

## Grant-Related Publications (from inception of project)

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## Final Report

We started this project with the explicit goal of bringing to bear new methods from experimental cognitive psychology -- in the domain of metacognition -- to understanding metacognitive development in adulthood and old age. At the time we started the project, there were a number of studies that had explored adult age differences in metacognitive monitoring, which can be defined as one's on-line assessment of the status of the cognitive system. Many more studies had evaluated age differences in beliefs about memory (e.g., Hultsch, Hertzog, & Dixon, 1987; Zelinski, Gilewski, & Anthony-Bergstone, 1990; Perlmutter, 1978), and studies had evaluated different kinds of metacognitive judgments, including list-wide predictions of performance or assessments or recently concluded performance (e.g. Bruce & Botwinick, 1982; Devolder, Brigham, & Pressley, 1990; Hertzog, Dixon, & Hultsch, 1990; Hertzog, Saylor, Fleece, & Dixon, 1994; Perlmutter, 1978; Rabinowitz, Ackerman, Hinchley, & Craik, 1982).

The 1980s and 1990s were characterized by the emergence of metacognition as a focus of study in cognitive psychology (see Dunlosky & Metcalfe, 2009; Nelson, 1996). Major progress was being made in testing alternative hypotheses about what people attended to when making metacognitive judgments (see Metcalfe & Shimamura, 1994). Cognitive psychologists like Nelson (e.g., Nelson & Narens, 1990), Metcalfe (e.g., Metcalfe, Schwartz, & Joaquim, 1993) and Koriat (e.g., Koriat, 1993, 1995) had built upon earlier experimental work (e.g., Arbuckle & Cuddy, 1967; Hart, 1967) to use metacognitive judgments for individual items or problems to assess monitoring in cognitive tasks, especially memory tasks. Nelson and Narens (1990) presented for a taxonomy of metamemory judgments, depending on when the judgments were collected (i.e., during encoding (acquisition), retention, or retrieval (test)). Different judgments, including ease-of-learning judgments, judgments of learning,

feeling-of-knowing judgments, and retrospective confidence judgments were compared and contrasted in terms of cognitive processes operating on accessible evidence as a basis for forming metacognitive judgments. Experimental psychologists had begun to converge on the argument that metacognitive judgments were based on access to different sources of information, which might be valid or invalid, regarding the state of the cognitive system. Instead of some kind of direct access to memory, for instance, people rating different items relied on observable or accessible information, ranging from observable stimulus characteristics to feelings of intuition, processing fluency, or familiarity. A critical development was that cognitive psychologists, influenced by work in judgment and decision-making, were differentiating between different kinds of accuracy of metacognitive judgments and what they might imply. There was an emerging emphasis on the importance of resolution, or relative accuracy, as the critical measure for assessing the accuracy of metacognitive judgments (Nelson, 1984, Nelson, 1996). Resolution, assessed by within-person correlations of variations in judgments with variations in memory outcomes, was seen as the critical indicator of monitoring effectiveness, because it ignored issues of how judgments were scaled and whether people were overconfident or underconfident.

In contrast, most metacognitive research with older adults at the time we began this project in 1995 had focused on questions of overconfidence. For instance, older adults mean predictions of memory performance were often higher than their actual performance, leading some researchers to argue that older adults were overconfident in their memory abilities (see Hertzog, Hulstsch, & Dixon, 1990). Newer perspectives from cognitive psychology had not had much impact on adult developmental research (see Hertzog & Hulstsch, 2000). One important exception was the feeling-of-knowing study by Butterfield, Nelson, & Peck (1988), which we discuss later. Although much of the early work on item-level judgments like judgments of learning (JOLs) or feeling-of-knowing (FOKs) had suggested little age differences in the accuracy of memory monitoring (e.g., Lachman, Lachman, & Thronesbury, 1979; Perlmutter, 1978; Rabinowitz et al., 1982), the earliest studies relied on measure of absolute accuracy, such as difference scores between mean judgments and mean recall. Few studies had evaluated measures of resolution, like the Goodman-Kruskal gamma correlation (Nelson, 1984); hence, relatively little was known about age differences in resolution. Likewise, studies of strategy use and aging rarely used item-levels strategy reports, relying instead on more global self-reports about strategies used (e.g., Camp et al., 1983; Zivian & Darjes, 1983) or contrasts between strategy instruction versus control conditions in mean performance (e.g., Sanders et al., 1980; see Kausler, 1994). Hence a major rationale for our first grant proposal was to use techniques from experimental studies of metacognition to better understand metacognitive monitoring and strategy use.

The principal investigator had begun a study of what was known as the delayed judgment of learning (JOL) effect with one postdoctoral fellow (Lisa T. Connor) when we were fortunate to welcome one of the discoverers of the delayed JOL effect, John Dunlosky, to the laboratory. Dunlosky's involvement added to the quality of the project. The empirical findings and subsequent publication of the data from this collaboration (Connor, Dunlosky, & Hertzog, 1997) and related work on age differences in metacognitive control (Dunlosky & Connor, 1997) led to the grant proposal and the subsequent award (to Hertzog and Dunlosky) that began this enterprise.

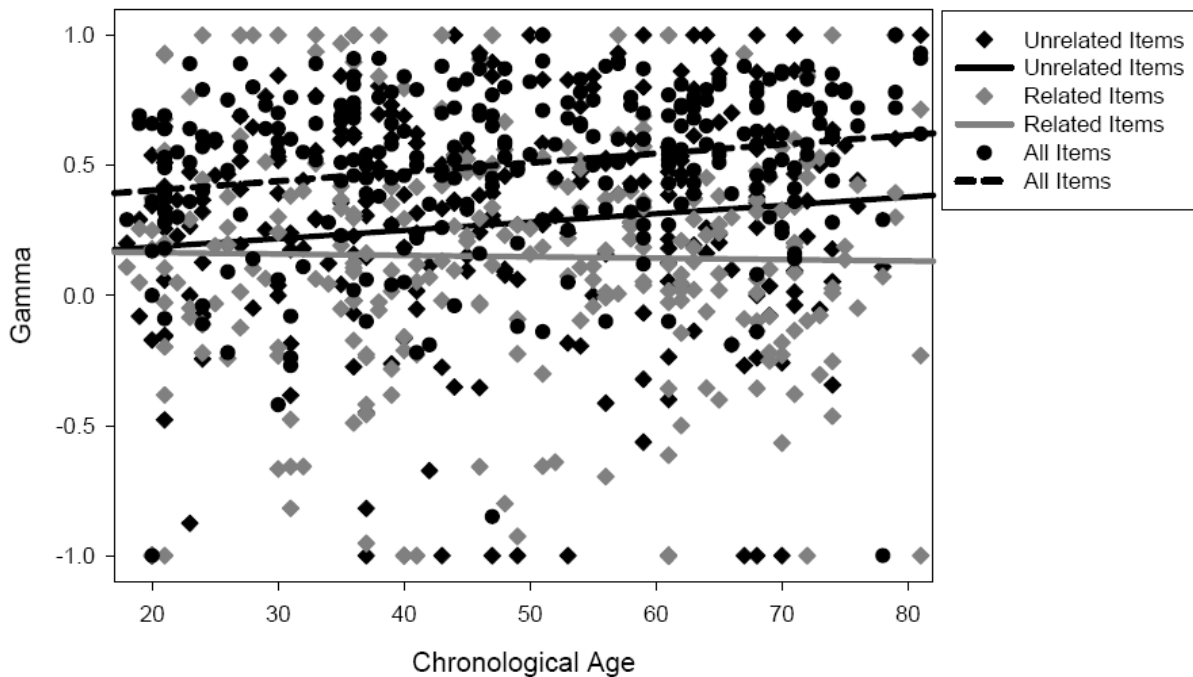
The project was intended not just to study metacognitive monitoring, as measured by JOLs and other judgments, but also to understand age differences in whether and how metacognitive monitoring contributed to cognitive control. We therefore investigated such topics as self-reported mnemonic strategy use, how people learn about strategy effectiveness, how people read text to optimize comprehension and later text memory, and control behaviors directly related to utilization of metacognitive monitoring, such as item selection and duration of item study in list-learning tasks. We also sought to provide answers to questions regarding the degree to which age-related differences in self-regulated learning contribute to age-related associative memory impairment. Our approach is to discover which components of self-regulated learning are negatively influenced by aging and which components are spared. For instance, older adults generated effective mediators during encoding when instructed to do so (evidence of sparing) but fail to consistently use these mediators at test (evidence of decline). Certainly it was the case that studies of this kind existed before our project (e.g., Murphy et al., 1981; Murphy et al., 1987), and these studies provided important insights into age differences in metacognitive control. Nevertheless, we believe the body of work described in this final report represents a coherent and compelling effort to understand aging and metacognition, in its various facets.

This final report is organized into different sections that describe the basic research questions and the provisional answers our work provides for those questions. Within each section below, we first develop (briefly) the theoretical and/or applied motivation that guides the series of experiments and tie it to what was known at the time our experiments were conducted. We also address remaining open questions the field needs to address.

### ***Age Differences in Metacognitive Monitoring***

We have used two different kinds of metacognitive judgments to study monitoring of encoding, judgments of learning (JOLs) and quality-of-encoding (QUE) ratings (Hertzog, Dunlosky, Kidder, & Robinson, 2003). JOLs ask individuals to rate their confidence in the likelihood they will later remember the item they just studied. QUEs request that individuals rate the quality of encoding of the item they just completed. JOLs may be divided into immediate JOLs – when predictions of future recall are made immediately after encoding, and delayed JOLs, when the predictions are given after some delay (ranging from a few seconds, following the study of other items, or after all items have been studied; Nelson & Dunlosky, 1991). Most of our studies have compared older and younger adults in extreme age group designs (Hertzog, 1996), evaluating whether there are age differences in metacognitive judgments and the resolution of these judgments. Several of our studies have shown that younger adults and older adults have equivalent resolution of immediate JOLs, as measured by gamma correlations of JOLs with paired-associate (PA) recall, even when the absolute accuracy of the immediate JOLs may differ between age groups (Connor et al., 1997; Dunlosky & Hertzog, 2000; Hertzog, Kidder, Powell-Moman, & Dunlosky, 2002; Hertzog, Sinclair, & Dunlosky, 2010; Robinson, Hertzog, & Dunlosky, 2006). Furthermore, experimental manipulations that influence immediate JOLs appear to have similar effects for older and younger adults. Connor et al. (1997) and Hertzog et al. (2002) found that associative relatedness (e.g., TABLE – CHAIR versus TICK – SPOON) had strong effects on both younger adults' and older adults' immediate JOLs. If anything, associative relatedness had a larger effect on older adults' JOLs, and might have even overshadowed other influences on JOLs (Hertzog et al., 2002). The fluency with which people generate mediators for associative learning has a substantial effect on young adults' JOLs (Hertzog et al., 2003). Encoding fluency (operationally defined by the latency to generate an interactive image) has similar effects on older and younger adults' JOLs (Robinson et al., 2006) even though it does not correlate with cued associative recall for concrete noun pairs. It is even the case that older and younger adults have similar reported confidence in the accuracy of their JOLs (Serra, Dunlosky, & Hertzog, 2008). Finally, it also appears that delayed-JOLs have equivalently high resolution for older and younger adults (e.g., Connor et al., 1997; Eakin & Hertzog, 2006; Dunlosky & Connor, 1997). This outcome is important for our intervention studies that are described later in this report.

In a recent study, we extended our evaluation of immediate JOL resolution to include a large cross-sectional sample of adults from ages 18 to 81 (Hertzog et al., 2010). We experimentally manipulated normative associative relatedness. Figure 1 shows the gamma correlations in the aggregate (ignoring relatedness and strategy use) and separately for related and unrelated items. There were no age declines in resolution across the adult life-span; in fact, there were reliable increases in the aggregate gamma correlations. We also used multilevel modeling to evaluate the joint effects of relatedness and strategy use on JOLs. In terms of Cohen's (1988)  $d$ , both sources of item variation had substantial effects on PA recall ( $d > 1.0$ ). However, as is often the case, JOLs were less affected by these variables than was recall, and there were no age X relatedness or age X strategy use interaction effects. Relatedness had a bigger effect on JOLs ( $d = 1.15$ ) than strategy use ( $d = 0.49$ ), large and medium effects by Cohen's benchmarks, respectively. The lack of age interactions with these effects supports the arguments that JOLs are constructed in an equivalent manner by adults of different ages.



**Figure 1, showing resolution (gamma) for persons of different ages**

What is also most impressive about the age-related sparing of JOL resolution, by and large, is that different variables that impact younger adults' JOLs and JOL resolution also influence older adults' JOLs and JOL resolution. For example, in the Hertzog, Sinclair, & Dunlosky (2010) study, we showed that associative relatedness and effective strategy use both impact JOLs and contribute to JOL resolution. However, we found no evidence of age differences in these relationships, despite considerable statistical power in our multilevel models to detect age X relatedness and age X strategy use interaction effects. Thus, this larger scale study confirms and extends our conclusion that monitoring of encoding processes remains intact across the adult life span (at least up to age 80).

There are some circumstances in which older adults manifest lower JOL resolution. Hertzog et al. (2002; Experiment 1) showed that when a discrete 6-point Likert scale format was used, and adults gave JOLs to associatively related and unrelated items, older adults had reliably lower JOL resolution for unrelated items. However, this effect disappeared when a continuous rating scale was used (0-100% confidence), suggesting that use of the discrete JOL rating scale, combined with a potent experimental variable (relatedness), not underlying metacognitive monitoring, was the culprit. Dunlosky, Kubat-Silman, and Hertzog (2003a) found that older adults had lower resolution for quality-of-encoding judgments (which are similar to JOLs) for related paired-associate items. More recently, Daniels, Hertzog, and Toth (2009) found that older adults had lower JOL resolution for predicting yes/no recognition memory for those items rated as recollections in a Remember/Know judgment that followed the item recognition test. This outcome may reflect age deficits in recollection instead of age deficits in the monitoring of learning. That is, younger adults experience a higher proportion of recollected items than older adults, and factors that operate to reduce recollection and increase familiarity in older adults could affect the correlation of JOLs to recollection outcomes, even when JOLs for younger and older adults are based on the same evidence at the time of encoding. Along these lines, Eakin and Hertzog (2010) found that immediate JOLs were not sensitive to associative set size, in contrast to delayed-JOLs and FOKs, which are arguably more aligned with accessibility of information during a retrieval attempt. So immediate JOLs in the Daniels et al. (2009) study may have been based upon the same kinds of cues for both older and younger adults, but nevertheless differed in their predictive validity for recognition because of age differences in the likelihood of a recollective

experience during yes/no recognition. Such findings are interesting and potentially important, but they do not detract from the larger message that monitoring of encoding processes is spared by the aging process.

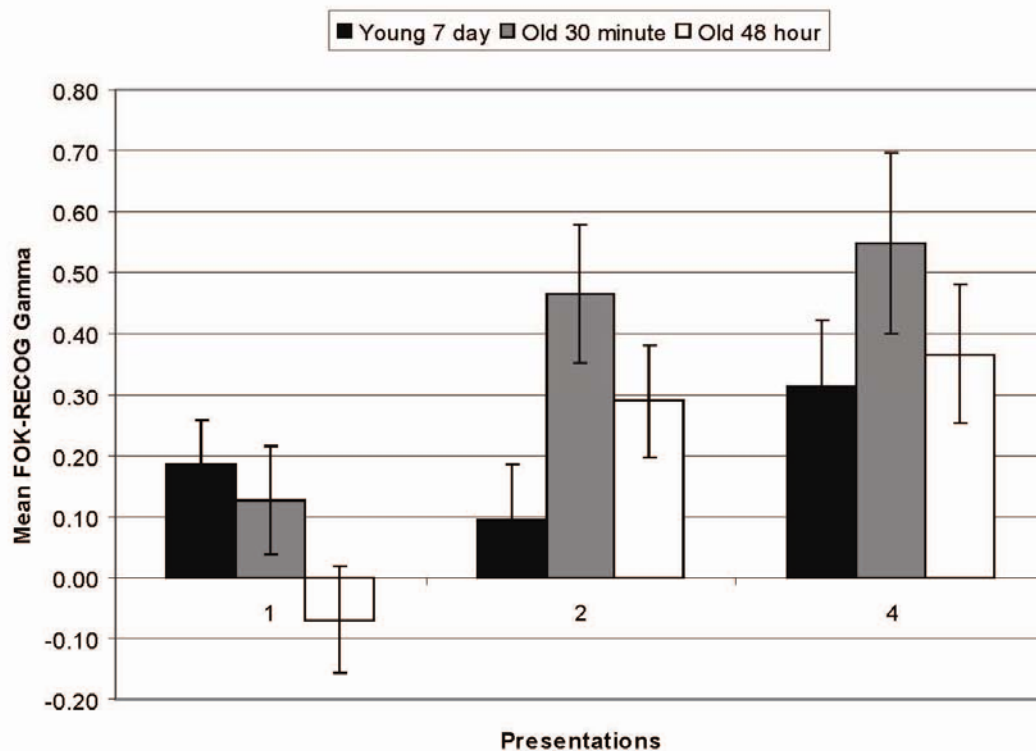
### **Effects of Aging on Episodic FOK Accuracy**

As noted earlier, recent work by Souchay and colleagues (e.g., Souchay et al., 2007) argues for a deficit in the resolution (relative accuracy) of episodic FOKs but not semantic FOKs. Deficient FOKs could have major implications for the self-regulation of recall (Koriat & Goldsmith, 1996). Kelley and Sahakyan (2003) demonstrated that older adults' miscalibrated confidence judgments (CJs) after a memory test were associated with impaired regulation of recall (see also Pansky, Goldsmith, Koriat, & Pearlman-Avni, 2009). Hence, impaired episodic FOKs could represent a source of poor self-regulation during memory tests. However, we have been unable to replicate the age-related episodic FOK deficit in our laboratory using standard PA lists. In a first study (MacLaverly & Hertzog, 2009), we manipulated the timing of FOK judgments and the timing of the recognition test. FOKs were collected either immediately after each item's recall test or with a delay, where FOKs were collected in a randomly ordered block following the completion of PA recall testing. Delaying JOLs improves their resolution (e.g., Nelson & Dunlosky, 1991). We expected the opposite effect might be observed for delayed FOKs. Our rationale was that delayed FOKs might produce a larger age deficit because older adults would not spontaneously engage in exhaustive retrieval search for the target before making the FOK, perhaps relying on inaccurate fast FOKs instead (Koriat & Levy-Sadot, 2001). Instead, we found age equivalence in the gamma correlations of FOKs with recognition tests for all items and for unrecalled items only, irrespective of the delay. FOK correlations with unrecalled items are typically emphasized, even though FOKs are collected for all cues, so as to determine whether people can forecast recognition of items they cannot recall. Souchay and colleagues find lower gamma correlations for older adults; we did not. MacLaverly and Hertzog (2009) also collected Remember/Know (RK) judgments after the four-alternative forced choice (4AFC) associative recognition test for each item. FOKs for unrecalled items reliably correlated with RK judgments, such that items given higher FOKs were more likely to be rated as having recollective experiences at the time of the recognition test (Hicks & Marsh, 2002). Importantly, our young and old adults produced equivalent correlations of FOKs with RK judgments, adding further support to the conclusion that older adults are not deficient in episodic FOK accuracy.

We were interested in testing the hypothesis that episodic FOK differences, when they occur, might be a consequence of the degree of underlying memory quality rather than a deficit in metacognitive monitoring per se (see Dunlosky & Metcalfe, 2009). That is, findings that older adults are deficient in episodic FOK accuracy might indicate that they have lower levels of underlying memory strength, and hence simply have less available information in memory that could be accessed for the purpose of making FOKs. Leading current theories of FOK accuracy argue for two kinds of cues, or types of information, that people access. They cannot have any kind of direct access to memory independent of the memory retrieval process, but (1) the cue can activate recognition processes that generate degrees of cue familiarity which may be diagnostic of subsequent recognition, and (2) the cue can trigger access to retrieval products, whether or not they derive from the searched-for target. In particular, if individuals can access contextual detail about the encoding experience or information about the target despite the inability to correctly recall it, they may make higher FOKs. To the extent that memory strength as a whole is low, the probability of accessing such information about the target may be reduced, causing FOKs to be based on less diagnostic cue familiarity effects.

To investigate this hypothesis, we (Hertzog, Dunlosky, & Sinclair, 2010) used a within-subjects manipulation of number of presentations within the study phase. The manipulation was inspired by early work by Nelson and colleagues (Carroll & Nelson, 1993; Nelson et al., 1982) that examined FOK accuracy after varying degrees of overlearning. In our study, items were presented once, twice, or four times within the single study period. Individuals were instructed to produce interactive imagery mediators and reported their success at doing so. Because repetition is a powerful enhancer of memory, it was necessary to delay recall and recognition tests to avoid ceiling effects for repeated items. We imposed different delays on young and old adults to equate performance on the recall and recognition tests. On the basis of pilot data, we tested two groups of older adults with a 30 minute delay and a 48-hour delay, and younger adults (university students) with a 7-day delay; performance on the latter two groups was similar, whereas older adults with a 30-minute delay had the best overall memory performance. Repeated presentations resulted in higher FOK resolution for both older adults and

younger adults, although the reliable age X repetition interaction showed the benefit was larger for older adults. There was no overall age difference between the young adults and the older adults tested with a 48 hour delay (see Figure 2). Older adults with an immediate test had the best recall performance and higher FOK resolution, underscoring the possible role of level memory in influencing episodic FOK accuracy. We also collected recognition test CJs. Both young and older adults showed reliable correlations of CJs with FOKs for unrecalled items, even when restricted to analyzing correct recognition responses only. This evidence suggests that FOKs for unrecalled items are based on sources of information correlated with memory strength below the recall threshold that later manifests as degree of confidence in the accuracy of the recognition memory response.



**Figure 2. Resolution of FOKs with 4AFC recognition accuracy for unrecalled items in Hertzog, Dunlosky, and Sinclair, 2010. Resolution increases as a function of the number of item presentations, without evidence of age-related impairments in resolution.**

This experiment supports the hypothesis that level of underlying memory strength influences episodic FOK accuracy. We do not believe that older adults with higher memory performance (those given a 30 min. delay) have superior FOK monitoring skills. Rather, their superior memory performance, given the shorter delay, produces more information that can be used for generating accurate FOKs. Moreover, this study is the first to show that an experimental manipulation that affects younger adults' FOK magnitude and resolution has similar effects in older adults. In both age groups, rich encoding experiences produce more diagnostic cues about the new association that is, in effect, below the recall threshold, and that can be accessed to produce more accurate FOKs. This outcome suggests that, when episodic FOK deficits are found for older adults, they could well be an artifact of older adults having lower levels of memory performance. In short, our data do not support the hypothesis of a frontally-mediated inferential deficit on the part of older adults, but rather indicate that episodic FOKs may be less accurate because of constraints on older adults' memory generated by typical designs, with equivalent conditions for old and young generating poorer memory performance for older adults. Semantic FOKs – in which people rate the likelihood of recognizing facts or information they may know but cannot recall (e.g., Who was the vice president of the United States under Dwight D. Eisenhower?) – would not be affected because older adults often have high levels of recall and also because individuals can rely on information that is not likely

to be accessed for episodic FOKs, such as familiarity with the specific knowledge domain, or partial information about related knowledge that could be diagnostic of the probability of recognizing the correct answer.

In sum, our work with metacognitive judgments suggests that elementary forms of memory monitoring are by and large spared by aging. Although there are important boundary constraints on this inference, we believe that many of those constraints are often a consequence of age differences in memory processes rather than metamemory processes. One important exception may be CJs for yes/no recognition tests, where older adults appear to be more likely to produce high-confidence false alarms (e.g., Dodson et al., 2007; Shing et al., 2009). Older adults also manifest lower resolution of CJs in a yes-no associative recognition task based on incidental learning of new associations (Hertzog & Touron, in press). However, CJs after forced-choice recognition tests do not manifest this type of distortion (Hines, Touron, & Hertzog, 2009). This effect may be due to increased reliance on familiarity processes in recognition memory, or it could represent a more active form of misrecollection (Dodson et al., 2007).

The relative age-related sparing of the accuracy of JOLs and FOKs is potentially important for shaping older adults' self-regulatory behavior in memory-demanding tasks, and forms the basis for the metacognitive intervention experiments we report below. Understanding the conditions under which monitoring of recognition memory outcomes (as reflected in CJs) is impaired in older adults may also suggest ways in which this kind of monitoring can be improved. Certainly, training people to differentiate recollection from familiarity experiences during recognition has been shown to enhance older adults' ability to resist responding to incorrect lures (e.g., Jennings & Jacoby, 2003). It may also influence their monitoring accuracy.

### **Aging and Metacomprehension of Text**

Our research on monitoring of encoding while learning simple materials (e.g., paired associates) demonstrated that older adults are not deficient in this important metacognitive ability. An issue arises, however, as to whether older adults will begin to show monitoring deficits when focal processing becomes more complex, such as when people are reading text materials and evaluating how well they have learned. To address this issue, we conducted a series of experiments that evaluated whether age-related deficits occurred in metacomprehension accuracy. In our first experiments (Dunlosky, Baker, Rawson, & Hertzog, 2006), we used a standard method to estimate the accuracy of people's metacomprehension judgments: Participants read a series of texts, and after reading each one, they judged how well they would perform on a test that covered the material in the text. Participants were then tested over the materials, and accuracy was measured as the correlation between each participant's judgments and performance across the texts. In two studies, accuracy did not differ for older and younger adults! Moreover, we also investigated *how* people made these judgments by evaluating the ease-of-processing hypothesis, which states that people's judgments are influenced by how easy a text is to read, regardless of whether ease is related to actual comprehension. Both older and younger adults appeared to be basing their judgments on the ease of processing, and as important, this reliance on ease of processing as a cue for metacomprehension limited the accuracy of the judgments. In particular, although age equivalence arose in judgment accuracy, the level of accuracy for both groups was relatively low (e.g., all correlations were around .20).

Although the lack of age differences in metacomprehension accuracy is encouraging, the overall low levels of accuracy were quite discouraging. The near floor levels of accuracy could be masking age effects that could arise when judgment accuracy is higher. Low accuracy also raises the issue as to whether metacomprehension processes could be used to control and guide comprehension. If people cannot achieve relatively high levels of judgment accuracy, they will have difficulties in efficiently controlling their learning of new text materials. In this case, they may spend too much time studying materials that they judged as not well learned (but that were), and even worse, not spend enough time studying materials that they judged as well learned (but that have not yet been learned). Accordingly, in a follow-up study (Baker, Dunlosky, & Hertzog, 2010), we investigated the degree to which *term-specific* judgments could boost people's accuracy. Standard metacomprehension judgments are made at the level of an entire text passage (as above, in Dunlosky et al., 2006); so, a person may read a long text and then make a single judgment that is supposed to reflect how well they have learned it. As argued by Dunlosky, Rawson, and Middleton (2005), these standard *global* judgments may limit accuracy artifactually, because the grain size of the judgment (one judgment for a lengthy text) does

not match the grain size of the test (i.e., multiple questions about specific concepts in the text). By contrast, term-specific judgments require people to judge how well they have learned specific (and the most important) concepts in a text, which subsequently appear on the criterion test. For instance, in a long text on measurement theory, two concepts may be “ordinal and nominal measurement”. Participants would be asked to judge how well they have learned each concept, and then would later be tested on their learning of them. As expected, these term-specific judgments were dramatically more accurate, with the mean correlations between term-specific judgments and test performance nearly reaching +.70! Moreover, Baker et al. (2010) found that older adults were just as good as younger adults at making these term-specific judgments. Such high levels of accuracy could support the efficient control of learning important concepts in text materials (see, e.g., Lipko et al., 2009), although this prediction has yet to be empirically evaluated.

### **Do Age Deficits Occur in Strategy Production During Encoding?**

It is well known that use of mediational strategies such as interactive imagery have major benefits for associative learning (Richardson, 1998). Our early collaborative work developed a simple but effective method of querying PA strategies at the item level; as with many methodological innovations, this research has had an impact on the field (Dunlosky & Hertzog, 1998a, 2001; Dunlosky, Hertzog, & Powell-Moman, 2005). Hertzog, Dunlosky, and Robinson (2009) used these item-level retrospective reports to evaluate age differences in spontaneous (uninstructed) use of strategies for paired-associate (PA) recall and free recall in a large cross-sectional sample of adults. Use of effective strategies was reliably correlated with both types of recall; indeed, about half the variance in PA recall was accounted for by the use of effective strategies. Individuals who used effective strategies in one memory task tended to use them in the other, a finding replicated by Bailey, Dunlosky, and Hertzog (2009) when studying episodic memory task strategies and working memory task strategies in the same sample. Abilities predicted strategy use, as did memory self-efficacy, a belief in personal control over memory, and knowledge about strategy effectiveness. In Hertzog et al. (2009), older adults were no less likely to use effective strategies spontaneously. Hertzog, Jopp and Dunlosky (in progress) ran a replication study of Hertzog et al. (2009) as part of a larger project, using identical procedures and measures. The patterns of individual differences predicting strategy use replicated, but there was a small age-related PA strategy production deficiency, consistent with earlier studies by Dunlosky and Hertzog (2001) and Hertzog, McGuire, & Lineweaver (1998). Hence, our multiple studies of strategy production in memory tasks leads to the following conclusions: (1) there is no major age-related strategy production deficit in episodic and working memory tasks; (2) individuals who spontaneously use effective strategies tend to use effective strategies in other memory tasks, but to some degree strategy use is task-specific (Bailey et al., 2009); (3) abilities, knowledge, and beliefs about one’s own memory control independently influence strategy use, and (4) it is not the case that age differences in the production of effective strategies play a major role in influencing age differences in associative learning, contrary to earlier conclusions (see Kausler, 1994).

Our newer studies have extended the self-report methodology to gain more information about mediator production and mediator access at the time of the memory test. Dunlosky et al. (2005) used a mediator report and retrieval method (extending a procedure from Yuille, 1973) to evaluate whether older adults have access at test to high-quality mediators they generated at study. After instructions to create images or sentences at study, individuals describe the mediator they produced. They are then asked to retrieve and report the mediator immediately after the recall test for each item. Transcripts are coded with respect to different types of mediator retrieval (e.g., gist or verbatim mediator recall, partial mediator recall). Older adults showed high rates of omission errors for mediators, being less able to retrieve mediators at test. These omission errors accounted for most of the age-related variance in PA recall. Other age effects also emerged. Older adults were more likely to incorrectly decode a successfully retrieved mediator to recover the target word (an inferential deficit at test). They were also less likely to retrieve the target after an unsuccessful attempt to generate a mediator, suggesting a binding deficit after nonspecific elaborative encoding (consistent with levels-of-processing research – Craik, 2002). However, we found no age differences in the coded quality of mediators produced at study. A recent study (Hertzog, Robinson, Mandivwala, Fulton, & Dunlosky, in progress) replicated and extended these findings using both concrete and abstract paired associates. As expected, mediator forgetting was greater for abstract items, as was the aged-related effect on mediator decoding. However, informal experimenter reports (validated

by transcript coding) noted occasional spontaneous recovery of targets when older individuals retrieved mediators, consistent with a retrieval strategy deficit. Surprisingly, even after explicit instructions to generate mediators during study, older adults may not spontaneously attempt to retrieve mediators while attempting to recover targets. On the whole, the evidence we have collected suggests that a combination of (1) binding and/or retrieval deficits, and (2) effective use of retrieval strategies account for most of the age-related variance in associative learning.

### **Knowledge Updating from Task Experience**

Knowledge about whether an encoding strategy is potentially useful in a given cognitive task is an important component of strategic self-regulation. An important question is whether older adults can learn from task experience about which strategies are effective in that task context. Dunlosky and Hertzog (2000) evaluated strategy knowledge updating in the paired-associate learning environment. Individuals were instructed to use an effective strategy (interactive imagery) or an ineffective strategy (rote repetition). People were given two different lists of PA items. Dunlosky and Hertzog (2000) then observed whether various metacognitive judgments about the performance with each strategy changed for a second list of items after experiencing recall performance using the two strategies on a first list of items. We found that both younger and older adults showed similar knowledge updating, as manifested in postdictions for imagery items and rote items. However, neither group showed knowledge updating on JOLs. Despite a substantial recall advantage for imagery, neither older nor younger adults mean JOLs changed appreciably to reflect the imagery-advantage in recall. In a subsequent experiment, Hertzog et al. (2009) showed that questionnaire ratings of strategy effectiveness were a better indicator of knowledge updating than either JOLs or postdictions, while also demonstrating that noncompliance with instructions (e.g., use of imagery when instructed to use repetition) could not account for the lack of updating. However, much more substantial knowledge updating occurred when test items were blocked (aggregated) into groups based on reported strategy used at encoding. That is, presenting people with small blocks of trials studied only with imagery (or with repetition) resulting in much greater knowledge updating effects. This outcome suggested that the relative lack of knowledge updating might be due to poor retention of strategy use-test result outcomes across a long list of items.

Price, Hertzog, and Dunlosky (2008) evaluated knowledge updating in younger and older adults using the blocked-testing manipulation. Younger adults showed larger benefits of blocked testing for knowledge about imagery effectiveness, as manifested in both strategy effectiveness ratings (see Figure 3) and postdictions. Older adults did learn, on average, that imagery was more effective, but the effect was attenuated relative to younger adults. In a subsequent study, Hertzog, Price, and Dunlosky (in press) showed that these knowledge updating differences had some impact on subsequent study behavior. Older and younger individuals were assigned to supervised learning (instructed imagery or rote repetition use, as in our earlier knowledge updating studies) or unsupervised learning (where people were free to use any encoding strategy they wished). On the second list, people in the supervised learning condition were encouraged to use any strategy they wished. The hypothesis was that structured experience of the effectiveness of the imagery strategy would lead to increased use of that strategy. There were few age differences in strategy use in the unsupervised condition, where people tended to use the same strategies on the second list that they had used on the first list. After structured experience with the two strategies, older adults were less likely to shift to imagery use, being more likely to continue using the rote repetition strategy. This tendency produced small but reliable age differences in improved recall on the second list. Apparently, the age difference in knowledge updating in this task environment does have some consequences for later strategy use and recall outcomes.

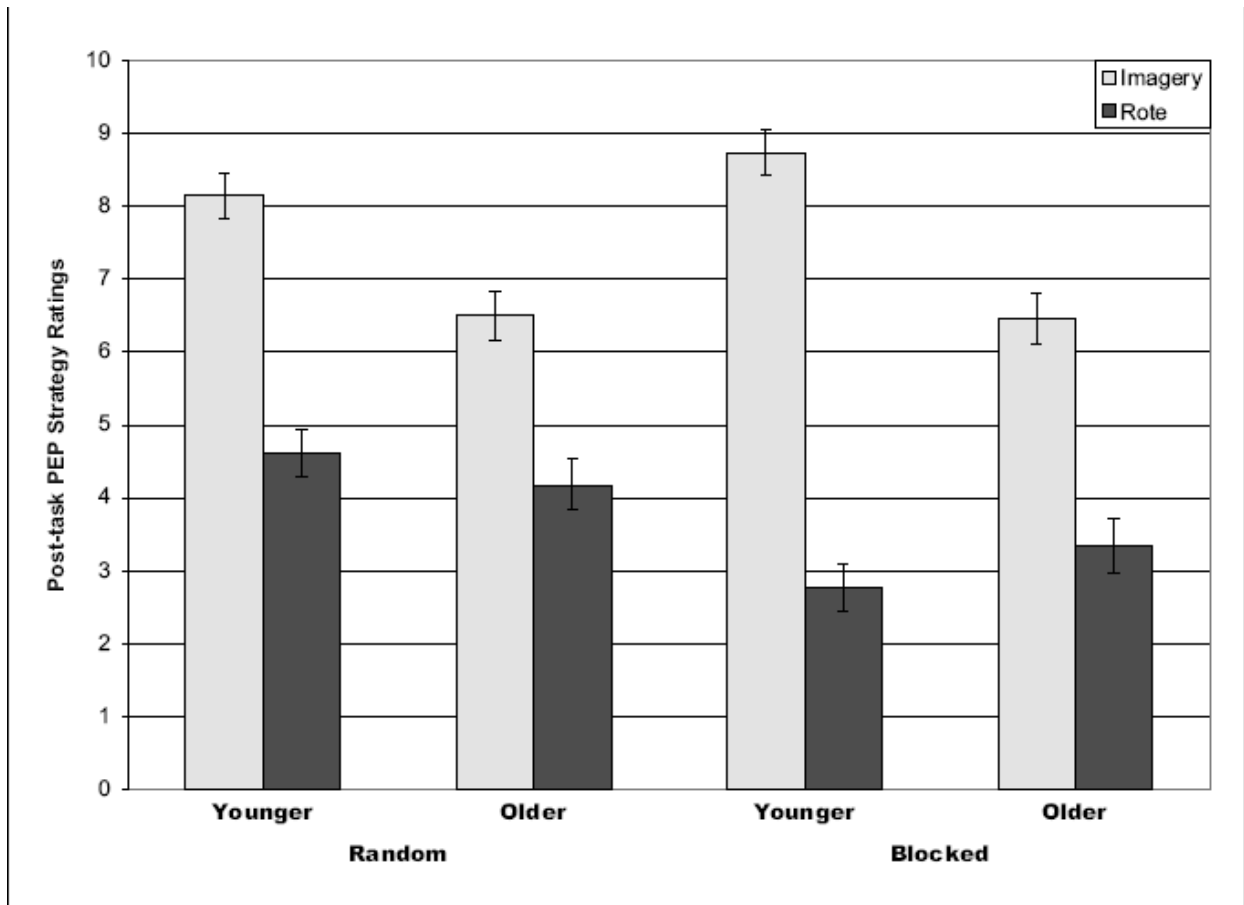


Figure 3. Strategy Effectiveness ratings for younger and older adults after task practice from Price et al. (2008). Imagery is rated as the better encoding strategy by young and older adults, but younger adults show a larger separation of ratings and a larger effect of blocked testing.

### Metacognition-Based Cognitive Control

As noted earlier, we have found that elementary forms of metacognitive monitoring, as manifested by JOLs and FOKs, are largely spared by the aging process. An interesting question, then, is whether there are age differences in the use of metacognitive monitoring to promote effective learning. The picture is mixed. In an early study, Dunlosky and Hertzog (1997) borrowed a paradigm from Nelson et al. (1994) to study how people select items for re-study in a multiple-trial associative learning task. Individuals made delayed JOLs while studying PA items, and then performed on a standard recall test. On a second study-trial, they were allowed to choose a subset of items for restudy. The question is whether older adults would choose to study items they had not recalled (or that had produced lower delayed-JOLs during initial study). Indeed, both age groups were likely to choose items they had not recalled or had given low delayed-JOLs for, consistent with the discrepancy-reduction model of self-regulation (Dunlosky & Hertzog, 1998b). A few older adults showed the tendency to restudy items they had previously learned. Such a pattern might indicate lower confidence in the ability to recall those items without additional rehearsal, which could also represent an adaptive strategy when the level of learning is intermediate (Pyc & Rawson, 2009).

Another way of measuring metacognitive control is to determine whether individuals allocate more time to study items they had not previously learned. Dunlosky and Connor (1997) showed that older adults did not show as clean a pattern of allocating more time to previously unlearned items as did younger adults. The correlations of study time with prior item recall or with prior delayed JOLs was lower for older adults. Again, this pattern could reflect deficient metacognitive control, or it could also reflect the emergence of a maintenance rehearsal strategy in older adults that is less common in younger adults. In an associative recognition paradigm, Hines,

Touron, and Hertzog (2009) found no age differences in study-time allocation on a second study opportunity. It is at present unclear as to whether there are age differences in effective metacognitive control. Given that other research shows that item selection and study time behavior are influenced by multiple factors, including performance goals (e.g., Ariel, Dunlosky, & Bailey, 2009; Thiede & Dunlosky, 1999), further research to disentangle the causes of any age differences in metacognitive control is needed.

Metcalf and colleagues (e.g., Metcalfe & Kornell, 2005) have argued that the discrepancy-reduction model for metacognitive control does not apply to learning situations where the to-be-learned information is graded in difficulty of learning. Whereas the discrepancy reduction model argues simply that people will prefer to study items they have not learned, Metcalfe argues instead for a region of proximal learning (RPL) hypothesis, which states that people will prefer to study and learn items that are just-noticeably-more-difficult than items they have already learned. That is, if they have mastered easy items they will next prefer to study items of moderate difficulty rather than items of high difficulty. This hypothesis is better suited to materials that are graded in difficulty (e.g., foreign language vocabulary) than items that are of relatively homogeneous difficulty (e.g., unrelated, concrete paired associates).

Price, Hertzog, and Dunlosky (2010) evaluated the RPL effect, using a procedure borrowed from Metcalfe. Spanish language vocabulary items that had been previously normed to be easy, medium, or difficult, were displayed in a 3 X 3 grid on the computer screen. The Spanish words were displayed, and participants could view the English translation by clicking on the Spanish word with the mouse. Consistent with Metcalfe's earlier work, the columns of the grids were known to contain easy words in the left-hand column, medium difficulty words in the middle column, and difficult words in the right-hand column. Price et al. measured the order in which items were selected for study and restudy, as well as the time allocated to item study. Both age groups tended to show RPL-like effects, preferring to study moderate-difficulty items before high-difficulty items. However, older adults manifested a mild tendency to avoid difficult items at later study opportunities, and this tendency was correlated with their rated memory self-efficacy. That is, older adults with lower rated memory ability were the most likely to avoid the difficult items. Thus, the data suggested relative similarity of item selection strategies, modified in the older adults by the tendency for low memory self-efficacy to produce less than optimal study behaviors.

An important metacognitively based strategy for learning is the use of self-testing. Earlier work by Murphy et al. (1987) showed that older adults were less likely to use self-testing as a spontaneous method for assessing that they had learned information sufficiently to be tested on it. In contrast, a recent study by Bailey, Dunlosky, and Hertzog (2010) found that older adults spontaneously used self-testing when presented with paired-associate items on flash cards. This led us to hypothesize that the nature of the materials might have an influence on spontaneous strategy use, with materials that provide a natural affordance for strategy implementation being more likely to elicit self-testing in older adults. We tested this hypothesis in a recent study (Bottiroli et al., 2010) that provided materials on either (1) a large display board (where self-testing would have to be an internally generated mnemonic) or (2) separate cards containing one word on one side and its associated word on the other side. This format is commonly known as flash cards, and people may have already used self-testing with flash cards in educational contexts to learn definitions or foreign language vocabulary. The separate-card format make it simple to implement the strategy. As hypothesized, Bottiroli et al. (2010) found preserved use of the self-testing strategy with the separate card format, but impaired spontaneous use of self-testing when pairs were presented on a mounted board. These results should remind us that it is important to test hypotheses about self-regulatory behavior in multiple task domains, and with explicit attention to the process by which a self-regulatory behavior would be implemented in different task contexts.

In sum, less is known about age differences in metacognitively guided control than in metacognitive monitoring. A preliminary inference, however, is that monitoring is relatively well preserved in old age but that older adults' metacognitively guided control is sometimes deficient. This pattern suggests that interventions that train the use of monitoring to enhance control over learning could have substantial benefits for older adults.

### **Do Interventions Based on Self-regulation Training Enhance Older Adults' Learning?**

In our first metacognitive intervention study, we demonstrated how self-regulation training can improve older adults' self-regulated learning (Dunlosky, Kubat-Silman, & Hertzog, 2003b). We trained older adults to

monitor their learning via self-testing, and then to use this monitoring to focus restudy on unlearned items. We showed that self-testing training produces reliably better performance improvements than more traditional memory encoding strategy training, but only when the adults were allowed to self-pace and self-select item study, which is a requirement for the best implementation of self-testing procedures. Subsequently we explored conditions under which this intervention is more or less effective (Dunlosky et al., 2007). Perhaps most important, we have also demonstrated that this intervention program is just as effective when administered using an at-home training manual (Bailey, Dunlosky, & Hertzog, 2010) as opposed to training in the laboratory. Such an outcome is important because it suggests that in-home training, when supported by contact with individuals in their home, can be effective, which broadens the scope of possibilities for the training intervention.

Nevertheless, consistent with other memory intervention programs, the effects of self-regulation training in our labs initially showed minimal transfer to non-trained tasks. A broad generalization of training to new performance contexts is an important goal of self-regulation training; in theory, one of the strengths of training people to be adaptive and selective in strategy implementation is that these kinds of self-regulation strategies might have broader transfer than training task-specific strategies alone. Given that transfer of training is highly valued, we have begun examining two techniques to promote transfer of self-testing procedures to untrained tasks. First, in some training groups, we explicitly discuss how the trained metacognitive strategies such as self-testing could be used to help trainees perform well on a different task. They do not practice applying the strategy to the new task, but just engage in a conversation with the trainer about how the metacognitive approach could be generalized to other tasks. These explicit *transfer instructions* apparently do help. In one study (Cavallini et al., in press), older adults were trained to use imagery and sentence generation to learn paired associates. Some participants also received transfer instructions in that they discussed how these strategies could be applied to a new task (i.e., learning a grocery list). The group who received these transfer instructions showed transfer to text learning – a task that they had never practiced or discussed during training. We recently replicated this transfer effect in an experiment that is just now being written up for publication.

Our second approach to promoting transfer is arguably even more innovative, and preliminary results suggest that it promotes transfer widely. This intervention involves training older adults to analyze memory tasks to determine how they can apply relational and item-specific process to the materials, so as to boost memory performance. Our first study (Bottiroli, Dunlosky, Cavalini, & Hertzog, in preparation) compared the influence of this task-analysis training to a standard strategy intervention and to a no-contact control group. Training involved practicing the techniques on paired associates and word lists, and criterion tasks included never-before-seen transfer tasks. In contrast to the control group, both training groups showed improved performance on the tasks practiced during training (i.e., paired associates and word lists). Most important, the control group and standard strategy group showed no transfer of training, whereas performance on the two pure transfer tasks (face-name learning and grocery-list learning) showed significant and large (15% on average) increases after training! One implication of these transfer effects is astounding. Namely, older adults may be able to learn to apply a few simple principles in order to construct a personally relevant strategy for any new memory task. This approach dramatically contrasts the standard approach in which older adults must learn a new mnemonic for every task – a daunting memory burden in its own right.

These outcomes suggest that the lack of transfer in previous studies does not necessarily arise from older adults' inability to generalize strategies to new task contexts, but instead because older adults may not realize that adapting trained strategies to new contexts requires a process of task evaluation to determine how and whether the strategy can be applied to new materials. It is well known in the training literature that transfer of trained cognitive skills is limited, although recent work suggests that training executive and attentional control processes may provide broader transfer than training specific cognitive skills (such as memory encoding strategies; see Lovden et al., 2010). Our current work adds to this approach by arguing that encouraging people to explicitly evaluate what strategies might be appropriate in a task context may enable them to adapt strategies to fit the new task environment. This kind of metacognitive self-regulation training could, if properly implemented, create the desired breadth of transfer. If these transfer effects are replicated (and extended) in a larger scale study, this task-analysis intervention could provide a substantial reward for our aging population and a new direction for training research. In a recent book chapter (Dunlosky, Bailey, & Hertzog, in press), we speculate how these approaches can also be combined with simple but effective

techniques for enhancing remembering such as active noticing (intentional allocation of attention), mindfulness, and spaced retrieval to create habits of mind or styles of engaging the world that may substantially benefit older adults' remembering in everyday life, not just in laboratory task environments.

## **Conclusions**

In many respects, the goals we set at the outset of this grant have been realized. We succeeded in promoting the use of techniques developed by cognitive psychologists to study adult metacognitive development, and have generated a large number of studies that have evaluated age differences in metacognitive monitoring and control. In 1998, we (Dunlosky & Hertzog, 1998b) proposed a framework for self-regulated learning that fundamentally guided our exploration of aging, metacognition, and cognition. This framework was updated in a subsequent publication (Hertzog & Dunlosky, 2004). This framework is shown in Figure 4. It assumes that background factors operate before one starts to learn material, and that metacognitive processes during study and test are involved in processes such as strategy selection, strategy production, and monitoring performance outcomes. We have systematically explored whether aging in adulthood influences almost every component of this framework and the degree to which such effects may contribute to concomitant deficits in cognition.

**Figure 4. Processing Flow Diagram For Metacognitive Control and Knowledge Updating Based on Strategic Behavior and Metacognitive Monitoring during Study and Test in Multi-trial Learning Tasks. (From Hertzog & Dunlosky, 2004).**

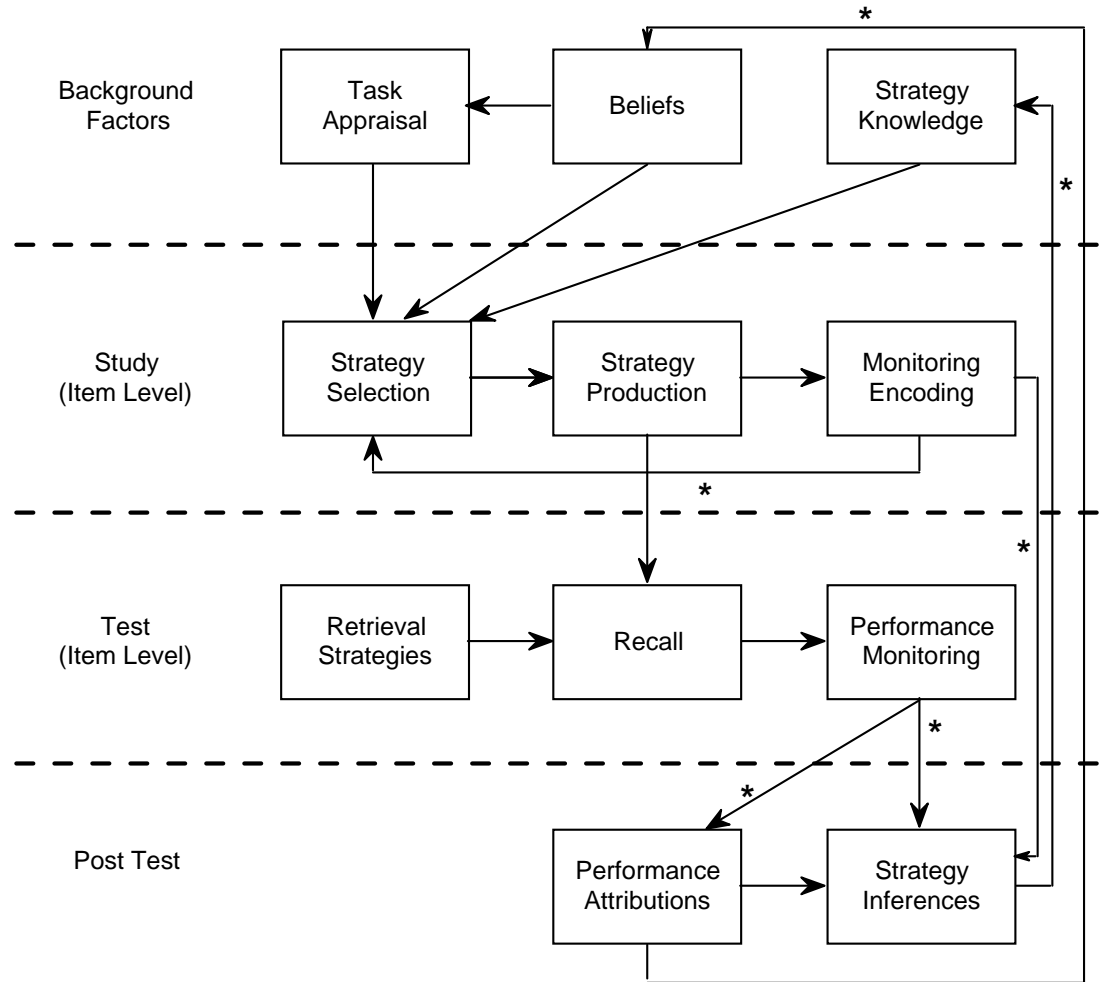


Figure 1

This body of work has led to a number of robust findings and conclusions about aging that has implications for theory as well as for how older adults may compensate for any deficits. In summary, our main

findings (largely working from the top of the framework downward) and conclusions include: (1) although older adults do show some deficits in strategy knowledge, with task experience using strategies, they can learn about the differential effectiveness of these strategies (see under, Background Factors); (2) even though older adults do learn about effective strategies (through performance feedback with task experience), they do not use this knowledge as much as younger adults when learning new materials (“Strategy Selection” at the “Study – Item level”; Hertzog et al., in press), which suggests that control processes in part contribute to older adults’ deficits in memory performance; (3) consistent with the above, older adults do show strategy production deficiencies that can contribute to their deficits in performance, although these deficits are relatively minor (Dunlosky & Hertzog, 2001); (4) accordingly, training older adults to use effective strategies is an effective means to boost their learning, which highlights the plasticity of memory performance in aging (e.g., Cavallini et al., in press); (5) older adults show minimal-to-no deficits in monitoring encoding (“Study – Item level), and when trained (in the laboratory or with an at home manual), they can use their intact monitoring skills to improve their self-regulated learning; (6) older adults’ performance monitoring (Test – Item level) also largely remains intact (Hertzog et al., 2010), suggesting a new kind of intervention aimed at helping older adults use their performance monitoring to more effectively guide retrieval; and finally, (7) new training programs aimed at teaching older adults how to use and adapt memory strategies in general show promise for producing transfer across many memory tasks.

Given these advances, our body of funded research – including 38 peer-reviewed articles and 17 chapters to date (and still counting) – is having and will continue to have a meaningful impact on aging research. In particular, we hope this body of research will foster enthusiasm for developing and evaluating the efficacy of metacognitive-based interventions to improve older adults’ cognitive functioning. Our latest training effort, which includes teaching task analysis, holds tremendous promise for helping older adults to become efficient and effective self-regulated learners. We suspect that further research to finalize this translational research will yield significant rewards for improving the metacognitive and cognitive fitness of the aging population.

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