual information by relying on semantic information when it is available, as in the case of concrete pictures. However, a different study using words and nonwords, which should share the same semantic/non-semantic distinction that concrete and abstract pictures have, did not find more false alarms for words than for nonwords for older adults. Memory for words versus nonwords also was not significantly different between young and older adults (Perfect & Dasgupta, 1997), indicating that older people did not have a greater reliance on semantic information as a perceptual/conceptual distinction theory would predict. Finally, older adults have been shown to use perceptual details to the same extent as younger adults on a "meaning recognition" task (Koutstaal, 2003).

Thus, there are conflicting results in the literature regarding older adults' ability to use perceptual information in episodic memory tasks. Experiment 1 further examined this question by manipulating perceptual details in a task that held semantic information constant. The experiment used stimuli consisting of words and pictures that represented concrete objects. The pictures had distinctive perceptual features, whereas the perceptual features of the words (i.e., letters) were relatively generic. In a recognition memory task, participants were forced to use recollective memory processes by the presence on the test list of "lure" items that represented the same semantic content as items on the study list, but with different perceptual features (e.g., a picture of a bowl on the study list, and the word "BOWL" on the test list). This technique assumes that the picture of an object and the word referent for an object activate the same concept in the semantic network (Carr, *et al*., 1982).

Participants were instructed to identify a stimulus as "old" only if they saw the exact stimulus on the study list. If older adults are specifically impaired in their processing of perceptual information, then their performance should be especially bad for items that have generic perceptual features (i.e. words) because older adults are unable to make the fine-grained distinctions necessary to correctly identify words as "old" or "new." Memory for items with very distinctive perceptual features (i.e., pictures) should be relatively preserved for older adults, since the damage to perceptual processing would less effectively wipe out discriminability of those items. If, on the other hand, information content is orthogonal to the age-related memory deficit, then older adults should be equally impaired on memory for words and pictures relative to younger adults.

2.2 METHODS

2.2.1 Participants

A specific effort was made to improve on previous studies by recruiting older adults who were representative of the general aged population. Sixty-one older adults, 41 females and 20 males (mean age = 82.2 years, range = 61-96; mean education = 13.8 years, range = 9-20 years), were recruited from the Pittsburgh region, including retirement communities and churches. The older adults received $7.00 compensation for participation.

Ninety young adults, 54 females and 36 males (mean age = 21.2 years, range = 18-39 years; mean education = 14.3 years, range = 12-23 years), were recruited from the University of Pittsburgh community and Introductory Psychology courses. The young adults received either $7.00, Psychology course credit, or extra credit for participation.

A core group of 34 young people and 37 old people participated in three experiments: Experiments 1, 2, and 3. An additional 56 young people and 24 older adults also participated in Experiments 2 and 3 (total *each* for Exps. 2 & 3 = 90 young & 61 older). Experiment order was randomly assigned to avoid order effects.

All participants were native English speakers, right-handed, and had no history of major medical, neurological, or psychiatric disorders. After the explanation of procedures and prior to testing, all participants provided written informed consent to participate using consent forms approved by the Institutional Review Board of the University of Pittsburgh.

2.2.2 Stimuli

Stimuli consisted of 95 words presented in black uppercase lettering against a white screen and 95 objects presented as black line drawings against a white screen (pictures; Snodgrass & Vanderwert, 1980). A pilot study with both older and young adults was conducted in order to determine the word referent of each member of the picture corpus. Pictures that produced multiple word referent variants (e.g., sofa, couch, davenport, loveseat, settee) were excluded from Experiment 1.

2.2.3 Design

Thirty-seven of the word stimuli and 37 of the picture stimuli were presented in random order, alternating word/picture for each participant during the study session. For the test session, 57 words and 57 pictures alternated (114 stimuli total, at test). The randomly ordered test list containing 19 items in each of the following conditions: word targets, picture targets, word lures, pictures lures, word distractors and picture distractors (See Table 2 in Appendix A).

2.2.4 Procedure

During the study session, participants were presented with a sequence of single pictures and words on the computer screen. Stimuli were presented until the participant responded or for a maximum of 5000 ms. After participants responded to each stimulus, another stimulus would appear. During the study session, participants were instructed to make a decision about the stimuli presented (e.g., "pleasant or unpleasant"). Making a judgment about the pleasantness of an item requires consideration of semantic properties and has repeatedly been shown to increase encoding and attention to the study stimuli (Hyde & Jenkins, 1969; Craik & Lockhart, 1972; Hyde & Jenkins, 1973). It was assumed that the pleasantness ratings would not result in any differences in emotional processing between age groups.

Participants were informed that they would be asked about the stimuli later in the experiment. Participants proceeded immediately from the study session to the test session instructions in which participants were instructed to make an "old/new" decision task. They were told that a "yes" response was to be given only if there was an exact physical match to previously seen study items. Test items that matched study items only in semantic information but not perceptual information (i.e., not identical physical matches) were to be considered "new" and served as lures. Test items that did not match the items at study semantically or perceptually were to be considered "new" and served as distractors. Trial sequence for study and test sessions are in Table 2 of Appendix A. After the participant pressed the space bar a new stimulus (word or picture) appeared, which remained until the participant made a response, or for a maximum of 3000 ms.

The experiment took place in true-to-life settings in retirement homes, apartments, and campus classrooms or offices. Lab settings were purposely avoided when testing the young subjects because the older adults were not tested in lab settings. The testing environment was always an isolated room with closed doors to decrease distraction. Each participant viewed the trials on a laptop computer screen in the testing room, while the experimenter was present in the room to ensure that participants did not progress to the next section of the experiment before they were required to do so. The experimenter was present in the room because in pilot studies, both young and older adults often failed to obey the instruction screen that stated, "STOP! ALERT EXPERIMENTER," despite repeated verbal instruction prior to the start of the experiment.

2.2.5 Analytic technique

Standard signal detection measures of hits ("yes" responses to targets) and false alarms ("yes" responses to lures and/or distractors) were used in the analyses of data for this experiment (MacMillan & Creelman, 1991; Green & Swets, 1966). For some analyses the difference between hits and false alarms was used as a measure of discrimination between old and new items.

2.3 RESULTS

Reaction times were displayed as box plots and subjects who consistently had reaction times (across multiple conditions) that were outliers were excluded. An outlier was defined as a reaction time that was more than 1.5 times the box length (interquartile range) away from the bottom or top edge of the box. Older adults had slower reaction times than young adults overall ($t(59) = -6.02$, $p < .001$, Cohen's $d = 1.57$). Mean RT for young adults was 1191 ms and for older adults was 1729 ms. For some conditions the older adults did not have enough correct responses (i.e., word lures) and for some conditions the young adults did not have enough incorrect responses (i.e., picture targets). Therefore, for each subject the median reaction times for each condition were averaged for all response types for which there were more than three responses.

It was expected that older adults' accuracy would be worse overall than the young adults' accuracy and that the older adults would benefit from the additional perceptual details available in the picture condition (over the word condition) and would do so to a greater extent than young adults. This was expected because according to the perceptual impairment hypothesis, older adults are not able to process perceptual cues as well as younger adults. Thus, an excess of unique perceptual cues in the picture condition as compared to the word condition should help the older adults and it should help them more than it should help the younger adults who are not impaired at perceptual processing. Finally, older adults should have a greater increase in false alarms for the lure condition than the distractor condition because the lures require more reliance on perceptual information (i.e., the lures have the same degree of semantic familiarity as the targets so semantic familiarity cannot distinguish lures from targets).

A 2 (condition) X 2 (stimulus format) X 2 (age group) split-plot univariate analysis of variance (ANOVA) was performed on the old/new discrimination data (hits minus false alarms) for the young (n=29) and older adults (n=32), with condition and stimulus format as within-subjects factors and age-group as a between subjects factor. This was conducted across the two false alarm conditions, lures and distractors, and the two stimulus forms, pictures and words, and across the two age groups, young and old.[1] As expected, young adults had better old/new discrimination than older adults (main effect of age) ($F(1,59)=71.02$, $p < .001$, $\eta^2=.546$). Also as expected, older adults benefited from the additional perceptual cues available from pictures more than young adults did (age X form interaction) ($F(1,59)=27.45$, $p<.001$, $\eta^2=.318$). As predicted, older adults had a greater difference in false alarms between lures and distractors than young adults did (age X condition interaction) ($F(1,59)=19.31$, $p<.001$, $\eta^2=.247$. Lastly, there was an

[1] All effects and interactions were significant (between age groups and all within-subjects effects and interactions) $p<.001$.

age group X form X condition interaction ($F(1,59)=11.19$, $p=.001$, $\eta^2=.159$. The extent to which older adults had a greater benefit of pictures than young adults was seen more in the comparison of targets to lures than in the comparison of targets to distractors. This is illustrated in Figure 1. Unlike distractors, lures lacked novel semantic information that older adults could use and this affected their responses to words more than to pictures. The nature of this interaction can be viewed in Figure 2.

Figure 2 shows false alarms for lures relative to distractors – the distractor false alarms provide a baseline for false alarms in general, and allow for comparison across conditions and age groups. Remember that use of the perceptual details is essential for identifying an item as a lure since the lures share conceptual details with the targets but they do not share perceptual details. The lure conditions tested whether participants could use perceptual details to reject items that were semantically identical to studied items. If perceptual processing (encoding or retrieval) is impaired, then older adults should have more difficulty rejecting word lures than picture lures because words have less distinctive perceptual characteristics than pictures. The increased false alarm rate for lures over and above distractors indicates the extent to which participants failed to use perceptual details to correctly reject items. That is, how much does having only new perceptual details impair identification of a lure more than having new perceptual *and* new conceptual details (distractor condition).

Younger adults had about the same increase in false alarms for lures regardless of the physical format of the lure. Older adults, on the other hand, made many more false alarms to word lures than to picture lures (relative to the distractors).

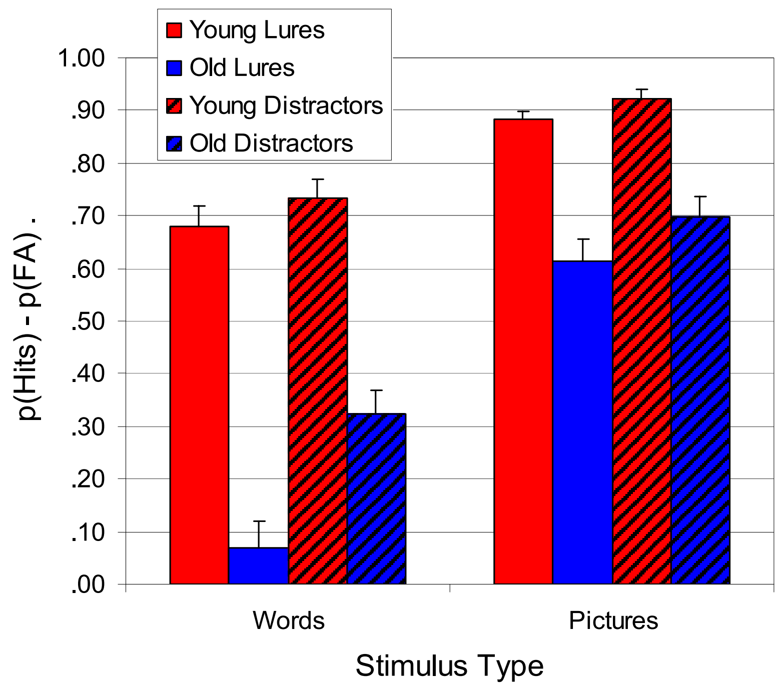


Figure 1. Old/new discrimination for young and older adults. Error bars represent standard error of the mean.

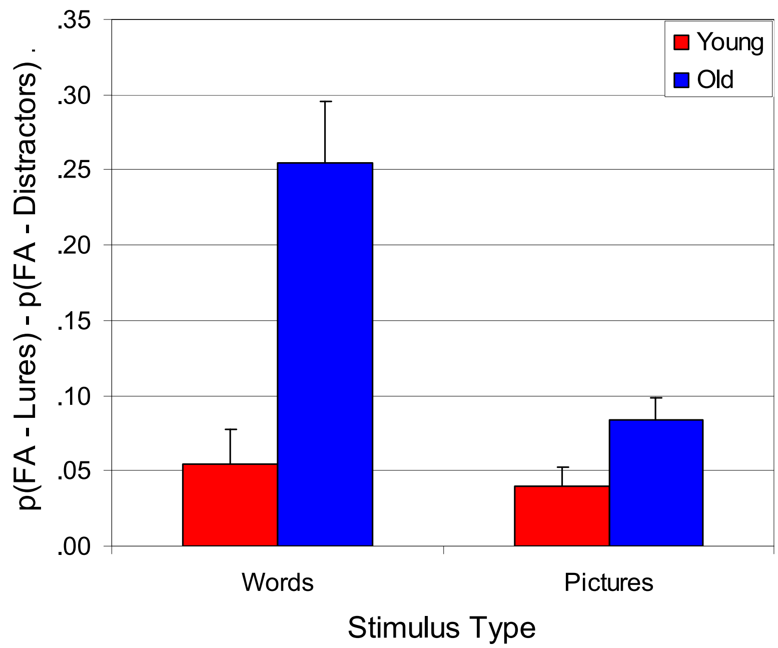


Figure 2. False alarms for words and pictures for young and older adults. Error bars represent standard error of the mean.

2.4 DISCUSSION

According to the perceptual impairment hypothesis, recollection critically depends on the encoding and retrieval of unique perceptual characteristics of the original episode in order to allow for reconstruction of the episode later. Recollection and familiarity might depend on both perceptual and conceptual information, but familiarity would not necessary fail for lack of perceptual details while recollection would. If older adults are impaired in processing of perceptual details, then in a task where the use of perceptual information is necessary to make memory judgments, the older adults' memory impairment (relative to young) should be less severe for perceptually distinctive items and more severe for perceptually generic items. Word memory should be more impaired than picture memory because perceptual deficit will hurt visual distinctiveness for words more than for pictures, which have many more distinctive perceptual features. If the perceptual distinctiveness of stimuli is manipulated while keeping semantic/conceptual information constant, we should be able to observe any differences in performance due to impaired processing of surface/perceptual features. Experiment 1 found that older adults were impaired by the absence of unique perceptual details much more than young adults. This lends supports to the hypothesis that older adults are processing perceptual details less effectively than young adults, especially when perceptual details are sparse as is the case with words.

3.0 EXPERIMENT 2

3.1 RATIONALE

Experiment 2 will test whether a problem with ensemble encoding causes age-related memory deficits. The ICE (item-context-ensemble) model explains age related deficits as an impairment of ensemble formation at encoding, or the ability to encode features of the study event that represent integrative information about item and context. The results of studies that manipulate encoding strategies are consistent with ICE because these experiments improved older adult performance by providing more time or encouragement for them to elaborate on the relationships between item and context information during the study sessions. If ensemble encoding is specifically impaired in older adults, then memory should be affected by manipulations of the relationship between item and context information. Only one study has been done that specifically tests this prediction of the ICE model in older adults (Bayen, *et al.*, 2000). That study found that young adults, and not older adults, performed better during recognition tasks in which study items were embedded in rich visual contexts, such as full visual scenes, than when they were in simple visual contexts. Older adults presumably did not show this benefit because they did not use the extra context information in ensemble formation (whereas the young adults did). Larger differences between older and young adults have also been found in a cued-recall task when the item and the context were unrelated than when they were related, possibly because it is harder to make an ensemble when the context and item are unrelated (Park, *et al.*, 1990;

Smith, *et al.*, 1998). Neither of these findings is readily explained by a specific deficit in controlled versus automatic processing or perceptual versus conceptual processing.

Recent studies (Criss & Shiffrin, 2005) have suggested that the formation of memory traces that use ensemble information occurs in paired-associate memory as well as item-context memory. That is, individuals encode integrative information about both items in a pair in a manner similar to the encoding of integrative information about an item and its surrounding context. If a deficit in forming integrative associations between item and context is to blame in older adults' impaired recollection, then this deficit in forming associations should also be seen in paired-associate memory.

3.2 METHODS

3.2.1 Participants

Sixty-one older adults and 90 young adults participated in Experiment 2. All of these people also participated in Experiment 3. Of the 61 older adults and 90 young adults who participated in Experiments 2 and 3, 37 of the older adults and 34 of the young adults were the same people who participated in Experiment 1. Experiment order was randomly assigned to avoid order effects.

3.2.2 Stimuli

The study used standardized black and white photographs of faces (see Criss & Shiffrin, 2005, for standardization details) and abstract words (Ex: incident) of varying environmental frequency

(M=18.59, range=1-245, SD=24.32; Kucera & Francis, 1967) and low imageability (M=341.69, range=129-400, SD=43.13; Colthart, 1981). The set of words did not include any words that might describe a face, a person, or a characteristic of either.

3.2.3 Design

The design of the study and test lists are illustrated in Table 3 in Appendix A. The conditions differ in the repetition both of individual items and pairs of items. Test pairs in the List 2 condition were composed of items that were seen in pairs on the second study list only. Test pairs in the Lists 1 & 2 Re-arranged condition consisted of items that were seen in pairs on both study lists, but whose pairings changed from one list to the other list. Test pairs in the Lists 1 & 2 Exact condition consisted of items that were seen on both study lists, in the same pair combination on each of the study lists. The other conditions (List 1 Exact and List 1&2 Re-arranged) were used as controls.

3.2.4 Procedure

The location and computer equipment were the same for this experiment as for Experiment 1. Participants received two study lists. The first study list contained 52 pairs of items and the second contained 60 pairs. On each trial of each list, participants performed an incidental task that involved rating each pair on the following question: "Are these items pleasant or unpleasant?" Items were presented until the participant responds or for a maximum of 5000 ms. Each study trial were separated by a 500 ms inter-stimulus interval (ISI). At the end of the first list, participants were reminded that they have just seen the first of two study lists. Participants were given a three minute break during which they completed a number search task and then advanced to the second study list, which was presented in the same manner as the first study list. Following the final study list, participants engaged in a 1 minute math task before being informed that they would take an unexpected memory test. Prior to the presentation of this 72 trial test list, participants were given examples of all the possible types of targets and lures and instructed to respond “yes" only if they have seen intact pairs from List 2 during the study session and to respond “no” to all other pairs.

3.2.5 Analytic technique

Standard signal detection measures of hits (“yes” responses to targets) and false alarms (“yes” responses to lures and/or distractors) were used in the analyses of data for this experiment (MacMillan & Creelman, 1991; Green & Swets, 1966). For some analyses the difference between hits and false alarms was used as a measure of discrimination between old and new items.

3.3 RESULTS

The same exclusion procedure for outliers used in Experiment 1 was used in Experiment 2. Older adults had slower reaction times than young adults for both correct ($t(132)= -5.81$, $p<.001$, Cohen’s $d=1.05$) and incorrect responses ($t(132)= -2.90$, $p=.004$, Cohen’s $d=.52$). Correct response mean RT for older adults was 2192 ms and mean RT for correct responses for young adults was 1730 ms. Mean RT for incorrect responses for older adults was 2165 ms and for young adults was 1922 ms.

A 4 (condition) by 2 (age-group) split-plot univariate analysis of variance (ANOVA) was performed for the young (n=84) and older adults (n=50), with condition as a within-subjects factor and age-group as a between subjects factor. For each of the four conditions, a measure of old/new discrimination was calculated by subtracting false alarms from hits. Figure 3 shows hits minus false alarms (i.e., old/new discrimination) in three conditions. In "Lists 1 & 2 Exact,"- a test pair was studied twice. In "Lists 1 & 2 Rearranged," twice-studied items were studied only once in pair form (on the 2nd list) and the individual items appeared once (on the 1st list paired with other items). In "List 2 Only," the items/pair were studied once (only on List 2, only in pair form). There was a small main effect of condition, $F(2.97, 392.52)=6.39$, $p<.001$, $\eta^2=.046$, and a very small condition by age group interaction, $F(2.97, 392.52)=4.37$, $p=.005$, $\eta^2=.032$, using the conservative Greenhouse-Geisser correction due to violation of the sphericity assumption (that the variance of the difference scores in a within-subjects design are equal across all the groups). There was also a main effect of age group, $F(1,132)=45.06$, $p<.001$, $\eta^2=.254$.

The main effect of condition was driven by the young adults. In the paired sample *t*-tests the old/new discrimination differed between conditions ($p<.01$) for all comparisons except the comparison of conditions "Lists 1&2 Rearranged" and "List 2 Only". Older adults did not have any condition effects which is the source of the condition by age group interaction. The nature of the interaction can be seen in Figure 3. Young adults' old/new discrimination was significantly improved in the Lists 1&2 Exact condition relative to the Lists 1&2 Rearranged and the List 2 Only conditions, whereas the older adults' old/new discrimination did not differ across conditions and was overall worse than young adults. The improved performance of the young adults in the Lists 1&2 Exact condition represents a specific benefit of pair repetition. The lack of benefit of pair repetition for the older adults suggests that they did not use associative information about pairs in their memory decisions.

Because some of the subjects in Experiment 2 did not participate in Experiment 1, a second analysis was performed excluding the people who did not participate in Experiment 1. Of the people who participated in Experiment 2, there were 32 young and 32 older adults who participated in Experiment 1. There was a main effect of condition ($F(2,124)=3.35$, $p=.038$, $\eta^2=.051$, but the condition by age group interaction was marginally significant ($F(2,124)=2.98$, $p=.054$, $\eta^2=.046$. There was also a main effect of age group ($F(1,62)=20.17$, $p<.001$, $\eta^2=.245$. Note that this effect size for age group in this analysis of only the subjects who participated in both Experiment 2 and Experiment 1 is equivalent to that in the larger group of all subjects who participated in Experiment 2 ($\eta^2=.254$).

For this additional analysis, older adults had slower reaction times than young adults for both correct ($t(62)= -4.97$, $p<.001$, Cohen's $d=1.26$) and incorrect responses ($t(62)= -2.32$, $p=.024$, Cohen's $d=.59$). Correct response mean RT for older adults was 2354 ms and mean RT for correct responses for young adults was 1803 ms. Mean RT for incorrect responses for older adults was 2281 ms and for young adults was 1988 ms. Figure 3 shows the results for the more inclusive analysis, not for the second analysis detailed above.

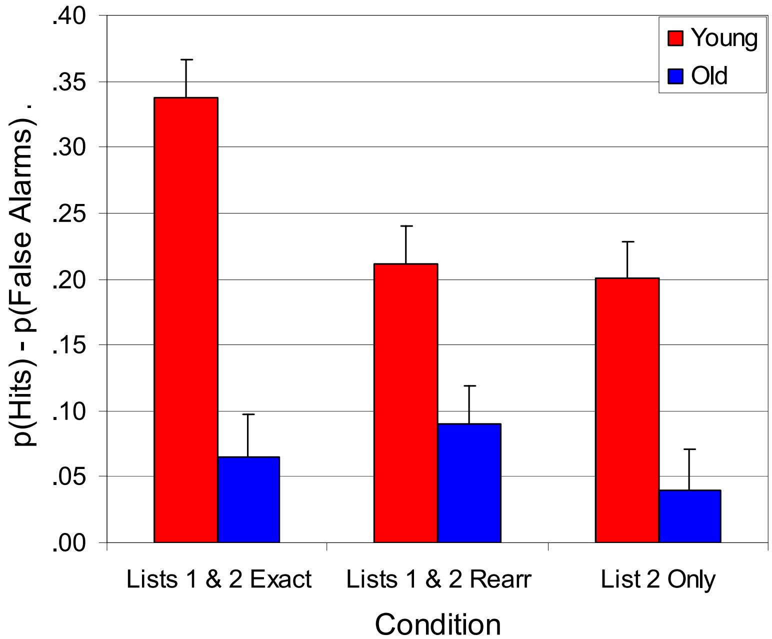


Figure 3. Old/new discrimination across three conditions for young and older adults. Error bars represent standard error of the mean.

3.4 DISCUSSION

According to the associative encoding theory of impairment, older adults are specifically impaired in the ability to form links between items and their contexts. Associative encoding might be critical to recollective-type memory because it enables the reconstruction of other information surrounding the item in the original episode, possibly in the form of extra features in the memory trace. Experiment 2 used pairs of words and faces to evaluate associative encoding. A recent study (Criss & Shiffrin, 2005) found that young people do use associative information in memory for pairs (not just individual item information), so if the age-related memory impairment is due to an inability to encode associative information between items and their contexts, then this impairment should also be seen in the encoding of associations between multiple items (e.g., paired-associate memory). The young people benefited from repetition of pairs, over and above any benefit of item repetition, but older adults showed no such benefit. In addition, older adults were worse overall at pair memory. Both findings indicate a deficit for associative encoding.

4.0 EXPERIMENT 3

4.1 RATIONALE

Experiment 3 attempted to replicate the alleged controlled processing deficit in older adults using a traditional process-dissociation paradigm. The purpose of Experiment 3 is for use as a baseline for the other two experiments since the process-dissociation framework has been so frequently used and the controlled processing deficit is the most common explanation for older adult memory impairment.

The controlled process thought to contribute primarily to recollection consists of an active search through memory traces of previously studied items for comparison to each test item (as opposed to an automatic evaluation of the global familiarity of each test item; Yonelinas, 2002). Typically in experiments that use the process-dissociation procedure it has been found that older adults' performance is based less on recollection than young adults' performance, but that both groups rely equally on familiarity (Dywan & Jacoby, 1990; Jennings & Jacoby, 1997; Titov & Knight, 1997).

The experiment used a process-dissociation procedure in order to identify the separate contributions of the putative controlled and automatic processing mechanisms. If both types of mechanisms occur in normal memory function, then they should both contribute in a recognition memory task. The process-dissociation procedure enables the researcher to estimate the contributions of each by using two different memory tests that tap the processes in different ways. A standard process-dissociation paradigm is to present two study lists to participants, one after another. During an inclusion test, participants are instructed to respond “yes” to any previously studied item, regardless of which study list it was on. In this case the controlled and automatic processes collaborate to produce a successful retrieval. During an exclusion test, participants are instructed to respond “yes” only to items from one of the study lists. In order to successfully complete the task, participants are required to reject familiar, recently studied items that did not appear on the target list. As a result, the automatic and controlled processes oppose one another and an index of recollection can be calculated by comparing data from the inclusion and exclusion tasks.

4.2 METHODS

4.2.1 Participants

Sixty-one older adults and 90 young adults participated in Experiment 3. All of these people also participated in Experiment 2. Of the 61 older adults and 90 young adults who participated in Experiments 2 and 3, 37 of the older adults and 34 of the young adults were the same people who participated in Experiment 1. Experiment order was randomly assigned to avoid order effects.

4.2.2 Stimuli

The study used the same database of abstract words detailed in Experiment 2, but none of the words were duplicates of those used in Experiment 2.

4.2.3 Design

Ninety-six abstract words were divided into four lists of 24 words. Two of the lists were randomly chosen to be study lists and the items on the other two lists were used as distractors during the test tasks. Every word on the two lists presented at study was a target word. All the target words were presented at test, but half were presented in the inclusion task and the other half in the exclusion task. The inclusion and exclusion tasks contained distractor words: thus, both the inclusion and exclusion tests consisted of 24 studied words (12 targets from each study list) and 24 new words (distractors).

4.2.4 Procedure

The location and computer equipment were the same for this experiment as for Experiments 1 & 2. Participants received two study lists and they were asked to complete an incidental encoding task that involves a pleasantness rating. Items were presented until the participants responded or for a maximum of 5000 ms, with a 500 ms inter-stimulus interval (ISI). At the end of the first list, participants were reminded that they had just seen the first of two study lists. Participants were given a three minute break during which they completed a number search task and then advanced to the second study list, which were presented in the same manner as the first study list. Following the final study list, participants engaged in a 1 minute math task before being informed that they were taking an unexpected memory test. The participant received either an inclusion or an exclusion memory test. Before taking the test, participants were given verbal instructions and were also able to read them on the computer screen. In the inclusion test, participants were asked to respond “yes” if they have seen the word during the study session and “no” if the word is new. The exclusion task instructions were identical except that participants were asked to respond “yes” only to words from a specific study list rather than all words from the study session and to respond “no” if a word is from the non-specified list or is a new word. Presentation of the study lists, and assignment of study lists to inclusion or exclusion task were counterbalanced.

4.2.5 Analytic technique

“Yes” responses to old items (List 1) in the exclusion task are false alarms and are assumed to result from dependence of only familiarity, not recollection (F only, no R) because using recollection would result in a correct rejection, whereas “yes” responses to List 1 items in the inclusion task are correct responses and are assumed to result from the contribution of either recollection or familiarity or both ((F+R)-(F*R)). The probability of R can be obtained by subtracting the probability of F only (exclusion “yes” responses) from the total probability of F or R (inclusion “yes” responses). Once the probability of R is derived, it can be used to calculate the value for F. “Yes” responses to List 1 items in the exclusion task reflect F only without R, thus false alarms = F-F*R. Solving the equation for F results in FA/(1-R) and R is already known from the previous calculation.

4.3 RESULTS

The same exclusion procedure for outliers used in Experiment 1 was used in Experiment 2. Older adults had significantly slower reaction times for correct responses than young adults

($t(129) = -8.15$, $p<.001$, Cohen's $d=1.48$). Correct response mean RT for older adults was 1316 ms and mean RT for correct responses for young adults was 996 ms.

Jacoby's process-dissociation procedure (1991) was used to create values of R (recollection) and F (familiarity) for each subject. The parameter for R was computed by subtracting proportion of "yes" responses to List 1 items in the exclusion task from proportion of "yes" responses to items in the inclusion task. The parameter F was computed by dividing the proportion of "yes" responses in the exclusion task by 1-R. This was done for each subject. In Figure 4, recollection (R) and familiarity (F) parameters were derived by comparing the inclusion and exclusion tasks. There was a main effect of age; young people had significantly higher values on both recollection and familiarity than older adults. There was also a main effect of memory type, the familiarity parameter value was greater than the recollection parameter value for both groups. Surprisingly, however, the expected interaction of age and memory type was not seen. A 2 (memory parameter) X 2 (age group) univariate split-plot ANOVA was performed for the young (n=80) and older (n=50) adults, with memory parameter as the within-subjects factor and age group as the between-subjects factor.

There was a main effect of memory parameter $F(1,128)=388.07$, $p<.001$, $\eta^2=.752$ and a main effect of age group $F(1,128)=96.20$, $p<.001$, $\eta^2=.429$ but the interaction was not significant, $F(1,128)=2.17$, $p=.143$, $\eta^2=.017$. The familiarity parameter was larger than the recollection parameter, for both age groups. Older adults had significantly smaller memory parameters overall, but were not specifically impaired on recollection compared to young adults.

Because some of the subjects in Experiment 3 did not participate in Experiment 1, another analysis was performed excluding the people who did not participate in Experiment 1. Of the people who participated in Experiment 3, there were 31 young and 33 older adults who participated in Experiment 1. The results were the same, no interaction was present $F(1,61)=.002$, $p=.969$, $\eta^2<.0001$ but there were main effects of memory parameter $F(1,61)=263.2$, $p<.001$, $\eta^2=.812$ and age group $F(1,61)=$, $p<.001$, $\eta^2=.337$. Note that the effect size for the age group parameter is similar for this smaller group that participated in both Experiment 3 and Experiment 1 ($\eta^2=.337$) and for the larger group of all Experiment 3 participants ($\eta^2=.429$), regardless of whether they participated in Experiment 1.

In this subset, older adults had significantly slower reaction times for correct responses than young adults ($t(61)= -5.30$, $p<.001$, Cohen's $d=1.36$). Correct response mean RT for older adults was 1333 ms and mean RT for correct responses for young adults was 1004 ms. For the inclusion task, some subjects did not have enough incorrect responses to compute reliable median RT so the RT for each subject was the average of median RT only for correct responses across the two conditions.

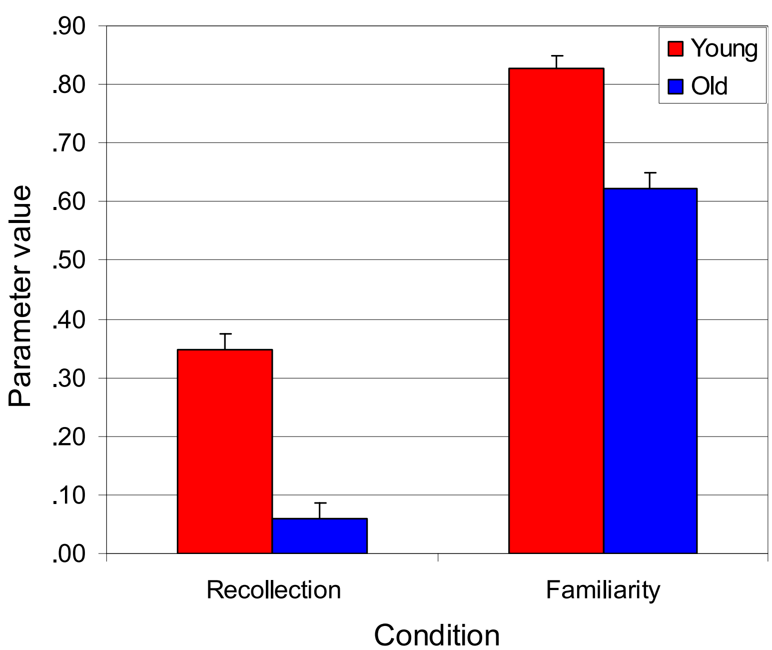


Figure 4. Recollection and familiarity parameters for young and older adults. Error bars represent standard error of the mean.

4.4 DISCUSSION

The most commonly accepted explanation for the episodic impairment in healthy older adults has been put forth by Jacoby (1991). His hypothesis is that aging decreases controlled processing ability, that is, the ability to do tasks that require the allocation of attentional resources. According to this view, recollective memory requires controlled processing whereas familiarity is supported by automatic processes that do not require attentional control. This hypothesis has been researched extensively by others often making use of an experimental design called the process-dissociation procedure (Jacoby, 1998) which teases out the respective contributions of recollection and familiarity to memory performance.

If the age-related memory impairment is due to degradation of attentional functions that support strategic memory search, then there should be larger differences between old and young adults for tasks that rely on recollection compared to tasks that rely on familiarity. Here, controlled processing was not specifically tested, but the process-dissociation procedure was used to provide a baseline for age-related differences among the current participant sample by which to judge the results of the other experiments.

In the process-dissociation paradigm there are two types of tests. In the inclusion test, the participants must say "yes" to items from either study list and it is believed that recollection and familiarity are working together in this task (Jacoby, 1991; Jacoby, 1998; Hay & Jacoby, 1999). In the exclusion test, the participants must say "yes" only to items from the second study list and it is believed that recollection and familiarity are working against each other in this task. Therefore, incorrectly including List 1 items in the exclusion task is evidence of the reliance on familiarity instead of recollection because recollection is an all-or-none process.

The difference between older and young adults for recollection was not significantly bigger than the difference between older and young adults for familiarity. This finding is inconsistent with several previous findings in studies which used the same process-dissociation procedure (Hay & Jacoby, 1999; Jennings & Jacoby, 1993; Jennings & Jacoby, 1997). When using the process-dissociation procedure to separate the relative contributions of recollection and familiarity, older adults have shown greater impairment in recollection than for familiarity compared to young adults. Those studies differed in regard to the modality of each list the and more notably the instructions given to the participants for the study session. In one of the studies (Jennings & Jacoby, 1993; Exp. 2) items were given to the participants as text on one list and verbally on the other list. That is, the lists differed on perceptual details, while the current study had the same delivery modality (text presentation) for both lists. In all the previous studies the older adults were told to read the words aloud in the study sessions. Auditory perceptual processing may be more impaired than visual perceptual processing which would explain why other studies showed a supposed "recollection-specific" deficit but the current study did not. The current study also had a larger group of older adults than most previous studies and a more representative sample of older adults than most previous studies. Therefore, the lack of recollection-specific deficit in the current study casts some doubt upon Jacoby's assumption that memory processes are neatly divided into recollection and familiarity components and that recollection is impaired while familiarity is spared.

5.0 CORRELATIONAL ANALYSIS OF BEHAVIORAL EXPERIMENTS

Many of the same participants participated in all three behavioral experiments. Correlational analyses were conducted to determine if there were patterns of performance across the experiments. Reaction times were highly correlated across all three experiments for both older and young adults (see Table 1). The proportion of correct responses was significantly correlated for Experiments 1 & 3 for older adults (R=.555, p<.001) and marginally correlated for Experiments 1 & 2 (R=.331, p-.069) and for Experiments 2 & 3 (R=.259, p=.075). The proportion of correct responses was significantly correlated for Experiments 1 & 3 (R=.511, p=.006) and for Experiments 2 & 3 (R=.292, p=.009) and marginally correlated for Experiments 1 & 2 (R=.344, p=.073). Thus, based on correct responses and reaction times, individuals' performance was quite consistent across the three experiments. An additional analysis compared the magnitudes of the age-related effects across experiments to determine whether the hypothesized age effects in each task were associated with the same underlying mechanisms. Significant correlations would suggest that similar cognitive processes were being measured in each experiment.

The measures used to represent the specific age-related impairment in each experiment were based on the predictions of each experiment. For Experiment 1, the difference in old/new discrimination (hits-lure false alarms) between pictures and words was used as a measure of age-related impairment (perceptual processing impairment). Age-related impairment should correspond to a greater difference in discrimination between pictures and words. For Experiment 2, the level of old/new discrimination (hits-false alarms) in the "List 1 & 2 Exact" condition represented the ability of older adults to use associative information. Age-related impairment should correspond to worse discrimination in this task. For Experiment 3, discrimination in the "exclusion" task was used (hits-false alarms to List 1 items). Age-related impairment should correspond to worse discrimination in this task. Only Experiments 1 and 2 were significantly correlated and only for young adults ($R=-.669$, $p<.001$). The negative correlation indicates that a greater benefit in the picture lure condition in Experiment 1 was related to worse pair memory in the "List 1 & 2 Exact" condition in Experiment 2.

The lack of correlation of performance on Experiment 3 with Experiments 1 & 2 is consistent with the finding that there was no specific age-related impairment and with the conclusion that the process-dissociation procedure is not the best method for detecting age-related memory impairments. The lack of correlation between Experiments 1 & 2 suggests that the specific age-related impairments may not have the same underlying causes. The perceptual impairment hypothesis and the associative encoding impairment hypothesis might represent two separate and independent age-related memory impairments. However, it is impossible to draw strong conclusions from the lack of correlation because this lack of correlation might simply reflect the noisiness of the data.

Table 1. Reaction time correlations across Experiments 1, 2, & 3 for older and young adults.

Group	Experiments	*N*	Correlation	Significance
	Exp. 1, 2	31	$R = .567$	$p = .001$
Old	Exp. 1, 3	31	$R = .530$	$p = .002$
	Exp. 2, 3	48	$R = .508$	$p < .001$
	Exp. 1, 2	28	$R = .571$	$p = .002$
Young	Exp. 1, 3	27	$R = .407$	$p = .035$
	Exp. 2, 3	78	$R = .554$	$p < .001$

6.0 EXPERIMENT 4

6.1 RATIONALE

Experiment 1 found that older adults had difficulty using perceptual details to distinguish lures from targets, and that this difficulty affected words more than pictures. If there are behavioral differences between older adults and young adults and if cognitive processes are supported by neural processes, then it stands to reason that electrophysiological differences between age groups should also exist for this task. Specifically, there should be differences between age groups in the topography and amplitude of waveforms associated with memory, such as the old/new left parietal effect (Curran & Cleary, 2003; Curran, 2000; Henson, *et al*., 1999) and the slow-wave late positivity (Ruchkin, *et al*., 2003). Therefore, the interesting results from Experiment 1 were further supplemented and extended by an event-related potential (ERP) experiment that used the same stimuli and similar experimental paradigm.

6.2 METHODS

6.2.1 Participants

Seventeen healthy older adults were recruited from a healthy older adult participant database at the University of Pittsburgh and received $15.00 for participation. The healthy older adults were

10 males and 7 female individuals (mean age = 73.18 years, range = 68-80; mean education = 16 years, range = 14-19 years). Twenty healthy young adults were recruited from the Psychology Subject Pool at the University of Pittsburgh and received Psychology course credit for participation. The healthy young adults were 13 male and 7 females (mean age = 20.5 years, range = 18-27; mean education = 14.2 years, range = 13-17 years). Behavioral data from one young adult and three older adults were excluded due to either poor accuracy or extremely long reaction times (>1000 ms). In addition to the exclusions based on behavioral problems, ERP data from one older adult and four young adults were excluded due to a high percentage of artifact trials. All participants were native English speakers, right-handed, and had no history of major medical, neurological, or psychiatric disorders. After the explanation of procedures and prior to testing, all participants were provided with written informed consent to participate using consent forms approved by the Institutional Review Board of the University of Pittsburgh.

6.2.2 Stimuli

The same set of picture and word stimuli were used for this experiment as for Experiment 1 (pictures; Snodgrass & Vanderwert, 1980).

6.2.3 Design

Seventy-eight of the word stimuli and 78 of the picture stimuli were presented in random order, alternating word/picture for each participant during the study session. For the test session, words and pictures again alternated. Two filler words and two filler pictures were presented first. These were followed by a randomly ordered list containing 39 items in each of the following conditions: word targets, picture targets, word lures, pictures lures, word distractors and picture distractors (See Table 2 in Appendix A for details).

6.2.4 ERP recording

A 15-in. cathode-ray tube (CRT) monitor working at a 60 Hz refresh rate displayed the instructions and stimuli. The experimental trials were controlled by commercial software, E-prime, which presented the trials and recorded the reaction times. It also sent event information to the EEG recording system. A 128-channel geodesic sensor net (EGI net station, Electrical Geodesics Inc., Eugene, Oregon) was used to collect the EEG data. All impedances were kept below 40Ω (Ferree, *et al*., 2001). A vertex reference was used in the recording, and the data were recomputed off-line against the average reference (Lehmann & Skrandies, 1980). Six eye channels were recorded to allow rejection of trials with eye movements and blinks. The signals were recorded continuously at 1000 Hz by NetStation with a 12-bit A/D converter. The hardware filter setting was between 0.1 and 200 Hz. The EGI net station also recorded all event onset times, reaction times, and accuracy for later use in data analysis.

6.2.5 Procedure

During the study session, participants were presented with a sequence of single pictures and words on the computer screen. Stimuli were presented until the participant responded or for a maximum of 5000 ms. After participants responded to each stimulus, another stimulus would appear. During the study session, participants were instructed to make a size decision about the stimuli presented (e.g., "bigger or smaller than a brick") to increase encoding and attention to the study stimuli. Participants were informed that they would be asked about the stimuli later in the experiment. Participants were given a 5 minute rest period between study and test sessions. Prior to the test session, participants were instructed to make an “old/new” decision task. They were told that a “yes” response was to be given only if there was an exact perceptual AND semantic match to previously seen study items. Test items that matched study items only in semantic information but not perceptual information were to be considered “new” and served as lures. Test items that did not match semantic information or perceptual information with items at study were to be considered “new” and served as distractors.

After the participant pressed the space bar a new stimulus (word or picture) appeared, which remained until the participant made a response, or for a maximum of 3000 ms. The experiment took place in a dedicated ERP lab, located in an isolated, quiet room. Each participant viewed the trials on a computer screen in the testing room, while the experimenter monitored the ERP recordings in an adjacent room.

6.2.6 Analytic technique

All analyses were conducted on ERPs from correct response trials only. Differences between ERP waves for conditions of interest (e.g., targets – lures) were examined for statistical significance. ERP waveform difference comparisons pose two problems: 1) there are so many timepoints that some correction must be applied, but a typical correction is so extreme that it would be likely to eliminate any effect and 2) if no correction is applied, many spurious effects were found because the different timepoints in the waveform are not independent of one another (e.g., they are autocorrelated). A method was developed to deal with these problems in which the degree of autocorrelation is estimated and the autocorrelation parameter is used to determine how many consecutive timepoints are necessary for a truly significant effect (Guthrie & Buchwald, 1991).

ERP waveform data was compared between age groups and four electrode clusters were specified prior to analysis: two frontal clusters and two occipitoparietal clusters (see Figure 5). Using the Guthrie & Buchwald (1991) method it was determined that 14 consecutive timepoints significant at $p<.1$ were necessary for the region to be significant, as a whole, at $p<.05$, controlling type I error across all comparisons for a given condition.

6.3 RESULTS

T-tests of group differences were computed at each point along the mean ERP for each condition for each subject. All time segments associated with significant differences between young and old participants in each condition are listed in Figures 15 & 16 in Appendix C. See Figures 11-14 in Appendix C for 10-20 plots of original ERP data).

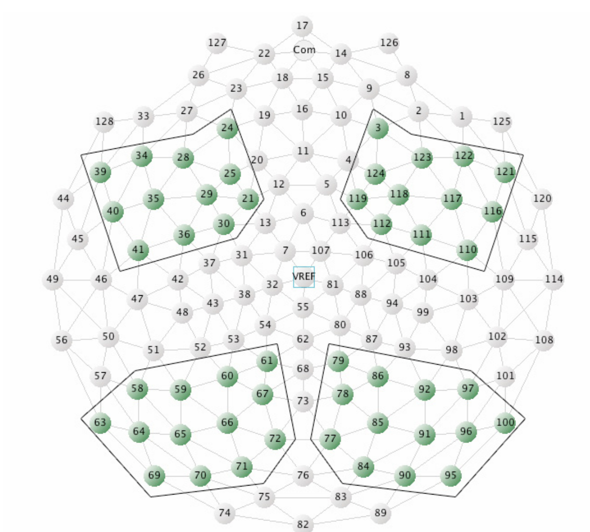


Figure 5. Clusters used in t-test analyses.

For frontal clusters, there were very few differences between older and young adults (see Figure 15 in Appendix C for visual comparison and statistics). For picture distractors there was a small period of significance from 370ms to 390ms in the left hemisphere in which older adults was more positive than young. There was no right hemisphere significance for picture distractors in the frontal cluster. For picture lures there were late periods of significance from 630ms to 680ms and 850ms to 1000ms in the left hemisphere and from 950ms to 990 ms in the right hemisphere in which young adults were more positive than older adults. There was a small early period of significance in the right hemisphere between 190ms and 210ms for picture lures in which older adults were more positive than young.

For picture targets there were no left hemisphere differences, but there was a small right hemisphere age group difference from 450ms to 500ms. For word distractors there were no age group differences in either hemisphere. For word lures there were three periods of significance between 810ms and 1000ms in the left hemisphere in which young was more positive than older adults and one period of significance between 960ms and 1000ms in the right hemisphere in which young was more positive than older adults. For word targets there were no left hemisphere differences between groups but there was one period of significance in the right hemisphere between 890ms and 980ms in which young was more positive than older adults.

For occipitoparietal clusters, there were many sustained periods of difference between older and young adults (see Figure 16 in Appendix C for visual comparison and statistics). For picture distractors there was a short very early period of difference between older and young adults in both hemispheres and a significant period for both hemispheres between 190ms and 220ms. There was a long time period in both the left and right hemispheres during which most of the timepoints were significantly different between older and young adults (young more positive than old, L: between 420ms and 800ms; R: between 320 and 730 ms). For picture lures there were brief significant difference in the right hemisphere while the left hemisphere showed sustained periods of significant differences between older and young adults (young more positive than old) from 620ms to 810ms. For picture targets, the same left to right hemisphere pattern was observed such that the right hemisphere showed a brief period of significance in which the older adults displayed higher positivities than the young. In comparison, in the left hemisphere there were sustained periods of significant differences between older and young adults from 340ms to 770ms in which young displayed higher positivities than old.

For word distractors, the left hemisphere showed much more differential activity than the right hemisphere (both young more positive than old; L: 290ms-940ms; R: 310ms-500ms). For word lures, both hemispheres showed young more positive than older adults for the long period between 350ms-950ms. For word targets, the left hemisphere showed slightly less early differences but from 340ms onward, both the right and left hemisphere showed significant age group differences such that young were more positive than older adults.

6.4 DISCUSSION

The raw ERP data show some notable similarities to the behavioral findings. In particular, the differences in ERP waveforms between age groups were observed more consistently in word conditions than in picture conditions. This is specifically consistent with the behavioral results of Experiment 1 which found that age differences in memory were greater for words than for pictures.

It has been shown that when memory is specifically tapped, young adults have a more positive electrophysiological response from approximately 400-800ms (referred to as the late positive component) than older adults do (Rugg, *et al*., 1997; Swick & Knight, 1997). Indeed, that is what I found in the waveform analysis of the ERP data in the occipitoparietal clusters, with the notable exception of picture targets in the right hemisphere for which young and older adult electrophysiological response was equivalent. Pictures have been shown to activate right occipitoparietal regions (Levelt, *et al*., 1998) and picture targets contain a wealth of perceptual characteristics. Given the performance boost that older adults receive from pictures (as shown in Experiment 1), it is not surprising that the electrophysiological response for young and older adults was equivalent for picture targets in the right occipitoparietal cluster. In the frontal clusters only, the left hemisphere showed this stronger positive electrophysiological response for young adults, and only for picture lures.

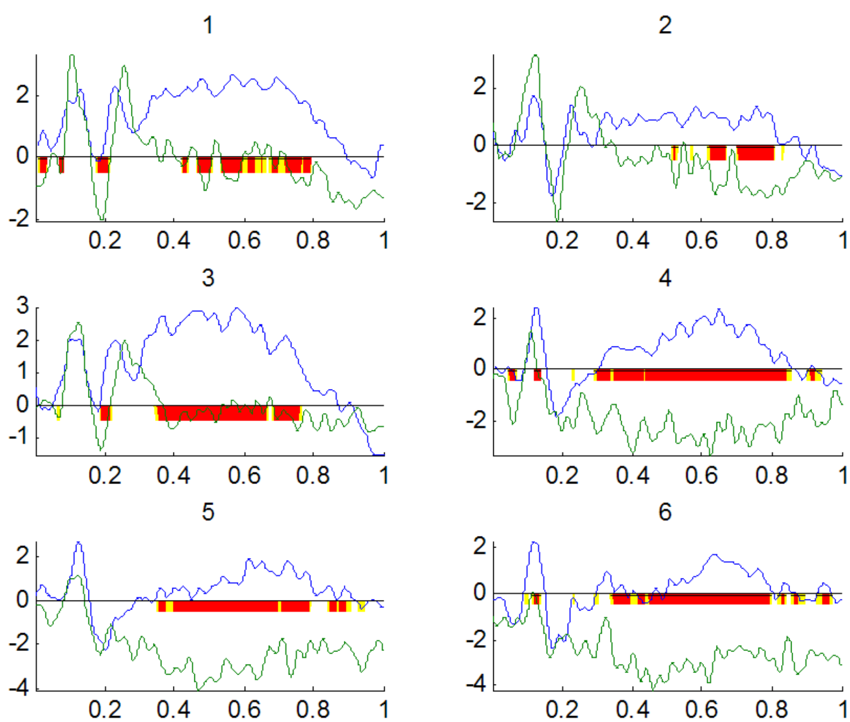


Figure 6. Left parietal ERP responses for young adults (blue) and older adults (green). Red markings indicate significant differences at p<.05 and yellow markings indicate marginal differences at p<.1

Additionally, there was a lack of left parietal old/new electrophysiological effect for older adults (Curran & Cleary, 2003; Curran, 2000; Henson, *et al*., 1999). The old/new effect begins 300-400 after stimulus presentation and lasts until very late (1500+ ms). Correctly recognized old items show a more positive electrophysiological response than new items and this response is maximal over the left parietal region. In the current data, young adults show a large positivity to correctly recognized old items, especially picture targets. Older adults do not show a similar large positivity, even though the items are correctly recognized as old, as evidenced by the correct behavioral responses. A recent study found that high-performing older adults had similar old/new left parietal ERP responses to young adults, but that low-performing older adults lacked the old/new left parietal ERP response that is supposed to index recollection (Duarte, *et al.*, 2006). Low performers were defined as the 50% below the median split for scores of overall recognition memory. The ERP pattern presented in the current study (lack of left parietal old/new effect) may be driven by low performers within the group. Future analyses will consider this interpretation by dividing the group into low and high performers (based on overall recognition memory performance) and examining the ERPs for the two groups separately.

The relationship of the behavioral findings to the electrophysiological results can also be seen over the left frontal cluster (see Figure 7). In this region the most reliable age-related differences are seen in the lure conditions for both pictures and words. This corresponds to the behavioral findings of Experiment 1, in which the greatest age-related differences are seen in the lure conditions.

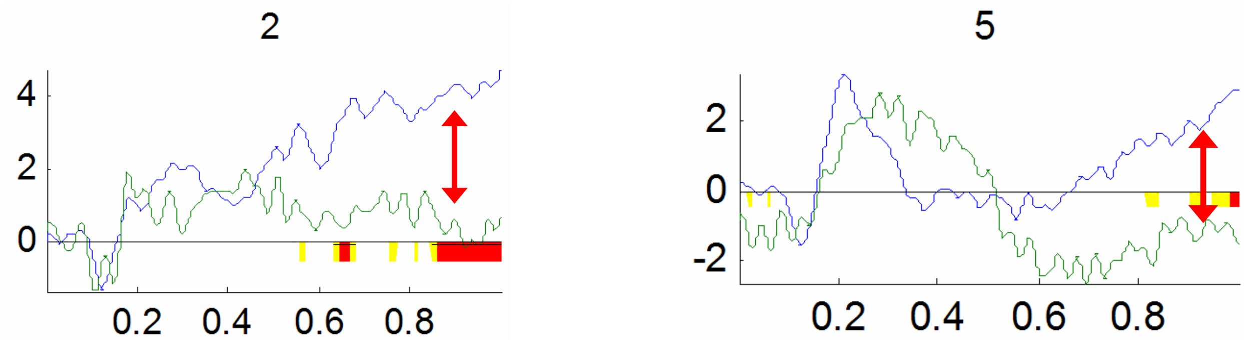


Figure 7. Left frontal late slow-wave positivity greater for young adults (blue) than older adults (green) for pictures lures (right) and word lure (left) conditions. Red markings indicate significant differences at p<.05 and yellow markings indicate marginal differences at p<.1.

This left very late positivity for young adults may be the slow-wave positivity associated with working memory processes (Ruchkin, *et al*., 2003). In this view, the initial perceptual and binding processes used at encoding are also active when items are represented in working memory. Prefrontal and posterior cortices work in synchrony to allow this representation in working memory. Indeed, in addition to the frontal differences between young and older adults for lure conditions in this experiment, occipitoparietal differences are also seen for picture and word lure conditions, particularly in the left hemisphere. The higher positive activity for young adults during lure conditions supports the hypothesis that young adults are better at initial perceptual processing which leads to better encoding and therefore, better storage and representation of items in memory. In the lure conditions it is necessary to represent in working memory (recollect) what one has seen previously in order to correctly reject the lure since lures share semantic information with targets and therefore familiarity cannot help one distinguish lures and targets. Young adults make use of their robust encoding and representational ability in order to correctly distinguish lures and this is reflected in young adults' late, slow-wave positivity which is absent for older adults.

7.0 GENERAL DISCUSSION

Three behavioral experiments and one ERP experiment were conducted to test three hypotheses: perceptual processing impairment hypotheses, associative encoding impairment hypothesis, and controlled processing impairment hypothesis. Experiments 1 & 2 found age-related memory effects that were consistent with their respective hypotheses, whereas Experiment 3 did not find the predicted age-related impairment in recollection. Experiment 4, which records ERPs within the behavioral paradigm of Experiment 1, found age-related differences in the electrophysiological response that were consistent with the behavioral results of Experiment 1. The implications of the findings of these four experiments are discussed below.

7.1 CONSIDERATION OF BEST EXPLANATION OF THE DATA

The perceptual processing deficit hypothesis accounts for Experiment 1 and could also account for Experiment 2. Words have fewer unique features than pictures. The scope of possible visual features of a word is constrained by the letters of the English language. The scope of possible visual features of a picture is only limited by dimension (2-dimensional). If older adults have an impairment in perceptual processing that is exhibited at initial encoding, then when they are given a cue it should be easier to find the match or non-match for the initially encoded picture than for the initially encoded word. This is because pictures have more unique visual features, and a greater total number of physical features, than words, and these features can be utilized by older adults, even if they have perceptual processing impairments. If retrieval of previously encoded material is sparse (impaired) then when given a cue, finding a match or non-match for the retrieved picture is easier than for retrieved words because pictures have more unique features. If you are only retrieving 10% of the picture, the probability that you are retrieving a unique feature is higher than if you are only retrieving 10% of a word where there are less total unique visual features. If the cue itself is a picture, there is an additional benefit to older adults because the cue also has many unique features, but it is only a benefit if the perceptual processing impairment is an encoding impairment. Consider Experiment 2; the only manner in which a perceptual processing impairment can affect associative binding is if the impairment in processing the perceptual details at encoding prevents or degrades the formation of an association. (AEH doesn't argue for encoding or retrieval specific impairment. According to AEH, it could be either; e.g., Naveh-Benjamin, 2000). In fact, it has been found that increasing support for older adults at encoding leads to better recollection (Luo, 2005). Two experiments were given to older adults. In the first experiment, "self-initiated processing" was reduced by showing pictures with words. This is based on the assumption that older adults have reduced processing resources, essentially, that older adults suffer from a controlled processing deficit. The experiments assert that the concrete and elaborative information is inherent in the material because the material is the word and picture representation of the word. In the second experiment "self-initiated processing" was not reduced. A definition was paired with the word and the word was in fragment form. The authors conclude that pictures improved recollection in older adults compared to the word/definition pair. They suggest that young adults carry out imagery processing spontaneously with words alone but older adults need pictures to achieve this type of processing because older adults do not use self-initiated elaborative processing. In fact, the results of this experiment can better be explained by a perceptual-processing deficit because in the second experiment there is no pictorial information; only words that form a definition. Therefore, the semantic information that the definition provides is arguably equal to the semantic information the picture provides. Where the two experiments differ most is in *perceptual* features. In the second experiment, the perceptual uniqueness is not as high as in the first experiment.

The perceptual processing deficit hypothesis is not inconsistent with Experiment 3 since it does not imply a recollection-specific deficit unless it is assumed that recollection uses perceptual processing and familiarity does not. This form of the perceptual processing deficit hypothesis, argued by Koutstaal & Schacter (1997), follows from the fuzzy-trace theory (Brainerd, *et al*., 1999) and was the basis of the perceptual processing deficit hypothesis outlined in the introduction. However, in light of the results of Experiments 1 and 3 it might not be necessary to define familiarity as purely conceptually-dependent with no perceptual content. Still, there has been data for older adults that show an apparent recollection-specific deficit. If the perceptual processing deficit hypothesis is going to account for this data from older adults then recollection must be more dependent on perceptual details than familiarity since recollection-specific deficits have been found (Benjamin & Craik, 2001; Caldwell & Masson, 2001; Jennings & Jacoby, 1993; Jacoby, 1999) but familiarity must also use perceptual details (Exps. 1 & 3 of this study). This is discussed further below.

The results of Experiment 4 are also consistent with the perceptual processing deficit hypothesis. Average ERP waveforms exhibited age-related effects that mirrored the behavioral effects found in Experiment 1. Additionally, PCA analysis identified components of the ERP data that differed across age groups in ways that suggested older adults had both increased reliance on semantic processing (due to perceptual processing impairment), and increased effort in rejecting familiar items based on perceptual features.

The associative deficit hypothesis accounts for Experiment 2 but does not account for Experiment 1 in which older adults are worse at remembering words, rather than pictures, when words and pictures share semantic information because in that experiment (Exp. 1) the difference between items is only perceptual. One could argue that the extra and unique features of the pictures provide a crutch for binding the semantic and perceptual information together, but many studies have found that type of information does not affect ability to form associations (Bastin & Van der Linden, 2003; Bastin & Van der Linden, 2006). The associative deficit hypothesis is not inconsistent with Experiment 3 since it does not predict a recollection-specific deficit. However, the results of Experiment 4 do not integrate as easily with the associative deficit hypothesis as with the perceptual processing impairment hypothesis.

The controlled processing deficit hypothesis does not account for any of the experiments unless it is assumed that associative encoding is a form of controlled processing. Even so, the data from Experiment 1 is not explained since an associative encoding deficit as controlled processing deficit hypothesis would predict recollection-specific impairments which were not found in Experiment 1. There are some aspects of Experiment 4 that are compatible with the controlled processing deficit hypothesis, such as the parietal old/new effects found in the PCA analysis. However, the lack of a recollection-specific deficit in Experiment 3 argues strongly against the usefulness of a controlled processing impairment as an explanation for age-related memory impairment.

7.2 COMPATIBILITY OF HYPOTHESES

The perceptual processing deficit hypothesis is the only one with the potential to account for all three experiments, but it might not be justifiable to conclude that the perceptual processing deficit is the only one that exists. Many researchers who study aging acknowledge that multiple causes for memory impairment are likely (Luszcz & Bryan, 1999a; Luszcz & Bryan, 1999b; Rabbitt, 1993; Light, 1991). The perceptual processing deficit hypothesis does find support in the literature. Some researchers argue for reduced effectiveness of encoding (Salthouse, 1994; Salthouse, 1996; Daselaar, *et al*., 2003; Grady, *et al.*, 1995) and this is frequently interpreted under a speed of processing theory (Salthouse, 1991). Salthouse states that older adults have difficulty encoding because they don't form elaborations quickly enough and therefore fail to retain information from one trial to the next. However, there is nothing that argues that the relevant information is not perceptual information. It seems likely, given the results of my experiments, that older adults have difficulty encoding because they don't process the perceptual features quickly enough. Salthouse speaks of "less of an opportunity to conduct additional processing of the stimulus information" but does not specify what the nature of the stimulus information is. I argue that the lack of perceptual information could impair the formation of associations but that older adults do not have an impairment in association formation itself. This explanation is actually supported by Salthouse's study because the materials used in the associative learning/memory tasks were pairs of abstract patterns and the patterns differed primarily in perceptual features. My results do not preclude a "speed of processing" explanation of older adult performance. But I present a more specific definition of what information is lost when processing is slow, namely, perceptual information. This more specific definition is supported by recent studies of visual perception and aging (Faubert, 2002; Faubert & Bellfeuille,

2002) which show that perception itself, rather than visual working memory (a controlled process) is impaired.

However, the associative encoding impairment hypothesis also has support in the literature. Several studies have found severe associative impairments in older adults, rather than general memory deficits (Naveh-Benjamin, 2000, 2002; Naveh-Benjamin, *et al*., 2003, 2004b) and divided attention tasks in young adults resulted in general memory deficits rather than association-specific deficits (Naveh-Benjamin, *et al*., 2004a). Another consideration is the lack of correlation between individuals who had age-specific memory impairments in Experiment 1 and age-specific memory impairments in Experiment 2. If a perceptual processing impairment is responsible for the results of both experiments, a correlation between the two would be expected. Thus, the associative deficit hypothesis has not been eliminated as a good way to characterize the age-related memory impairments. Further investigation of the properties of an associative-specific impairment in older adults is necessary in order to determine if it can be combined with a perceptual processing impairment to explain age-related memory impairment or if a perceptual processing impairment alone explains age-related memory impairment.

7.3 EXPERIMENT 3: RELATING TO PREVIOUS FINDINGS

Other studies have found recollection-specific impairments in older adult memory (Benjamin & Craik, 2001; Caldwell & Masson, 2001; Jennings & Jacoby, 1993; Jacoby, 1999). Some conflicting results have been found when recollection is very high (R>.60; Jennings & Jacoby, 1997; Davidson & Glisky, 2002). The conflicting results were explained as being due to ceiling effects in recollection which preclude the detection of an age-related interaction. However, my data shows that older adults have both impaired recollection and familiarity even though recollection is not high (Recollection <.10).

Further doubt is cast on the controlled vs. automatic distinction by a recent study of divided attention in memory (Naveh-Benjamin, *et al*., 2004a). Controlled processes are typically assumed to depend on attentional resources (see Craik & Byrd, 1982), and one of the classic paradigms used to argue for the controlled processing deficit hypothesis is the divided attention paradigm. In this task young adults are forced to divide their attention at encoding (or retrieval) and their recollection performance appears to mirror that of older adults (Jennings & Jacoby, 1993). However, Naveh-Benjamin *et al*. (2004b) found that the similarity between older adult performance and the performance of younger adults under divided attention conditions is only superficial. In that study, associative encoding of pairs of words was examined. Participants were instructed to make note of both individual items and the pairs in which they appeared as they would be tested on both. Young adults were assigned to either a divided-attention task or a full attention task. Older adults participated in only the full attention task. The divided attention task resulted in decreased recollection, compared to the full attention task, for the young adults and the older adults had decreased recollection compared to the young adults in the full attention task. However, the decrease in recollection that the young adults showed as a result of the divided attention task was not similar in nature to the decreased recollection that the older adults showed. Specifically, the young adults had similar hit rates for the associative memory test and the item memory test. Older adults were impaired much more on the association of items in a pair. For young adults, dividing attention decreased their ability to encode all information while for older adults there was only a decrease in ability to encode associations between items. The item test had a significantly higher hit rate than the association test. Thus, divided attention has the same effect on items in an episode and their relationship to each other, whereas the age-related memory impairment is specific to associative binding. Thus, an artificially-contrived recollection impairment in young adults may result in similar memory performance to older adults in some cases, but it may not be an valid simulation of the age-related impairment in older adults.

In summary, although some studies of the age-related memory impairment have found recollection-specific impairments using the process-dissociation procedure, the results of the current experiment agree with those of another study (Jennings & Jacoby, 1997) that found recollection and familiarity to be similarly impaired in older adults. Taken together with recent evidence that divided attention paradigms may not accurately simulate older adult memory performance, the overall support for the controlled processing deficit hypothesis is questionable.

7.4 LIMITATIONS & FUTURE DIRECTIONS

The experiments reported here possessed some shortcomings that should be addressed with further research. First, there was no independent assessment of cognitive impairment in older adults. A neuropsychological test such as the Mini Mental Status Examination would allow for a comparison of general intellectual ability to memory ability for each participant and would allow for screening of participants who may appear to have normal cognitive function but actually have mild cognitive impairment. Second, some of the experiments made assumptions that may need to be examined. For instance, the use of pleasantness ratings assumed that emotional processing was similar in young and older participants and therefore did not contribute to age-related effects. Future experiments should make use of other deep encoding tasks to ensure that the effects are not dependent on the pleasantness rating task. Third, the design of Experiment 2 did not rule out an explanation based on a perceptual processing impairment. Future experiments will need to contrast the perceptual processing impairment hypothesis and the associative encoding impairment hypothesis more directly in order to determine whether one can be ruled out. An associative memory task that explicitly manipulates perceptual content might provide a good test of both hypotheses within the same experiment. Fourth, Experiment 3 should be repeated using alternate stimuli. Repeating the experiment with low frequency words or non-verbal stimuli may be informative in understanding the discrepancy between the results of the current process-dissociation procedure results and those of others studies in which a recollection-specific deficit was found. It may be that what is referred to as a controlled processing impairment is actually an impairment in encoding, working memory manipulation, or retrieval of particular classes of stimuli. Fifth, additional participants need to be run to add power to the ERP study. Limited conclusions can be made due to the low number of good subjects, especially in the older adult age group in difficult conditions. This is a common problem in ERP studies of older adults. A new data-cleaning method also may be employed in an attempt to salvage some of the subjects who had an adequate number of trials but had artifacts due to eye blinks.

More research is needed in order to more firmly conclude whether the associative deficit hypothesis or the perceptual processing deficit hypothesis is the best explanation for age-related memory problems. A study of paired-associates memory in which perceptual features were held constant within group and groups were constructed to be perceptually impoverished or perceptually enriched may give some insight to the relative contributions of perceptual processing versus associative ability in older adults. Some additional studies should be conducted to solidify the interpretation of the current non-effect for the process-dissociation paradigm. It is possible that the recollection-specific effect is due to stimuli-specific characteristics so materials with different perceptual properties could be used. To date, there has not been a simple picture-list study conducted using the process-dissociation paradigm as my word list study was conducted.

7.5 NOVEL FINDINGS

Although additional research is needed to clarify and expand the current interpretations, this study presents a significant advantage over other studies of older adult memory for three reasons. One, it samples from community-dwelling adults who are much more representative of the true older adult population than are the samples often used in research studies of memory and aging. Two, the sample size for the behavioral studies is much larger than many research studies of older adults and thus the power is quite high. Third, the sample of individuals participated in all three behavioral studies allowing for within-subject comparisons, something that is uncommon in many older adult studies.

The behavioral data give evidence for a perceptual processing deficit explanation for age-related memory impairment, rather than a memory-specific impairment. The ERP data, though limited, lends some support to this explanation as it reveals perceptual and semantic processing differences between young and older adults.

APPENDIX A

BEHAVIORAL PARADIGM DETAILS

In this appendix are the trial sequences for Experiment1 and Experiment 2.

Table 2. An example of each study and test condition for Experiment 1.

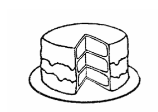
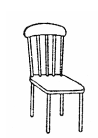
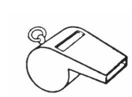
Study Presentation	Test Presentation	Condition Label
"BICYCLE"	"BICYCLE"	Word Target
		Picture Target
"CAKE"		Picture Lure
	"CHAIR"	Word Lure
	"SKUNK"	Word Distractor
		Picture Distractor

Table 3. An example of each study and test condition for Experiment 2.

Study List 1	Study List 2	Test Pair	Condition Label
face11-scarce *face12-essence*	**face11-scarce** *face12-essence*	**face11-scarce** (target) *face12*-**scarce** (lure)	Lists 1 & 2 Exact
face3-*lymph* face4-**zeal** *face7*-yore	**face3-zeal** *face7-lymph*	**face3-zeal** (target) *face7*-**zeal** (lure)	Lists 1 & 2 Re-arranged
	face8-cite *face9-origin*	**face8-cite** (target) *face9*-**cite** (lure)	List 2
face5-reign face6-believe		*face5-reign* (lure) *face5*-believe (lure)	List 1

Note: Numbers refer to faces in the actual experiment. In the actual experiment no item would be repeated during test (as illustrated here simply to conserve space). Table adapted from (Criss & Shiffrin, 2005).

APPENDIX B

SUPPLEMENTAL PCA MATERIALS

In this appendix is a table of the number of correct trials and usable subjects for the PCA analysis, clusters used in the PCA analysis, traditional 10-20 plots of the ERP waveforms, and factor loadings for the word and picture PCAs and corresponding topographies.

It is helpful to use converging methods of analysis to understand the ERP data. Principal Component Analysis (PCA) is a statistical method that identifies correlated data in the ERP signal to decompose the waveforms into a set of orthogonal factors. The factors can be interpreted as the underlying electrophysiological components that make up the overall waveform (Dien & Frishkoff, 2005). The PCA conducted for this study was a temporal PCA meaning that it identified time-varying components of the ERP signal. It was carried out on participant averages, based on 250 4-ms time samples, making up the entire 1000 ms recording time period.

Three factors captured age-related effects. Factor 4, in the word tPCA, and Factors 1 and 4 in the picture tPCA (see Figures 13 & 14 in this Appendix for topographies and waveforms). Across all three of these factors, age differences were consistently found in the left parietal cluster. For the two picture factors, age differences were also found in the left posterior temporal cluster. The main effects of group were seen only for the factors from the picture tPCA and were generally driven by a higher positive electrophysiological response from the older adults. What is interesting in light of the three hypotheses of age-related memory impairment is that age differences vary by condition.

Older adults had much fewer correct responses to words than to pictures, which resulted in less usable data for the word conditions (see Table 5 in the Appendix). Therefore, separate word and picture tPCAs were performed in order to retain additional subjects for the picture tPCA. (Five of the subjects in the picture tPCA did not have word data that was usable.) Input for the word tPCA were a data matrix of 129 electrodes, 18 participants (young=12, older=6) and 3 stimuli conditions (target, distractor, lure) or 6,966 observations for each 4-ms time sample. Input for the picture tPCA were a data matrix of 129 electrodes, 22 participants (young=11, older=11) and 3 stimuli conditions (target, distractor, lure) or 8, 514 observations for each 4-ms time sample. A correlation matrix with Varimax rotation were used (Picton, *et al*., 2000). Ten factors were retained (See Figure 13 for factor loadings for words and Figure 14 for factor loadings for pictures)

PCA scores were used as dependent measures in an age group X cluster X condition ANOVA. Left and right frontal, parietal, occipital, anterior temporal and posterior temporal clusters were used (see Figure 8 in this Appendix). Due to a low number of good subjects and good data per subject (see Table 5 in this Appendix), particularly for the older adults in the word conditions, there was low power for this study. Only significant age effects are described below since the purpose of this study was to examine age-related effects. The factors for which there were age-related effects are summarized in Table 4.

Table 4. PCA factors of interest for young and older adults combined.

	Factor #	Peak (ms)
Words	4	445
Pictures	4	431
	1	747

For Factor 4 of the word tPCA there was a marginally non-significant interaction of group X condition X cluster, $F(18, 288)=1.52$, $p=.083$, $\eta^2=.089$. Although non-significant, this effect was investigated further using separate group X condition ANOVAs for each cluster. For the left parietal cluster there was a group X condition interaction, $F(2, 32)=4.44$, $p=.020$, $\eta^2=.217$. In paired samples t-tests comparing the conditions within each age group, distractors were more positive than lures for older adults $t(5)=3.40$, $p=.01$, Cohen's $d=3.23$. Young participants did not exhibit any significant differences between conditions in the left parietal cluster.

For Factor 4 of the picture tPCA there was a cluster X group effect, $F(9, 180)=2.87$, $p=.003$, $\eta^2=.126$. There was a main effect of age in the left parietal cluster, $F(1, 20)=8.09$, $p=.010$, $\eta^2=.288$, the left posterior temporal, $F(1, 20)=5.53$, $p=.029$, $\eta^2=.217$, and the right anterior temporal, $F(1, 20)=5.25$, $p=.033$, $\eta^2=.208$. Independent samples t-tests were conducted to compare age groups within each cluster and condition. Older participants were more positive than younger participants in the left parietal cluster for targets, $t(20)=-2.84$, p=.01, Cohen's $d=1.27$, distractors, $t(20)=-2.16$, p=.043, Cohen's $d=.97$, and lures, $t(20)=-2.30$, p=.033, Cohen's $d=1.03$. Older participants were more positive than younger participants in the left posterior temporal cluster for targets, $t(20)=-2.40$, p=.026, Cohen's $d=1.07$, and lures, $t(20)=-2.24$, p=.037, Cohen's *d*=1.00. For the right anterior temporal cluster, young participants were more positive than older participants for lures only, $t(20)=2.39$, p=.027, Cohen's *d*=1.07.

For Factor 1 of the picture tPCA there a cluster X group interaction, $F(9,180)=2.07$, $p=.035$, $\eta^2=.094$. There was a main effect of age in the left parietal cluster, $F(1, 20)=11.03$, $p=.003$, $\eta^2=.356$, the left posterior temporal, $F(1, 20)=10.66$, $p=.004$, $\eta^2=.348$, and the right occipital, $F(1, 20)=4.33$, $p=.05$, $\eta^2=.178$. Independent samples t-tests were conducted to compare age groups within each cluster and condition. Older participants were more positive than younger adults in the left parietal cluster for distractors, $t(20)=-2.52$, p=.02, Cohen's *d*=1.13, and lures, $t(20)=-3.72$, p=.001, Cohen's *d*=1.66. In the left posterior temporal cluster, older participants were more positive than younger adults for distractors, $t(20)=-3.05$, p=.006, Cohen's *d*=1.36, and lures, $t(20)=-2.82$, p=.011, Cohen's *d*=1.26. In the right occipital cluster, older participants were more positive than younger adults for distractors, $t(20)=-2.19$, p=.040, Cohen's *d*=.98.

For Factor 4 (peak 445 ms) for words, the older adults show a differentiation based on semantic familiarity. The lures have a more negative electrophysiological response than the distractors. The distractors and lures both have new perceptual features but only the lures have old semantic features. Factor 4 is temporally aligned with semantic components such as P300 and N400, suggesting that it reflects semantic processing. The observation of semantic differentiation in older adults is consistent with the hypothesis that older adults rely more heavily on semantic information in memory decisions perhaps due to an impaired ability to use perceptual information.

For Factor 1 (peak 747 ms) for pictures, older adults show a long-lasting late differentiation, starting at approximately 500ms and lasting until the end of the measured time period. Older adults' electrophysiological response was significantly more positive than young adults for lures and distractors but not for targets and it was more positive for lures than for distractors. This corresponds to the age-related late positivity in which older adults show a sustained late positive electrophysiological response to non-target items that is notably absent for target items even when older adults correctly reject non-target items (Dywan, *et al*., 1998). This can be interpreted as older adults' difficulty in inhibiting response tendencies and may reflect the extra effort required for older adults to reject new items, especially if the items are semantically familiar.

For Factor 4 (peak 431 ms) for pictures, older adults had higher positivities than young adults for all three conditions (target, lure, distractor) but the difference was most statistically significant for targets. The electrophysiological response to targets is consistent with the old/new left parietal effect (Curran, 2000) in which ERPs elicited by correct responses to old items are typically more positive over left parietal regions. The positive response to lures and distractors may indicate a "recall to reject" process (Curran & Cleary, 2003) in which memory of the study list is used to correctly reject new items.

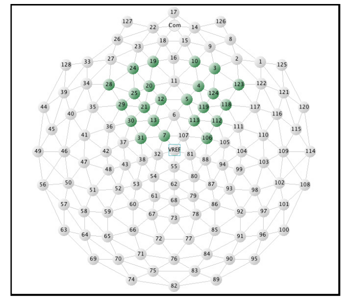
Table 5. Number of usable subjects for ERP experiment by category and condition.

Words	Young (n=12)			Old (n=6)		
	Distractors	Lures	Targets	Distractors	Lures	Targets
Good trials	22	23	16	22	21	10

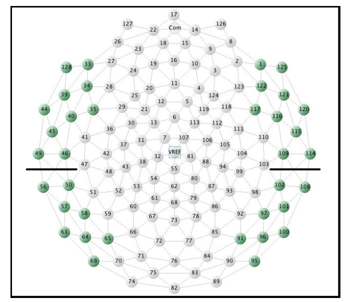
Pictures	Young (n=11)			Old (n=11)		
	Distractors	Lures	Targets	Distractors	Lures	Targets
Good trials	27	22	25	21	19	20

Figure 8. Channel groupings for tPCA of 128-channel ERPs.

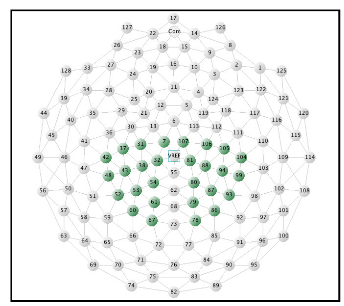
Left Frontal	7 12 13 19 20 21 24 25 28 29 30 31
Right Frontal	3 4 5 10 106 107 112 113 118 119 123 124



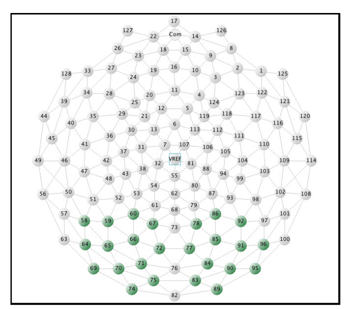
Left Anterotemporal	33 34 35 39 40 41 44 45 46 49 128
Right Anterotemporal	1 109 110 114 115 116 117 120 121 122 125
Left Posterotemporal	50 56 57 58 63 64 65 69
Right Posterotemporal	91 95 96 97 100 101 102 108



Left Parietal	7 31 32 37 38 42 43 48 52 53 54 60 61 67
Right Parietal	78 79 80 81 86 87 88 93 94 99 104 105 106 107



Left Occipital	59 60 64 65 66 67 69 70 71 72 74 75
Right Occipital	77 78 83 84 85 86 89 90 91 92 95 96



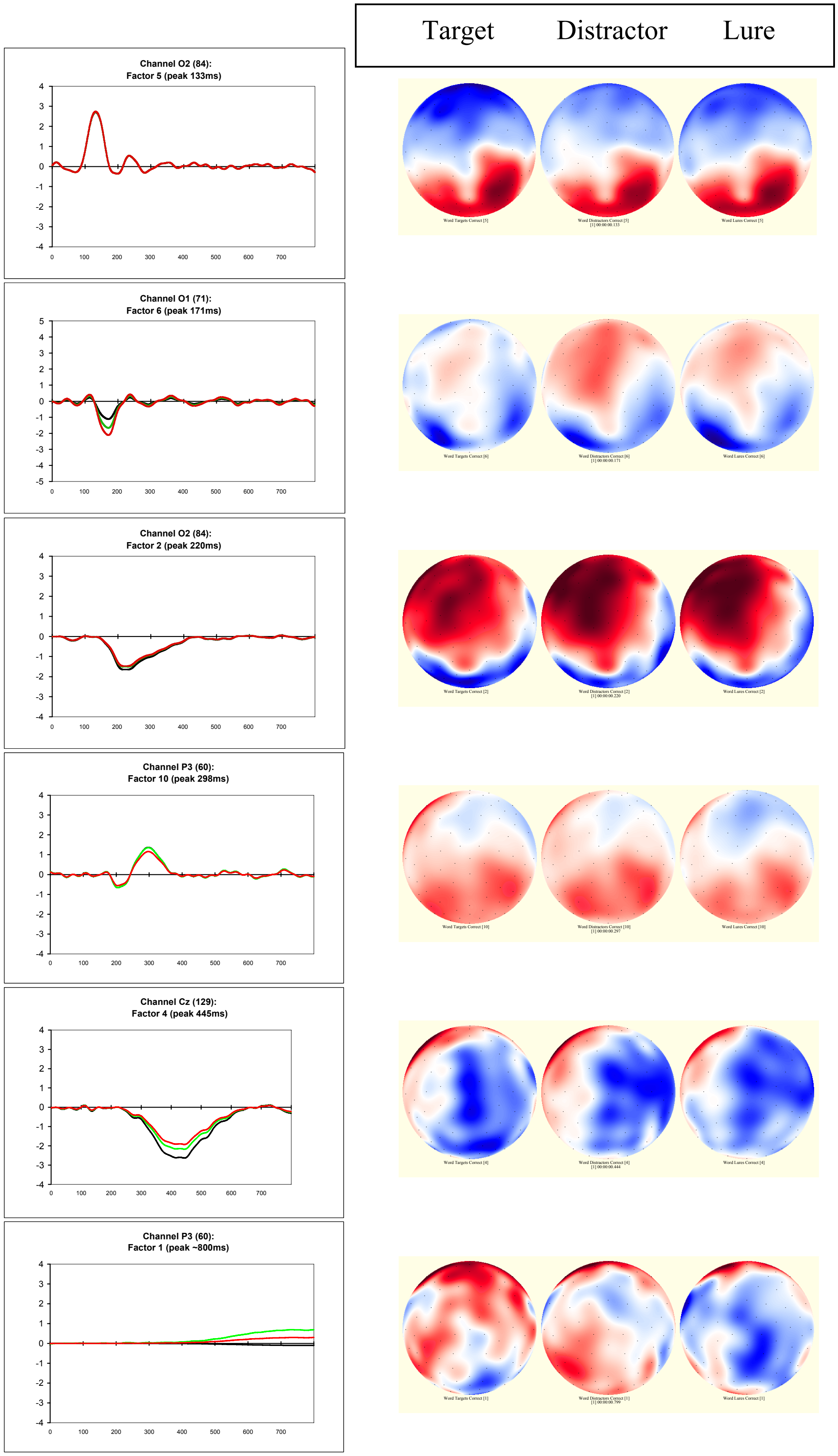


Figure 9. PCA factor loadings for words and corresponding topographies.

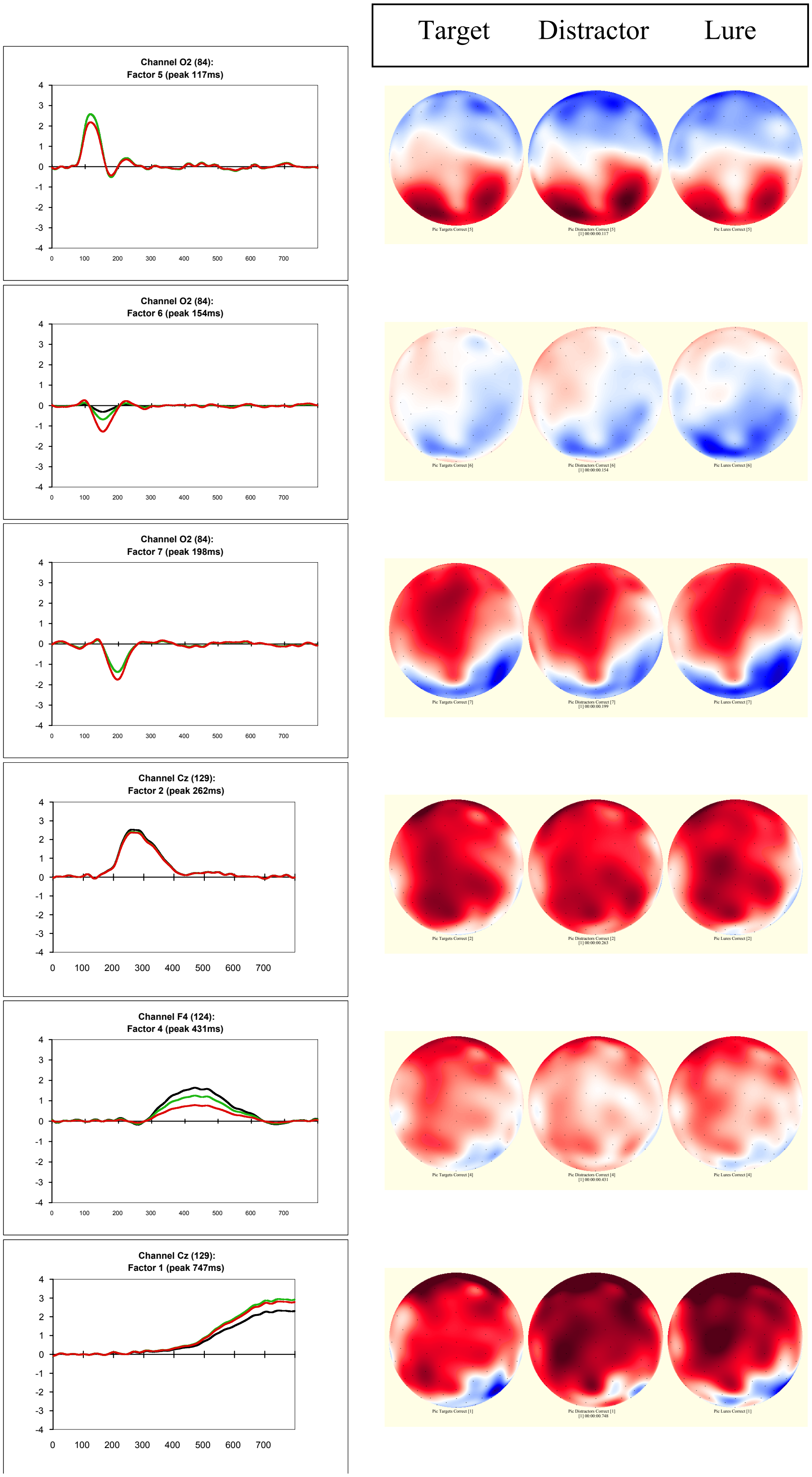


Figure 10. PCA factor loadings for pictures and corresponding topographies.

APPENDIX C

RAW ERP DATA

This appendix contains the raw ERP data plotted in traditional 10-20 format and plots of the entire age group statistical comparison for each word and picture condition. The highlights of this comparison are discussed in the section 6.3.

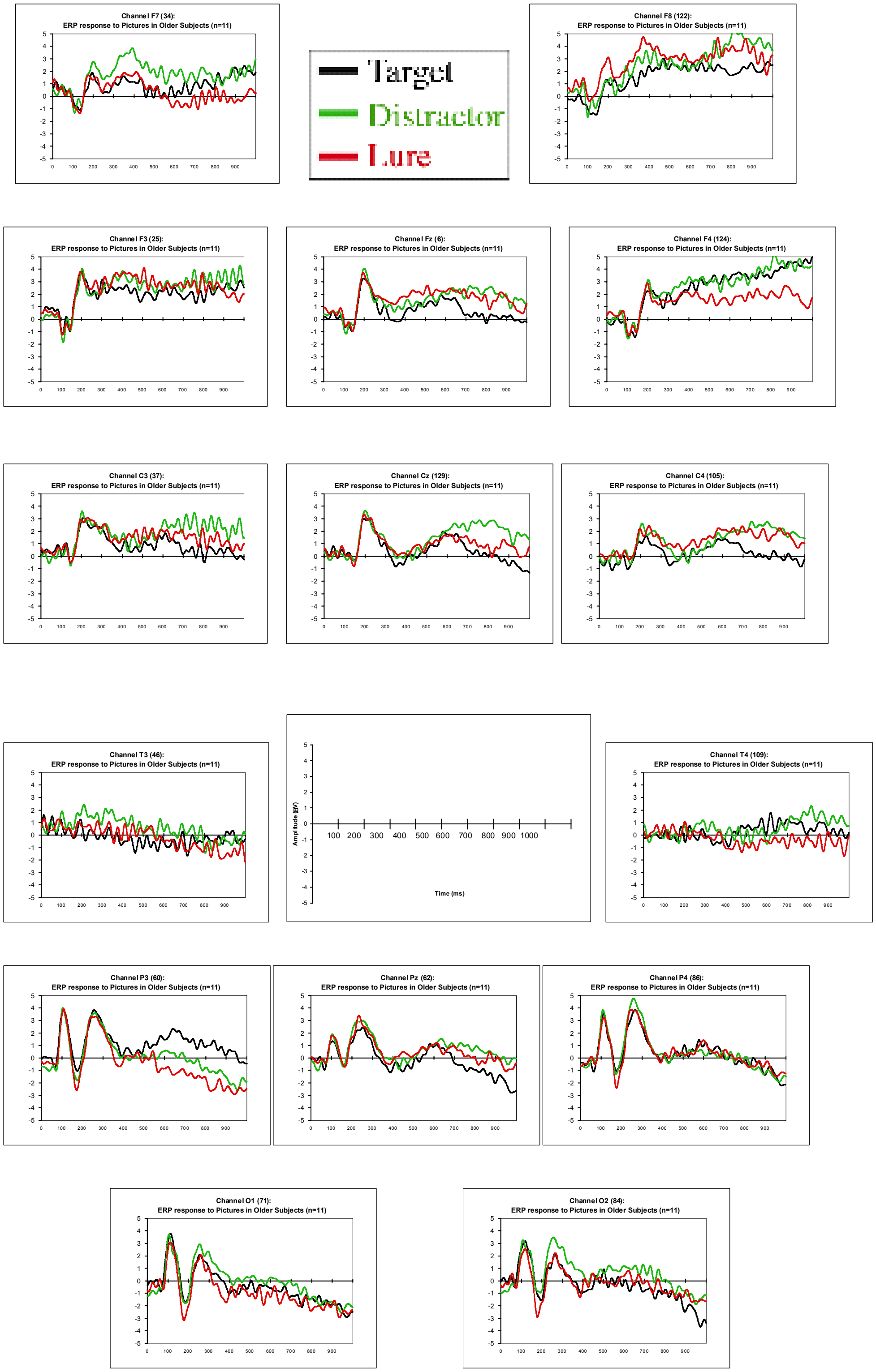
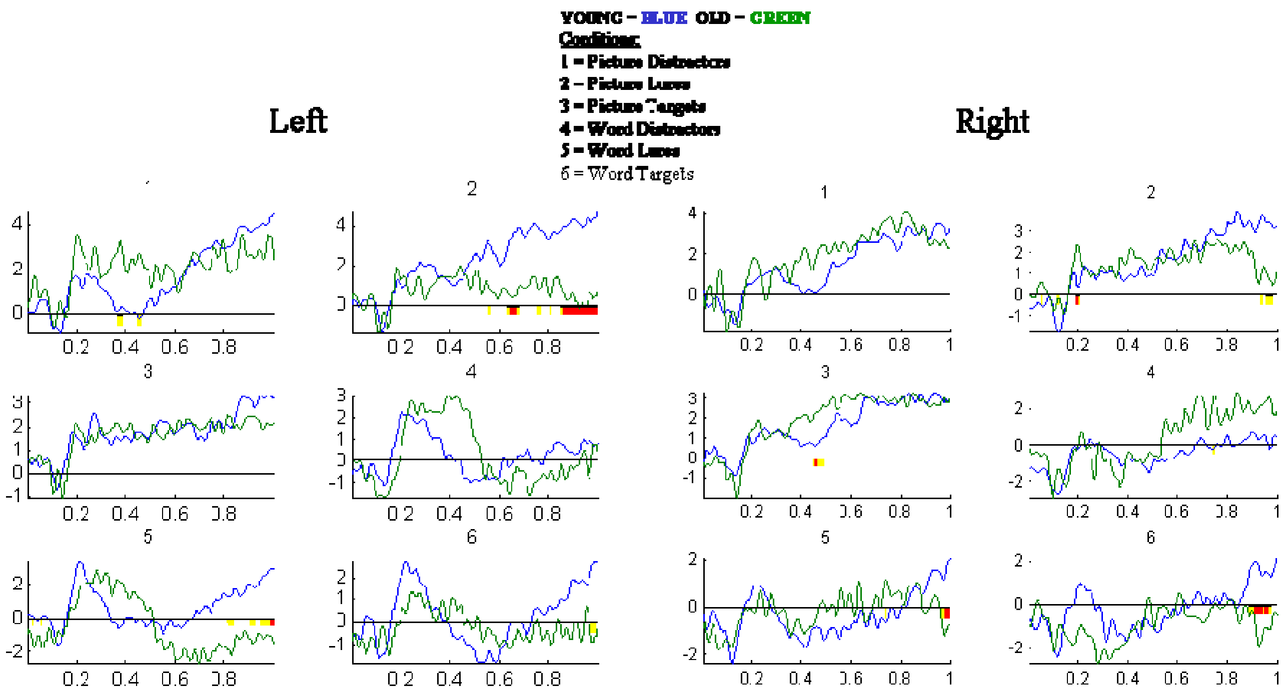


Figure 11. 10-20 view of ERP response in older adults to pictures.

Figure 12. 10-20 view of ERP response in older adults to words.

Figure 13. 10-20 view of ERP response in young adults to pictures.

Figure 14. 10-20 view of ERP response in young adults to words.



Condition 1: 0.37 to 0.39s: t(27)=-1.83, p=0.08, d=-0.68

Condition 2: 0.63 to 0.68s: t(27)=2.11, p=0.04, d=0.79
0.85 to 1.00s: t(27)=2.37, p=0.03, d=0.88

Condition 5: 0.81 to 0.84s: t(27)=1.91, p=0.07, d=0.71
0.91 to 0.93s: t(27)=1.80, p=0.08, d=0.67
0.95 to 1.00s: t(27)=2.07, p=0.05, d=0.77

Condition 2: 0.19 to 0.21s: t(27)=-2.22, p=0.03, d=-0.83
0.95 to 0.97s: t(27)=1.87, p=0.07, D=2.67, d=0.69

Condition 3: 0.45 to 0.50s: t(27)=-1.99, p=0.06, d=-0.74

Condition 5: 0.96 to 1.00s: t(27)=2.40, p=0.02, d=0.89

Condition 6: 0.89 to 0.98s: t(27)=2.22, p=0.04, d=0.82

Figure 15. Older and young adult electrophysiological response for correct responses in frontal clusters. Red indicates significant differences at p<.05 and yellow indicates differences significant differences at p<.1.

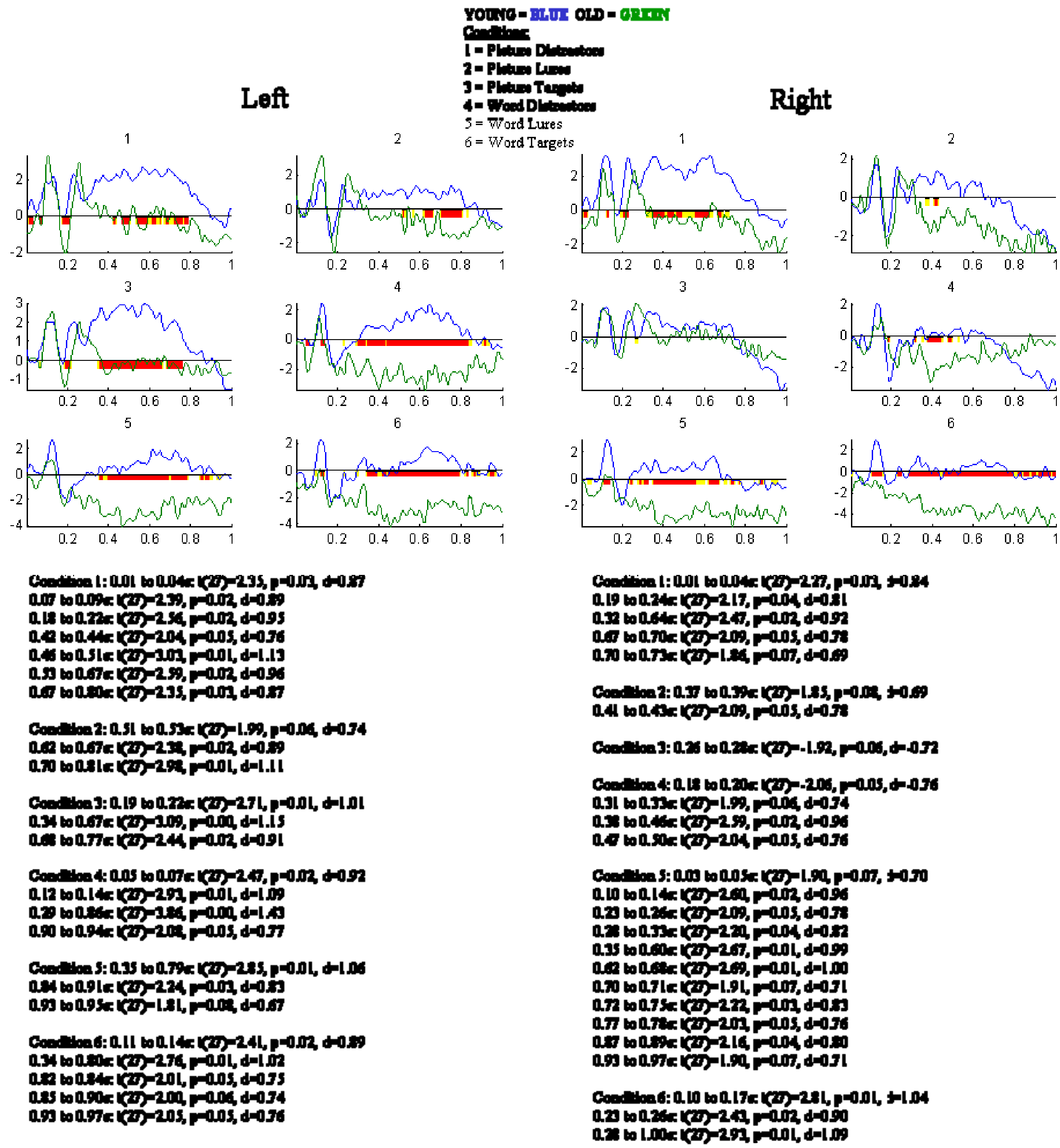


Figure 16. Older and young adult electrophysiological response for correct responses in occipitoparietal clusters. Red indicates significant differences at p<.05 and yellow indicates significant differences significant at p<.1

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