PAYING ATTENTION TO BINDING: IS THE ASSOCIATIVE DEFICIT OF OLDER ADULTS MEDIATED BY REDUCED ATTENTIONAL RESOURCES?

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by
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The undersigned, appointed by the Dean of the Graduate School, have examined the thesis entitled:

PAYING ATTENTION TO BINDING: IS THE ASSOCIATIVE DEFICIT OF OLDER ADULTS MEDIATED BY REDUCED ATTENTIONAL RESOURCES?

Presented by Angela Kilb

A candidate for the degree of Master of Arts

And hereby certify that, in their opinion, it is worthy of acceptance.

Moshe Naveh-Benjamin 2/25/05

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ABSTRACT

One notion put forth to explain age-related, episodic memory problems is the associative-deficit hypothesis, stating that they are due to older adults' decreased binding ability (i.e., their ability to encode separate components into a cohesive unit). The present experiments investigated whether such a binding deficit is mediated by a reduction of attentional resources by using a dual task procedure where participants were asked to study lists of words while completing an auditory reaction time task. Results show that when younger adults' resources were manipulated using divided attention, they did not simulate the deficit of older adults. Furthermore, older adults who underwent the same divided attention procedure did not show a larger associative deficit than that seen under full attention. A follow-up experiment (in which participants separately learned the components or their associations) showed similar results in terms of memory accuracy, replicating the associative deficit seen in older adults. This second experiment also investigated the separate attentional costs for learning the components or their associations. These results reveal that older adults had a larger attentional cost during encoding than younger adults overall; however, the costs to the older adults were not larger for tasks involving the binding of components than for tasks involving the learning of components alone when compared to younger adults. These data do not support the suggestion that the associative deficit is mediated by a reduction of attentional resources.

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INTRODUCTION

Evidence shows that memory abilities decrease with age (see Craik & Jennings, 1992, for a review); however, older adults' memories are affected differentially depending on the type of information being processed. For instance, an older person may be able to retrieve obscure vocabulary words without a problem while being unable to recall where last Christmas was spent. One fundamental distinction here is between semantic memory (memory for general knowledge) and episodic, or autobiographical, memory. Research shows that older adults are able to retain semantic information as well as younger adults (Rabinowitz, Craik, & Ackerman, 1982), yet it is more difficult for them to retain episodic information in which they must encode events along with their corresponding contexts (see Zacks, Hasher, & Li, 2000, for a review).

Several hypotheses have been suggested over the years to explain age-related memory problems. For example, Salthouse (1996) supports the claim that they stem from older adults having reduced processing speed in carrying out cognitive tasks. Here, the notion is that older adults are not able to fully process information before it begins to degrade, resulting in poorer memory. Others, including Craik (1982, 1983, 1986; Rabinowitz, Craik, & Ackerman, 1982; Craik & McDowd, 1987; Castel & Craik, 2003), maintain that age differences are a result of older adults having reduced processing *resources*. In other words, memory deficits may more likely be due to reduced capacity in older adults, meaning that they are not able to process information as efficiently as younger adults. These two views certainly do not exhaust the possible explanations for age differences in memory.

Another suggestion, related to the processing resources view, is that older adults are more dependent on environmental support than younger adults (Craik, 1983). This is reflected, for example, by greater age differences in recall than recognition since recall offers fewer cues and requires more "self-initiation." An overabundance of environmental stimuli, however, may not be beneficial. Zacks & Hasher (1994) argue that older adults are less efficient at inhibiting irrelevant details. As a result of processing unnecessary information, they become distracted and are less able to focus their attention on the task at hand than younger adults. These explanations may each play a role in determining the causes of age-related memory problems.

Still others suggest that older adults display poorer memory because of difficulties in learning and remembering contextual information. In a meta-analysis published by Spencer & Raz (1995), it was shown that older adults had greater impairments in memory for context than content relative to younger adults. More recently, Dumas & Hartman (2003) demonstrated that older adults have a deficit in temporal memory despite being equated with younger adults in item recognition. An additional hypothesis emphasizing the role of context includes that of familiarity versus recollection (Jennings & Jacoby, 1997; Hay & Jacoby, 1999). This line of research indicates that there are no age differences for memories that do not rely on context (e.g., Have you met Sarah?); however, there are significant age differences for memories that do rely on context (e.g., Was Sarah at the party last night?).

Recently, a binding hypothesis was suggested to explain the memory deficits described above, stating that they are a result of problems in associating focal elements and their contexts (Chalfonte & Johnson, 1996; Bayen, Phelps, & Spaniol, 2000).

Chalfonte & Johnson (1996) demonstrated this by presenting younger and older subjects with an array of symbols presented in various colors. When given recognition tests over either the colors or symbols, older adults' performance was comparable to younger adults. Recognition tests over the color of a given symbol, however, produced poorer results for the older adults than the younger adults, showing that the older adults' memory for associations between focal elements and their contexts was worse than their memory for components relative to the younger adults.

Using a procedure similar to that of Chalfonte & Johnson (1996), Mitchell, Johnson, Raye, Mather, & D'Esposito (2000) have obtained results showing this binding problem in older adults for working memory. In each trial, participants were shown three grids (each appearing for one second and containing a new object in a new location), then an unfilled 8-second delay, and a test. As with Chalfonte & Johnson's (1996) earlier results, showing a binding deficit in long-term memory, these authors found that older adults performed more poorly when tested over combinations of objects and their locations than the individual features when compared to the younger adults.

Naveh-Benjamin (2000; 2002; Naveh-Benjamin, Hussain, Guez, & Bar-On, 2003) has also investigated this pattern of findings and proposes an associative-deficit hypothesis (ADH), suggesting that binding problems are not limited to the associations between an item and its context. Rather, binding problems can also occur with two focal items. This was demonstrated by presenting younger and older adults with unrelated word pairs or word-nonword pairs and giving separate tests over the items and their pairings (Naveh-Benjamin, 2000). Results show that older adults displayed poorer performance in the pair test than in the item test relative to the younger adults, characterizing an associative deficit.

Castel & Craik (2003) also show support for an ADH in two experiments in which younger and older subjects were visually presented with word pairs and told to learn both the items and the pairs. During two separate memory tests, they were asked to discriminate items or pairs seen at study from various types of lures (e.g., two recombined words, an old word matched with a new word, or two new words). Older adults were found to have a greater deficit in remembering the correct pairings than the items relative to the younger adults. These results are in agreement with Naveh-Benjamin (2000; 2002; Naveh-Benjamin, Hussain, Guez, & Bar-On, 2003), despite the use of a slightly different paradigm.

Naveh-Benjamin, Hussain, Guez, & Bar-On (2003; Experiment 1) have demonstrated the associative deficit with pictorial stimuli. When younger and older adults were asked to learn pairs of unrelated pictures, it was found that older adults showed greater memory impairment for learning the pairings than for learning the individual pictures. In a more ecologically valid study, older adults' memories were comparable to younger adults in remembering individual names or faces, yet they were poorer at remembering the name-face associations relative to the younger adults (Naveh-Benjamin, Guez, Kilb, & Reedy, 2004).

The above findings lead to questions regarding the source of this associative deficit in older adults. For instance, can it be due to older adults having poorer strategies in learning paired stimuli than younger adults? Naveh-Benjamin (2000; Experiment 2) outlines a study in which younger and older adults were presented with unrelated word pairs under intentional or incidental encoding. In the intentional encoding condition, participants were told to learn the pairings of the words in order to later differentiate between old and new pairs during test. Conversely, participants in the incidental encoding condition were told to learn the individual words for an item recognition test. After the study phase, both encoding groups were given a memory test over the pairs. If the associative deficit is due only to a difference in strategy for younger and older adults, then the deficit should be eliminated in the incidental learning group since participants would not have incorporated a strategy for learning the word pairs. The results of this experiment show that although the associative deficit was largest under intentional encoding (indicating a strategic deficit), it was also manifested under incidental encoding (i.e., even after adjusting for item memory performance, younger adults still performed at significantly higher levels than older adults when tested over the pairs). This indicates that the binding deficit of the older adults (in this case, binding words into word pairs) may also involve automatic processes.

Others might argue that binding is not automatic and requires a fair amount of attentional resources because the information is context-specific. In an experiment conducted by Troyer et al. (1999) in which attention was divided at retrieval, younger adults were auditorally presented with words that were read by either a male or female speaker. When subjects were later given recognition tests under divided attention, they displayed worse performance during the secondary task while retrieving source information (the gender of the speaker's voice for a particular word) than while retrieving the item itself. In a later experiment, Troyer & Craik (2000) show that dividing attention at both encoding and retrieval caused a greater decrement to memory for temporal order of a study item relative to memory for item or color information. Taken together, these results suggest that binding an item with aspects of its context requires more attentional resources than memory for the item alone. It seems plausible then that binding in general may not be an automatic process.

Further evidence from neuropsychology supports the involvement of both strategic and automatic processes in binding, primarily mediated by the frontal and medial temporal lobes. Glisky (2002; Glisky et al., 2001) shows, for example, that the frontal lobes are responsible for encoding relationships between items and their contexts. Although brain activity was measured somewhat indirectly (through the use of neuropsychological tests), her results indicate that older adults' poorer memory for associations may be due to poor frontal functioning. This is consistent with more direct measures of brain activity since neuroimaging studies comparing younger and older adults demonstrate that younger adults show more prefrontal cortex (PFC) activation during encoding than older adults (Cabeza et al., 2000; Anderson et al., 2000). Also of interest is a study by Raz et al. (1998), linking age-related PFC shrinkage to increased perseverative errors in the Wisconsin Card Sorting Task, which is an indication of strategic inflexibility. These results suggest that older adults may be poorer at binding information because they have diminished use of strategic processes provided by the frontal lobes. However, other processes involving the medial temporal lobes (namely, the hippocampus) also seem to play a key role in binding. For instance, Eichenbaum and his colleagues have published numerous studies, supporting that the hippocampus is involved in the "chunking" of item information (Cohen et al., 1993; Eichenbaum, 1995; Wallenstein et al., 1998; Eichenbaum, 2003a; Eichenbaum, 2003b). One example, taken from the animal research, shows that rats with parahippocampal lesions are impaired (relative to normal rats) in associative recognition tasks in which it is necessary to discriminate between intact and recombined odor pairs (Eichenbaum & Bunsey, 1995). Eichenbaum (2003b) postulates that the cortical areas may be responsible for sending and receiving information to the hippocampus, which in turn binds the information together. Other studies show similar evidence implicating the hippocampus as a binder in humans (Henke et al., 1997; Kroll et al., 1996).

Kroll et al. (1996) compared individuals with and without hippocampal lesions on tasks requiring associative memory for words as well as associative memory for pictures. In the first experiment, words were displayed such that some previously presented syllables were recombined to form new words (e.g., “valley” and “barter” might be recombined to form “barley”). In a continuous recognition task, participants were asked to judge whether each word was “old” (previously seen in the list) or “new” (presented for the first time in the list). They found that the patients with left hippocampal lesions had considerably more conjunction errors (i.e., they were more likely to respond “old” to a recombined pairing of previously presented syllables) than controls despite their ability to correctly recognize true repetitions. In their second experiment, the same participants were shown a study list of faces and later had to discriminate between old and new faces at test (here, a new face might be composed of the eyes of one study stimulus and the nose and mouth of another). Using this visual/spatial paradigm, patients with both left and right hippocampal lesions had more conjunction errors than controls.

Finally, Mitchell, Johnson, Raye, & D’Esposito (2000) found that younger adults, in contrast to older adults, showed more activation in the hippocampus when learning combinations of items and their locations than when learning the individual features. These findings assert that the hippocampus plays an important role in the binding of components.

Moscovitch (1994; Moscovitch & Winocur, 1992) claims that these two systems (i.e., the frontal and medial temporal lobes) work together to bind information both strategically and automatically. He suggests that the hippocampus "lacks intelligence" and will bind anything that is available to it, whereas the frontal lobes are more discriminative and are capable of organization. Together, these constitute a "working-with-memory" system in which the hippocampus and frontal lobes join forces in order to bind information more efficiently. Support for this view comes from a series of experiments showing that tasks involving the frontal lobes (e.g., recall of a categorized list) are impaired under divided attention, whereas tasks involving the medial temporal lobes (e.g., recall during the buildup of proactive interference) are minimally affected by the manipulation of attention (Moscovitch, 1994). This differential effect of attention reveals that frontal activity requires more resources than that of the medial temporal lobes. It may be the case that neuropsychological deficits to the frontal and medial-temporal lobes account for the associative deficit that Naveh-Benjamin (2000; Experiment 2) observed under both intentional and incidental encoding.

I am interested in studying the question of whether the associative deficit is mediated by a reduction in attentional resources as would be suggested by Craik (1982, 1983, 1986; Rabinowitz, Craik, & Ackerman, 1982; Craik & McDowd, 1987). Craik's view is that a shortage of available resources in older adults results in poorer memory because information is being encoded more generally. This was demonstrated in a series of experiments by Craik and his colleagues (Rabinowitz, Craik, & Ackerman, 1982).

In Experiment 1, younger and older adults were presented with a list of words and were told to generate an associate for each. For some words, they were told to give “common” associates that others would be likely to name. In contrast, they assigned “unique” associates to another set of words, which were based on a personal life experience that would probably not be generated by other people. When these associates were later used as stimuli in a cued recall test, large age differences emerged for the “unique” cues (younger adults showing higher performance), whereas minimal age differences were seen for the “common” cues. Rabinowitz et al. (1982) use these results to argue that older adults have more difficulty in encoding context-specific material and are likelier to encode information in a more stereotyped (and automatic) way because of a lack of attentional resources. They then deduced that if this is the underlying cause of older adults’ poorer memories, then it should be possible to simulate this behavior in younger adults by reducing their resources as well.

In a later experiment, Rabinowitz et al. (1982; Experiment 3) attempted to mimic the behavior of older adults by experimentally manipulating younger adults’ available resources through use of a divided attention task. This secondary task was thought to decrease the attentional resources necessary to encode the information, thereby limiting the quality of processing. After presenting word pairs under both full attention (FA) and divided attention (DA), younger subjects were given a modified cued recall test in which they were shown either the first word of a study pair or a general phrase not presented at study describing the target word (e.g., “a professional occupation”). They found that the subjects performed better in the recall test when cues were context-specific than when cues were stereotypical phrases. This difference was larger under FA than DA, suggesting that younger adults will encode information in a more general way when resources are limited, which is similar to older adults.

Another study, carried out by Jennings & Jacoby (1993), shows the same similarity between younger adults under DA (young-DA) and older adults. In this experiment, three groups of participants (young, young-DA, and old) were presented with people's names and later given memory tests over them. The memory results reveal significant differences between the younger adults under FA when compared to the other two groups; however, there was little difference between the young-DA group and the older adults, further supporting Craik's position that age-related memory problems are due to a reduction of attentional resources.

Similar results have been found in studies examining the effects of aging and attention on social judgments. For instance, Chen & Blanchard-Fields (2000) presented young, young-DA, and old subjects with written criminal reports that included false information (always presented in italics) which either exacerbated the crime (e.g., Tom was *shouting obscenities at pedestrians* while hitching a ride) or deflated it (e.g., Tom was *stopping to chat with some old friends* while hitching a ride). Subjects were asked to read the reports and to ignore the information in italics because they were taken from an unrelated event. Afterwards, they were asked to recommend a prison term and to rate the suspect's dangerousness. The findings reveal that the young-DA and old groups showed the same level of susceptibility to the false information, differing from the younger adults under FA. This similar pattern of performance for older adults and young-DA is once more in line with the reduced resources hypothesis.

Again, evidence from neuropsychology supports the behavioral findings. For example, Grady et al. (1995) found that when compared to older adults, younger adults had increased activity in the hippocampus, PFC, and temporal cortex at encoding. This indicates that older adults may not be using their encoding networks appropriately under FA. In addition, Anderson et al. (2000) identified a reduction in the left inferior PFC for both older adults under FA and young-DA, showing that reducing resources in younger adults mimics the effects of age at the level of brain activity.

The successful simulation of older adults by using young-DA supports the notion that age-related memory deficits are due to older adults having fewer attentional resources. With this in mind, it makes sense that reducing the resources of older adults using a DA task should further reduce their performance and amplify any negative effects seen in young-DA. Put more simply, an interaction between age and attention should emerge. This has been observed in free recall tests for lists of words studied under DA (Park et al., 1989) as well as for more ecologically valid tasks. Lindenberger, Marsiske, & Baltes (2000) show that older adults have increased difficulty in walking compared to younger adults while trying to memorize a list of words. Also, Ponds, Brouwer, & van Wolffelaar (1988) confirm that older adults display poorer driving performance relative to younger adults, and their poorer performance is exacerbated when simultaneously responding to a choice-reaction time task.

In addition to the interference effects of a secondary task on memory accuracy, measures from performance on the secondary task can also be useful in evaluating attentional resources. For instance, performance for the secondary task under DA can be compared to a baseline, and the difference between these scores can offer a measure of the attentional cost of completing the memory task. According to the reduced resources hypothesis, this cost should be greater for older adults than for younger adults. By implementing DA at retrieval, Macht & Buschke (1983) report that free recall induces larger attentional costs for older adults when compared to younger adults, and Craik & McDowd (1987) show that cued recall is more resource demanding than recognition for older adults relative to younger adults (evidenced by significantly higher reaction times to a secondary task). In addition, Anderson, Craik, & Naveh-Benjamin (1998) show age differences in attentional cost for recognition, cued recall, and free recall. More recently, Naveh-Benjamin, Craik, Guez, & Kreuger (in press) have shown that older adults demonstrate a higher cost at encoding and especially at retrieval when utilizing a strategy than when using no strategy, whereas younger adults show minimal differences in cost for these two conditions.

In the following experiments, a DA paradigm was used to test whether such a resource reduction in the old may mediate the associative deficit. If dividing attention creates an associative deficit in younger adults or if dividing attention exacerbates the associative deficit in older adults, then it can be deduced that the associative deficit of older adults is mediated by reduced attentional resources. However, if dividing attention does not differentially affect memory for components and memory for associations, the results would support a strong version of an ADH, specifying that the deficit might be underlined by problems with binding.

Some recent evidence indicates that younger adults under DA do not simulate older adults (Naveh-Benjamin, Guez, & Marom, 2003; Naveh-Benjamin, Guez, Kilb, & Reedy, 2004); however, Castel & Craik (2003) reported somewhat different results. As with the current study, their notion was that young-DA would mimic older adults and show an associative deficit due to their joint reduction in attentional resources. Using their paradigm involving various types of lures (mentioned previously), they show that younger adults had differentially poorer memory performance for words pairs than for individual items when their attention was divided.

The current study differs from Castel & Craik (2003) in at least two major aspects. First, my procedure should offer a clearer indication of item memory performance. In their study, Castel & Craik (2003) used an indirect measure of item memory that was calculated by comparing accuracy among the different lure conditions. The paradigm that I have chosen is similar to those used by Naveh-Benjamin and colleagues (2000; Naveh-Benjamin, Hussain, Guez, and Bar-On, 2003) and offers a cleaner measure for item memory. Second, I am interested in how older adults will respond under DA conditions whereas Castel & Craik (2003) only manipulated attention for younger adults.

EXPERIMENT 1

Experiment 1 addressed the question of whether the associative deficit would be affected by dividing attention at study. I investigated this by presenting younger and older subjects with unrelated word pairs and later testing them separately over the components and their associations.[1] If the deficit is indeed mediated by reduced attentional resources, then we would expect that reducing the available resources using DA would affect the associative deficit. The reduced resources hypothesis predicts that (1) younger adults will show an associative deficit under DA, and (2) older adults will show a larger associative deficit under DA relative to FA. On the other hand, if the associative deficit is a result of pure binding problems, we would not expect the attention manipulation to have a differential effect on the two memory tests in either age group. Besides memory accuracy, other dependent measures collected for this experiment include retrieval latency and reaction times to the secondary task.

Method

Participants

Participants were 24 younger adults (ages 18-26; *M*=20.4, *SD*=2.2) and 24 older adults (ages 62-77; *M*=68.9, *SD*=4.6) that were equated in terms of years of education (*M*=14.1, *SD*=2.1 and *M*=13.8, *SD*=1.6 for young and old, respectively). The younger adults were students at the University of Missouri-Columbia receiving course credit for an introductory Psychology class. The older adults were community-dwelling residents of Mid-Missouri who were each reimbursed with $15. All older adults reported being in good mental and physical health with no major hearing or vision problems.

Design

The independent within-subjects variables were attention (FA or DA at encoding) and type of test (item or associative); the independent between-subjects variable was age

[1] Results collected from Naveh-Benjamin, Guez, & Marom (2003) show that these two retrieval tasks require the same amount of attentional resources in younger adults and therefore are equal in difficulty.

(young or old). The dependent variables were memory accuracy, retrieval latency, and reaction time to the secondary task.

Materials

For the primary task, two lists of 30 word pairs each were used. Pairs were comprised of two-syllable, high frequency, concrete nouns, and their assignment to the various lists was random. Their frequencies range from 3 – 196 per million (Kucera & Frances, 1967). Words within a given pair were unrelated (e.g., mustard-armpit; see Appendix).

For the secondary task, subjects performed a choice-reaction time task in which they discriminated among three pitches that could be identified as low, medium, or high. These tones (each spanning 300 ms) were presented over headphones, and subjects responded by pressing one of three designated keys on the keyboard. The task was self-paced, where each response elicited the next tone. There were 200 ms between the time that the subjects responded to the tone and the time that the next tone was presented.

Procedure

Each participant was visually presented with two study-test blocks along with three secondary task baseline blocks. One study-test block was presented under FA and the other under DA at encoding. The order of the two study lists was counterbalanced. Word pairs were presented one every 6 seconds. After each list's study phase, participants were given an interpolated activity consisting of counting backwards by 3's for 60 seconds. Next, they received the two recognition tests described below, the order of which was counterbalanced between subjects. For each participant, there was no overlap between the two test lists such that no word appeared in both the item and the associative test; however, the words were counterbalanced so that a given word did not always appear in the same type of test each time the experiment was run. The two memory tests are further described below.

1. *Item test*. Twenty individual target words (derived from ten study pairs) along with 20 lures were used for a self-paced, forced-choice item test. Each word from the study list was paired with one lure under the constraint that half of the targets were presented on the left side of the pair, and the other half of the targets were presented on the right side of the pair, totaling 20 pairs. Participants responded by pressing a designated key if the target appeared on the left versus another key if the target appeared on the right.

2. *Associative test*. Twenty pairs from the study list were used to create the self-paced associative test. Ten of these were left unchanged for the intact pairs (targets), and the remaining 10 were recombined (lures); that is, intact pairs appeared together in the study phase, whereas recombined pairs did not. Participants responded by pressing a designated key if the pair was intact versus another key if the pair was recombined.

Under FA conditions, participants were instructed to learn both the individual items and their pairings in preparation for the two upcoming memory tests. For baseline secondary task blocks, they were asked to respond as quickly and accurately as possible to the three tones. In the DA conditions, they were instructed to pay equal attention to both the primary task (remembering the items and the pairs) and the secondary task (responding to the tones). Before presentation of each list, participants were told which condition to expect. The two study-test blocks were alternated with three secondary task baseline blocks. These baselines each lasted 90 seconds.[2]

Instructions were given to participants before the experiment, detailing the nature of the item and associative tests. For the item test, they were told that half the studied words would appear on the left and half would appear on the right; for the associative test, they were told that half of the pairs would be intact and half would be recombined. Participants were also given practice blocks consisting of a FA block (complete with both item and associative tests) and a baseline secondary block. Performance on the baseline secondary task was reviewed before proceeding to the final practice block under DA to ensure that the participants had enough preparation with responding to the tones.

Results

Memory accuracy

The group means for memory accuracy (measured as proportion of hits – proportion of false alarms) are displayed in Table 1[3]. Main effects were found to be significant for all three independent variables. That is, younger adults outperformed the older adults, $F(1,46)=7.80$, $p<.05$, performance was poorer for both age groups under DA relative to FA, $F(1,46)=24.46$, $p<.05$, and finally, participants showed higher scores for the item test than for the associative test, $F(1,46)=9.41$, $p<.05$. To investigate the presence of an associative deficit in older adults, both age groups were compared under

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[2] The total time for each baseline was half of the total time for each study phase. This was done because it was thought that having subjects perform the secondary task for 180 s would be too tedious and would elicit fatigue effects.

[3] For the forced-choice item test, responses were considered to be hits if the target appeared on the right, and the subject recognized the word on the right. In contrast, responses were considered to be false alarms if the target appeared on the left, but the subject falsely recognized the word on the right. This allowed participants to be penalized for always using the same response (see Macmillan & Creelman, 1991).

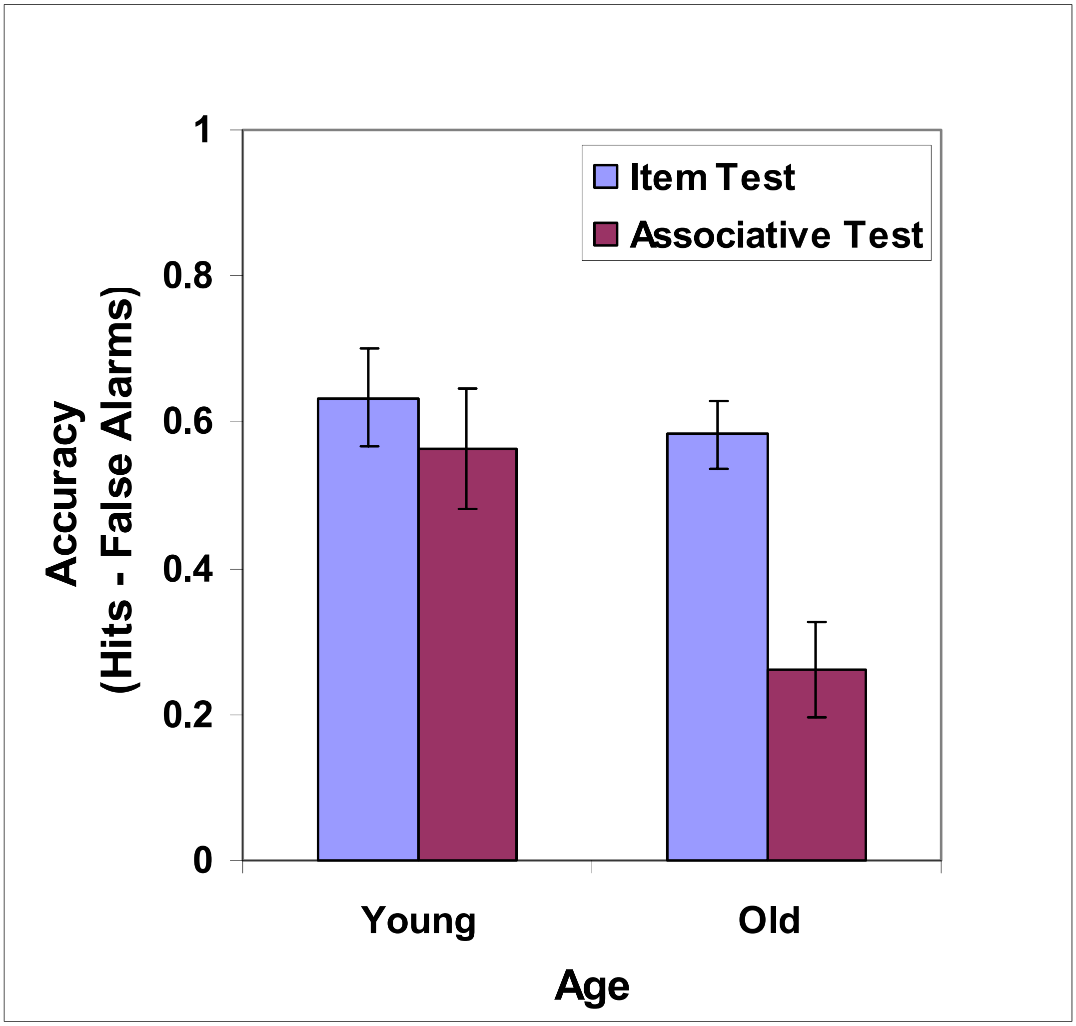
FA and tested for an age x test interaction. The results from a 2-way ANOVA were significant, $F(1,46)=6.09$, $p<.05$. Interestingly, post-hoc comparisons showed no age differences in the item test, $t(46)=.62$, $p>.05$, but significant ones in the associative test, $t(46)=2.85$, $p<.05$, revealing that older adults showed poorer performance in the associative test than in the item test relative to the younger adults (see Figure 1).

Table 1.

	Full Attention		Divided Attention	
	Item	Associative	Item	Associative
Younger Adults	.63 (.33)	.56 (.41)	.40 (.33)	.37 (.26)
Older Adults	.58 (.23)	.26 (.32)	.27 (.33)	.16 (.29)

Mean memory accuracy (proportion correct) as a function of attention and test for younger and older adults in Experiment 1 (standard deviations in parentheses).

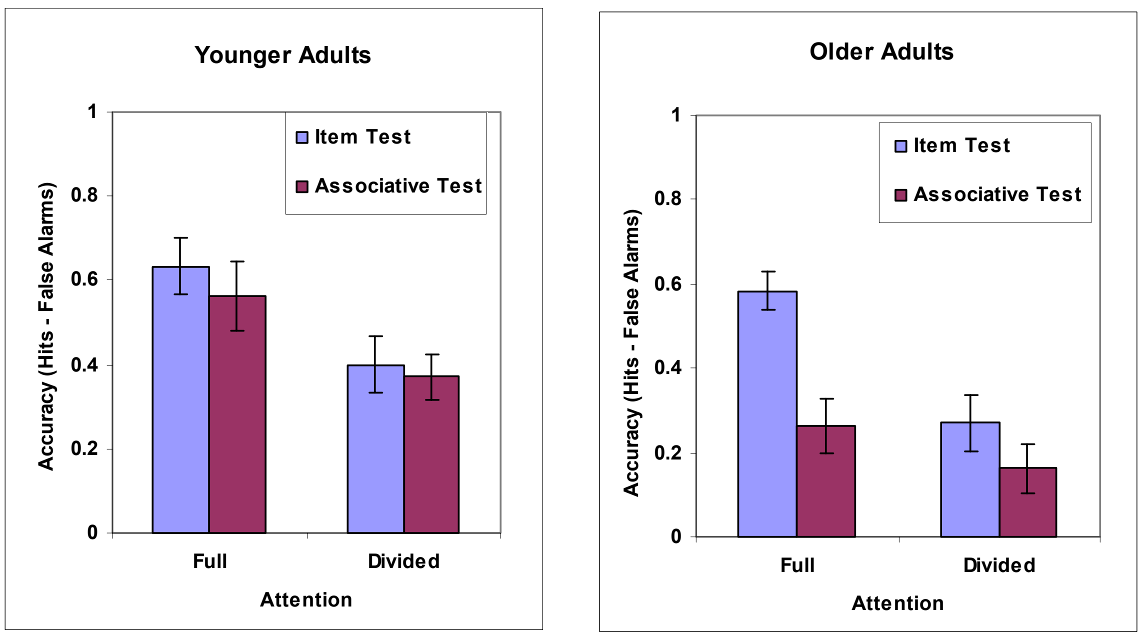
Figure 1.



Mean memory accuracy as a function of age and test under full attention conditions in Experiment 1 (error bars represent the standard error around the mean).

Next, it was tested whether the associative deficit shown by older adults is mediated by reduced attentional resources. The first prediction made by the resource reduction hypothesis is that dividing the attention of younger adults should elicit an associative deficit. In order to examine this, a 2-way ANOVA (with attention and test) was carried out on the younger adults' data to test the presence of an attention x test interaction. The results of this analysis yielded a main effect for attention, $F(1,23)=15.62$, $p<.05$, but no main effect for test, $F(1,23)=.66$, $p>.05$. There was also no evidence for an interaction, $F(1, 23)=.26$, $p>.05$ (see Figure 2, left panel). The second prediction from the reduced resources hypothesis states that any associative deficit seen in older adults under FA should become exacerbated under DA. Another 2-way ANOVA (also using the variables attention and test) carried out on the older adults' data showed significant effects for attention, $F(1,23)=9.94$, $p<.05$, test, $F(1,23)=12.66$, $p<.05$, and an interaction, $F(1,23)=7.07$, $p<.05$. Although the interaction was significant, this does not support the reduced resources hypothesis since the associative deficit is actually becoming *smaller* under DA, which is directly opposite of the predicted direction (see Figure 2, right panel). The lack of a significant triple interaction of age, attention, and test, $F(46)=2.21$, $p>.05$, is in line with the above-mentioned analyses.

Figure 2.



Mean memory accuracy as a function of age, attention, and test in Experiment 1 (errors bars represent the standard error around the mean).

Retrieval latency

The group means for retrieval latency are displayed in Table 2[4]. Results given by a 3-way ANOVA using age, attention, and test showed no significant main effect of age, $F(1,43)=2.27$, $p>.05$[5], or attention, $F(1,43)=.02$, $p>.05$, but a marginally significant effect of test, $F(1,43)=3.03$, $p=.09$. There was an interaction between age and test, $F(1,43)=6.12$, $p<.05$, reflecting that there were no age differences in the item test, $t(43)=.67$, $p>.05$; however, older adults were taking longer to respond than younger adults in the associative test, $t(43)=2.13$, $p<.05$ (see Figure 3). This particular finding mirrors the pattern observed from the memory accuracy results, which characterizes an associative deficit. The interaction between attention and test was also significant, $F(1,43)=20.75$, $p<.05$. Follow-up analyses revealed that response times were longer in the associative test under FA, $t(44)=3.57$, $p<.05$, while performance was equivalent for the two memory tests under DA, $t(44)=.83$, $p>.05$. The triple interaction was nonsignificant, $F(1,43)=.40$, $p>.05$.

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[4] Two younger and 1 older participants were excluded because their average latencies were more than 2 standard deviations from the mean for their respective age groups.

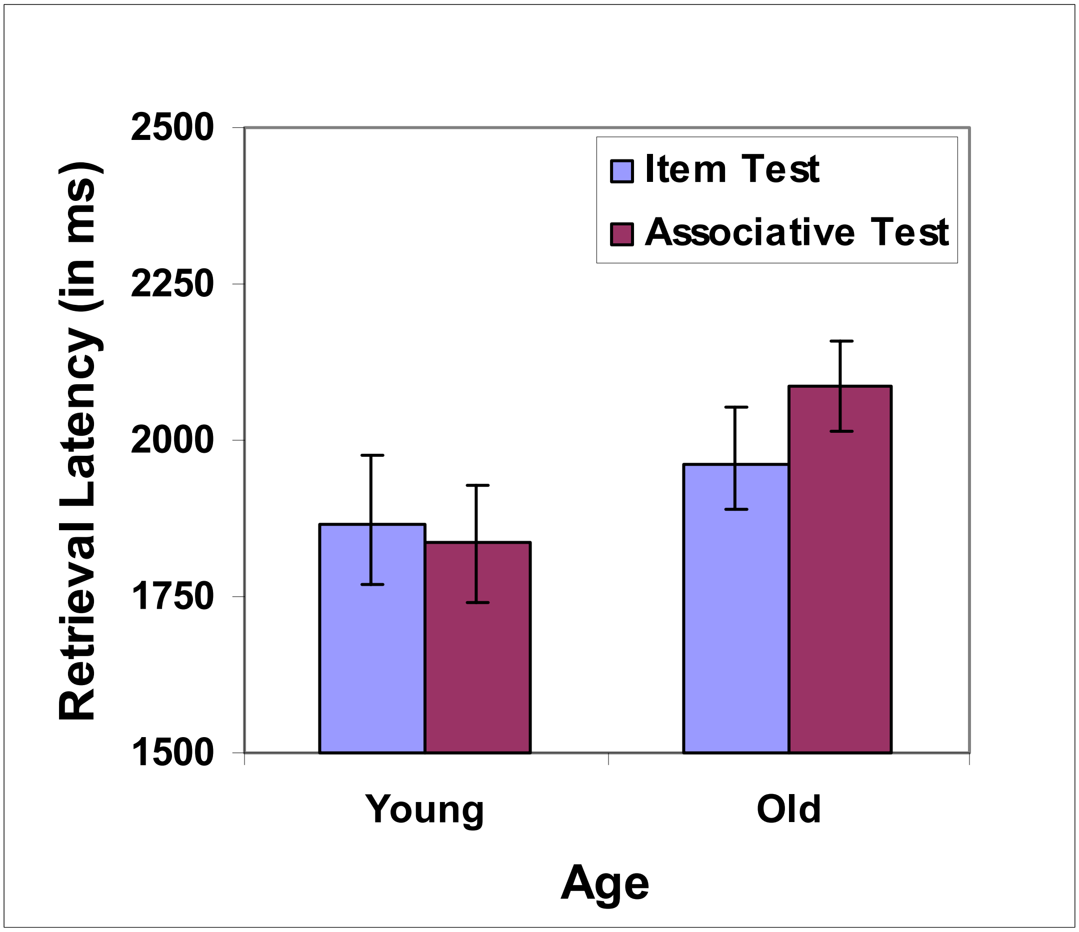
[5] An additional participant was more than 2 standard deviations from the mean in only one of the four conditions (responding to the item test under divided attention). When this person was also excluded from the analyses, the patterns were the same except there was a marginal main effect of age, $F(1,42)=3.63$, $p=.06$.

Table 2.

	Full Attention		Divided Attention	
	Item	Associative	Item	Associative
Younger Adults	1752 (495)	1839 (440)	1830 (574)	1690 (455)
Older Adults	1816 (385)	2055 (332)	1927 (354)	1993 (346)

Mean retrieval latency (in ms) as a function of attention and test for younger and older adults in Experiment 1 (standard deviations in parentheses).

Figure 3.



Mean retrieval latency as a function of age and test in Experiment 1 (error bars represent the standard error around the mean).

Secondary task performance

Table 3 displays the reaction times obtained for the secondary task.[6] A 2-way ANOVA with age and attention (here, the two levels were baseline and divided attention) showed significant effects for age, $F(1,41)=11.69$, $p<.05$, and attention, $F(1,41)=187.97$, $p<.05$, but no significant effect for an interaction, $F(1,41)=1.36$, $p>.05$ (see Figure 4). Because post-hoc comparisons showed that the baselines for young and old were different, $t(41)=3.54$, $p<.05$, scores were converted to relative attentional costs (calculated as [DA – baseline]/baseline). These scores, too, showed similar patterns for young and old in regards to attention, $t(41)=.37$, $p>.05$. This particular finding was not one of the main predictions in this experiment, but will be further explored in Experiment 2.

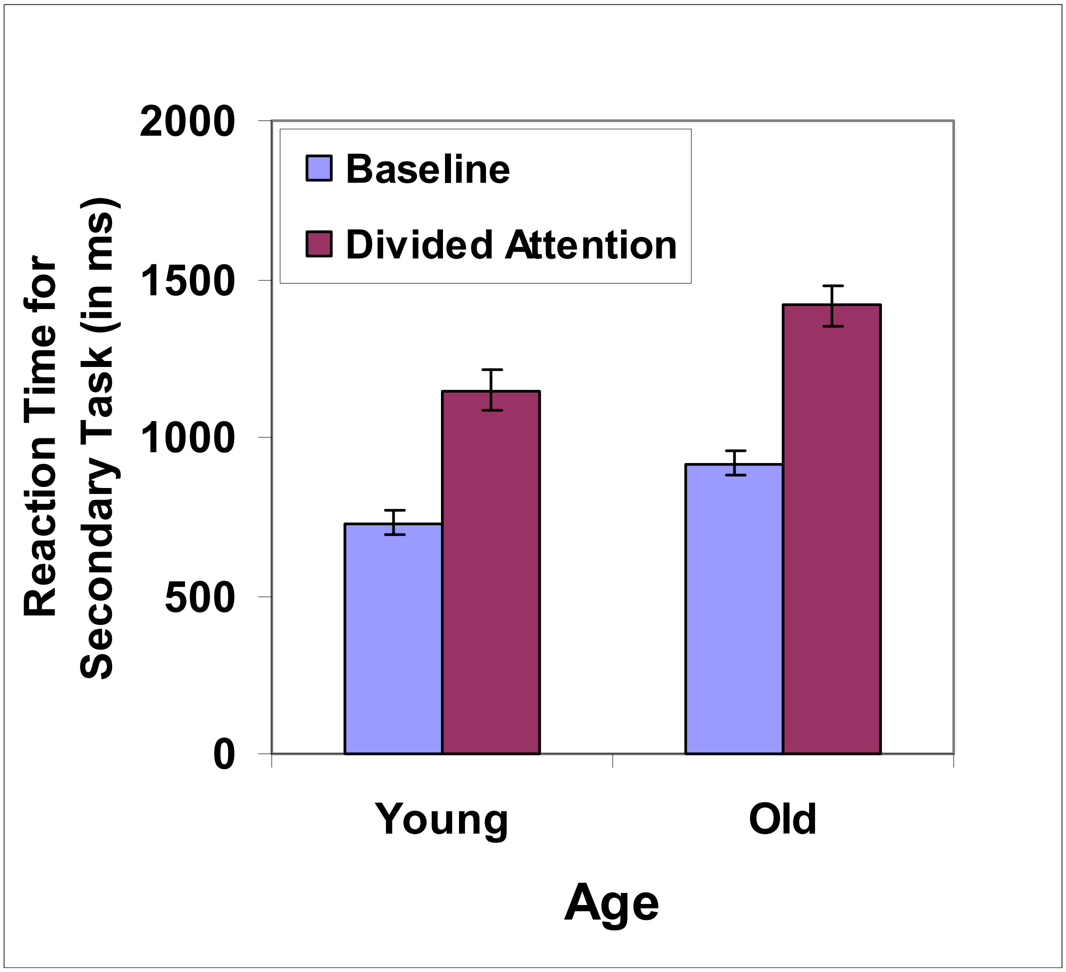
[6] Three younger and two older adults were excluded from the reaction time analyses because their responses were more than 2 standard deviations from the mean in either the baseline or divided attention conditions for their respective age groups.

Table 3.

	Baseline	Divided Attention	Attentional Cost
Younger Adults	728 (183)	1148 (300)	.60 (.28)
Older Adults	917 (166)	1415 (296)	.56 (.32)

Mean reaction times to the secondary task (in ms) as a function of attention and relative attentional costs (see text) for younger and older adults in Experiment 1 (standard deviations in parentheses).

Figure 4.



Mean reaction times to the secondary task as a function of attention in Experiment 1 (error bars represent standard errors around the mean).

Discussion

Findings from Experiment 1 do not lend support for the hypothesis that the associative deficit in older adults is mediated by reduced attentional resources. This proposed explanation claims that older adults are impaired at learning associations because they have fewer resources than their younger counterparts. The predictions made by this hypothesis are that young-DA would show a similar associative deficit, and older adults under DA would show a larger associative deficit than under FA. In order to evaluate these predictions, analyses of variance were implemented. Although an associative deficit was found in older adults under FA, it was not observed in young-DA. These results are inconsistent with the first prediction made by the reduced resources hypothesis. Furthermore, results from the current experiment are in disagreement with the second prediction from the reduced resources hypothesis, stating that older adults' associative deficit should increase under DA.

Similar patterns emerged for memory accuracy and retrieval latency in the sense that performance was equivalent for the two age groups in the item test, yet older adults demonstrated poorer performance than the younger adults in the associative test. The retrieval latency data also showed an interaction between attention and test, but it is not clear what this means, and it is unrelated to the current hypotheses.

Experiment 1 also revealed some interesting results regarding the reaction times to the secondary task. Specifically, it was found that the older adults did not require more attentional resources for learning the study list than the younger adults; however, since participants were instructed to learn both the items and pairs simultaneously, separate attentional costs required for learning components and associations cannot be calculated.

In Experiment 2, this was remedied by having subjects learn either the items or the pairs under both FA and DA. This way, it can be determined if learning the associations requires more attentional resources than learning the items for the older adults relative to the younger adults.

EXPERIMENT 2

There are several motivations for Experiment 2, the first of which was to replicate the results of Experiment 1. Experiment 2 also provided further tests of an ADH by examining the possibility that older adults perform worse in association tests because they only have enough resources to perform one learning task at a time. Previous studies, including Experiment 1 in this report, typically required subjects to learn both the items and the pairs, and the question addressed in this experiment is whether the associative deficit in older adults will disappear if they only concentrate on one aspect of the study list at a time. I tested this by instructing participants to learn either the items or the pairs for each study list rather than learning both at once (as in Experiment 1). If the associative deficit is mediated by a reduction in attentional resources, then instructing participants to concentrate on only the pairs in preparation for an associative test should eliminate the interaction between age and test.

An additional motivation for the second experiment was to compare reaction times to the secondary task in more detail. Experiment 1 made it possible to calculate a measure of overall attentional costs involved in studying the items and their associations, but it may be more beneficial to calculate separate costs for learning the items versus learning their pairings. According to the reduced resources hypothesis, the older adults should show a larger attentional cost for learning the pairs than the items relative to the younger adults because of the greater strain on their resources. Conversely, if attentional resources are not the cause for the associative deficit, we would not expect an interaction between study instructions and age group.

Method

Participants

Participants were 52 younger (ages 18-31; *M*=21.8, *SD*=2.9) and 51 older adults (ages 62-82; *M*=71.9, *SD*=5.5) taken from the same pools of participants as in Experiment 1[7]. These adults were equated in terms of years of education (*M*=14.6, *SD*=1.6 and *M*=14.6, *SD*=1.7 for young and old, respectively). None of these participants took part in Experiment 1.

Design

The within-subjects independent variables used were type of test (the item test following the item instructions or the associative test following the pair instructions) and attention (FA or DA at encoding); the between-subjects independent variable used was age (young or old).[8] The dependent variables were memory accuracy and reaction time to the secondary task.[9]

Materials

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[7] Half of these participants were also required to make remember/know/guess responses during their memory tests. The pattern of results reported below for these participants was similar to those participants that did not make these responses.

[8] Gender differences were also explored. There were no significant interactions among the variables; however, there was a main effect, showing that females outperformed the males in memory accuracy, $F(1,99)=5.92$, $p<.05$. There were not enough males in Experiment 1 to perform this analysis.

[9] Retrieval latency was not recorded for Experiment 2 due to programming constraints.

Four study lists, each containing 34 unrelated word pairs were used. Lists were created using the same word pools as in Experiment 1. The first and last two pairs were used as buffers to control for primacy and recency effects. The secondary task was identical to that used in Experiment 1.

Procedure

Each participant was visually presented with four study-test blocks interwoven with three blocks of the baseline secondary task. Two of the lists were performed under FA, and the other two were performed under DA. For each of these two attention conditions, one list included instructions for studying the individual items (learning the paired words separately) while the other list was accompanied by instructions for studying the pairs (learning which words were presented together). The study instructions determined which memory test would follow (the type of test was compatible with the study instructions). The order of these four conditions was counterbalanced between subjects, and the order of the study lists was counterbalanced using a Latin cross design. Study pairs were presented one every 6 seconds. After each list's study phase, participants were asked to count backwards by 3's as an interpolated activity for 60 seconds before taking the corresponding memory test. The intervening baseline secondary task blocks were each 90 seconds.

In contrast to Experiment 1, an old/new paradigm was used for the item test. The advantage of the forced-choice paradigm used in Experiment 1 is that the item and associative tests are equated in terms of the amount of information presented; however, the advantage of the old/new paradigm in Experiment 2 is that the item and associative tests are equated in terms of the subjects' responses (i.e., the subject could respond "old" or “new” depending on whether they recognized the word in the item test or the pair in the associative test). Previous research has shown that the associative deficit is observed regardless of this manipulation (Naveh-Benjamin, Guez, & Shulman, in press). The current item test was composed of 20 single words (10 targets and 10 lures), which appeared one at a time. During this test, subjects were asked to say “old” if the word appeared at study and to say “new” if it did not. The associative test used identical responses in which “old” represented an intact pair and “new” represented a recombined pair. Other than the changes mentioned here, these test lists were prepared exactly as in Experiment 1.

Under FA conditions, participants were instructed to learn either the individual items or their pairings in preparation for the upcoming memory test. For baseline secondary task blocks, they were asked to respond as quickly and accurately as possible to the tones. In the DA conditions, they were asked to pay equal attention to both the primary task (learning either the individual items or the pairings) and the secondary task (responding to the tones). Before presentation of each list, participants were told which condition to expect.

Instructions were given to the participants before the experiment, detailing the nature of the item and associative tests. For each test, they were told that half of the presented stimuli would be “old” and half would be “new.” Participants were also given practice blocks consisting of a FA condition and a baseline secondary task. Performance on the baseline secondary task was assessed before proceeding to the final practice block under DA to ensure that the participants had adequate preparation. The study instructions (along with their corresponding test types) were counterbalanced during practice so that half of the participants were told to learn the items under FA and the pairs under DA while the other half was told to learn the pairs under FA and the items under DA.

Results

Memory accuracy

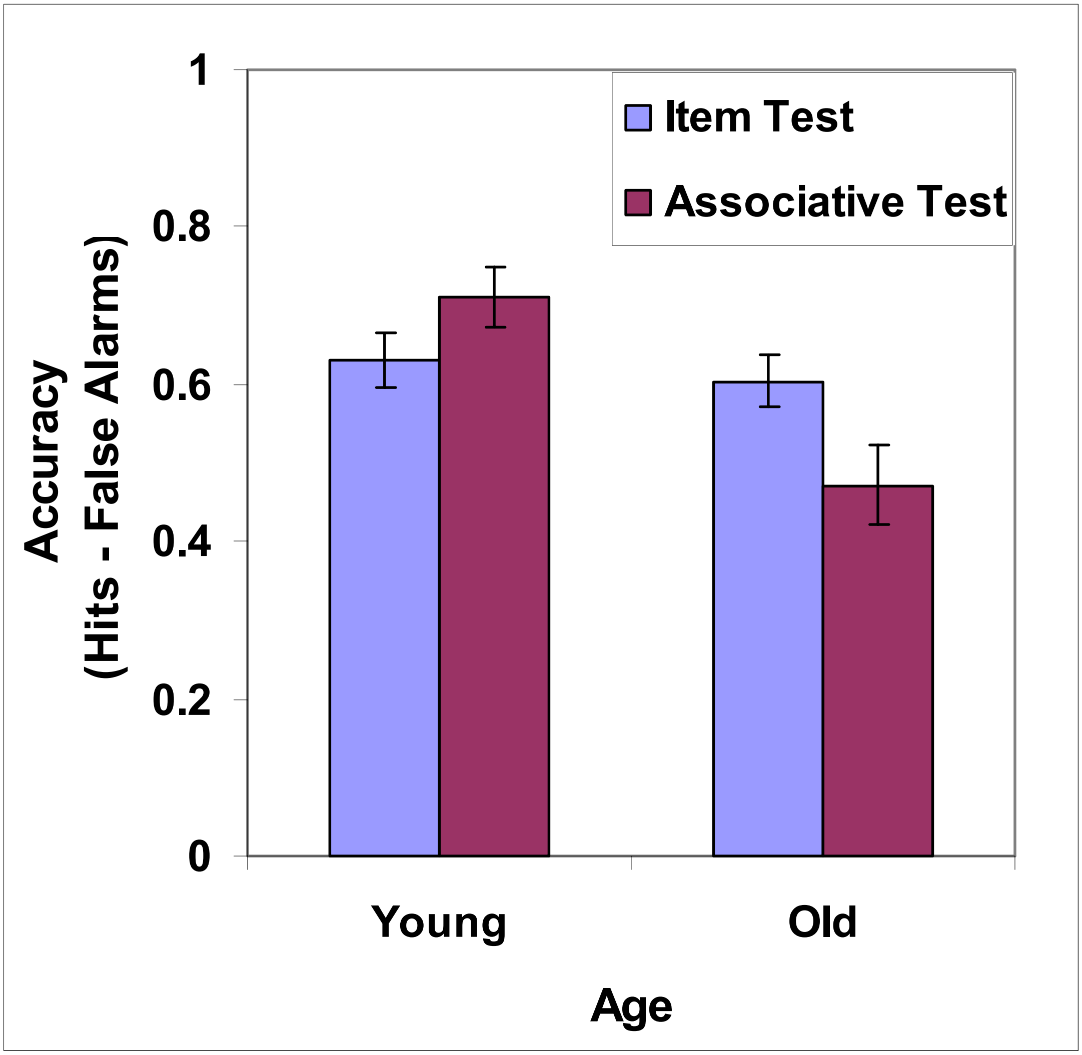
Descriptive statistics for memory accuracy obtained from Experiment 2 can be seen in Table 4. Main effects (in the same direction as in Experiment 1) were found for age, $F(1,101)=11.08$, $p<.05$, and for attention, $F(1,101)=142.78$, $p<.05$, but no main effect was found for test, $F(1,101)=.026$, $p>.05$. As in Experiment 1, a 2-way ANOVA using age and test (under FA conditions only) was run to confirm that an associative deficit was observed for the older adults. The crossover interaction between these two variables was significant, $F(1,101)=10.94$, $p<.05$ (see Figure 5). Post-hoc comparisons show that younger and older adults were equated in item memory performance, $t(101)=.53$, $p>.05$, though significant differences were observed in associative memory performance, $t(101)=3.82$, $p<.05$.

Table 4.

	Full Attention		Divided Attention	
	Item	Associative	Item	Associative
Younger Adults	.63 (.26)	.71 (.27)	.34 (.29)	.43 (.30)
Older Adults	.60 (.25)	.47 (.36)	.28 (.29)	.24 (.28)

Mean memory accuracy (proportion correct) as a function of attention and test for younger and older adults in Experiment 2 (standard deviations in parentheses).

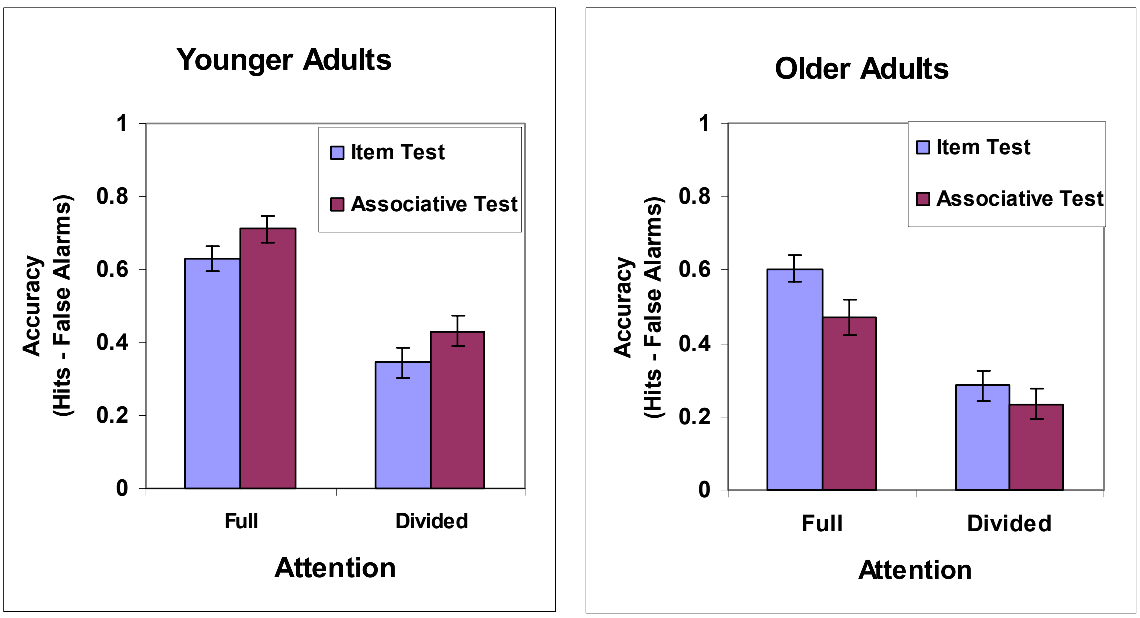
Figure 5.



Mean memory accuracy as a function of age and test in Experiment 2 (error bars represent the standard error around the mean).

As in Experiment 1, a further analysis was conducted to determine whether or not an interaction existed between attention and test for the younger adults only. A 2-way ANOVA using these variables showed significant main effects for attention, $F(1,151)=68.58$, $p<.05$, and for test, $F(1,151)=6.36$, $p<.05$, but no significant interaction, $F(1,51)=.01$, $p>.05$ (see Figure 6, left panel). To examine whether the associative deficit was larger under DA for the older adults, a similar 2-way ANOVA was performed on the older adults' data. This analysis resulted in main effects for both attention, $F(1,50)=74.88$, $p<.05$, and test, $F(1,50)=4.98$, $p<.05$, but no interaction, $F(1,52)=1.65$, $p<.05$ (see Figure 6, right panel). These findings are consistent with a 3-way ANOVA using age, attention, and test, showing no significant triple interaction, $F(1,101)=.68$, $p>.05$.

Figure 6.



Mean memory accuracy as a function of age, attention and test in Experiment 2 (errors bars represent the standard error around the mean).

Secondary task performance

Also of interest here is performance on the secondary task[10] (see Tables 5 and 6 for descriptive statistics). Two separate comparisons were made: (1) baseline reaction times vs. DA reaction times (averaged across study instructions), (2) performance when studying items vs. performance when studying pairs. For the first comparison, a 2-way ANOVA was used which included the factors of age and attention condition. There was a significant main effect of age, $F(1,99)=64.65$, $p<.05$, where older adults showed slower performance overall. There was also a main effect of attention, $F(1,99)=261.90$, $p<.05$, showing slower reaction times under DA. The interaction between these two variables was also significant, $F(1,99)=21.39$, $p<.05$, indicating that the absolute attentional cost (calculated as DA-baseline) was larger for the older adults than the younger adults, $t(101)=3.99$, $p<.05$ (see Figure 7). The larger increase in attentional cost for the older adults was also observed using relative reaction time scores, $t(99)=2.46$, $p<.05$, which were computed like in Experiment 1 as (DA – baseline)/baseline.

[10] One younger and one older adult were excluded from the reaction time analyses because their responses were more than 2 standard deviations from the mean in either the baseline or divided attention conditions for their respective age groups.

Table 5.

		Divided Attention	
	Baseline	Study Items	Study Pairs
Younger Adults	648 (123)	1018 (335)	1052 (347)
Older Adults	877 (160)	1536 (443)	1665 (810)

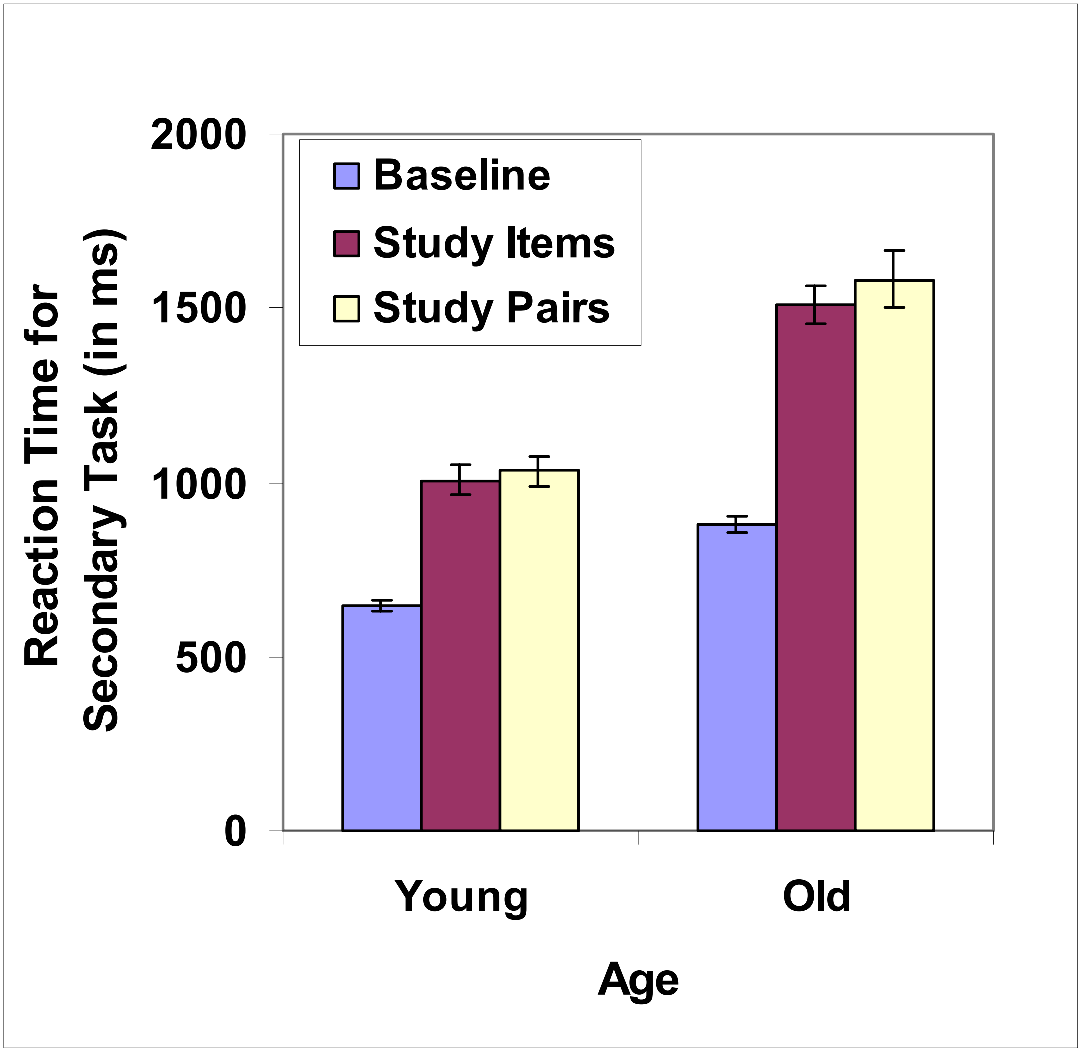
Mean reaction times for the secondary task (in ms) as a function of attention and study instructions for younger and older adults in Experiment 2 (standard deviations in parentheses).

Table 6.

	Average Attentional Cost	Item Attentional Cost	Associative Attentional Cost
Younger Adults	.61 (.43)	.57 (.39)	.64 (.53)
Older Adults	.83 (.58)	.76 (.44)	.90 (.83)

Mean relative attentional costs as a function of study instructions for younger and older adults in Experiment 2 (standard deviations in parentheses).

Figure 7.



Mean reaction times to the secondary task as a function of study condition in Experiment 2 (error bars represent standard errors around the mean).

For the second comparison, separate scores for attentional cost were calculated for the two study conditions (these were calculated in the same manner as in Experiment 1). The results of a 2-way ANOVA using age and study condition showed a main effect of age, $F(1,99)=21.39$, $p<.05$, but no significant effects were found for the effect of study condition, $F(1,99)=2.02$, $p>.05$, or for the interaction between these two variables, $F(1,99)=.49$, $p>.05$. Similar patterns were observed when relative scores were used in the analysis. The effect of age remained significant, $F(1,99)=6.05$, $p<.05$, the effect of study condition approached significance, $F(1,99)=2.74$, $p=.10$, but the interaction was nonsignificant, $F(1,99)=.09$, $p>.05$.

Discussion

Despite the manipulation of study instructions, the current experiment showed a similar pattern of memory performance to that observed in Experiment 1. Specifically, the associative deficit was shown in older adults even when participants were instructed to learn the items and pairs separately. The reduced resources hypothesis predicted that isolating these learning tasks should allow more resources to be contributed to each task, and as a result, older adults should show higher performance in the associative task. The fact that an associative deficit remained suggests that it is not due to a mediation of attentional resources.

Other predictions from the reduced resources hypothesis are also not in line with the current results. The young-DA did not show poorer memory performance in the associative test than in the item test relative to FA. Likewise, older adults did not show a larger associative deficit under DA than under FA. These results again replicate and extend the findings of Experiment 1.

The older adults did show an overall larger attentional cost for the secondary task during study as evidenced by the significant interaction between age and attention condition. Of greater interest, however, is the finding that older adults did not show a larger attentional cost for learning the associations than for learning the items relative to the younger adults. This indicates that older adults are not employing more resources to remembering combined pieces of information than to remembering individual components relative to the younger adults. This finding would not be expected if the associative deficit is mediated by a reduction of attentional resources.

GENERAL DISCUSSION

The two experiments reported here each replicated the associative deficit in older adults that has been observed in previous research (Naveh-Benjamin, 2000; Castel & Craik, 2003; Naveh-Benjamin, Hussain, Guez, & Bar-On, 2003; Naveh-Benjamin, Guez, Kilb, & Reedy, 2004; Naveh-Benjamin, Craik, Guez, & Kreuger, in press; Naveh-Benjamin, Guez, & Shulman, in press). Although the benchmark for this phenomenon has been specific to patterns in memory accuracy, Experiment 1 revealed a similar pattern in retrieval latency where older adults are slower to respond in the associative test relative to the younger adults despite no age differences in item test performance. Future studies should explore this finding and its possible implications for hypotheses pertaining to reduced processing speed in older adults (Salthouse, 1996).

These experiments do not provide evidence to support the hypothesis that the associative deficit is mediated by a reduction in attentional resources. Of the predictions made by this hypothesis, none were consistent with the current findings. In Experiment 1, it was shown that reducing the resources of younger adults did not simulate the behavior of older adults, since dividing attention in younger adults did not produce an associative deficit. Similarly, reducing the resources of older adults by dividing their attention did not cause a larger associative deficit than seen under FA conditions. Altogether, the prediction that each age group should show poorer memory for associations when attention is divided has not been supported here. These findings are consistent with the recent literature showing no interaction between type of memory task (memory for components versus memory for associations) and attention in younger adults (Naveh-Benjamin, Guez, & Marom, 2003; Naveh-Benjamin, Guez, Kilb, & Reedy, 2004; but see Castel & Craik, 2003).

Because Experiment 1 required participants to learn both the components and their associations simultaneously, it is feasible to consider such a learning task alone as a dual task. Thus, one possible explanation for the observed associative deficit could be that older adults do not possess enough resources for learning both the components *and* their associations. This possibility was tested in Experiment 2 by instructing participants to learn the components and the associations separately for a given study list. The subsequent results replicated the patterns observed in Experiment 1 despite the new study instructions, suggesting once again that the associative deficit shown by older adults is not a result of reduced resources. One interesting difference between these two experiments, however, is that both age groups had higher accuracy scores in the associative test in Experiment 2 than in Experiment 1, whereas item scores remained unchanged.[11] That is, each age group benefited by the study associations instructions in Experiment 2 to the same degree, indicating that instructions at study to concentrate on encoding associations improve associative memory accuracy, though there was no differential age effect as was predicted by the reduced resources hypothesis.

Another line of evidence that does not support the reduced resources hypothesis is derived from the reaction time data for the secondary task. In Experiment 1, the reaction times recorded at baseline were compared to those recorded under DA to determine the attentional cost of learning both the components and the associations simultaneously. These costs were the same for younger and older adults, which was inconsistent with the literature (Anderson, Craik, & Naveh-Benjamin, 1998). Since this result was somewhat unexpected, it was of interest to investigate it further in Experiment 2. In the second experiment, costs were separated into item costs (those obtained when learning only the items) and associative costs (those obtained when learning only the associations). Unsurprisingly, when these scores were combined for an average attentional cost, the older adults showed a significantly higher overall cost than the younger adults. This result is consistent with the literature and was expected (see Macht & Bushke, 1983; Craik & McDowd, 1987; Anderson, Craik, & Naveh-Benjamin, 1998; Naveh-Benjamin, Craik, Guez, & Kreuger, in press). The finding that is more germane to the current hypothesis is that the older adults did not have a higher cost for studying the associations than for studying the items, relative to the younger adults. If learning associations indeed

[11] The data for the 2 experiments were entered into a 4-way ANOVA with the variables age, attention, test, and experiment. These results showed no significant triple interaction of test, experiment, and age, $F(1,147)=.01$, $p>.05$, but showed a significant interaction of test and experiment, $F(1,147)=7.04$, $p<.05$. Post-hoc comparisons specify that there were no significant differences in the item test across experiments, $t(149)=.16$, $p>.05$, while there were significant differences in the associative test, $t(149)=2.50$, $p<.05$.

requires more resources than learning the components, it would be expected that the associative cost would be especially high for the older adults; however, this prediction also was not supported by the results.

The results of the current experiments do not support the claim that the associative deficit shown in older adults is due to a reduction in resources. Rather, this deficit would be better explained in terms of more automatic binding processes that do not demand additional resources. This is not to say that attentional resources are not required for processing information in general. Indeed, studying the word lists required attention (as seen in the increased response time to the secondary task from the baseline). However, the older adults' attentional cost of learning the associations was not relatively larger than their item cost when compared to the younger adults, which demonstrates that learning associations does not require more attentional resources than learning individual components. These findings are in line with the neuropsychological research, suggesting that automatic processes in the hippocampus are responsible for binding (Cohen et al., 1993; Eichenbaum, 1995; Wallenstein et al., 1998; Eichenbaum, 2003a; Eichenbaum, 2003b; Henke et al., 1997; Kroll et al., 1996).

Although the current experiments build support for an age-related deficit in automatic binding processes, these findings are not inconsistent with the literature that implicates strategic binding as part of the problem. In order to demonstrate this, the present results were combined across Experiments 1 and 2 and then analyzed separately according to whether the stimuli were "automatically" encoded (DA conditions) or "strategically" encoded (FA conditions). A 2-way ANOVA, for the DA data only, showed a marginally significant interaction between age and test, $F(1,149)=3.69$, $p=.06$, reflecting an associative deficit for the older adults. This pattern became stronger in the FA data, $F(1,149)=16.44$, $p<.001$[12]. These results are in line with those obtained by Naveh-Benjamin (2000; Experiment 2), which have shown that the associative deficit of older adults can be seen when information has been encoded automatically, while the deficit is larger when information has been encoded strategically (suggesting that both automatic and strategic processes may be responsible for the associative deficit). The current findings are also consistent with neuropsychological evidence that points to a "working-with-memory" system that requires both the hippocampus and the frontal lobes for proper binding (Moscovitch, 1994; Moscovitch & Winocur, 1992).

One remaining question lies in the inconsistency between the current results and those of Castel & Craik (2003), which show the predicted greater decline in memory for associations than for items in young-DA. As noted earlier, one possible explanation for this incongruence could be the difference in paradigms, and consequently, in the dependent measures obtained. Because there were varying types of targets and lures in their study, it was possible to calculate item memory performance in a number of ways whereas the current two experiments offer a more straightforward measure. Another possibly relevant difference could pertain to the secondary tasks that were used. Castel & Craik used variations of a digit monitoring task in which subjects responded whenever they heard a specific stimulus. These stimuli were presented at a constant rate, which the participants could not control. Conversely, the secondary task used in the present experiments allowed subjects to respond at their own pace. Rohrer & Pashler (2003) argue that self-paced secondary tasks may be too easy because participants are capable of

[12] The triple interaction among age, test, and attention was not significant, $F(1,149)=2.14$, $p>.05$.

slowing their responses in order to compensate for performing two tasks at once. If this is true, then one possibility for the divergent results is that the secondary task used in the current experiments was not challenging enough; however, one recent study shows only minimal differences, if any, in memory accuracy in divided attention conditions that use either subject-paced or experimenter-paced secondary tasks (Naveh-Benjamin, Kilb, & Fisher, in press). This suggests that the inconsistencies between the current experiments and those of Castel & Craik are more likely due to the differences in measuring item memory performance than to differences in the pace of the secondary task.

Although the data reported here build a strong case for a substantial involvement of a "pure" binding mechanism in the associative deficit, there are other possible mediators that have yet to be investigated such as the speed of processing or the inhibition of attention (mentioned earlier). For instance, one reason that older adults demonstrate problems in binding could be that they have insufficient time to fully process the information. These limitations might be due to either external factors (e.g., the presentation rate of the stimuli) or internal factors (e.g., being able to hold a piece of information in memory so that another operation can be carried out on it). Although manipulating external factors seems easier to carry out in a laboratory setting, Salthouse (1996) argues that it is more advantageous to evaluate internal factors when determining the influence of processing speed. For example, speed can be taken into account when looking at age differences in memory by estimating processing speed via a diagnostic test and then using that measure as a covariate. Similarly, it might be possible to determine whether inhibition plays a role in the associative deficit by adjusting for older adults' performance in a task that requires participants to ignore irrelevant information (e.g., a

Stroop task). In summary, the evidence provided in the current experiment is not consistent with attentional resources being a mediator in the associative deficit of older adults while it is consistent with a pure, automatic binding degradation as a possible mediator of the deficit.

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APPENDIX

LIST A[13]

Study List	Item Test	Associative Test
cavern-leather	fixture	chapter-muscle
capsule-oboe	peacock	lilac-permit
fixture-passion	outlet	fountain-outline
isle-theorem	puzzle	*actor-belly
surgeon-shower	*question	birthmark-chopstick
morsel-flicker	*rabbit	*beehive-shower
major-powder	*reason	isle-theorem
pursuit-coffee	*program	*freighter-eclipse
actor-lightning	*sandwich	cushion-fighter
fountain-outline	interest	*briefcase-lightning
freighter-grapefruit	*robber	*blacksmith-grapefruit
outlet-prospect	pursuit	*surgeon-auction
birthmark-chopstick	*pony	*effect-sinus
interest-tractor	*ribbon	*duty-pollen
meeting-sinus	voyage	*cinder-patent
cushion-fighter	morsel	mustard-armpit
barber-receipt	axle	error-pillar
cinder-pollen	rival	*meeting-rider
annex-laughter	*pocket	annex-laughter
duty-patent	receipt	major-powder
tavern-voyage		
chapter-muscle		
effect-rider		
entry-rival		
lilac-permit		
blacksmith-eclipse		
drugstore-axle		
error-pillar		
briefcase-belly		
concert-peacock		
mustard-armpit		
beehive-auction		
bagpipe-sunset		
creature-fabric		

[13] Lures are denoted by asterisks.

LIST B

Study List	Item Test	Associative Test
kayak-anthrax	*island	*founder-number
eyebrow-learning	starlight	cyclist-daughter
method-organ	beetle	subject-parade
series-pressure	*ferret	dolphin-carton
cricket-number	*grassland	expert-corset
airplane-lobby	*hotdog	bottom-opera
expert-corset	*earning	*absence-nothing
army-mermaid	method	*cricket-armchair
factor-motion	plaster	*saucepan-tablet
bottom-opera	banker	conquest-sunbeam
kitten-tablet	*dinner	column-ticket
beetle-tyrant	*hammock	*kitten-earthquake
dolphin-carton	*empire	*factor-parrot
judgment-money	judgment	series-pressure
absence-wrinkle	smoker	bagel-circus
column-ticket	*earthworm	*sorrow-wrinkle
alcove-banker	estate	skillet-diesel
blindfold-center	*frontier	*lipstick-motion
bagel-circus	airplane	*blindfold-problem
oatmeal-problem		*oatmeal-center
fortress-smoker		
cyclist-daughter		
sorrow-nothing		
collar-estate		
conquest-sunbeam		
saucepan-earthquake		
monarch-starlight		
subject-parade		
lipstick-parrot		
hero-plaster		
skillet-diesel		
founder-armchair		
canine-hotel		
disguise-chimney		

LIST C

Study List	Item Test	Associative Test
journey-custom	package	*hatchet-master
lawyer-total	*standard	cobalt-loophole
copper-pilot	*stanza	era-system
abyss-teapot	*story	*supper-mural
tassel-person	forehead	*tassel-kingdom
array-worship	*sister	*brandy-curtain
cobalt-loophole	array	*bumper-person
package-footstep	rattle	*butter-double
county-double	*shepherd	cowboy-traitor
supper-pathway	*shoelace	*buffet-meadow
chemist-highway	layer	affair-staircase
copy-motor	piper	*county-player
cowboy-traitor	copy	abyss-teapot
layer-balloon	copper	chemist-highway
hatchet-bonfire	*stocking	sequel-sweater
era-system	*speaker	*escort-bonfire
comrade-doorbell	*silence	cattle-tonic
brandy-meadow	doorbell	basket-mission
sequel-sweater	taxi	*shipping-pathway
buffet-curtain	*slipper	bracelet-salad
passage-rattle		
bracelet-salad		
escort-master		
million-piper		
shipping-mural		
cattle-tonic		
broomstick-forehead		
affair-staircase		
butter-player		
level-taxi		
basket-mission		
bumper-kingdom		
genius-spirit		
beggar-triumph		

LIST D

Study List	Item Test	Associative Test
plateau-painting	churchyard	talent-single
cluster-darkness	*paper	*aisle-playmate
printer-dollar	missile	poem-treatment
section-mother	status	dwelling-penny
missile-almond	twilight	mirror-product
status-mistake	*patience	section-mother
mallet-checkbook	*parent	*limit-virtue
pigeon-unit	cradle	*saucer-checkbook
carol-women	*nephew	resource-poker
hunter-mixture	*mayor	*hunter-trumpet
poem-treatment	terrace	*spinach-cement
cocoa-lover	*metal	siding-picture
peanut-theory	*motive	*printer-streetcar
cobweb-impact	pigeon	*barrette-legend
limit-playmate	*music	*mallet-concrete
dwelling-penny	*mischief	acre-blessing
barrette-cement	*offense	*rowboat-mixture
platter-terrace	cocoa	carol-women
spinach-legend	device	peanut-theory
mirror-product	cobweb	*planter-dollar
carbon-device		
acre-blessing		
aisle-virtue		
toaster-cradle		
rowboat-trumpet		
siding-picture		
saucer-concrete		
resource-poker		
kindness-twilight		
planter-streetcar		
talent-single		
apple-churchyard		
lumber-pigment		
prairie-steward		