Developmental Psychology
2005, Vol. 41, No. 2, 389–400

0012-1649/05/$12.00 DOI: 10.1037/0012-1649.41.2.389

The Contribution of Mediator-Based Deficiencies to Age Differences in Associative Learning

John Dunlosky
University of North Carolina at Greensboro

Christopher Hertzog and Amy Powell-Moman
Georgia Institute of Technology

Production, mediational, and utilization deficiencies, which describe how strategy use may contribute to developmental trends in episodic memory, have been intensively investigated. Using a mediator report-and-retrieval method, the authors present evidence concerning the degree to which 2 previously unexplored mediator-based deficits—retrieval and decoding deficiencies—account for age deficits in learning. During study, older and younger adults were instructed to use a strategy (imagery or sentence generation) to associate words within paired associates. They also reported each mediator and later attempted to retrieve each response and the mediator produced at study. Substantial deficits occurred in mediator recall, and small differences were observed in decoding mediators. Mediator recall also accounted for a substantial proportion of the age deficits in criterion recall independently of fluid or crystallized intelligence. Discussion focuses on mediator-based deficiencies and their implications for theories of age deficits in episodic memory.

It has long been known that older adults perform more poorly than younger adults on many tasks that tap episodic memory, including associating faces with names, associating events within a given episode, remembering the sources of information, and associating pairs of words (see Kausler, 1994). What underlies these deficits in episodic memory? Recent work has emphasized the distinction between an age-related associative deficit versus a general memory deficit (e.g., Naveh-Benjamin, 2000; Naveh-Benjamin, Hussain, Guez, & Bar-On, 2003). Do older adults have more difficulties associating elements within an event (e.g., associating a name with a particular face), which in turn results in poorer episodic memory, or is their greatest difficulty in simply learning any particular set of elements that comprise an event (e.g., learning all of the particular names on a list)? Although aging may create both kinds of deficit, age-related declines in episodic memory appear more closely tied to associative deficits than to a general deficit per se.

In one experiment (Naveh-Benjamin, 2000, Experiment 2), participants studied unrelated word pairs and were instructed to prepare for a test of the specific words (an item test) or for a test of the word pairings themselves (an associative test). Instructions were crossed with the kind of test, which was either a recognition test of the individual items or an associative recognition test. Age differences were reliable but small for the item test, and consistent with an associative deficit hypothesis, the age differences were larger for the associative recognition test. On the basis of this and other evidence, Naveh-Benjamin (2000) concluded that "the glue that links together the various aspects (attributes) of an episode is not as efficient in old age" (p. 1185). However, the nature of such "glue" in this line of work has not yet been delineated, nor has the associative deficit been related to more general factors that are influenced by aging, such as fluid and crystallized intelligence.

A major goal of the present research was to provide a detailed analysis of the nature of the underlying association deficit. To do so, we focused on the kinds of mediator that individuals use to learn paired associates (e.g., dog–spoon). A paired-associate task is particularly useful for investigating association deficits because the mediators people use to study individual pairs comprise a main form of effectively associating words within a pair. For instance, recall performance is greater for pairs of unrelated words when individuals use mediational strategies to form associations than when they merely repeat the words to themselves (for a review, see Richardson, 1998). Effective mediational strategies include imagining the referents of the two words in a pair interacting (interactive imagery) or generating a sentence that includes both words (sentence generation). Just as important, these mediators can be validly described at the level of individual items (Dunlosky & Hertzog, 2001), which allows experimental scrutiny of whether age-related changes exist in the associations formed at study.

Although previous research has focused on whether developmental changes in memory over the life span are related to changes in the production of effective mediators, our research involves a more exhaustive evaluation of the nature of the mediators that are produced and their later accessibility in the service of associative recall. How might differences in mediator-based processing manifest in an association deficit? Five possible answers to this question are described in Table 1 in terms of the kinds of deficiency older adults may show in mediator-based processing.[1]

John Dunlosky, Department of Psychology, University of North Carolina at Greensboro; Christopher Hertzog and Amy Powell-Moman, Department of Psychology, Georgia Institute of Technology.

This research was supported by Grant R37 AG13148 from the National Institute on Aging, one of the National Institutes of Health.

Correspondence concerning this article should be addressed to John Dunlosky, who is now at P.O. Box 5190, Department of Psychology, Kent State University, Kent, OH 44242. E-mail: jdunlosk@kent.edu

[1] The first three deficiencies have already received attention in the field, and their specific definitions and utility have been debated (most notably with respect to utilization deficiencies, Miller, 2000; Waters, 2000). Given that such debates remain unresolved, our approach was to define all of the deficiencies in a manner that connects with the broadest perspectives within child and adult developmental research (e.g., Kausler, 1994; Waters, 2000).

Table 1
Description of Mediator-Based Deficiencies

Kind of deficiency	Description
Production	Do not spontaneously generate mediators but are successful at generating effective mediators when instructed
Mediation	Do not generate mediators even when support is available
Utilization	When a mediator is produced, it affects memory but does so less effectively
Retrieval	Mediators are less likely to be recalled during the criterion test
Decoding	Mediators are retrieved but are less likely to be decoded correctly

Understanding how these deficiencies contribute to age deficits in recall will not only yield a more fine-grained description of the association deficit itself but will also have implications for encoding-based explanations of adult age changes in memory in general. For instance, Craik and colleagues have interpreted recent evidence from neuroimaging and dual-task studies as indicating that older adults suffer from reduced semantic elaboration during encoding (e.g., Anderson, Craik, & Naveh-Benjamin, 1998; Anderson et al., 2000; Castel & Craik, 2003). They argue that older adults need more cognitive support during study and test to overcome the deleterious effects of age on processing resources that are available for semantic elaboration at encoding. At present, it is unclear whether the encoding difficulties identified by these researchers are related to the nature of older adults' mediators formed during associative learning. Is reduced semantic elaboration by older adults reflected in age differences in the properties of mediators produced at study, or are age deficits in elaborative encoding manifested in other ways?

To place the present research in broader context, we briefly review evidence relevant to whether each deficiency described in Table 1 contributes to age-related deficits in episodic memory. In doing so, we highlight major gaps in the literature. Most notably, research to date has not evaluated the role of retrieval or decoding deficiencies. In discussing these two deficiencies, we introduce a technique—called the *mediator report-and-retrieval method*—that was critical in estimating their contribution in the present research. After this review, we discuss two critical analyses (one concerning mediator features and the other concerning analysis of individual differences) that further reveal the causes and nature of the association deficit shown by older adults.

Contribution of Mediator Deficiencies to Age Deficits in Memory: A Brief Review

Production, Mediation, and Utilization Deficiencies

A production deficiency occurs when an individual does not spontaneously produce an effective mediator but can successfully produce the mediator when instructed to do so. To evaluate whether production deficiencies contribute to age-related declines in episodic memory, researchers have often asked participants to report which mediators—if any—had been used during study. Multiple lines of evidence suggest that production deficiencies may play a minor role in determining age-related deficits in associative learning. For instance, age-related differences in reported use of mediators are typically small in magnitude (e.g., Dunlosky & Hertzog, 2001; Hulicka & Grossman, 1967; Rowe & Schnore, 1971), and even when differences in mediator production occur, they are eliminated when older adults are merely informed about using the mediators (Dunlosky & Hertzog, 1998, 2001; Treat & Reese, 1976).

Similar to production deficiencies, mediational deficiencies refer to situations in which individuals do not spontaneously produce mediators. For a mediational deficiency, however, individuals do not produce an effective mediator even when appropriate support is provided, such as when they are instructed to use one. The outcomes described above suggest that mediational deficiencies also play a minor role in producing age deficits in learning (for converging evidence, see Kausler, 1994). Namely, when instructed to use mediators, older adults report complying with those instructions to the same degree as younger adults. In fact, with such instructional support, older adults report virtually the same profile of mediators as do younger adults (Dunlosky & Hertzog, 1998, 2001).

Although production and mediational deficiencies do not adequately describe the age-related deficits in episodic memory, it may be the case that age differences occur in the effectiveness with which strategies—such as sentence generation and imagery—are used. In the case of this utilization deficiency, mediators benefit older adults' recall performance, but to a limited extent. For instance, older adults may often produce normatively effective mediators but yet receive minimal gains in recall performance compared with when they use no mediator. To investigate utilization deficiencies, one must identify the strategies individuals produce for every item of a list. The few studies that measured strategy production in this manner (Dunlosky & Hertzog, 1998, 2001) have shown that, similar to the criterion recall performance of younger adults, older adults' criterion recall performance is better when they generate effective mediators at study (e.g., imagery) than when they generate ineffective ones (e.g., rote repetition). Thus, the bulk of the evidence strongly suggests that production, mediation, and utilization deficiencies contribute little to the association deficits shown by older adults.

Retrieval and Decoding Deficiencies

A core assumption of why mediators are effective is that when cued with a stimulus word at test, an individual retrieves the original mediator and then decodes it to retrieve the correct response (Richardson, 1998). A retrieval deficiency occurs when during the criterion test an individual does not have access to the mediators that had been successfully produced at study. For a decoding deficiency, an individual successfully retrieves the mediator at the time of test yet fails to decode it properly and hence does not produce the correct response. Yuille (1973) evaluated whether a retrieval deficiency or a decoding deficiency constrained younger adults' associative learning. During study, participants studied pairs and reported the mediator generated for each one. When a given stimulus was presented at test, participants were asked to recall the response and then report the mediator that had been generated at study. Yuille reported a high conditional probability of recall, given mediator recall. Thus, younger adults' recall was primarily driven by the success of mediator recall and not by deficiencies in decoding mediators. Despite the extensive literature on aging and other mediator-related deficiencies, we are not aware

of any investigation using this method to evaluate whether older adults have more difficulties in retrieving mediators or in decoding those that they do retrieve.

To address this issue, we had older and younger adults study paired associates and then describe the specific mediator they had used to study each one. Participants then were asked to recall each mediator they had produced at study immediately after the recall attempt of each response. Thus, participants both reported mediators generated at study and later attempted to retrieve them during the criterion test. This mediator report-and-retrieval method provides outcomes relevant to all the mediator deficiencies. With respect to retrieval and decoding deficiencies, if the former contributes to age-related declines in recall performance, then the proportion of correct mediator recall at test will be lower for older than for younger adults. If a decoding deficiency contributes to age differences in recall, then older adults will manifest a lower probability of correct recall when mediators are successfully retrieved.

Mediator Features: Does Aging Influence the Quality of Mediators?

The mediator report-and-retrieval method also allows fine-grained analysis of the features of mediators produced at study. Analyzing these features provides information that is essential to adequately evaluating the mediator-based deficiencies and the nature of the underlying association deficit. For instance, older and younger adults report producing images to study pairs when instructed to do so, yet age deficits in recall remain. Although this evidence does not accord well with a production deficiency, it may be that age differences exist in the features of the mediators. That is, although both age groups may produce images, their images may differ with respect to critical features. Experimental studies show that interactive images are more effective than separated images of the two words in a pair for later associative recall (Begg, 1978). If older adults are less likely to spontaneously produce *interactive* images, a production deficiency may contribute to their association deficit.

The available evidence, although limited in scope, suggests that age-related differences in mediator features are minimal (Marshall et al., 1978; Smith, Park, Earles, Shaw, & Whiting, 1998). However, both of these studies focused entirely on *verbal* mediators, and even if aging does not influence verbal encoding, it could still substantially influence imaginal encoding. For instance, older adults sometimes avoid using imagery (e.g., Hulicka & Grossman, 1967; Mason & Smith, 1977; Rowe & Schnore, 1971; but see Dunlosky & Hertzog, 1998, 2001), perhaps because they have more difficulty generating images during resource-demanding tasks (Bruyer & Scailquin, 2000; Dirkx & Craik, 1992; Dror & Kosslyn, 1994). Even when older adults successfully produce an image, the image itself may lack detail or the imaginal referents of the to-be-learned words may not be integrated.

To explore these issues, we evaluated the features of both imaginal and sentence mediators. We instructed participants to study 30 paired associates using either interactive imagery or sentence generation. Immediately after studying a pair, participants were instructed either to report the sentence or to describe the image verbally.[2] The reports were then transcribed and scored on various features, which included whether the stimulus and response interacted in the mediator. As discussed above, analyses of these features provide critical evidence for specifying the nature of the association deficit.

Individual Differences and Age Deficits in Associative Learning

A primary issue in the current research involved understanding how the use and quality of mediators account for age-related differences in episodic memory. A large literature exists on the development of individual differences in episodic memory in childhood (e.g., Schneider & Pressley, 1997) and individual differences in memory change during adulthood and aging (e.g., Hultsch, Hertzog, Dixon, & Small, 1998). A dominant metaphor for this research has involved processing resources that are available for encoding, retaining, and retrieving to-be-remembered information (e.g., Craik & Byrd, 1982; Hultsch et al., 1998; Light, 1996; Salthouse, 1996). A leading explanation for the life span development of episodic memory has been changes in processing speed and the benefits that fast and efficient processing have for encoding and retention of new information (Kail & Salthouse, 1994).

Increases in processing efficiency should be associated with memory improvements during child development, and decreases in processing efficiency can contribute to encoding deficits (e.g., through limiting the time available for elaborated rehearsal; Kausler, 1994; Salthouse, 1996). Indeed, Salthouse (1996) has argued that age changes in perceptual speed account for most of the age-related variance in episodic memory performance in adulthood. His evidence derives from regression models in which the direct effects of age on episodic memory are greatly reduced when perceptual speed is included as a predictor of episodic memory (directly and indirectly through working memory). Crystallized intelligence is another factor that is relevant for individual differences in memory performance in that high levels of vocabulary are known to be related to better episodic memory (Dunlosky & Hertzog, 1998; Hultsch et al., 1998; Kyllonen, Tirre, & Christal, 1991; Meyer, 1987).

A major, unresolved issue in studies of individual differences in memory, including developmental research, concerns the mechanisms by which cognitive resources influence episodic memory. In the present study, we used the mediator report-and-retrieval method to estimate the extent to which age differences in resources—construed here as processing speed and vocabulary—explain age differences in mediator outcomes relevant to the deficiencies we reviewed earlier. On one hand, this approach allows us to determine whether the focal variables we have identified are the pathways that enable resource variables to mediate some of the effects of aging on associative recall. On the other hand, this approach provides a more subtle and elaborate test of the

[2] Certainly, verbal protocols for capturing qualities of image mediators have some limitations. For instance, participants' mediator descriptions were often relatively brief (e.g., "I see a *dog* with a *spoon* in his mouth"). Sparse descriptions may not reveal all relevant imaginal qualities (e.g., vividness of the image) that could be relevant to the likelihood of recall (Ericsson & Simon, 1980). Even with such limitations, the descriptions were invaluable in allowing us to address critical questions such as whether older adults are less likely to generate interactive images (e.g., "a dog with a spoon in his mouth") than separate images (e.g., "a dog standing beside a spoon").

resource hypothesis by determining whether there are age-related sources of variance in associative recall, including proximal factors such as mediator retrieval, that are not predicted by variables such as perceptual speed and vocabulary. To the extent that mediator forgetting predicts age differences in associative recall independently of perceptual speed, then the standard processing-speed explanation for age changes in memory would be severely challenged. To address such issues, we used path analysis in predicting criterion recall with mediation-related variables that could potentially account for age deficits in recall performance, and we evaluated their prediction of associative recall in the presence of measures of the resource variables of vocabulary and perceptual speed.

Method

Design and Participants

The experiment consisted of a 2 (age group: young or old) × 2 (mediator type: interactive imagery or sentence generation) × 2 (mediator report: verbal report or no report of mediator) factorial design. The participants were instructed either to use sentences to associate words in each pair (sentence mediators) or to form an interactive image for the words in each pair (imagery mediator). Participants either were not asked to verbally report their mediators at study or were asked to report them. Thus, mediator type and mediator report were between-subjects factors.

Participants included 119 young adults and 137 older adults. Some participants were excluded from the experiment because of failures in tape recording, primarily inaudible mediator reports. For older adults who reported mediators, 28 and 33 participants remained in the sentence and imagery groups, respectively. For younger adults, 25 and 26 participants remained in these two groups. For the groups who did not report mediators, there were 28 and 23 older participants in the sentence and imagery groups, respectively. For younger adults, 21 and 19 participants remained in these two groups. Of these participants, 50 younger and 58 older adults were male, and 41 younger and 54 older adults were female.

The younger adult participants (mean age = 19.6 years, $SD = 2.0$) were undergraduate students from either the Georgia Institute of Technology or the University of North Carolina at Greensboro. The older adults were community-dwelling inhabitants of the metropolitan Atlanta area. Older adults were recruited by a locator service, which employed random digit dialing supplemented with additional snowballing techniques. The older adults (mean age = 69.5 years, $SD = 6.4$) were well educated (mean years of education = 14.9, $SD = 2.6$). They rated themselves as being in average health ($M = 1.7$, $SD = 0.6$) and in average health relative to same-age peers ($M = 1.3$, $SD = 0.5$), and they took, on average, 2.2 ($SD = 2.4$) different medications. No other information regarding this sample's sociodemographic characteristics is available.

Apparatus, Tasks, and Materials

Paired-associate task. The paired-associate task was programmed in HyperCard 2.0 on Macintosh computers. The item list consisted of 30 unrelated noun–noun word pairs, which are presented in the Appendix. Five similar items were used for practice trials.

Subjective judgments. Participants made a quality-of-encoding judgment immediately after studying each word pair (for details, see Hertzog, Dunlosky, Robinson, & Kidder, 2003). Because these subjective judgments did not have bearing on the core issues examined in this article, they are not presented here.

Mediator reports. After studying each item, participants reported aloud the mediator they had produced during study. The mediator reports were self-paced and were recorded using Panasonic Model RQ-L317 tape recorders. Audiotapes were later transcribed for scoring of mediator recall and mediator features.

Tests and questionnaires. We also obtained measures of vocabulary and speed of processing. For the former, a modified version of the Educational Testing Service Advanced Vocabulary Test, V-4 (Ekstrom, French, Harman, & Dermen, 1976) was completed. Perceptual speed was evaluated by administering the Letter Comparison and Pattern Comparison tests (Salthouse, 1996). Several other questionnaires were administered but were not pertinent to the core issues of this investigation and hence are not discussed.

Procedure

For the paired-associate task, the experimenter read aloud the task instructions while the participants followed along with instructions presented on the computer. After each screen, the experimenter asked the participants if they had any questions. For the paired-associate task, the participants were given three examples of paired-associate items along with experimenter-provided mediators (either sentences or interactive images according to the mediator group to which each participant had been assigned). Then each participant was provided with two additional practice items. For each one, the participant generated a mediator and described it to the experimenter. Following practice, study of the critical items began. Each trial began with a computer-generated tone that reminded the participants to read the cue of the paired associate aloud. Each item was presented for 8 s. After the offset of an item, either the next item was presented for study (for participants who did not report mediators) or the mediator generated for that item was reported.

After all 30 items had been studied, participants were instructed to press a key to initiate the recall portion of the task. Each stimulus was presented individually, and participants were asked to recall the corresponding response, both by typing in the response on the computer keyboard and by repeating the word aloud for the tape recorder. The computer scored an answer as correct if the first 3 letters matched the correct response (which correlates .99 with human scoring). After attempting to recall a response, participants in the mediator report groups were prompted to recall aloud the mediator they had used to study the item. These participants had not been previously informed that they would have to recall the mediators generated at study. This procedure was approved by the institutional review boards at the participating universities, which provided protection for all those who participated in this experiment.

Mediator Scoring and Coding

Reported mediators were coded in several ways that pertained to the main goals of this research. The mediator coding scheme was designed to score the similarity between the mediator produced at study and the mediator produced at test for each item. The coders were explicitly instructed to code only mediator similarity, ignoring the recalled response. The rationale behind this decision was that the participants could have recalled the response incorrectly yet still have recalled the mediator correctly. Reliability was above an acceptable level (.90 or better) for scoring mediator recall. *Omission* errors involved participants either reporting that they had generated no mediator at study or reporting that they had generated one but did not remember it. *Commission* errors involved retrieving a mediator for a pair that was not similar at all to the mediator originally produced at study. *Partial recall* indicated that the recalled mediator had the same structure and argument as the mediator produced at study but was missing key elements. For example, partial recall would be scored for the pair *clown–paper* if a participant produced the following mediator at study, "The clown made the audience laugh with a paper hat," yet recalled the following during the criterion test, "The clown did something to make the audience laugh." For the pair *turtle–milk* an example of partial recall would be if the participant reported at study "a turtle swimming in a lake of milk" and then later recalled "a turtle floating." *Correct recall* included verbatim or gist recall of the mediators. For gist recall, the meaning of the recalled mediator was the same as the one generated at study yet there were (a)

slight changes in wording, (b) synonyms used, (c) tense changes, or (d) changes in articles. For example, mediator recall for *turtle–milk* would be scored as correct if at study the mediator produced was "a turtle swimming in a lake of milk," and the mediator retrieved at test was "a lake of milk with a turtle swimming in it."

To code the features of the mediators generated at study, we scored each mediator that was produced on the following dimensions. The reliability of the scoring was computed with a measure of consistency appropriate for the properties of each measure, and it was above an acceptable level (.80 or above) for all of the following measures. First, each mediator was scored as to whether the stimulus and response of an item interacted (or were integrated) in the mediator itself. For the pair *monarch–doll*, the mediator "The monarch played with the golden doll" would be scored as interacting, whereas the mediator "The monarch sat beside a golden doll" would be scored as noninteracting. Second, we counted both the total number of words in a mediator as well as the number of content words. Finally, we coded the role of the stimulus and the response within each mediator: subject, object, within a prepositional phrase, not included in the mediator, and other (mainly adjectives, but also including verbs and other rare syntactic forms). For the examples above, *monarch* would be scored as the subject and *doll* would be scored as being embedded within a prepositional phrase.

Results

Criterion Recall Performance

The proportion of correct recall performance was analyzed using a 2 (age) × 2 (mediator type) × 2 (mediator report) analysis of variance (ANOVA). Recall was slightly higher under imagery instructions than under sentence instructions for both age groups (marginal mean differences of less than .10 in each group), but this difference was not reliable, $F(1, 195) = 2.44$, $p > .10$, $MSE = 0.04$. The analysis also revealed a reliable main effect of mediator report, $F(1, 195) = 9.14$, $p < .01$, $MSE = 0.04$. Providing a mediator report boosted criterion recall (marginal means of 61% vs. 52%), presumably because of additional rehearsal allowed by reporting the mediator.

Most important, the analysis revealed a main effect of age, $F(1, 195) = 111.03$, $p < .01$, $MSE = 0.04$, with younger adults recalling .74 of the correct responses and older adults recalling only .44 of them. Thus, even though both age groups were instructed to use effective mediators, an age-related memory impairment was evident. One explanation for this age deficit concerns the influence of reporting mediators during study. The possibility exists that older adults' recall suffered because of an undue influence of the time needed to report the mediator. If so, the age deficit in recall should be greater for the groups who reported mediators than for the control groups. In contrast to this possibility, the effects of mediator report on criterion recall were not significantly different for younger adults (8% increase in recall for the mediator report group vs. the control group) and for older adults (9% increase), $F < 1.0$, $MSE = 0.04$.

Can the substantial deficit in criterion recall be attributed to concomitant differences in the mediator deficiencies we have identified? In each of the following sections, we first describe the key effects and then briefly explain their relevance to the mediator-based deficiencies.

Mediator Production Outcomes

Success of mediator production at study. For each participant, we computed the proportion of items for which he or she had reported generating a mediator. Older adults reported more mediators immediately after study than did younger adults, both when they were instructed to use interactive imagery (mean proportion = .86 for older adults vs. .79 for younger adults) and when they were instructed to generate sentences ($M = .93$ for older adults vs. .87 for younger adults), $F(1, 108) = 7.46$, $p < .01$, $MSE = 0.02$. The main effect of mediator type was also reliable, $F(1, 108) = 8.21$, $p < .01$, $MSE = 0.02$, indicating that participants reported generating more sentence mediators ($M = .90$) than imaginal mediators ($M = .83$). Consistent with the bulk of previous research, older adults here were not deficient at generating mediators for the pairs. Thus, a mediational deficiency does not provide an adequate description of the age-related association deficits.

Criterion recall as a function of mediator production. We computed the proportion of correct criterion recall as a function of whether a mediator had been produced at study. These values are reported in Table 2. This analysis pertains to the role of a utilization deficiency, because although age differences in mediator production were minimal, perhaps older adults did not benefit as much from generating a mediator at study.

A 2 (age) × 2 (mediator type) × 2 (mediator production: produced vs. not produced) ANOVA revealed two reliable ($p < .01$) main effects: age, $F(1, 74) = 63.7$, $MSE = 0.08$, and mediator production, $F(1, 74) = 80.1$, $MSE = 0.04$. The main effect of mediator type (imagery vs. sentence) approached significance, $F(1, 74) = 3.16$, $p = .08$, $MSE = 0.08$, and all interactions were not reliable (Fs < 2.80, ps $> .10$). Both older and younger adults showed large benefits from generating mediators under the two strategy instructions, an outcome that cannot readily be explained if a utilization deficiency was responsible for an age-related association deficit.

Another outcome of interest is that younger adults recalled .52 ($SEM = .05$) of the items that they did not produce a mediator for at study, whereas older adults recalled only .19 ($SEM = .04$) of these items, $F(1, 83) = 24.17$, $p < .01$, $MSE = 0.09$. Although these particular age-related differences cannot account for the majority of the age-related deficit obtained in criterion recall (because both age groups produced mediators for the majority of pairs), this difference also cannot be explained by any of the mediator-related deficiencies identified from the associative learning literature (see Table 1). It may reflect the type of impaired semantic elaboration during encoding identified by Craik and colleagues (e.g., Castel & Craik, 2003)—a theoretical point we return to in the Discussion section.

Table 2
Mean Proportions of Correct Paired-Associate Recall as a Function of Whether a Mediator Was Produced at Study

	Mediator produced		Mediator not produced	
Age and instruction	*M*	*SEM*	*M*	*SEM*
Younger adult				
Imagery	.86	.04	.56	.07
Sentence	.84	.04	.48	.08
Older adult				
Imagery	.59	.03	.20	.06
Sentence	.44	.04	.16	.07

Mediator Recall Outcomes

Mediator recall. A major goal was to evaluate whether a mediator-based retrieval deficiency contributed to age deficits in episodic recall. To do so, we analyzed items for which a mediator was produced at study, calculating the proportion of times that (a) mediators were correctly retrieved at criterion recall, (b) mediators were partially (but not entirely) retrieved at criterion recall, (c) mediators were completely omitted at criterion recall, and (d) mediators were incorrectly retrieved at criterion recall (i.e., commission errors). Given the literature on text recall, and the fact that identical images could be described in different language at study and test, we used a gist criterion to score recall (e.g., van Dijk & Kintsch, 1983; see Method for details). Note that the measures exhaust the possible outcomes and hence are not statistically independent—for example, high scores on correct mediator recall dictate low values on the sum of other measures. Accordingly, we restricted our inferential analyses to correct mediator recall. For completeness, mean proportions for each of these measures are reported in Figure 1.

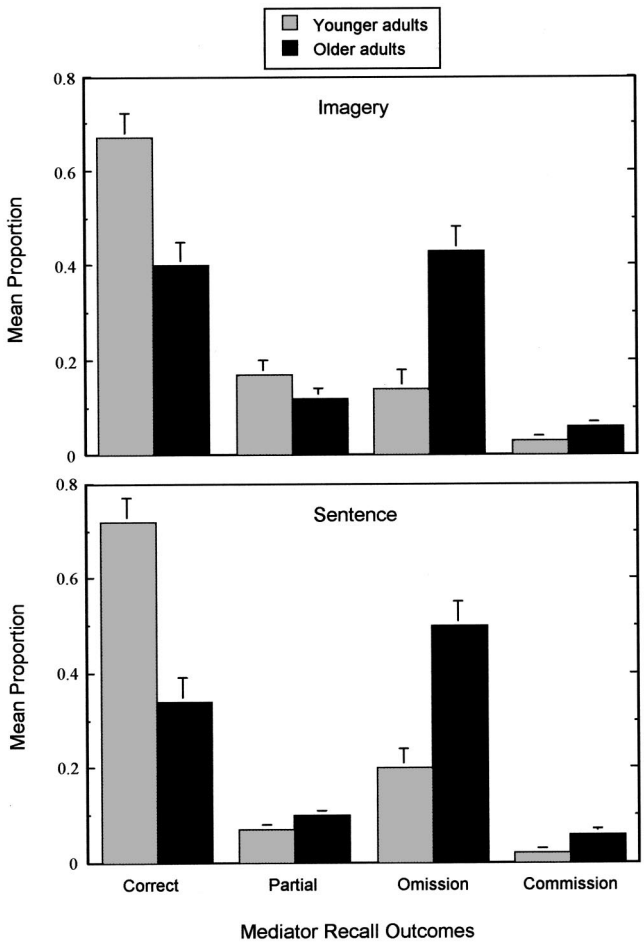

Figure 1. Mean proportion of various outcomes during mediator retrieval for those mediators that had originally been produced during study. Correct = mediator was correctly recalled during the criterion test; Partial = mediator was partially recalled; Omission = no mediator was retrieved during the criterion test; Commission = an incorrect mediator was retrieved during the criterion test. See text for details on scoring.

Correct mediator recall was substantially lower for older adults than for younger adults, $F(1, 108) = 47.87$, $p < .01$, $MSE = 0.06$, and mediator type did not reliably interact with age. Thus, as is evident from inspection of Figure 1, older adults had substantially greater difficulty recalling mediators they had generated at study, which implicates a mediator-based retrieval deficiency in age-related association deficits.

Criterion recall as a function of mediator recall. We also examined the proportion of criterion recall as a function of three classes of mediator recall: correct recall, partial recall, and omission errors. For mediators that were correctly recalled at the criterion test, this measure pertains to the likelihood of accurately decoding mediators during the test, and hence it bears on decoding deficiencies. Given that the frequency of commission errors was near the floor (Figure 1), they were omitted from the inferential analyses. Mean proportions of correct criterion recall for each class are reported in Figure 2.

Although the conditional probability of criterion recall given mediator recall was in general quite high, it was greater for younger adults than for older adults, $F(1, 91) = 6.80$, $p < .01$, $MSE = 0.02$. The effect of mediator type and the Age × Mediator Type interaction were not reliable (Fs < 1.40). Moreover, when participants could only partially recall the mediator at test, criterion recall was also reliably less for older adults than for younger adults, $F(1, 90) = 8.68$, $p < .01$, $MSE = 0.11$. Finally, when mediators were omitted at the test, both younger and older adults correctly recalled some responses—the apparent trend favoring older adults was not statistically reliable ($F < 1$). Overall, these outcomes demonstrate an age-related decoding deficiency, because even when mediators were successfully retrieved at test, the likelihood of retrieving the correct response word was lower for older adults.

Features of Mediators Produced at Study

To evaluate whether age-related differences occurred in the nature of the mediators generated at study, we coded each mediator on multiple features. The first feature was whether the stimulus and response interacted within the mediator itself. For example, given the item, *clown–paper*, imagining a clown wearing a paper hat is an interactive image, in that the two concepts are well integrated within a single image. Imagining a clown standing next to a newspaper stand represents a less interactive image. This dimension is particularly important for the present research, because interactive mediators tend to yield higher levels of criterion recall than noninteractive mediators (e.g., Begg, 1978). The remainder of the dimensions were meant to provide a description of the mediators and consisted of coding for particular features, including word counts of the mediators and the syntactic role of the stimulus and the response in each pair. Thus, although these mediators were not necessarily expected to predict criterion recall performance, they provided critical information pertaining to whether the structure of older and younger adults' mediators substantively differed. The mean proportions of occurrence for each of the features are reported in Table 3.

Inspection of Table 3 reveals that age-related differences in the features of the mediators were negligible, with both age groups reporting qualitatively similar mediators regardless of whether they were instructed to produce images or sentences during study. Concerning the proportion of interactive mediators, a 2 (age) × 2

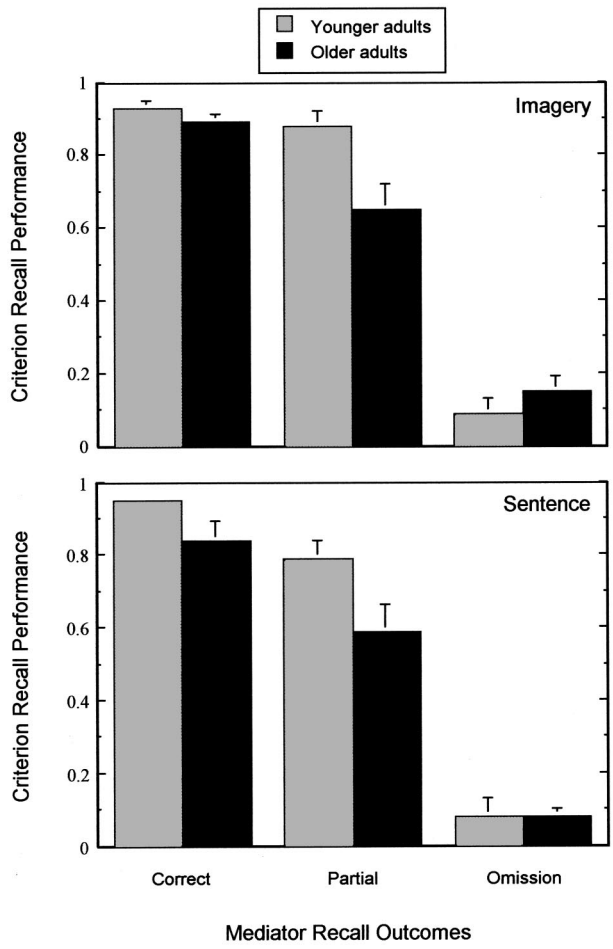

Figure 2. Mean proportion of correct performance on the criterion test of paired-associate recall, plotted as a function of various outcomes during mediator retrieval. Correct = mediator was correctly recalled during the criterion test; Partial = mediator was partially recalled; Omission = no mediator was retrieved during the criterion test. See text for details on scoring.

(mediator type) ANOVA revealed no main effects, Fs < 2.90, $MSE = 0.02$, and no reliable interaction, $F < 1.0$, $MSE = 0.02$. As expected, however, the Pearson product–moment correlation between this measure and recall was .20 ($p < .05$), indicating that interactive mediators resulted in reliably higher levels of recall than did noninteractive mediators.

For the total number of words, an ANOVA again revealed no age effects or interaction, Fs < 1.4, $MSE = 5.4$, although mediator reports were longer for imaginal mediators than for sentence mediators, $F(1, 85) = 6.09$, $MSE = 5.4$. Inferential analyses of the number of content words yielded the same conclusions. Neither total words ($r = -.15$) nor content words ($r = -.05$) were reliably correlated with criterion recall performance (ps $> .10$).

Finally, a 2 (age) × 2 (mediator type) × 2 (stimulus vs. response) × 4 (syntactic role: subject, object, prepositional phrase, absent from mediator report) ANOVA was conducted. The main effect of age and all interactions involving age did not approach reliability (Fs < 2.40, ps $> .10$), indicating that age had a negligible influence on the features of the mediators. The different syntactic roles were not used uniformly, $F(3, 255) = 239.65$, $p < .01$, $MSE = 0.01$. Both the stimulus and the response of the pairs were more likely to occur as the subject or in a prepositional phrase than as the object of the mediator, especially for imagery mediators. In summary, age-related differences in the underlying representation of the mediators generated at study were negligible.

Analyses of Individual Differences in Mediator Production and Recall, Perceptual Speed, Vocabulary, and Criterion Recall

A primary goal of the current research involved evaluating the degree to which various mediator-based deficiencies could account for the substantial age-related differences obtained in episodic memory. The previous analyses indicate that a retrieval deficiency shows the most promise of accounting for the age-related variability in criterion recall. Of course, even though age differences in mediator recall were evident, it is still not clear whether these differences mediate the age-related variability in criterion recall. Accordingly, we conducted a path analysis that included the probability of correctly retrieving a mediator at test (Figure 1) but also included other variables that could predict individual differences in criterion recall: (a) vocabulary, (b) perceptual speed (combined standard scores from letter and pattern comparison tests), (c) the probability that an interactive mediator was generated at study (see Table 3, first column), and (d) the probability of producing a mediator. Verbal knowledge and speed have been shown to be relevant predictors of learning (Kyllonen et al., 1991) and can account for age-related variance in memory, perhaps by predicting the degree of mediator recall. Verbal ability predicted mediator production in our earlier work (Dunlosky & Hertzog, 1998). The measure relevant to the decoding deficiency (i.e., the probability of incorrect criterion recall given correct mediator recall) was not included in the model because it was not significantly correlated with other central measures (i.e., perceptual speed, vocabulary, or mediator production) and did not substantively contribute to explaining individual differences in criterion recall.

Data from a total of 203 participants were included in the path analysis, which was estimated in LISREL 8.53 (Jöreskog & Sörbom, 1996) using full-information maximum-likelihood (FIML) estimation. We used this procedure to account for the fact that control participants produced no mediator reports, and hence contributed no information regarding mediator production, mediator interaction, or mediator recall, but did contribute information on age, abilities, and criterion recall. Because persons were assigned at random to the experimental conditions, we were justified in assuming that the control data were missing at random—a key assumption for FIML estimation—and we were able to use all the available data to estimate model parameters. Given that the strategy instructions (imagery or sentence generation) did not have a qualitatively different effect on any of our outcomes, we collapsed across the two groups to increase the statistical power of the analysis.

In summary, to account for variability in criterion recall as well as to explore general theories of cognitive aging based on changes in perceptual speed, the following variables were included in the path analysis: age (the categorical group variable: younger vs. older), probability of mediator production at study, degree of interaction of stimulus and response in the generated mediator (which we refer to as *mediator integration*), probability of medi-

Table 3
Mediator Features as a Function of Age and Strategy Instruction

Age and instruction	Interactive	Total	Content	Stimulus				Response			
				Subject	Object	PP	Absent	Subject	Object	PP	Absent
Younger adult											
Imagery	.56	8.9 (.68)	4.5 (.27)	.26	.16	.39	.08	.36	.17	.32	.06
Sentence	.49	7.6 (.27)	3.8 (.16)	.31	.25	.30	.01	.25	.24	.42	.01
Older adult											
Imagery	.51	9.4 (.54)	4.7 (.28)	.29	.17	.33	.07	.29	.15	.39	.06
Sentence	.49	8.2 (.30)	3.9 (.13)	.28	.26	.30	.01	.24	.24	.40	.02

Note. Interactive refers to the mean proportion of items (across participants) in which the stimulus and response interacted in the mediator. Total and Content refer to the mean number of words—total or content words, respectively—in the mediators. For stimulus and response headings, subheadings refer to the mean proportion of time that the word was in each particular syntactic role (PP = prepositional phrase). The stimulus and response occurred 15% or less of the time in syntactic roles not listed (e.g., adjective, verb, and other rare syntactic roles). Standard errors of the means appear in parentheses; all means without a corresponding value in parentheses have an $SEM < .05$.

ator recall at test, vocabulary, and perceptual speed. Zero-order correlations among these variables (along with corresponding standard deviations) are reported in Table 4.

Our initial path model specified relations of ability measures to each of the mediator variables, but several of these paths were not reliable and were trimmed from the model. The results from the final path model are presented in Figure 3. The fit of the model was excellent, $\chi^2(10, N = 107) = 12.48$, $p = .25$, root-mean-square error of approximation (Steiger, 1990) = .035. The R^2 for criterion recall was .66, indicating a substantial degree of prediction by age, mediator production, and mediator recall. The estimated regression coefficients in Figure 3 are called direct effects (Bollen, 1989); the total effects of one variable on another are the sum of the direct effect and implied indirect effects that are mediated (or carried) by an intervening variable (see Kenny, 1979, for a useful introduction to these concepts). For example, in Figure 3, age has a direct effect on criterion recall but also has indirect effects that are mediated by age effects on mediator recall and perceptual speed.

Several features of the model merit consideration. First, individual differences in mediator production did not account for the age deficits in criterion recall (indeed, there was no direct effect of age on mediator production), which was not surprising given that both older and younger adults successfully produced mediators at study (Figure 1). More interesting, age was positively related to vocabulary, which in turn was related to mediator production (as in Dunlosky & Hertzog, 1998). The direct path coefficients implied a weak, indirect effect of age on mediator production (carried by older adults' higher vocabulary scores) of .10, with older adults producing slightly more mediators than did younger adults. Given that mediator production is positively related to criterion recall, age-related gains in vocabulary may to a small degree offset some of the deficits in criterion recall.

Second, and most important, mediator recall accounted for a substantial amount of age-related variability in criterion recall, as indicated by the strong direct effect of mediator recall on criterion recall and the reliable paths from age and perceptual speed to mediator recall. This effect controls for all other predictors of criterion recall, including mediator production and mediator integration. This outcome confirms the hypothesis that deficiencies in mediator recall are substantively responsible for the age-related declines in associative learning. Also, mediator integration was reliably predictive of mediator recall, confirming that the degree of interaction between elements in the mediator promotes the recall of mediators at test.

Third, the results demonstrate that perceptual speed carries only a modest proportion of the age-related variance in mediator recall. The indirect effect of age on mediator recall (which is carried by perceptual speed) was −.16, compared with the total effect of −.54. That is, only 30% of the total effect of age on mediator recall was carried by perceptual speed.

Finally, age reliably predicted criterion recall, even after we controlled for perceptual speed and mediator recall. Thus, even

Table 4
Correlations Among Variables Entered Into the Path Analysis as Predictors of Criterion Paired-Associate Recall

Variable	*SD*	1	2	3	4	5	6	7
1. Criterion recall ($N = 203$)	0.25	—						
2. Age ($N = 203$)	0.50	−.59*	—					
3. Mediator production ($N = 112$)	0.14	−.11	−.24*	—				
4. Interactive ($N = 112$)	0.14	.19*	−.10	−.04	–			
5. Mediator recall ($N = 112$)	0.29	.75*	−.55*	.001	.27*	—		
6. Vocabulary ($N = 202$)	7.70	.02	.36*	−.29*	.15	.09	—	
7. Perceptual speed ($N = 196$)	0.94	.53*	−.67*	.11	.07	.45*	−.05	—

Note. Age: young = 1, old = 2. Interactive refers to the mean proportion of items (across participants) in which the stimulus and response interacted in the mediator. See text for details on computation of other variables.
* $p < .05$.

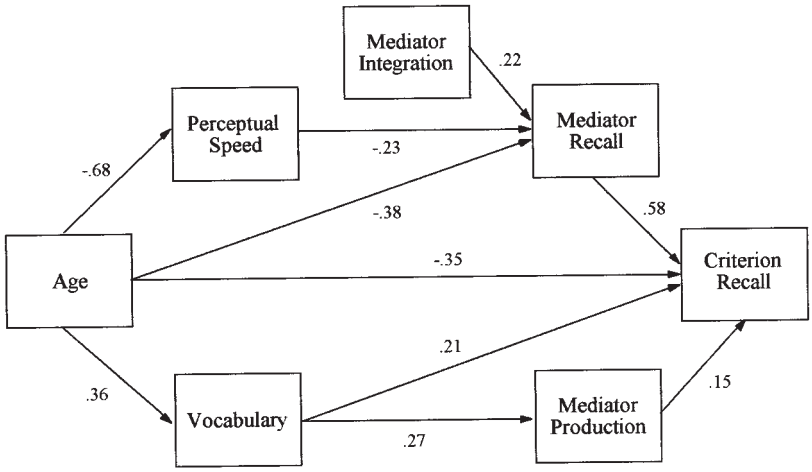

Figure 3. Estimated path model emphasizing the contribution of mediator production and mediator retrieval in accounting for age-related variability in criterion recall.

though both of these latter variables are highly related to age per se, neither can completely account for the age deficits in criterion recall. In fact, the total effect of age was −.60, with −.25 of this effect (42%) being indirectly carried by mediator recall. The direct path from age to criterion recall suggests that other (perhaps nonstrategic) factors associated with age explain substantial variance in paired-associate recall. This particular conclusion is consistent with the outcomes described above. Namely, even when no mediators were produced at study, younger adults still correctly recalled about half the responses, whereas older adults recalled fewer than 20% of them. Also, younger adults were more likely than were older adults to recall the response word when they could achieve only partial recall of the mediator. In this sense, recall appears to be more contingent on successful mediator recall for older adults than for younger adults.

The path analysis demonstrated that producing and retrieving mediators are critical for effective learning, with age-related differences in mediator recall accounting for a reliable proportion of the age deficits in criterion recall. Moreover, this retrieval deficiency could not be entirely understood as a consequence of age-related slowing in information-processing speed, at least as measured by perceptual speed tests.

Discussion

A major theoretical goal for research in developmental psychology has been to explain why learning changes over the course of the life span. For aging in adulthood, a major hypothesis that has received empirical support is that older adults suffer from an association deficit. Theoretical questions answered in the present research included: What is the specific nature of the association deficit? And is this deficit entirely contingent on age-related changes in vocabulary and processing speed? In the Discussion section, we explore these and other theoretical issues as they arise in relation to the mediator-based deficiencies.

Mediational and Utilization Deficiency

Consistent with conclusions from previous research (see Dunlosky & Hertzog, 1998, 2001), evidence from the current study disconfirms the hypothesis that mediational deficiencies explain age-related deficits in associative learning. In particular, with supportive instructions about which strategies to use (either sentence generation or interactive imagery), older adults were just as successful at producing appropriate mediators. More revealing were outcomes relevant to a utilization deficiency, which has not been widely investigated. The evidence reported here suggests that a utilization deficiency also cannot account for age-related deficits in episodic memory. Older and younger adults benefited equally by producing mediators at study. Thus, at least in terms of criterion recall, the imaginal mediators and the sentence mediators appeared no less effective for older adults than for younger adults.

Although the aforementioned analysis of mediator use involves describing the kinds of mediator produced for individual items, the grain size of analysis is not fine enough to evaluate how the particular mediators were represented immediately after elaborative encoding occurred. Descriptions at this level of representation, however, were available from the analysis of mediator features. As is evident from inspection of Table 3, the words of each pair largely appeared as the subject or in the prepositional phrase of each verbal report, and the two words comprising pairs also interacted about half the time—a dimension of the underlying association that was predictive of criterion recall. Most important, the qualitative nature of the sentence and imagery mediators did not differ for the two age groups. Concerning sentence generation, this conclusion is consistent with those from previous research that has examined verbal mediators for various kinds of material (Marshall et al., 1978; Smith et al., 1998). Concerning images, even though older adults have shown some deficits in imaginal-based processing (e.g., Bruyer & Scailquin, 2000; Dirkx & Craik, 1992; Dror & Kosslyn, 1994), our analysis of mediator reports suggests that the kinds of elaborative processing that support imagery lead to a similar association for both age groups. That is, the features of older and younger adults' imaginal mediators were virtually identical even on the dimension of interaction.

At first glance, these results seem difficult to reconcile with arguments concerning age-related processing deficits in semantic elaboration during encoding (e.g., Anderson et al., 1998; Castel & Craik, 2003; Naveh-Benjamin, 2000). In our view, however, the

findings are not necessarily incompatible. Craik and his colleagues (Castel & Craik, 2003) have shown that both younger and older adults are adversely affected by divided attention during encoding, more so than divided attention at retrieval. As these authors pointed out, encoding places greater resource demands on older adults, and these demands can act to reduce elaborative rehearsal at encoding, and differentially so for older adults. Nevertheless, provided that *sufficient* resources are available, older adults may still be able to generate high-quality mediators during encoding even though doing so may tax their resources to a greater degree. Thus, the information-processing constraints on older adults' encoding may prevent successful mediator formation in some experimental task conditions, but not in the ones we used in this study (see also Dunlosky & Hertzog, 1998).

A consequence of the greater demand on older adults' resources is that they may benefit less from nonspecific semantic elaboration during encoding. That is, for items in which an explicit association has not been formed at encoding, younger adults may benefit more from nonspecific elaboration. Results were consistent with this proposal in that criterion recall was greater for younger adults when mediators were not produced at study (see Table 2). This benefit could arise for younger adults because in attempting to generate a mediator during study, they may activate information about the semantic properties of word concepts, which in turn leads to greater activation of related semantic concepts during encoding (e.g., Nelson, McEvoy, & Pointer, 2003). When these concepts are activated again by presenting a stimulus cue during the test, they may in turn increase the likelihood of implicitly activating the response—even though an explicit, associative mediator had not been generated at study. Given the high rate of mediator production in the present study, however, this particular age-related deficiency in nonspecific elaborative encoding likely accounts for a small portion of the overall age declines in criterion recall.

Retrieval and Decoding Deficiencies

Older adults were substantially more likely to forget mediators at the upcoming test (a mediator-based retrieval deficiency), and even when older adults did recall mediators, they were somewhat less able to recall the correct response (a decoding deficiency). The substantial retrieval deficit for mediators is analogous to other phenomena reported in the literature in which aging is related to forgetting of contextual materials, such as the color of targets (Park & Puglisi, 1985), whether a speaker was male or female (Bayen & Murnane, 1996), and various aspects of source memory (for a review and meta-analysis demonstrating age deficits in contextual retrieval, see Spencer & Raz, 1995). The deficiencies reported here have implications for current hypotheses of age declines in these kinds of episodic memory task, which rely on associating—or binding—events within a given episode.

First, the association deficit in our task was apparently less a function of the creation of associations at encoding and was more apparent in the accessibility and use of mediators at test. Thus, encoding manipulations may not necessarily influence age differences in associative memory. For instance, instructing older adults to associate words in a pair during study does not reduce age-related differences in associative learning (such as in Naveh-Benjamin, 2000), because even though older adults are capable of creating these associations, they fail to remember many of them during the criterion test.

Second, age-related declines in central processing resources may undermine older adults' success at recalling mediators, just as such declines are argued to account for age-related deficits in episodic memory. Consistent with this hypothesis, perceptual speed mediated a reliable proportion of the age-related deficits in mediator recall (Figure 3). This outcome is in line with the emphasis that some developmental psychologists have placed on the importance of changes in perceptual speed as a reflection of the status of underlying changes in cognitive architecture during development across the life span (e.g., Kail & Salthouse, 1994; Salthouse, 1996). Perhaps more surprising, however, was that perceptual speed accounted for less than 30% of the age deficit in mediator recall and accounted for only a small portion of the overall age-related declines in associative learning.

Finally, a decoding deficit was also apparent in which older adults were less likely to recall correct responses when they correctly retrieved the gist of mediators. This deficit may reflect age differences in a type of cognitive control over recall output (Koriat, Goldsmith, & Pansky, 2000) that may be affected by aging (Kelley & Sahakyan, 2003). Images were, as expected, more prone to decoding problems in general, which suggests that participants may have retrieved the correct image but selected the wrong verbal concept when constructing their response. A larger implication of the decoding deficit is that it indicates that a mediator-based retrieval deficiency cannot entirely explain the age-related deficits in associative learning. In other words, the associative deficit is apparently not produced by a single mechanism. Instead, the associative deficit arises from mediator retrieval, decoding difficulties, and (perhaps) a nonspecific semantic elaboration deficit.

One caveat here concerns the correlational nature of the present investigation. Constructs such as a decoding deficit were not experimentally manipulated but rather were inferred from criterion recall conditionalized on mediator recall. We cannot rule out the possibility that some third variable may account for the age-related effects on these conditional outcomes. Thus, what we have referred to as a failure to decode a mediator could be an instantiation of an unmeasured memory-based association deficit. To take this rationale one step further, this same underlying factor may also account for mediator recall, implying that all recall failures (i.e., in criterion recall, mediator recall, and not recalling responses when mediators were accessed) are entirely a function of a single factor.

Although possible, some evidence from the present research suggests that a single underlying factor is not responsible for the entire pattern of age-related deficits in recall failures. First, individual differences in mediator recall do not entirely account for differences in criterion recall ($R^2 = .56$). Second, the *unique* variability between these factors is also revealing in that recall failures (e.g., criterion response recall and mediator recall) differentially load on age and perceptual speed (Figure 3). These outcomes suggest that a single association-deficit construct cannot entirely account for forgetting of mediators and responses alike. Although admittedly the correlational nature of the current evidence means that it cannot definitively resolve this issue, our preferred interpretation is that the age deficits shown in criterion recall are due mostly to the independent difficulties older adults

have in recalling mediators and to a lesser degree to (a) nonspecific semantic elaboration (when no mediator could be produced) and (b) difficulties in decoding some mediators that are retrieved. Future research should attempt to isolate the specific mechanisms involved.

Conclusion

The mediator report-and-retrieval method used in the present study allowed us to estimate the relative contribution of multiple mediator-based deficiencies to age-related deficits in associative learning, including two deficiencies (the retrieval and decoding deficiencies) that have not yet received attention in the field. A major conclusion is that age-related deficits in encoding behavior play a smaller role in producing deficits in associative learning than would be expected from the earlier literature. In the present case, older and younger adults were equally effective at producing mediators during study, and the qualitative nature of their mediators were also similar. Thus, although elaborative encoding may be more difficult for older adults during encoding, the product of such elaborations—the mediators themselves—appears to be satisfactorily generated by older adults. By contrast, significant age-related differences were evident in the retrieval of mediators during the test, and they accounted for a substantial portion of the age-related deficits shown in associative learning. Importantly, the mediator report-and-retrieval method used here can be adapted to explore further the conditions in which deficits in strategic behavior contribute to changes in associative learning that arise across the life span.

References

Anderson, N. D., Craik, F. I. M., & Naveh-Benjamin, M. (1998). The attentional demands of encoding and retrieval in younger and older adults: I. Evidence from divided attention costs. *Psychology and Aging, 13,* 405–423.

Anderson, N. D., Iidaka, T., Cabeza, R., Kapur, S., McIntosh, A. R., & Craik, F. I. M. (2000). The effects of divided attention on encoding- and retrieval-related brain activity: A PET study of younger and older adults. *Journal of Cognitive Neuroscience, 12,* 775–792.

Bayen, U. J., & Murnane, K. (1996). Aging and the use of perceptual and temporal information in source memory tasks. *Psychology and Aging, 11,* 293–303.

Begg, I. (1978). Imagery and organization in memory: Instructional effects. *Memory & Cognition, 6,* 171–183.

Bollen, K. A. (1989). *Structural equations with latent variables.* New York: Wiley.

Bruyer, R., & Scailquin, J.-C. (2000). Effects of aging on the generation of mental images. *Experimental Aging Research, 26,* 337–351.

Castel, A. D., & Craik, F. I. M. (2003). The effects of aging and divided attention on memory for item and associative information. *Psychology and Aging, 18,* 873–885.

Craik, F. I. M., & Byrd, M. (1982). Aging and cognitive deficits: The role of attentional resources. In F. I. M. Craik & S. Trehub (Eds.), *Aging and cognitive processes* (pp. 191–211). New York: Plenum Press.

Dirkx, E., & Craik, F. I. M. (1992). Age-related differences in memory as a function of imagery processing. *Psychology and Aging, 7,* 352–358.

Dror, I. E., & Kosslyn, S. M. (1994). Mental imagery and aging. *Psychology and Aging, 9,* 90–102.

Dunlosky, J., & Hertzog, C. (1998). Aging and deficits in associative memory: What is the role of strategy production? *Psychology and Aging, 13,* 597–607.

Dunlosky, J., & Hertzog, C. (2001). Measuring strategy production during associative learning: The relative utility of concurrent versus retrospective reports. *Memory & Cognition, 29,* 247–253.

Ekstrom, R. B., French, J. W., Harman, H. H., & Dermen, D. (1976). *Manual for kit of factor-referenced cognitive tests.* Princeton, NJ: Educational Testing Service.

Ericsson, K. A., & Simon, H. A. (1980). Verbal reports as data. *Psychological Review, 87,* 215–251.

Hertzog, C., Dunlosky, J., Robinson, E., & Kidder, D. (2003). Encoding fluency is a cue used for judgments about learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29,* 22–34.

Hulicka, I. M., & Grossman, J. L. (1967). Age group comparisons for the use of mediators in paired-associate learning. *Journal of Gerontology, 22,* 46–51.

Hultsch, D. F., Hertzog, C., Dixon, R. A., & Small, B. J. (1998). *Memory change in the aged.* Cambridge, England: Cambridge University Press.

Jöreskog, K. G., & Sörbom, D. (1996). *LISREL 8: User's reference guide.* Chicago: Scientific Software International.

Kail, R., & Salthouse, T. A. (1994). Processing speed as a mental capacity. *Acta Psychologica, 86,* 199–225.

Kausler, D. H. (1994). *Learning and memory in normal aging.* New York: Academic Press.

Kelley, C. M., & Sahakyan, L. (2003). Memory, monitoring, and control in the attainment of memory accuracy. *Journal of Memory and Language, 48,* 704–721.

Kenny, D. A. (1979). *Correlation and causality.* New York: Wiley.

Koriat, A., Goldsmith, M., & Pansky, A. (2000). Toward a psychology of memory accuracy. *Annual Review of Psychology, 51,* 481–537.

Kyllonen, P. C., Tirre, W. C., & Christal, R. E. (1991). Knowledge and processing speed as determinants of associative learning. *Journal of Experimental Psychology, 120,* 57–79.

Light, L. (1996). Memory and aging. In E. L. Bjork & R. A. Bjork (Eds.), *Handbook of perception and cognition* (2nd ed., pp. 443–490). San Diego, CA: Academic Press.

Marshall, P. H., Elias, J. W., Webber, S. M., Gist, B. A., Winn, F. J., & King, P. (1978). Age differences in verbal mediation: A structural and functional analysis. *Experimental Aging Research, 4,* 175–193.

Mason, S. E., & Smith, A. D. (1977). Imagery in the aged. *Experimental Aging Research, 3,* 17–32.

Meyer, B. J. F. (1987). Reading comprehension and aging. *Annual Review of Gerontology and Geriatrics, 7,* 93–115.

Miller, P. H. (2000). How best to utilize a deficiency. *Child Development, 71,* 1013–1017.

Naveh-Benjamin, M. (2000). Adult age differences in memory performance: Tests of an associative deficit hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26,* 1170–1187.

Naveh-Benjamin, M., Hussain, Z., Guez, J., & Bar-On, M. (2003). Adult age differences in episodic memory: Further support for an associative-deficit hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29,* 826–837.

Nelson, D. L., McEvoy, C. L., & Pointer, L. (2003). Spreading activation or spooky action at a distance? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29,* 42–51.

Park, D. C., & Puglisi, J. T. (1985). Older adults' memory for the color of pictures and words. *Journal of Gerontology: Psychological Science, 40,* 198–204.

Richardson, J. T. E. (1998). The availability and effectiveness of reported

mediators in associative learning: A historical review and an experimental investigation. *Psychonomic Bulletin & Review, 5,* 597–614.

Rowe, E. J., & Schnore, M. M. (1971). Item concreteness and reported strategies in paired-associate learning as a function of age. *Journal of Gerontology, 26,* 470–475.

Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review, 103,* 403–428.

Schneider, W., & Pressley, W. (1997). *Memory development between two and twenty* (2nd ed.). Mahwah, NJ: Erlbaum.

Smith, A. D., Park, D. C., Earles, J. L. K., Shaw, R. J., & Whiting, W. L. (1998). Age differences in context integration in memory. *Psychology and Aging, 31,* 21–28.

Spencer, W. D., & Raz, R. (1995). Differential effects of aging on memory for content and context: A meta-analysis. *Psychology and Aging, 10,* 527–539.

Steiger, J. H. (1990). Structural model evaluation and modification: An interval estimation approach. *Multivariate Behavioral Research, 25,* 173–180.

Treat, N. J., & Reese, H. W. (1976). Age, imagery, and pacing in paired-associate learning. *Developmental Psychology, 12,* 119–124.

van Dijk, T. A., & Kintsch, W. (1983). *Strategies of discourse comprehension.* San Diego, CA: Academic Press.

Waters, H. S. (2000). Memory strategy development: Do we need yet another deficiency? *Child Development, 71,* 1004–1012.

Yuille, J. C. (1973). A detailed examination of mediation in PA learning. *Memory & Cognition, 1,* 333–342.

Appendix

List of Pairs Presented During the Critical Study Trial

Stimulus	Response	Stimulus	Response
arm	market	diamond	umbrella
banner	nun	door	officer
barrel	star	glacier	cord
beast	fabric	grass	whale
blister	cabin	icebox	acrobat
blossom	locker	jail	coffee
bullet	yacht	lawn	book
candy	prairie	macaroni	bar
cat	jury	monarch	doll
cellar	elbow	pelt	brain
church	mammal	piston	boulder
claw	salad	rattle	board
corn	planet	slipper	dove
cotton	reptile	vest	bird
daffodil	blood	woods	chin

Received January 28, 2004
Revision received June 28, 2004
Accepted August 18, 2004 ■