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Age-related Decline in Associative Memory: Understanding the Roles of Controlled and Automatic Processes

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1. INTRODUCTION

A substantial volume of past research has demonstrated that memory capabilities decline in old age (e.g., see Craik & Jennings, 1992; Hoyer & Verhaeghen, 2006; Zacks, Hasher, & Li, 2000, for reviews). This decline is highly noticeable based on tasks assessing episodic memory, which require remembering information about events at specific times and places (e.g., Craik & Jennings, 1992; Naveh-Benjamin & Old, 2008; Zacks et al., 2000). The exact cognitive mechanism that accounted for this prominent age-related decline in episodic memory has not been well-understood, and the multitude of mechanisms that were proposed have drawn a credible amount of research and discussions (for reviews, see Light, 1991; Salthouse, 1991; Hoyer & Verhaeghen, 2006).

With an intention to provide a more valid account of this exceptional age-related deficit, this review focuses on an associative-binding hypothesis that was suggested to form the basis of age-related declines in episodic memories. According to the associative deficit hypothesis (ADH) (Naveh-Benjamin, 2000; see also Bayen, Phelps, & Spaniol, 2000; Chalfonte & Johnson, 1996; Naveh-Benjamin, Hussain, Guez, & Bar-On, 2003), older adults' poorer episodic memory is attributed to the difficulties they experience in formulating relations or links between single units of information, binding them together into a coherent distinctive unit, and retrieving the links between the component features/units whenever necessary. A coherent

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1 distinct unit is generally regarded to comprise of two units of information, either of
2 which can manifest itself in the form of items (e.g., words, faces, pictures; see
3 Naveh-Benjamin, 2000; Naveh-Benjamin et al., 2003; Naveh-Benjamin, Guez, Kilb,
4 & Reedy, 2004) or contextual elements/features (e.g., colors, object locations; see
5 Mitchell, Johnson, Raye, Mather, & D'Esposito, 2000b).

6 The ADH is supported by numerous experiments showing that older adults are
7 deficient at preserving the links between the two basic components of an episode,
8 despite having relatively intact memory for the separate components. This pattern
9 of results, commonly based on a recognition memory testing paradigm, has been
10 reported for associations between paired words (Castel & Craik, 2003; Healy, Light,
11 & Chung, 2005; Light, Patterson, Chung, & Healy, 2004; Naveh-Benjamin, 2000,
12 Experiment 2), paired faces (Bastin & Van der Linden, 2005), paired pictures
13 (Naveh-Benjamin et al., 2003), pairings of words and non-words (Naveh-Benjamin,
14 2000, Experiment 1), pairings between words and their fonts (Naveh-Benjamin,
15 1995, Experiment 1; Naveh-Benjamin, 2000, Experiment 3), pairings of names and
16 faces (James, Fogler, & Tauber, 2008; Naveh-Benjamin et al., 2004; Rendell, Castel,
17 & Craik, 2005), pairings of pictograms of objects and their locations on a grid
18 (Mitchell et al., 2000b), and pairings of people and activities (Kersten, Earles,
19 Curtayne, & Lane, 2008). These studies typically present younger and older adults
20 with learning episodes containing two components each (e.g., word and non-word
21 pairs) before testing their memory of the components using an item recognition test
22 and the associations between the items using an associative recognition test. The

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1 strength of this testing paradigm lies in its ability to provide a direct measure of an
2 individual's level of associative learning without being hindered by potential
3 individual differences in retrieval processes. Notably, it circumvents the problems
4 posed by the cued-recall task (e.g., see Dunlosky & Hertzog, 1998, 2001), which
5 requires the learning of paired associates followed by the recall of one of its item
6 after being cued by its affiliate. Such problems are encapsulated by not being able to
7 clarify whether the deficit shown by older adults in those tasks is due to a decline in
8 associative memory or reflective of some additional age-related deficits in item
9 retrieval under the presence of cues (see Old & Naveh-Benjamin, 2008). Hence, in
10 comparison, the associative recognition paradigm endorsed by the aforementioned
11 studies could be seen as engendering a more precise account of older adults' poorer
12 memory performance – one that is untainted by the extraneous influence of
13 retrieval processes.

14 These findings generated more discussions of the general cognitive processes
15 or mechanisms underlying the associative memory deficit in older adults. A notable
16 concern of memory performances lies in the distinction between automatic and
17 controlled (i.e., effortful-strategic) processes (Hasher & Zacks, 1979). Strategic-
18 effortful processes are commonly characterized as conscious, slow-occurring,
19 intentional, and cognitively demanding whereas automatic processes are generally
20 regarded as unconscious, implicit, fast-occurring, and non-effortful (e.g., see Hasher
21 & Zacks, 1979; Posner & Snyder, 1975; Schneider & Shiffrin, 1977).

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1 In view of the considerable volume of research that has been generated
2 investigating whether older adults' associative deficit is due to the lack of
3 appropriate strategies to bind together two components, by an inability to bind
4 them automatically, or by both, the focus of this review will be on the empirical
5 studies that sought to delineate the roles of these types of processes in engendering
6 the decline of episodic/associative memory in older adults. I will discuss the studies
7 that implicated the involvement of strategic-effortful/controlled processes in the
8 age-related decline in associative memory, brought about by the influences of
9 instructions, attention, strategies, and automatic processes. These comparisons will
10 be followed up by a survey of the neural correlates that were implicated to be
11 underpinning the age-related deficit in associative memory. Based on an overview of
12 the studies, limitations and recommendations for future research will be proposed
13 for a better understanding of the sources of this associative deficit.

15 **2. THE ROLE OF INSTRUCTIONS ON ASSOCIATIVE LEARNING**

17 A foremost indicator of older adults' deficiency in strategic-effortful processing
18 relates to the meta-analytic finding that the age effect derived from associative
19 memory tasks (with younger adults having higher scores than older adults) is
20 greater under intentional learning instructions – whereby participants were
21 specifically told to prepare for a particular memory task – than under incidental
22 learning instructions that do not provide details of the upcoming task (Old &

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1 Naveh-Benjamin, 2008). This suggests that older adults' associative memory deficit
2 is mediated by difficulties in the optimal allocation of cognitive resources or the use
3 of appropriate strategies for encoding associations. In comparison with younger
4 adults, older adults did not seem to be able to take advantage of the strategy
5 provided by intentional instructions to facilitate their associate learning, and
6 consequently was not able to exhibit any noticeable improvement in their
7 association memory performance (see Naveh-Benjamin, 2000; Experiment 2). This
8 inability of older adults to adapt to the use of specific strategies can also be seen
9 from studies that showed them to have applied a smaller proportion of strategies
10 (based on verbal and mental imagery mediators) than younger adults in the correct
11 recall of paired associates (e.g., Smith, Park, Earles, Shaw, & Whiting, 1998;
12 Dunlosky & Hertzog, 2001).

13 The first study that explored the differential effects of incidental and
14 intentional instructions on item and associative memory respectively was performed
15 by Naveh-Benjamin et al. (2000). In their second experiment, they showed younger
16 (mean age of 22) and older adults (mean age of 71.1) word-nonword pairs in a
17 sequential manner, with one pair appearing after another on each trial. In each age
18 group, half of the participants were given incidental instructions to study the words
19 in each pair individually in preparation for the upcoming item recognition test
20 whereas the other half were given intentional instructions to study the paired items
21 in preparation for the upcoming associative recognition test. In the recognition
22 tests, the original items or pairs were intermixed with a proportionate number of

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distracter items. Distracter items from the word and nonword recognition tests were novel items that were not shown during the study phase and distracter items from the word-nonword recognition test referred to different combinations of previously studied pairs that were not observed. To avoid any carryover effects, a word or nonword appeared only once in each of the three recognition tests.

The results were computed in terms of a discriminability index—proportion hits minus proportion false alarms—that serves as a normative index for evaluating recognition memory performance. A differential pattern of results emerged for both age groups under the different types of instructions. In the item recognition memory test, there was a main effect of age (in favor of the younger adults) with no significant interaction of age and instructions. In contrast, there was a significant interaction effect between age and instruction in the associative test, with the age group difference being relatively larger (i.e., younger adults achieving higher scores) under intentional learning (see Figure 1.1)¹. These peculiar findings from the associative test suggest that younger adults benefited more from intentional instructions that explicitly emphasized the conjunctive encoding of item pairs. Older adults, on the other hand, exhibited the same level of associative memory performance irrespective of the type of instructions they were given, and did not appear to have adapted their cognitive processing in a way that adequately addressed the demands of the relational/connective strategy that is intrinsic to the

¹ See Appendix for figures.

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1 intentional instructions. Notably, this pattern of results in the associative test was
2 replicated when nonwords were substituted by different types of fonts serving as
3 contextual cues (i.e., transformation from a test of word-nonword pairs to a test of
4 word-font pairs, see Naveh-Benjamin, 2000, Experiment 3).

5 In another experiment that utilized the similar procedures for the study of
6 name-face pairs (Naveh-Benjamin et al., 2009), younger and older participants were
7 told to attend to faces, names and the relations between them in preparation for the
8 upcoming item and associative tests of recognition memory under the intentional
9 instructions, and were not told about any of the upcoming tests under the incidental
10 instructions. Instead, they performed an incidental learning exercise that involved
11 the evaluation of how well matched the different faces and names were when
12 compared with each other. Results from the first experiment that implemented
13 intentional learning showed that both age groups were equivalent in the recognition
14 of both names and faces but younger adults outperformed older adults in the
15 associative test. Unlike what Naveh-Benjamin et al. (2000) found, the younger
16 adults were less able to direct the intentional instructions towards an improved
17 learning of face-name associations, showing a noticeable decline in recognition
18 performance in the associative test relative to the item tests. However, older adults
19 exhibited an even greater decline in their associative memory performance relative
20 to their item memory ones, and that suggests that they encountered more
21 difficulties than the younger adults in the implementation of the connective
22 strategy proposed by the intentional instructions (see Figure 1.2). This significant

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1 interaction between age group and test was not duplicated when incidental
2 instructions were administered in the second experiment. Incidental learning led to
3 similar rates of decline in recognition memory performance for both age groups
4 when deducting their lower associative test scores from higher item/component
5 scores (Figure 1.2). These results were similar to those of Naveh-Benjamin et al.
6 (2000) that showed that incidental instructions did not lead to differential effects on
7 item and associative memory performance.

8 Taken together, these studies suggested that older adults were less able to
9 utilize the connective/relational strategy that was advocated by intentional
10 instructions to improve their episodic memory of word-nonword pairs. They also
11 faced more difficulties than the younger adults at directing the same type of
12 strategy towards the encoding of name-face pairs. This could mean that older adults
13 are either deficient at the effective use of a given strategy or at the production of
14 other strategies that are not task-relevant. Further evidence for these possibilities
15 could be seen from the recognition test results which showed a consistent age group
16 difference with regards to the recognition of distractor pairs (i.e., randomly
17 rearranged pairs) but not to that of originally studied pairs. The relatively higher
18 proportion of false alarms (i.e., falsely recognizing distracter pairs as correct)
19 committed by older adults suggest that they are over-relying on the process of
20 *familiarity* when retrieving the details of the individual components. As familiarity
21 is an automatic/implicit process that operates without the need of contextual
22 information (Yonelinas, 2002), it is possible that older adults' dependence on

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familiarity interfered with their correct recognition of paired items, notably name-face pairs, under intentional instructions. In consideration that the associative recognition memory test utilized by Naveh-Benjamin and colleagues rests on the premise of *recollection*, which stipulates that an item is retrieved simultaneously with its context, the next section shall address how older adults' associative memory deficit is mediated by familiarity and recollection.

3. CONTRIBUTIONS OF FAMILIARITY AND RECOLLECTION PROCESSES

In item recognition memory tests, familiarity and recollection processes are usually differentiated based on the use of “remember” and “know” responses (Tulving, 1985). The former requires participants to report about whether they had recollected an item (i.e., based on recalling its exact appearance) whereas the latter enquires about whether they knew that the item had been previously studied (i.e., based on a gist knowledge of it without recalling its features in detail). There is converging evidence from numerous aging studies that suggest that people's ability to use recollection-based processes to retrieve learned information declines with age, but their corresponding ability to use familiarity-based processes does not (e.g., Bastin & Van der Linden, 2003; Hay & Jacoby, 1999; Jennings & Jacoby, 1993; Light et al., 2004; Maylor, 1995). Studies that endeavored to show the qualitative difference between familiarity and recollection demonstrated that “remember”

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1 responses were more prevalent than “know” responses in associative memory
2 recognition tests whereas the reverse trend occurred in the item memory tests
3 (Hockley & Consoli, 1999). Notably, studies which examined receiver-operating
4 characteristics (ROCs) in recognition memory assessments—functions that relate
5 hits (i.e., correct recognition of old items) to false alarms (incorrect recognition of
6 lures)—showed that a curvilinear function applied to the modeling of familiarity
7 judgments whereas a linear function applied to the modeling of recollection
8 judgments (e.g., see Yonelinas, 1997). These findings were consistent with dual
9 process theories that proposed memory judgments to be contingent on two
10 qualitatively different processes of systems (e.g., Atkinson & Juola, 1974, Jacoby &
11 Dallas, 1981; Mandler, 1980). Specifically, the different functions computed by
12 Yonelinas (1997) based on his experimental data implicated that item judgments
13 depended on a combination of familiarity and recollection whereas associative
14 judgments depended on recollection only.

15 To understand how the differential reliance on familiarity and recollection
16 could affect performance on a recognition memory test, the use of familiarity need to
17 be regarded as contributing to high performance in item recognition but low
18 performance in associative/paired recognition. This is due to the familiar-looking
19 appearing of recombined distractor pairs (i.e., pairs created from the random
20 rearrangement of formerly studied items) that will entice the participant to
21 recognize them erroneously as previously studied pairs. Such errors are most likely
22 to occur in the absence of recollection processes that counter the effect of this

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1 automatic strategy that does not elaborate on the links between encoded items. In
2 this way, the findings of Naveh-Benjamin et al. (2009) of older adults making more
3 false alarms than younger adults in responding to recombined name-face pairs
4 could be interpreted as an over-reliance on familiarity-based processes. This
5 potential over-reliance on familiarity could also reflect older adults' under-
6 recruitment or difficulties with using recollection-based processes or strategies.
7 Other studies showing similar trends of higher rates of false alarms committed by
8 cognitively intact older adults in the associative recognition of conjunction pairs of
9 faces (i.e., recombination of previously seen faces) (Rhodes, Castel, & Jacoby, 2008)
10 and random landmark-scene combinations (i.e., landmarks set against scenes that
11 are not observed from navigating a virtual environment) (Head and Isom, 2010)
12 gave more evidence to support the view that older adults are deficient at adopting a
13 "recall-to-reject" cognitive process or strategy. Interestingly, it is also worth noting
14 that familiarity-based processes, which are resistant to an age-related decline,
15 hampered rather than reinforced older adult's associative memory.

17 4. EFFECTS OF DIVIDED ATTENTION ON CONTROLLED 18 PROCESSES

19
20 Apart from the types of instructions and familiarity- and recollection-based
21 processes, the effects of divided attention on memory performance are of great
22 concern to memory researchers. Some typical situations when attention becomes

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divided occur when one gets introduced to a new acquaintance and has to register his/her name amidst competing social cues, and when one attempts to retrieve information while carrying out a second complex task (e.g., keeping track of one's location on the GPS device while driving). These situations and many others deter people from focusing on one task alone and will affect them adversely if they need to retrieve information from some of the tasks subsequently.

The studies on divided attention generally examined its effects at the encoding and retrieval stages. Based on dual-task paradigms in which participants (mainly college- and middle-aged) performed two tasks simultaneously, previous research demonstrated decrements in memory performance on both primary (memory-based) and secondary (distractor) tasks under divided attention condition relative to full attention condition (e.g., Baddeley, Lewis, Eldridge, & Thomson, 1984; Craik, Govoni, Naveh-Benjamin, & Anderson, 1996). With respect to retrieval, divided attention has been shown to minimally affect performance on the primary memory performance task, despite producing a similar decline in secondary task performance. This shows that retrieval processes were relatively more resistant to the interference posed by divided attention (Craik et al., 1996).

Aging studies that compared the extents to which memory performance were disrupted by divided attention for younger and older adults produced mixed results with regards to the interruption of encoding processes by divided attention. When encoding information under divided attention situations, although some studies found larger memory decrements for older than for younger adults (e.g., Park,

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Smith, Dudley, & Lafronza, 1989; Salthouse, Rogan, & Prill, 1984), there were many other studies that showed similar levels of memory decrements for both age groups (e.g., Anderson, Craik, & Naveh-Benjamin, 1998; Baddeley, Logie, Bressi, Della Sala, & Spinnler, 1986; Light & Prull, 1995; Park, Puglisi, & Smith, 1986). In contrast, the retrieval of information under divided attention produced findings which were more congruous with one another. Like the younger adults, older adults have been shown to be minimally affected by secondary task performance during information retrieval (Anderson et al., 1998; Macht & Buschke, 1983; Nyberg, Nilsson, Olofsson, & Bäckman, 1997; Park et al., 1989; Whiting & Smith, 1997). However, older adults showcased *attentional costs* based on their relatively poorer secondary task performance (Anderson et al., 1998; Craik & McDowd, 1987; Macht & Buschke, 1983; Whiting & Smith, 1997). Such costs generally refer to the decrements in performance when the secondary task was performed under divided attention compared to when it got performed under full attention (see Craik, Naveh-Benjamin, & Anderson, 1998). The presence of these attentional costs for older adults suggests that they have reduced attentional resources for episodic memory formation (Craik, 1982, 1983; Craik & Byrd, 1982), which led to their difficulties with the successful completion of the concurrent task.

The first study that systematically examined the age-related effects of divided attention at both encoding and retrieval on memory and secondary task performance was conducted by Naveh-Benjamin, Craik, Guez, & Kreuger (2005). In that study, the authors applied a cued-recall paradigm that was regarded as

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1 imposing high demands for cognitive resources both at encoding and at retrieval
2 (see Craik et al., 1996). The primary associative memory task involved the learning
3 of word-pairs that were presented aurally within 3 seconds (followed by a 3 second
4 delay before another word pair was presented) while the secondary task involved
5 the following of a moving green asterisk with a white dot that was controlled by the
6 participants. To perform the latter task well, participants had to move the white dot
7 with the mouse and keep it as close as possible to the asterisk while following it.
8 The dependent variable for this task is being recorded as the distance (in
9 millimeters) between the dot and the asterisk. In the full attention condition, these
10 two tasks were performed separately, with performance on the secondary tracking
11 task treated as the baseline. In contrast, in the divided attention condition, the two
12 tasks were performed simultaneously under the instructions to pay equal attention
13 to each. Retrieval was conducted under full attention for both conditions and
14 participants had to produce the target words after being cued with their affiliates
15 within 6 seconds on each trial.

16 In the analysis of results, the authors addressed the question of whether there
17 are specific processes during encoding and retrieval that consume more resources in
18 older adults by dividing up the encoding and retrieval periods of each word pair (6
19 seconds each) into three temporal phases respectively. For encoding, these phases
20 were stimulus perception (the first 650 milliseconds), stimulus elaboration (the next
21 1.5 seconds), and learning (the final 3.85 seconds). For retrieval, its phases spanned
22 the same periods as those of encoding and referred to cue perception, cue

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1 elaboration, and search plus retrieval mode. The comparison of younger and older
2 adults with respect to attentional costs (i.e., secondary tracking costs), computed as
3 the arithmetic difference between single- and dual-task performance, demonstrated
4 significant age group differences in the elaboration and learning phases of encoding,
5 as well as across the three phases of retrieval, with the age group difference being
6 the most salient during the second retrieval phase (see Figure 1.3). Overall,
7 attentional costs are comparatively greater for older adults at retrieval than at
8 encoding. When the data was analyzed based on whether the words are successfully
9 or unsuccessfully retrieved, a similar trend of age group differences across the
10 retrieval phases were produced. This suggests that searching and producing the
11 target words to the cues was attentionally demanding irrespective of whether they
12 were properly recalled. The common trend of higher increases in attentional costs
13 shown by the older adults from the first to the second phase of encoding and
14 retrieval suggest that reduced attentional resources have substantial negative
15 effects on older adults' rehearsal of the stimuli upon first exposure and their
16 subsequent search processes. Along with the higher attentional costs incurred by
17 older adults at the final retrieval phase, the findings implicate that cue-elaboration,
18 word search and production, and maintaining a retrieval mode become difficult and
19 resource demanding in older age.

20 To find out whether these findings were consistent with the proposed
21 associative memory deficit in older adults, Kilb & Naveh-Benjamin (2007) carried
22 out a study that compared the item and associative memory performance of younger

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1 and older adults under full and divided attention conditions. In the item/component
2 test, they applied a forced-choice paradigm that balanced the amount of stimuli (i.e.,
3 words) presented on each item trial with that presented on each associative trial.
4 The words appeared in pairs and studied words were presented on the left and right
5 sides of the screen in equal proportions. The participants pressed two keys to
6 respond to target words appearing on the left and right sides of the screen
7 respectively. In the associative test, paired words appeared on each trial and
8 participants had to press a key if they recognized the pair as previously studied and
9 another key if they recognized it as a recombination of previously studied words. As
10 for the secondary/concurrent task devised to induce divided attention, it was an
11 auditory response task that required participants to discriminate among three
12 pitches. The tones were presented sequentially and participants had to press one of
13 three buttons that correspond to the appropriate tone.

14 The results demonstrated an associative deficit (i.e., the difference between
15 item and associative memory performance) under both full and divided attention
16 condition for older adults but not for younger adults, who only demonstrated similar
17 rates of decline in item and associative memory performance when comparing the
18 full and divided attention conditions. Despite demonstrating that older adults
19 suffered from an associative deficit under divided attention, the findings could not
20 be interpreted as supporting the argument that reduced attentional resources
21 mediate older adults' associative memory. This is due to the surprising finding of
22 older adults showing an unexpected lower degree of associative deficit under the

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divided attention condition than under the full attention condition. Unlike the item memory performance that declined under divided attention, associative memory performance remained fairly stable across both attentional conditions. These peculiar findings suggest that the attentional costs experienced by older adults do not necessarily have to affect their studying of combined units of information. More importantly, the findings provided reasons to support the involvement of other mechanisms that are involved in the associative memory deficit of older adults. Such mechanisms refer to explicit strategies and automatic binding processes that may exert greater influences than attentional resources in determining the integrity of associative memory in younger and older adults.

5. STRATEGIES FOR IMPROVING ASSOCIATIVE MEMORY

The need to understand the role of conscious strategies for the encoding and retrieval of episodic/associative memories is pertinent in view of the studies that showed older adults to make greater false recognition of recombined distractor pairs than younger adults (e.g., Head & Isom, 2010; Naveh-Benjamin et al., 2009; Rhodes et al., 2008, as aforementioned). These findings not only suggest that older adults are over-relying on habitual or automatic processes when processing such misleading information, but are also probably suffering from an inability to utilize appropriate retrieval processes. These retrieval processes, as well as complementary encoding process, can be characterized as associative learning and

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1 recall strategies that require a considerable amount of cognitive effort. These
2 strategies are proposed based on the assumption that older adults either do not use
3 them or use them ineffectively (Kausler, 1994). Hence, providing older adults with
4 the opportunities to learn and practice them may be a way to improve their
5 associative memory.

6 To examine the potential benefits of strategies, a study by Naveh-Benjamin,
7 Brav, & Levy (2007) compared three conditions where participants were given
8 intentional instructions only (i.e., no specific strategy), associative strategy at
9 encoding, and associative strategy as both encoding and retrieval. The participants
10 studied lists of unrelated word pairs and subsequently did item and associative
11 recognition tests. Distractor items were unrelated to the target words and were
12 matched in terms of linguistic properties (i.e., word frequency, semantics, and
13 phonemes). In line with the conventional practice, distractor pairs were formed
14 based on randomly re-pairings of the component words that constitute the studied
15 word pairs. During the study phase, participants are given intentional instructions
16 under all conditions. Under the condition where no specific strategy was given,
17 participants were told about the nature of the upcoming tests and to study the word
18 pairs in order to stay prepared. In the second condition, another group of
19 participants were told about using an associative strategy to link together each pair
20 of words using a sentence that meaningfully connects them. Finally, a third group of
21 participants was told not just to use sentence connectors during encoding but to re-
22 apply them during retrieval to help them decide on whether a word or a pair had

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1 been studied. The authors designed this third condition based on the view that the
2 associative strategic deficit of older adults could occur at both encoding and
3 retrieval phases (Naveh-Benjamin et al., 2005), and that if such a deficit indeed
4 exists under both scenarios, a suggestion for consistent strategy use would be of
5 optimal benefit for older adults.

6 The findings in terms of the index of hits minus false alarms showed that older
7 adults exhibited the usual associative memory deficit under the first condition
8 where only intentional instructions was given but showed marked improvement in
9 associative recognition under the two strategy conditions—an improvement that
10 was comparatively greater than that shown by the younger adults (see Figure 1.4).
11 Notably, the improvement appear to be additive, with steady increments in
12 associative performance for older adults from the first condition where no
13 associative strategy was given to the third condition where strategy use was
14 encouraged at both encoding and retrieval.

15 Importantly, these findings suggest that the use of relevant strategies
16 enhanced older adults' engagement with controlled processes or attentional
17 resources. They related well to the earlier findings by Naveh-Benjamin et al. (2005)
18 that showed older adults to exhibit higher attentional costs (i.e., poorer performance
19 on the secondary task due to reduced attentional resources) than younger adults
20 when the strategic use of sentence or imagery mediators occurred during both
21 encoding and retrieval. Moreover, this view of effortful processing being linked to
22 strategy use was supported by previous studies which showed that age-related

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1 differences in episodic memory were diminished when older adults were told to
2 deliberate about the relations between an item and its context at retrieval (Glisky,
3 Rubin, & Davidson, 2001), and to utilize meaningful sentences to connect
4 contextually related picture pairs at encoding (Smith et al., 1998).

5 Together, the findings by Naveh-Benjamin and colleagues suggest that older
6 adults' associative deficit was due to their inability to readily generate associative
7 strategies—a production deficiency—rather than an inability to use strategies
8 efficiently. According to the latter view, older adults' associative deficit stemmed
9 primarily from their irregular use of an associative strategy, which subsequently
10 leads to its inefficient use under circumstances that require it (e.g., see Craik &
11 Rabinowitz, 1985; Dunlosky & Hertzog, 1998; Erber, Galt, & Botwinick, 1985).
12 Consequently, even when older adults are able to produce a particular associative
13 strategy successfully, they will not reach the same level of performance as younger
14 adults simply due to their inexperience with utilizing it in an efficient or effective
15 way. An example would be older adults forming fewer sentences than younger
16 adults that describe actions which connected the words in a pair together (Smith et
17 al., 1998). This possibility of inefficiency in strategy use thereby offers reason for
18 caution in the belief that intentional instructions to use associative strategies will
19 automatically improve older adults' associative memory. Training in the efficient
20 creation of sentences or images relating word pairs together may be as important as
21 the instructions to use specific strategy use, if not more. Hertzog, Price, and
22 Dunlosky (2012) showed that although younger and older adults were comparable

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1 in the production of an interactive imagery strategy that represents word pairs
2 through imaginations of meaningful actions or activities, older adults were
3 relatively less accurate in the cued recall of the target words. The authors also
4 showed that older adults were less likely than younger adults to utilize the
5 interactive imagery strategy again in the learning of a second list of word pairs,
6 suggesting that they are less confident or effective at implementing such a strategy.
7 Interestingly, even though older adults are poorer at executing the interactive
8 imagery strategy than younger adults, its use eliminated older adults' associative
9 memory deficit (Patterson & Hertzog, 2010). Instructing older adults to form images
10 of the individual words in each pair prior to forming interactive imageries improved
11 their memory performance (on both item and associative tasks) to levels that were
12 slightly below the memory performance of younger adults.

14 6. PRESERVATION OF IMPLICIT ASSOCIATIVE MEMORY IN OLD 15 AGE

17 Aside from considering the influences of recollection-based, effortful and
18 strategic processes on encoding and retrieval, it is also important to consider the
19 role of familiarity-based automatic processes in associative memory formation. In
20 contrast to the strategic-effortful processes that produced prominent age group
21 differences, many studies have demonstrated that the operation of automatic
22 processes generally remains intact in old age (e.g., Dew & Giovanello, 2010; Jacoby,

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1 Toth, & Yonelinas, 1993; Jennings & Jacoby, 1993; Hay & Jacoby, 1999; Kessels,
2 van Doormaal, & Janzen, 2011; Koutstaal, 2003; Titov & Knight, 1997). The
3 classical paradigm used for identifying the preservation of automatic processes in
4 old age was based on a word stem completion task that operates on a process-
5 dissociation procedure (see Jacoby et al., 1993). The word stem completion task
6 requires the completion of words that have their first three letters presented (e.g.,
7 mot--). Such words can be old words that were previously studied or new words that
8 are freely generated by the participants. The process-dissociation procedure
9 determines the types of words that the participants should generate. It is based on
10 either an inclusion or exclusion test of the memory of previously studied words. In
11 the inclusion test, the word stem is accompanied by a message of “old”, and
12 participants were instructed to use the stem as a cue for recall of a studied word;
13 and to complete the stem with the first word that came to mind if they could not do
14 so. In this way, the inclusion test is akin to a test of cued recall with additional
15 instructions to guess when recollection fails. On the other hand, the exclusion test
16 has the message “new” displayed alongside the word stem and participants were
17 instructed to use the stem as a cue for recall of a studied word but not to apply the
18 recalled word to complete the stem. In other words, participants were told to
19 exclude the studied words that they recalled and complete the stems only with new
20 words that had not been studied.

21 When an inclusion or exclusion test immediately followed presentation of it a
22 particular word, no significant age differences were observed, indicating that older

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adults understood and followed instructions. However, when numerous items intervened between the presentation of a word and its inclusion or exclusion test, older adults performed significantly poorer than younger adults. Namely, in the inclusion test, older adults completed less word stems correctly than younger adults, but completed more word stems correctly under the exclusion test. The poorer performance of older adults in the inclusion test could be explained by the age-related decline in recollection-based processing, whereas their better performance on the exclusion test could be explained by their overreliance on automatic processes that compensated for their deficits in recollection. These explanations were backed up by the quantitative estimates of the conscious and unconscious influences of memory, which showed equally high estimates of unconscious processing by both age groups, but relatively lower estimates of conscious processing by older adults (Jacoby et al., 1993).

While the word stem completion paradigm with inclusion and exclusion tests examined the dissociation between automatic and controlled processes in affecting item memory, subsequent research by Hay and Jacoby (1999) dissociated the influences of these processes on associative memory. Their experiment was separated into three phases. In the first phase, younger and older participants were exposed to associatively related word pairs (e.g., *organ–music*, *organ–piano*) at varying frequencies (e.g., 25% versus 75%) to induce habits of linking cue words to target words that appear at higher frequencies (e.g., linking *organ* to *music*, which appeared on 75% of the trials). In the second phase, participants studied short lists

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1 of word pairs that had studied pairs that previously appeared at high and low
2 frequencies, labeled as congruent and non-congruent pairs respectively. In the third
3 testing phase, participants were cued with the first word of a pair (e.g., organ—____)
4 and told to fill in the blank with the studied word that they could recall. Results
5 showed that both age groups were alike in reporting high frequency target words
6 (e.g., *music*) for completing congruent pairs but older adults were more likely to
7 erroneously recall the same target words to complete incongruent pairs. The
8 authors explained these results with referral to a dual-process model that propose
9 older adults to rely more on their habit or tendency to automatically link cues with
10 their high frequency counterparts for completing incongruent word pairs. This
11 model suggests that automatic processing by older adults is induced through a
12 repetition of familiar information and that it is older adults' preferred mode of
13 retrieval under circumstances when recollection fails.

14 Further research by Koutstaal (2003, 2006) showed that this automatic habit
15 of combining frequently seen items is analogous to the acquisition of *gist knowledge*
16 by older adults (i.e., knowing that items belong to the same concepts or categories
17 without remembering their specific details). Koutstaal (2003) tested younger and
18 older adults on the recognition of specific objects and the association of their
19 different exemplars to their common categories. Results showed that younger adults
20 were better than older adults at recognizing the same exemplars (i.e., objects that
21 were identical to those that were studied) as compared to different exemplars
22 (alternative objects that belong to the same category as the studied object, e.g., two

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different umbrellas) but no significant age group difference occurred with regards to recognizing the two different types of exemplars as belonging to the same conceptual category. There was also no age group difference in repetition priming, which requires making rapid decisions about whether the exemplars were larger than their real-world referents; both age groups exhibited larger priming effects (i.e., faster responses to exemplars than to lures/distractors) in responding to the same exemplars than to different exemplars. These results suggest that although older adults encoded details about the objects, they used them less effectively than the younger adults under the context that requires the recollection of their specific features. They were further supported by subsequent findings by Koutstaal (2006) showing that the sensitivity to gist knowledge was virtually identical between both younger and older adults under category-based recognition. Notably, older adults demonstrated themselves to be only slightly worse than the younger adults at *flexible remembering*—typified by switching between automatic and controlled-effortful processes to suit the optimal recollection of gist and item-specific knowledge respectively.

The engagement of gist knowledge for making verifications about different exemplars from a common category can also be likened to reliance on previous in order to remember associations. Several studies by Castel and colleagues (e.g., Castel, 2005, 2007; McGillivray & Castel, 2010) have shown that when older adults had to bind together several pieces of information that they are well acquainted with (e.g., grocery items and prices, faces and ages of different people, sets of

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numerical and object information), they were able to apply their previous knowledge or expertise and demonstrate little or no age-related associative deficit. Retrieving information from a knowledge base also reduces older adults' need to engage in processes that require the conscious engagement of fluid intelligence (i.e., novel problem solving, abstract reasoning), and deters older adults' daily functioning from being over-affected by the age-related decline in fluid intelligence (Salthouse, 2004).

Cumulatively, these studies showed that older adults are able to use automatic processes in the forms of habit, gist or abstract knowledge, together with previous knowledge that is well-honed through numerous exposures. Although these automatic processes benefitted older adults in the retrieval of items that were high related in terms of frequency and concept, they adversely affected older adults' recognition of items and paired associates that required the processing of fine-grained details. This shows that older adults' use of automatic processes for the encoding and retrieval of associative memory is optimally suited for circumstances that do not require controlled-effortful processes.

7. BRAIN CHANGES ASSOCIATED WITH THE AGE-RELATED DECLINE IN ASSOCIATIVE/EPISODIC MEMORY

Apart from all the behavioral evidences that implicated the age-related decline in associative memory, it is important to understand the functional and structural changes in the brain that contribute to older adults' poorer

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1 associative/episodic memory. The brain region that is proposed to be a 'binder' of
2 memories is the hippocampus (Cohen et al., 1999), and numerous neuroimaging
3 studies that examined associative learning have implicated it to be involved in the
4 automatic binding of information (e.g., Cohen & Eichenbaum, 1993; Eichenbaum,
5 2003; Eichenbaum & Bunsey, 1995; Henke, Buck, Weber, & Wieser, 1997; Kroll,
6 Knight, Metcalfe, Wolf, & Tulving, 1996; Wallenstein, Eichenbaum, & Hasselmo,
7 1998). These automatic binding processes, normally activated under incidental
8 learning conditions, have been shown to be negatively affected in older adults (e.g.,
9 see Grady et al., 1995; Moscovitch, 1994; Mitchell, Johnson, Raye, & D'Esposito,
10 2000). For instance, Mitchell, Johnson, Raye, and D'Esposito (2000) found that older
11 adults exhibited lower hippocampal activation than younger adults when learning
12 the associations between items and their locations as compared with the items'
13 individual features. Moreover, they revealed the same pattern of age-related
14 differences in activation in the medial prefrontal cortex (mPFC) with older adults
15 having lower activation. Consistent with proposals of the hippocampus and mPFC
16 being the neural correlates of automatic and strategic-effortful binding processes
17 respectively (Moscovitch & Winocur, 1992, Moscovitch, 1994), these findings
18 interestingly suggest that the processing of associative or episodic information may
19 engage parallel but distinct binding processes in both the mPFC and the
20 hippocampus.

21 The close links between the mPFC and the hippocampus have also been
22 highlighted by neurocomputational research which showed that senescent changes

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1 in the neuromodulatory mechanisms underlying the fronto-hippocampal circuitry
2 play a basic role in accounting for the associative deficit of older adults (Li, Naveh-
3 Benjamin, & Lindenberger, 2005). More importantly, MRI studies on older adults
4 have related reductions in hippocampal activation and volume with reduction in
5 memory performance over a 6 year period (Persson et al., 2012), and proposed that
6 the preservation of intact associative memory among some high-functioning older
7 adults may be attributed to the preservation of hippocampal function together with
8 a high level of PFC responsivity (Pudas et al., 2013).

9 Furthermore, numerous studies have interpreted the positive relationship
10 between additional recruitment of certain brain regions—particularly the bilateral
11 recruitment of PFC among older adults which contrasted with its unilateral
12 recruitment among younger adults—and better memory performance as evidence
13 for neural compensation, and negative relationships as against this interpretation
14 (e.g., Cabeza, Anderson, Locantore, & McIntosh, 2002; Cabeza, et al., 1997; Davis,
15 Kragel, Madden, & Cabeza, 2012; Duarte, Henson, & Graham, 2008; Dulas &
16 Duarte, 2012; Eyler et al., 2011; Huang, Polk, Goh, & Park, 2012; Morcom &
17 Friston, 2012; Rajah & D'Esposito, 2005; Rosen et al., 2002). Depending on the
18 demand characteristics of a cognitive task, older adults' level of PFC activation can
19 be either reduced or elevated relative to younger adults (Grady 2012; Spaniol &
20 Grady, 2012). While some studies found that younger adults have higher PFC
21 activation than older adults during encoding (e.g., Anderson et al., 2000; Cabeza,
22 Anderson, Mangels, & Nyberg, 2000), many others have documented a greater

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1 bilateral activation of the PFC in older than in younger adults (e.g., Cabeza, 2002;
2 Eyler et al., 2011; Grady et al., 1995; Park, Polk, Mikels, Taylor, & Marshuetz,
3 2001; Park & Reuter-Lorenz, 2009; Rajah & D'Esposito, 2005; Reuter-Lorenz, 2002).
4 This greater bilaterality of PFC activity is dubbed Hemispheric Asymmetry
5 Reduction in OLDer adults (HAROLD) (Cabeza, 2002), and has been seen as giving
6 support for the notion that older adults can compensate for the decline in cognitive
7 resources by implementing adaptive strategies or reserve resources (Cabeza &
8 Dennis, 2013; Collins & Mohr, 2013; Freund & Baltes, 2002; Steffener & Stern,
9 2012). Nonetheless, there have been concerns that the additional recruitment of the
10 right PFC for the encoding of paired associates (i.e., word pairs) may reflect the
11 deleterious effect of *dedifferentiation*, which is characterized by the loss of
12 specification of cortical recruitment to regions supporting task-relevant processes
13 (see de Chastelaine, Wang, Minton Muftule, & Rugg, 2011; see also Grady, 2012, for
14 a review). Alternatively, dedifferentiation may also arise as an outcome of a decline
15 in the functional integrity of neural networks that accompanies normal aging
16 (Grady, 2012).

17 In the study by de Chastelaine et al. (2011), older adults was found to exhibit
18 higher activation in the right PFC during the recognition of word pairs. In contrast
19 to the improvement in memory performance as what the HAROLD model will
20 predict, activation in the right PFC negatively correlated with associative memory
21 performance, and the authors interpreted this finding as evidence for the
22 inadequacy of the compensatory process that preserves memory performance in the

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presence of age-related neural decline. They primarily explained this finding based on the notion of ‘partial’ compensation—which relates older adults’ higher recruitment of the right PFC to the engagement of processes that compensate for the inability of the left PFC to meet all the online demands of the study task. However, this higher activation in the right PFC, unlike that in the left PFC, contributes little or nothing to episodic memory encoding. Despite the abstractness of this explanation, the “partial compensation hypothesis” has also been favored by other researchers who view compensatory processes as not being able to completely offset the deleterious effect of neural decline or insult (e.g., Bäckman & Dixon, 1992; Buckner, 2004; Daselaar & Cabeza, 2005; Duarte, Henson, & Graham, 2008; Duverne et al., 2009; Persson et al., 2006; Stern et al., 2005; Zarahn et al., 2007). Importantly, the consideration of partial neural compensation highlights a need for future research to investigate the influences of individual differences in cognitive function on the self-initialization of compensatory processes. It is possible that partial or full neural compensation is more readily endorsed by older adults with more intact or better preserved cognitive functions than those without.

8. LIMITATIONS AND FUTURE DIRECTIONS

Based on the studies that were reviewed, an age-related decline in the strategic-effortful or recollection-based processing has a greater detrimental impact on the encoding and retrieval of associative memories of older adults when

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1 compared with automatic or familiarity-based processes that are relatively well-
2 preserved in old age. Although the majority of these studies highlighted the
3 pertinence of conscious mechanisms and strategies for the memory of paired
4 associates, they are not unequivocal in attributing older adults' poorer encoding and
5 retrieval of paired associates to a deficiency in information processing resources.
6 This is exemplified by Kilb and Naveh-Benjamin's (2007) surprising finding of older
7 adults having an almost equivalent level of associative memory performance under
8 the divided attention condition as that under the full attention condition,
9 culminating in an associate memory deficit that was larger under the former
10 condition than under the latter condition. Such findings are at odds with the
11 perception that dual task conditions limit the allocation of attentional resources for
12 processing bound information and suggest that individual differences among the
13 older adults in terms of other cognitive abilities may play a part in determining
14 their relatively intact associative memory performance under the divided attention
15 condition.

16 Alternatively, it may also mean that the concurrent/secondary tasks used in
17 some of the aforementioned studies are not demanding enough to affect subsequent
18 associative memory differentially under the two types of attention conditions. For
19 instance, the effect of such concurrent tasks would be minimal for older adults who
20 implemented non-conventional strategies or heuristics that differed from an
21 effortful associative learning approach. Therefore, future research should seek to
22 design more suitable concurrent tasks that adequately intervene with older adults'

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1 informational processing, as well as address how individual differences in cognitive
2 functions could affect older adults' associative or episodic memory.

3 Future research on the effects of individual differences is important since
4 previous studies have shown that the differential production of associative
5 strategies affects subsequent recognition of paired associates (Naveh-Benjamin et
6 al., 2007) and that different levels of effective strategy use are positively related to
7 different levels of word recall (Lachman & Andreoletti, 2006). Moreover, many
8 studies have shown that there are age differences in metacognitive self-efficacy—
9 generally defined as the belief in one's ability to complete a task successfully (see,
10 e.g., Hertzog & Hultsch, 2000; Lachman, 2006; McDougall & Kang, 2003; Rebok &
11 Balcerak, 1989)—and that it could positively affect memory performance through
12 the mediating effect of strategy use (Hertzog, Dunlosky, & Robinson, 2009;
13 Lachman & Andreoletti, 2006). This means that individual differences in the
14 generation or efficiency of use of memory strategies is under the higher influence of
15 memory self-efficacy or perceived control of memory performance, and that strategy
16 use per se is not the prime actor in bringing about optimal memory performance.
17 Older adults with higher self-efficacy or perceived control of their memory functions
18 generally perform better than their counterparts with lower self-efficacy/perceived
19 control (see, e.g., de Frias et al., 2003; Hertzog, Dunlosky, & Robinson, 2009;
20 Lachman & Agrigoroaei, 2012; Lachman & Andreoletti, 2006); and older adults who
21 are better at monitoring their progress towards goals in a memory task (i.e.,
22 memory monitoring) have been shown be more likely to use memory strategies

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effectively (Hertzog, Price, & Dunlosky, 2012). In view that older adults can be trained to self-regulate or monitor their metacognition that subsequently led to them having better recall of paired associates (Dunlosky, Kubat-Silman, & Hertzog, 2003), just like the way that they can be trained to use associative memory strategies (Naveh-Benjamin et al., 2007), future studies could focus on integrating training regimens in both metacognitive monitoring and memory strategy use for a double-pronged approach to improving older adults' episodic or associative memory performance.

Furthermore, a better knowledge of individual differences in metacognitive self-regulation and strategy use among older adults may give us the evidence to clarify the contentious issue of neuronal compensation in the prefrontal lobes. A direction that future neuroimaging research can embark on is to figure out whether bilateral activation in the prefrontal lobes of older adults is associated with higher metacognitive monitoring and effective strategy use.

Finally, it is worth noting that most of the interventions used to distinguish controlled from automatic processes assessed the macrolevel of behavior based on manipulations of study instructions, which included the relevant memory strategies to adopt (e.g., Naveh-Benjamin et al., 2005, 2007; Patterson & Hertzog, 2010), without a more fine-grained analysis of the microlevel features of behavior. Microlevel analysis refers to the studies that utilized dual-task paradigms to implicate a constraint on cognitive resources under the divided attention condition (e.g., Craik, 1982, 1996; Naveh-Benjamin et al., 2005) and studies that examined

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different processes during pre-specified phases of encoding and retrieval (Naveh-Benjamin et al., 2005). Due to the requirements for higher standards of experimental testing and statistical analyses, such studies have not been prevalent, and so future studies can be conducted using more intricate designs to differentiate the components of automatic and controlled processes, and pinpoint their roles in the age-related decline in associative memory.

9. SUMMARY

Numerous behavioral studies to date examined the roles of automatic and controlled processes in the formation and retrieval of associative memories and generally suggest an age-related decline in controlled processing to account for older adults' associative deficit. These studies showed that older adults are less able than younger adults at: (a) using associative strategies presented to them through intentional instructions; (b) generating associative strategies on their own accord; (c) recalling previously studied items and paired associates based on recollection-based processes. In spite of older adults' declining cognitive abilities in these aspects, older adults generally preserve their implicit memories of bound information and are capable of forming a "gist" knowledge of items in memory by linking them with high-order concepts or categories. The presence of bilateral prefrontal activation in older adults seems to suggest that they are engaging in compensatory neural resources to ward off the negative effects of the memory

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1 decline. Yet the variability of this bilateral activation across tasks of varying
2 demand characteristics makes the claim of compensatory mechanisms an equivocal
3 one. Individual differences in cognitive functions, metacognitive self-regulation (i.e.,
4 metacognitive self-efficacy and monitoring), and strategic processes (i.e., production
5 and efficiency of use) are likely to produce variation in activation in the prefrontal
6 cortex, as well as in other brain regions like the parahippocampal/hippocampal
7 formation. Further studies employing more rigorous methodologies and fine-grained
8 statistical analyses are needed to investigate the converging influences of these
9 individual differences on the neural, cognitive, and behavioral functioning of older
10 adults.

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Appendix: Supplementary Figures

Figure 1.1. Proportion of hits minus proportion of false for different age groups in the item and associative recognition tests under the different study conditions. ‘Hits’ refer to correct recognition of old items whereas ‘false alarms’ refer to the incorrect recognition of distractors/lures. Bars represent ± 1 SE. Source: Naveh-Benjamin, M., 2000, *Journal of Experimental Psychology: Learning, Memory, & Cognition*, 26, 1170–1187. Reproduced with permission.

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Figure 1.2. Proportion of hits minus proportion of false for different age groups in the item and associative recognition tests under intentional (left) and incidental learning instructions (right). Bars represent ± 1 SE. Source: Naveh-Benjamin, M., Shing, Y.-L., Kilb, A., Werkle-Bergner, M., Lindenberger, U., & Li, S.-C. (2009). Adult age differences in memory for name-face associations: The effects of intentional and incidental learning. *Memory*, 17, 220–232). Reproduced with permission.

Figure 1.3. Temporal distribution of secondary tracking costs for younger and older adults averaged across the 6-seconds encoding and retrieval periods. Tracking costs represented attentional costs and were computed by subtracting the performance measure--the difference in distance between the white dot (controlled by participants) and a green asterisk (moving on the screen)--of the dual-task (divided attention) condition from the single-task (full attention) condition. Source: Naveh-Benjamin, M., Craik, F. I. M., Guez, J., & Krueger, S. (2005). Divided attention in younger and older adults: Effects of strategy and relatedness on memory performance and secondary task costs. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, 31, 520–537. Reproduced with permission.

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Figure 1.4. Proportion of hits minus proportion of false alarms for different age groups in the item and associative recognition tests in three conditions of intentional instructions with two involving strategy use. Bars represent ± 1 SE. Source: Naveh-Benjamin, M., Brav, T. K., & Levy, O. (2007). The associative memory deficit of older adults: The role of strategy utilization. *Psychology and Aging*, 22, 202–208. Reproduced with permission.