Published in final edited form as:
Psychol Aging. 2009 March ; 24(1): 82–92. doi:10.1037/a0014078.

Does Differential Strategy Use Account for Age-Related Deficits in Working-Memory Performance?

Heather Bailey,
Department of Psychology, Kent State University.

John Dunlosky, and
Department of Psychology, Kent State University.

Christopher Hertzog
School of Psychology, Georgia Institute of Technology.

Abstract

The *strategy-deficit hypothesis* states that age differences in the use of effective strategies contribute to the age-related deficits in working memory (WM) span performance. To evaluate this hypothesis, strategy use was measured using set-by-set strategy reports during the reading span (RSPAN) task (Experiments 1 and 2) and the operation span (OSPAN) task (Experiment 2). Individual differences in the reported use of effective strategies accounted for substantial variance in span performance. In contrast to the strategy-deficit hypothesis, however, young and older adults reported using the same proportion of normatively effective strategies on both span tasks. Measures of processing speed accounted for a substantial proportion of the age-related variance in span performance. Thus, although using normatively effective strategies accounts for individual differences in span performance, age differences in effective strategy use cannot explain the age-related variance in that performance.

Working memory (WM) refers to the process of holding information in a temprorarily activated state while working with it to achieve performance goals (Baddeley, 1986). The hallmark of working memory, as opposed to the construct of short-term memory, is the requirement for concurrent processing while holding the information in memory. The reading span (RSPAN) task developed by Daneman and Carpenter (1980) is representative of WM span tasks. In a modified version of the RSPAN task, participants are presented with a sentence and an unrelated word (e.g., "Mr. Owens left the lawnmower in the lemon. ? eagle"). They read the sentence aloud, decide whether it is coherent, read the word aloud (e.g., eagle), and then the next sentence-word pair is presented (e.g., "Emily was invited to the party on Saturday. ? rock"). Participants complete several of these sentence-word pairs. Following the final pair of each trial, they attempt to recall the words in the correct serial order (e.g., eagle, rock …). Performance on the RSPAN task can be scored by the mean proportion of correctly-recalled words, aggregated over multiple trials regardless of set size (as recommended by Conway, Kane, Bunting, Hambrick, Wilhelm, & Engle, 2005).

Correspondence concerning this article should be addressed to John Dunlosky, P.O. Box 5190, Department of Psychology, Kent State University, Kent, Ohio 44242-0001. E-mail: jdunlosk@kent.edu.

Age-related deficits in working memory WM span performance have consistently been demonstrated across many span tasks (Salthouse, 1994; for an exception, see May, Hasher, & Kane, 1999). Moreover, these deficits may contribute to age-related declines in performance on other cognitive measures (Salthouse & Babcock, 1991). This reason, in particular, has motivated many of the studies aimed at understanding age-related differences in span performance. Some of the most popular explanations involve a general cognitive process being compromised with age. In the current paper, we briefly discuss one of the leading general process theories in the WM and aging literature – the processing speed account (for an alternative account, see Hasher & Zacks, 1988). Afterwards, we present a complementary hypothesis about age differences in the use of effective strategies on span tasks.

Processing Speed Account

The processing speed account states that many cognitive processes are dependent upon the speed with which an individual processes information (Salthouse, 1991; 1994; Salthouse & Babcock, 1991). Thus, when processing speed slows, cognitive performance also suffers because relevant operations cannot be successfully carried out. Because of a well-documented finding that older adults process information slower than do young adults (e.g., Hertzog, 1989; Salthouse, 1996), it follows that the age-related deficit in WM span may be due to the slower activation and subvocal rehearsal of information with age (Salthouse, 1992; 1994). Thus, when participants are engaged in a span task, the secondary task (e.g., reading sentences in the RSPAN task) disrupts rehearsal of the to-be-remembered information more severely for older than young adults, which in turn leads to lower span performance (Jenkins, Myerson, Hale, & Fry, 1999).

Evidence in support of the processing speed account involves studies in which young and older adults complete various span tasks along with measures of perceptual speed, such as the letter comparison and pattern comparison tasks. After calculating the proportion of variance in span performance due to age, performance on the perceptual speed measures is statistically controlled. Salthouse and Babcock (1991) found that after accounting for speed, the age-related variance in span performance was minimized, a finding that has been widely replicated.

Strategy-Deficit Hypothesis of Age-related Differences in Span Performance

The purpose of the current studies was to introduce and evaluate the *strategy-deficit hypothesis*, which states that strategy use contributes to age-related deficits in span performance. We view this hypothesis as complementary to previous theories because deficient strategies and degraded cognitive processing mechanisms may combine to reduce older adults' performance on span tasks. Two relevant lines of research have examined the role of strategy use in cognition, and more specifically, in span performance. First, studies have demonstrated that individual differences in strategy use account for a reliable amount of variance in span performance (Dunlosky & Kane, 2007; Friedman & Miyake, 2004; Kaakinen & Hyona, in press; McNamara & Scott, 2001; Turley-Ames & Whitfield, 2003). In particular, span performance is usually higher for individuals who report using normatively effective strategies (e.g., interactive imagery or sentence generation) to process the to-be-remembered words than for individuals who report using less effective ones (e.g., rote repetition or no rehearsal). Thus, strategies do influence individual differences in span performance, but the fast-paced nature of span tasks makes using strategies difficult, so strategy use is far from prevalent. For instance, Dunlosky and Kane (2007) found that only 30% of younger adults report using effective strategies on the operation span (OSPAN) task, which is a span task similar to the RSPAN task and is described in detail in the introduction to Experiment 2.

Second, age differences in strategy use have been observed on episodic memory tasks. For example, Hertzog, McGuire, and Lineweaver (1998) found that a larger percentage of young adults than older adults produce effective strategies on a free recall task (see also Zivian & Darjes, 1983). Older adults are also less likely to spontaneously use verbal or imaginal mediators for associative memory tests (Kausler, 1994; Dunlosky & Hertzog, 2001; for an exception, see Hertzog, Dunlosky, & Robinson, 2008). Thus, age-related deficits in span performance may arise because young adults are also more strategic on span tasks than are older adults. As compared to episodic memory tasks, span tasks place more demands on the central executive by requiring concurrent processing while encoding the to-be-remembered words (Engle, Tuholski, Laughlin, & Conway, 1999). More cognitively-demanding tasks may exaggerate the age differences in strategy production by constraining allocation of resources needed to implement encoding strategies (Naveh-Benjamin, Craik, Guez, & Krueger, 2005). Any speed-of-processing constraints on implementing strategies could have a larger effect on older adults, given age-related slowing of information processing speed (Verhaeghen & Marcoen, 1994). Age-related deficiencies in executive functioning, combined with the difficulty in producing strategies on span tasks, could produce larger age differences in strategy use on span tasks than has been observed with episodic memory tasks. The strategy-deficit hypothesis predicts (a) that age-related deficits will arise in the production of effective encoding strategies while performing a span task, and in turn, (b) these strategic deficits will account for some of the age-related variance in span performance.

Experiment 1

To evaluate the strategy-deficit hypothesis in Experiment 1, we compared young and older adults' strategy production on the RSPAN task. Strategy production was measured through strategy reports about which strategy was used to remember the words for each set. After each trial, participants were probed on whether they used reading, repetition, sentence generation, mental imagery, meaningful grouping, or some other strategy to remember the critical words in that set. These particular strategy options were chosen because prior research indicated that people use them on verbal span tasks (Dunlosky & Kane, 2007; Turley-Ames & Whitfield, 2003). Each strategy was described in a jargon-free manner, such as repetition means that "I repeated the words as much as possible" and sentence generation means that "I used a sentence to link the words together" (for an example of the full prompt used to obtain strategy reports, see Dunlosky & Kane, 2007). As important, we did not provide information regarding which strategies are the normatively most effective in an attempt to minimize demand characteristics on strategy production. Making these strategy reports during the task has had minimal reactive effects on reported strategies and on task performance (Dunloksy & Kane, 2007; Dunlosky & Hertzog, 2001). Nevertheless, given that the strategies were listed on each trial, the use of any given strategy by a participant may not have been entirely spontaneous.

In Experiment 1, we used the RSPAN task to assess whether age-related deficits in the production of effective encoding strategies arise during a span task. To do so, two analytic methods can be used. The first is the *a priori* method in which strategies are first categorized into two classes (normatively effective strategies and normatively less effective ones) before analyses of span performance are conducted for that experiment. In the present case, this categorization is based on decades of memory research indicating that memory performance is usually greater for imagery, sentence generation, and grouping (hence, normatively more effective strategies) than for reading and repetition (for reviews, see Dunlosky & Kane, 2007; Hertzog et al., 1998; Richardson, 1998). Next, the a priori categorization is validated against previous research by comparing span performance for the two classes of strategies. By contrast, for the *empirical* method, effective and less effective strategies are first determined by analyses of span performance for the given data set. For instance, in Experiment 1, strategies that yielded the highest span performance are categorized as effective, whereas strategies that yielded lower performance would be categorized as less effective.

Both methods have advantages and disadvantages. The a priori method may result in miscategorizing a particular strategy report for a given experiment (e.g., categorizing "reading" as normatively less effective for an experiment even though when people reported using it, they actually performed well). The empirical method can constrain the data such that individual differences in the use of empirically effective strategies *must* be related to span performance. For instance, as long as one kind of strategy yields high levels of span performance, then by fiat participants who more often use that strategy (even if it is merely "reading" the words) will perform the best on the span task. This potential problem with circularity is sidestepped by the a priori method. Given this rationale and to remain consistent with the a priori method used in similar research (for reviews, see Dunlosky & Hertzog, 1998; Richardson, 1998; Touron, Oransky, Meier, & Hines, 2007), we report results from the a priori method. Even so, we did conduct both analytic methods, and they supported the same conclusions in all cases but one, which we briefly mention in the Results section of Experiment 2.

After categorizing the strategies on the RSPAN task using the a priori method, we evaluated the strategy-deficit hypothesis by comparing how often young and older adults reported using normatively effective strategies and by evaluating whether individual differences in effective strategy use accounted for age-related variance in span performance.

Method

Participants—A total of 27 undergraduates (17 females) from introductory psychology courses at Kent State University participated to complete a course requirement. Their mean age was 19.2 years and mean years of education were 12.2 years. Older adults were recruited through a newspaper advertisement in northeast Ohio. Participants were screened for history of dementia, stroke, and medications for memory problems. After exclusions, a total of 25 older adults (13 females) participated in this experiment. Each person was paid $20 for their participation. The mean age for the older adults was 69 years and their mean years of education were 15.4 years.

All participants completed two measures of perceptual speed, the letter comparison task and the pattern comparison task, and one measure of vocabulary knowledge. The classic pattern of age differences was found in which young adults performed reliably better than older adults on both perceptual tasks, but older adults displayed reliably higher vocabulary knowledge than did young adults (Table 1).

Materials

RSPAN: Participants were presented either a conceptually valid or invalid sentence along with an unrelated word. They were instructed to read the sentence aloud, report whether it made sense, and then read the word aloud. Once the word was read aloud, the next sentence-word pair appeared on-screen. After the final pair of each set was presented, a recall cue prompted participants to write the target words in serial order. RSPAN consisted of 15 experimenter-paced trials that ranged from three to seven sentence-word pairs. In Experiment 1, pairs were presented in a descending format (i.e., the largest sets were presented first and the smallest sets were presented last) as in inspired by May et al. (1999), so that any age-related differences in span performance would be less attributable to deficits in inhibition.

Procedure—Participants completed a 2-hour session with multiple tasks. The first task was the RSPAN task. Following recall on each trial, participants provided set-by-set strategy reports. The pairs from each set were presented together on-screen, and participants indicated which strategy they used to remember the words in that set. The strategy options included passive reading, rote repetition, sentence generation, imagery, meaningful grouping, and “other.” After the RSPAN task, participants completed a demographics questionnaire, the letter comparison task, the pattern comparison task, and the vocabulary knowledge task, in that order.

Results

We first report overall RSPAN performance to demonstrate that age-related deficits occurred, and then we report span performance as a function of strategy use. Most important, to assess the strategy-deficit hypothesis, we present the proportion of each strategy that participants reported using and the degree to which production deficiencies can account for age-related variance in span performance.

RSPAN Performance—Overall performance on the RSPAN task was computed using partial-credit unit scoring, which is the mean proportion of correctly-recalled words not weighted by set size (for details, see Conway et al., 2005). As expected, age-related differences arose in RSPAN performance. Young adults recalled .53 of the to-be-remembered words, whereas older adults recalled .40 of the words, $t(50) = 3.38$, $p < .001$, Cohen’s (1988) $d = 0.96$.

WM Performance as a Function of Reported Strategy Use—We first computed span performance for each trial as a function of reported strategy, and then for each participant, we averaged across all trials for each kind of strategy report (Table 2). Next, we analyzed the performance data using the a priori method in which we categorized the strategy reports into two classes (as in Dunlosky & Kane, 2007): normatively effective strategies and normatively less effective ones. As in previous research, we considered interactive imagery, sentence generation, and grouping to be normatively effective, whereas passive reading and rote repetition were considered to be normatively less effective (for a review, Richardson, 1998). The “other” option was not a priori categorizable as effective or less effective, so it was not included in either class.

Using these two classes, we conducted the inferential analysis on span performance as a function of normatively effective versus less effective strategies (Figure 1). A 2 (age) × 2 (strategy type: effective vs. less effective) repeated-measures ANOVA revealed a reliable main effect for type of strategy, $F(1,36) = 13.75$, $p < .01$, $\eta^2 = .266$. RSPAN performance was greater when participants reported using effective than less effective strategies. The main effect of age approached significance, $F(1,36) = 3.186$, $p = .08$, $\eta^2 = .08$, but the Age × Strategy Type interaction was not reliable, $F(1,36) = 1.84$, $p = .18$, $\eta^2 = .03$. Because a trend toward an interaction is evident in Figure 1, we conducted a power analysis, which indicated that an additional 101 participants would be needed in both groups to obtain a reliable interaction with the obtained effect size (Faul, Erdfelder, Lang, & Buchner, 2007). In any event, the trend was in the direction of older adults demonstrating greater gains by using effective strategies. Older adults not only use effective strategies while performing a span task, they also benefit from using them.

We analyzed span performance as a function of effective strategy use and set size, separated into large (6 and 7) and small (3 and 4) set sizes. A 2 (age) × 2 (set size: large vs. small) repeated-measures ANOVA yielded a reliable main effect of set size, $F(1,26) = 37.19$, $p < .001$, $\eta^2 = .59$, indicating that participants performed significantly better on smaller (proportion correct = .70) as compared to larger set sizes (proportion correct = .41). Neither the main effect of age nor the Age × Set Size interaction were reliable, both *F*s < 1.

Proportion of Reported Strategy Use—The proportion of RSPAN trials on which each strategy was reported being used are presented in Table 3. Unexpectedly, young and older adults reported using a similar proportion of normatively effective strategies. Overall, young adults reported using effective strategies on approximately .27 of the RSPAN trials, whereas older adults reported using them on approximately .34 of the trials, $t(50) = .93$, $p = .18$, $d = .26$. The direction of the effect favored older adults, ruling out the strategy-deficit hypothesis in its most general form.

Averaged across trials and participants, young and older adults have similar proportions of reported strategy use. Yet, the same proportion of strategy use averaged across participants may actually result from a different pattern of strategy use at the level of individuals. For instance, each older adult may choose a single strategy across all trials, whereas young adults may switch strategies throughout the task. To explore this possibility, we examined the variability in strategy selection by assessing the total number of strategies used by each participant. As evident from inspection of Table 4, most participants used at least 2 or more different strategies and the variability of strategy selection did not differ reliably between the two age groups, Mann-Whitney $U = 287.5$, $p = .62$.

Although age-related equivalence in effective strategy use across all set sizes is apparent, perhaps averaging across set sizes masked an embedded interaction. In particular, effective strategies may have been used less frequently by older adults (as compared to younger adults) on the larger set sizes (e.g., 6 and 7) and more frequently by older adults on the smaller ones (e.g., 3 and 4). To evaluate this possibility, we conducted a 2 (age) × 2 (set size: large vs. small) repeated-measures ANOVA on the proportion of effective strategies. It revealed a reliable main effect of set size, $F(1,50) = 5.07$, $p < .05$, $\eta^2 = .09$, indicating that participants report using a significantly higher proportion of effective strategies on smaller sets (0.38) than on larger sets (0.28). More important, neither the main effect of age nor interaction of age and set size were reliable (both *F*s < 1). Young and older adults were equally strategic at both large (young $M = .25$; older $M = .31$, $d = 0.19$) and small set sizes (young $M = .33$; older $M = .43$, $d = 0.27$).

Accounting for Age-Related Variance in Span Performance—A hierarchical regression was conducted to compare the total amount of variance in RSPAN performance associated with age to the amount of variance in span performance associated with age after controlling for the proportion of effective strategy use. As would be expected from the direction of the age differences in strategy production, the proportion of effective strategy use did not account for any age-related variance in RSPAN performance. The total amount of variance in RSPAN performance associated with age was $R^2 = .19$, $\beta = -.14$, $p < .01$. After controlling for effective strategy use, age still accounted for RSPAN performance, $R^2 = .22$, $\beta = -.15$, $p < .001$.

To evaluate a prediction from the processing speed hypothesis, a second hierarchical regression was conducted to examine the amount of age-related variance in RSPAN performance after controlling for a composite perceptual speed variable (the average standardized scores on the letter comparison and pattern comparison tasks). After controlling for speed, the change in R^2 for age was .05, $\beta = -.08$, $p = .08$, compared to $R^2 = .19$, indicating that partialing on a measure of perceptual speed reduced the amount of age-related variance in span performance by 74 percent.

Discussion

Results from Experiment 1 demonstrated reliable age-related differences in RSPAN performance. Surprisingly, even though the span task demands executive functioning and older adults have shown strategy production deficits in other cognitive task domains, they reported using normatively effective strategies just as often as young adults did. Moreover, none of the age-related variance in span performance was accounted for by a strategy-production deficiency. These outcomes disconfirm the strategy-deficit hypothesis.

Experiment 2

Given the unexpected lack of support for the strategy-deficit hypothesis, it was critical to replicate the age equivalence in strategy use and to extend this surprising outcome to a different span task. Accordingly, we ran a new experiment with the RSPAN task to replicate outcomes from Experiment 1, and also added the OSPAN task. Moreover, Experiment 1 used a descending order of set-size presentation, which may have made the task less demanding (as in May et al., 1999), increasing the likelihood that older adults could successfully generate strategies. In Experiment 2, we used a random order of set sizes to provide more favorable conditions for the strategy-deficit hypothesis. If this hypothesis is disconfirmed for both span tasks under the revised task design, a strategic account of age-related deficits in WM span performance would appear untenable.

Finally, to further investigate the contribution of strategy use to memory performance, all participants completed two standard episodic memory tasks (paired-associate recall and free recall) and reported their strategy use. Previous research has reported either small age-related deficits or equivalencies in effective strategy use on these memory tasks (e.g., Dunlosky & Hertzog, 2001; Hertzog et al., 1998). Nevertheless, strategy production on them does provide evidence relevant to two secondary issues: (a) perhaps older adults in the present samples are more strategic than typical, which would be indicated by them reporting the use of more strategies (as compared to younger adults) on the episodic memory tasks (i.e., typically, age-related deficits or equivalence is reported); and (b) we could evaluate the degree to which individual differences in effective strategy use are stable across various memory tasks. Regarding the latter issue, if some people are consistently more strategic (e.g., strategic behavior forms a latent construct), then the correlations involving effective strategy use among all tasks should be high. If there are differences in strategic behavior for WM and episodic memory tasks, then strategy production in the two span tasks should correlate more highly with each other than with strategy production in the episodic memory tasks.

Method

Participants—A total of 35 undergraduates (24 females) from introductory psychology courses at Kent State University participated to complete a course requirement. Their mean age was 18.9 years and mean years of education were 12.1 years. Data for the older adult group from this experiment was collected at the Georgia Institute of Technology. A total of 33 older adults (22 females) participated in this experiment and each person was paid $20 for their participation. The mean age for the older adults was 71.1 years and their mean years of education were 15.9 years.

As in Experiment 1, all participants completed the two perceptual speed and vocabulary knowledge tasks. Again, young adults performed reliably better than older adults on both perceptual tasks, but older adults had reliably higher vocabulary scores than did young adults (Table 1).

Materials—The RSPAN task was conducted in a similar manner as in Experiment 1, with two exceptions. First, the range of set size difficulty was reduced to sets from three to six sentence-word pairs. Second, the order of set sizes was changed from a descending order to a randomized order that was used for all participants.

We modified the OSPAN task from Engle, Tuholski, Laughlin, and Conway (1999). Participants saw a mathematical operation and a to-be-remembered word (e.g., “Is (3 × 2) + 5 = 10? phone”). They read the equation aloud, reported whether it was correct, and then read the word aloud. Immediately thereafter, the next operation-word pair appeared on-screen. A recall cue followed the final pair of the trial, and participants wrote the target words in serial order. OSPAN consisted of 16 experimenter-paced trials that ranged from three to six operation-word pairs. The order of set sizes was initially randomized and that order was used for all participants. As in the RSPAN task, participants completed the set-by-set strategy reports.

Free recall: A list of 20 words appeared individually on-screen at a 5-second rate. Participants read recall instructions (to mitigate against a recency effect) and then recalled the words in any order. After recall, participants described the strategies they used to help them remember the words and they could indicate using more than one strategy. The percentage of participants that reported any given strategy was computed.

Paired-associate recall: Participants studied 40 unrelated word pairs (e.g., DOCTOR – LOBSTER) presented on the computer screen at a 5-second rate. During the recall phase, the cue (e.g., DOCTOR) was presented and participants typed in the correct response (e.g., LOBSTER). Following recall, participants were presented with the list again, and completed a strategy report in which they recounted which specific strategy (passive reading, rote repetition, interactive imagery, sentence generation, or "other") they had used to study each word pair (Dunlosky & Hertzog, 2001).

Procedure—Participants completed a 2-hour session in which the order of tasks for each individual consisted of completing the RSPAN task, a demographics questionnaire, the perceptual speed and vocabulary tasks, the free recall task, the OSPAN task, and the paired-associate recall task.

Results

Performance on Span Tasks and on the Standard Memory Tasks—Performance on both span tasks is presented in Table 5. In accord with previous research, performance on the two span tasks was highly correlated (all participants, $r = .78$; young adults only, $r = .71$; older adults only, $r = .77$). A reliable age-related difference was observed on the RSPAN task, $t(66) = 3.38$, $p < .001$, $d = 0.83$. Although changing the format of the RSPAN task seemed to improve overall span performance (as compared to outcomes from Experiment 1), this increase most likely was due to dropping set size 7 in the second experiment. A reliable age difference also was found on the OSPAN task, $t(66) = 2.09$, $p < .05$, $d = 0.51$.

The proportion of correctly recalled words for the episodic memory tasks is also reported in Table 5. Reliable age-related differences occurred on the paired-associate recall task, $t(61) = 3.2$, $p < .001$, $d = 0.82$, and on the free-recall task, $t(72) = 2.97$, $p < .01$, $d = 0.70$.

WM Performance as a Function of Reported Strategy Use—Span performance as a function of strategy reports is reported in Table 6. Given that our focus was on differences between normatively effective versus less effective strategies, we conducted analyses collapsed across them. Separate 2 (age) × 2 (strategy type) repeated-measures ANOVAs were conducted for each of the span tasks.

For OSPAN, performance as a function of strategy effectiveness is presented in the top panel of Figure 2. The ANOVA on the OSPAN task revealed two reliable main effects: age, $F(1,32) = 7.34$, $p < .05$, $\eta^2 = .19$, and strategy type, $F(1,32) = 7.45$, $p < .05$, $\eta^2 = .16$. The Age × Strategy Type interaction was not reliable, $F(1,32) = 0.37$, $p = .55$, $\eta^2 = .01$. For the RSPAN task (bottom panel of Figure 2), the ANOVA revealed a reliable main effect for strategy type, $F(1,46) = 4.07$, $p < .05$, $\eta^2 = .08$. Neither the main effect for age nor the Age × Strategy interaction were reliable, Fs < 1.62, ps >.21, η^2s < .03. The lack of age effects occurred despite the reliable main effects of strategy type on both span tasks.

Again, analyses of span performance as a function of effective strategy use and set size yielded a reliable main effect of set size, RSPAN: $F(1,40) = 64.76$, $p < .001$, $\eta^2 = .62$, OSPAN: $F(1,27) = 22.16$, $p < .001$, $\eta^2 = .45$, indicating that participants perform significantly better on smaller (RSPAN = .81; OSPAN = .91) as compared to larger set sizes (RSPAN = .58; OSPAN = .69). No reliable main effects of age or Age × Set Size interactions for either RSPAN or OSPAN performance, all *F*s < 1. Results indicate that young and older adults benefit similarly from effective strategies at both large and small set sizes.

Episodic Memory Performance as a Function of Effective Strategy Use—For the paired-associate task, mean proportion of correct recall performance was .72 (*SEM* = .07) when younger adults reported using effective strategies (imagery, sentence generation) and .27 (*SEM* = .07) when they used less effective ones (reading and repetition); mean recall was .58 (*SEM* = .06) when older adults reported using effective strategies and .08 (*SEM* = .04) when they used less effective ones. A 2 X 2 ANOVA revealed a reliable main effect of age, $F(1,43) = 5.90$, $p < .05$, $\eta^2 = .12$, and reliable main effect of strategy type, $F(1,43) = 5.06$, $p < .001$, $\eta^2 = .64$. The Age × Strategy Type interaction was not reliable, $F(1,43) = 0.21$, $p = .65$.

For free recall, strategy reports were not collected for individual words. Thus, to examine performance as a function of strategy use, we compared the proportion of correctly-recalled words for participants who reported using an effective strategy (imagery, sentence generation and grouping) versus those who only reported using less effective ones (reading and repetition). The proportion of mean recall for younger adults who reported using effective strategies was . 54 (*SEM* = .04) and was .40 (*SEM* = .03) for those who used less effective ones; the corresponding values for older adults were .40 (*SEM* = .05) and .29 (*SEM* = .03), respectively. A 2 X 2 full-factorial ANOVA revealed a reliable main effect of age, $F(1,70) = 10.1$, $p < .05$, $\eta^2 = .02$, and reliable main effect of strategy type, $F(1,70) = 11.5$, $p < .01$, $\eta^2 = .02$. The Age × Strategy Type interaction was not reliable, $F(1,70) = 0.22$, $p = .64$.

Proportion of Reported Strategy Use

Span tasks: Table 7 presents the proportion of trials that participants reported using each strategy on the RSPAN task and on the OSPAN task. As in Experiment 1, we analyzed the reports by dividing them into two categories: normatively effective strategies and normatively less effective ones. No age differences occurred in the proportion of effective strategies reported for the RSPAN task (.36 for young adults; .34 for older adults; $t(66) = 0.18$, $p = .43$, $d = .04$) and for the OSPAN task (.29 for young adults; .28 for older adults; $t(63) = .15$, $p = .44$, $d = .04$).[1]

To further examine strategy use, we evaluated whether age-related differences occurred in the number of different strategies that individual participants reported using (Table 4). The variability of strategy selection did not differ significantly between the two age groups either on the RSPAN task, $U = 537.5$, $p = .61$, or the OSPAN task, $U = 504.0$, $p = .36$.

Again, we examined whether age-related differences in strategy production exist at either large (e.g., 5 and 6) or small (e.g., 3 and 4) set sizes separately for the RSPAN and OSPAN tasks. 2 (age) × 2 (set size) repeated-measures ANOVAs revealed no reliable main effects of age or set size and no reliable Age × Set Size interaction on either span task. Of particular interest is that

[1]The only analysis in which results from the a priori and empirical methods diverge is on the OSPAN task. Using the empirical method, repetition and sentence generation yielded the highest span performance and would be considered effective strategies, whereas reading, imagery, and grouping would have been considered less effective strategies. With this classification, effective strategies (and in particular, repetition) were produced on significantly more trials by young adults than by older adults. Most important, age-related differences in effective strategies (based on the empirical method) did not account for the observed deficit in span performance. Thus, both analytic methods yielded identical conclusions about the strategydeficit hypothesis.

young and older adults report using similar proportions of effective strategies at large set sizes on both the RSPAN task (young *M* = .35; older *M* = .37, *d* = 0.07) and OSPAN task (young *M* = .28; older *M* = .32, *d* = 0.10).

Episodic memory tasks: Reported strategy use on the episodic memory tasks is presented in Table 7. On the paired-associate task, young adults reported using normatively effective strategies (such as interactive imagery and sentence generation) on 53% of the word pairs and older adults reported using them on 48% of the pairs, $t(61) = 0.63$, $p = .27$, $d = .16$. On the free recall task, 59% of young adults reported using effective strategies, whereas 49% of older adults did so, $t(72) = 0.70$, $p = .25$, $d = .16$. These outcomes are consistent with previous research, which demonstrated small (Dunlosky & Hertzog, 2001;Hertzog et al., 1998) to minimal (Hertzog et al., 2008) age-related deficits in strategy production.

Accounting for Age-Related Variance in Span Performance—To evaluate whether strategy production and processing speed accounted for the age-related variance in span performance, hierarchical regressions were conducted separately for the RSPAN and OSPAN tasks. For the RSPAN task, the total amount of variance in span performance associated with age was $R^2 = .15$, $\beta = -.13$, $p < .001$. After controlling for effective strategy use, the change in R^2 for adding age was .14, $\beta = -.12$, $p < .001$, which was only a 5 percent reduction in age-related variance. By contrast, when the variance due to processing speed was controlled, the change in R^2 for adding age was .04, $\beta = -.08$, $p = .07$. This change in R^2 translates into a 72 percent reduction in age-related variance in span performance.

For the OSPAN task, the total amount of age-related variance in span performance was $R^2 = .11$, $\beta = -.12$, $p < .01$, and after controlling for effective strategy use, the change in R^2 for adding age was .11, $\beta = -.12$, $p < .01$. Thus, controlling for effective strategy use did not reduce the age-related variance in span performance. By contrast, partialing the variance associated with processing speed produced a change in R^2 for adding age equal to .05, $\beta = -.09$, $p = .08$, which translates into a 59 percent reduction in age-related variance in span performance.

Correlations of Effective Strategy Use Among the Four Memory Tasks—Finally, we examined the relationships of effective strategy use among the four tasks. Across individuals, we correlated the proportion of reported effective strategy use among the RSPAN, OSPAN, paired-associate, and free-recall tasks. For free recall, each individual received either a 1 if they reported using any effective strategies or a 0 if they did not. Given that reliable age-related differences did not arise in strategy production, we conducted these correlational analysis collapsed across age groups. The correlation involving the proportion of effective strategy use between the RSPAN and OSPAN tasks was .72, $p < .01$. The correlations involving effective strategy use on the free-recall task were .47 with the RSPAN task, $p < .01$, .29 with the OSPAN task, $p < .05$, and .16 with the paired-associate task, $p > .05$. The correlations involving the paired-associate task and both the span tasks were less than .18, *p*s > .05. Strategy use on the span tasks was highly consistent, suggesting reliable individual differences in strategic behavior and convergent validity of the two span tasks. More strategic participants on the span tasks were more strategic on the free recall task. Nevertheless, participants who were the most strategic on one task were not necessarily the most strategic on all of them, suggesting that effective strategy use varies across the type of memory task being assessed.

Discussion

In Experiment 2, age-related differences in overall span performance occurred both on the RSPAN task and on the OSPAN task. As in Experiment 1, young and older adults reported using similar proportions of effective strategy use on both tasks. These outcomes disconfirm the strategy-deficit hypothesis. Results from Experiment 2 also rule out an uninteresting explanation for why we failed to find age-related deficits in strategy production; namely, that the lack of an age-related strategy deficit on the span tasks cannot be due to the fact that the current sample of older adults is more proficient at employing strategies, thereby masking a WM strategy production deficit. In particular, our earlier work has found that age differences in effective strategy production on episodic memory tasks are either relatively small in size (Dunlosky & Hertzog, 2001; Hertzog et al., 1998) or are virtually nonexistent (Dunlosky & Hertzog, 1998). The results from the present experiment are consistent with these previous findings (i.e., unreliable trends toward an age-related deficit in strategy production). Furthermore, the high correlation of span task strategy production for the RSPAN and OSPAN tasks indicates consistent individual differences in reported effective strategy use. Together with the strong relationship of strategy production reports to span performance, the data suggest good reliability of the strategy report measures.

General Discussion

A major goal of the present experiments was to evaluate the degree to which age-related deficits in strategy production account for the well-documented age differences in WM span performance. Evidence from two experiments consistently disconfirmed the strategy-deficit hypothesis. In particular, young and older adults reported using the same proportion of normatively effective strategies on both the RSPAN and OSPAN tasks (Table 3 & Table 7). This outcome may seem surprising given the demanding nature of span tasks and strategy deployment, but we recently became aware of an independent study that also demonstrated age equivalence in strategy production on the OSPAN task (Touron et al., 2007). Although Touron et al.'s (2007) focus was on metacognitive monitoring during span tasks, they collected set-by-set strategy reports in Experiment 2. In contrast to the present experiments in which participants made concurrent strategy reports, participants in their experiment first completed the entire OSPAN task and then made a strategy report for each set. Their retrospective strategy reports of effective strategy use were not reliably different for the younger and older adults. Thus, evidence from two laboratories converges on the conclusion that age-related deficits in strategy production during verbal span tasks cannot account for deficits on those tasks.

Given these outcomes, the question arises as to whether strategic behavior of any kind can account for age-related deficits in span performance. That is, whereas the strategy-deficit hypothesis focuses on a production deficiency at encoding, other aspects of strategy use may contribute to the age differences in span performance. Another type of strategic deficiency relevant to age-related deficits in memory is the utilization deficiency. A utilization deficiency is when mediators are produced at encoding, yet they have a minimal influence on task performance (Miller, 1994; Miller, Seier, Barron, & Probert, 1994). Our results are inconsistent with a utilization deficiency because both young and older adults on average benefited from the use of normatively effective strategies.

Two other kinds of deficiency are relevant: a *retrieval deficiency*, in which the mediators are less likely to be retrieved at test by older adults than by young adults, and a *decoding deficiency*, in which mediators are retrieved but less likely to be decoded correctly by older adults. Both of these deficiencies account for some of the age-related deficits demonstrated in associative learning. In particular, even when older and younger adults produce effective mediators while learning word pairs, older adults are more likely to forget the mediators during the test, and when they remember them, they are less likely to produce the correct response (Dunlosky, Hertzog, & Powell-Moman, 2005). To directly evaluate the contribution of these deficiencies, one would need to measure the specific strategies (e.g., the specific images or sentences generated) at encoding and have participants attempt to recall those strategies again at test, which was not done in the present study. However, evidence from Figure 1 and Figure 2 indirectly suggest that these deficiencies will account for only a small proportion (if any) of the age-related variance in WM span performance. For instance, when they reported using normatively effective strategies, older adults obtained almost the same levels of span performance as did young adults, which suggests that both groups are just as effective at retrieving and decoding their mediators. Moreover, in contrast to paired-associate tasks that have relatively long retention intervals between encoding and test trials, mediators are unlikely to be forgotten or incorrectly decoded on span tasks when the retention interval is minimal.

Importantly, however, even though effective strategy production did not account for age-related deficits in span performance, individual differences in effective strategy use did account for a large proportion of the variance in span performance. To further demonstrate this empirical generalization (see also, outcomes from regression analysis reported above), we computed correlations between the proportion of normatively effective strategy use and span performance. In Experiment 1, Pearson *r*s equaled .42 and .37, for younger and older adults, respectively. In Experiment 2, for younger and older adults, respectively, *r*s equaled .23 ($p = .09$) and .60 for the RSPAN task, and .40 and .52 for the OSPAN task. When computed across all participants, the *r*s ranged from 0.27 to 0.44 (all ps $< .05$) across both experiments. These outcomes are consistent with reports that strategy use influences span performance in young adults (Dunlosky & Kane, 2007; Kaakinen & Hyona, in press; McNamara & Scott, 2001; Turley-Ames & Whitfield, 2003), and importantly, extends them to older adults. Thus, strategy use is an important determinant of individual differences in span performance across the life span, even though it cannot account for age-related deficits in span performance.

Although our main goal was to evaluate the strategy-deficit hypothesis, evidence from these experiments are consistent with the processing-speed account (Salthouse, 1991) described in our Introduction. That is, after controlling for processing speed, the age-related variance in span performance was reduced by between 59 percent (Experiment 2) and 74 percent (Experiment 1). Even as the results demonstrated that performance on perceptual speed tasks explains a large amount of the relationship between span performance and age, processing speed may not necessarily be the underlying cause of the age-related deficit. Lindenberger and Baltes (1997) reported that measures of perceptual speed and sensorimotor abilities shared approximately 72% of their variance, which could suggest that processing speed is a marker for reduced sensory functioning or degeneration of another neural mechanism altogether.

In summary, the current experiments evaluated a plausible hypothesis for why age-related deficits arise on verbal span tasks; namely, that as compared to younger adults, older adults have more difficulties in producing effective strategies. Although effective strategy use explained a substantial proportion of variance in span performance, it could not explain any of the age-related variance in span performance, which was better accounted for by structural deficits as measured by speed of processing.

References

Baddeley, AD. Working memory. Oxford University Press; 1986.

Cohen, J. Statistical power analysis for the behavioral sciences. Vol. 2nd ed.. Hillsdale, NJ: Erlbaum; 1988.

Conway ARA, Kane MJ, Bunting MF, Hambrick DZ, Wilhelm O, Engle RW. Working memory span tasks: A methodological review and user's guide. Psychonomic Bulletin and Review 2005;12:769–786. [PubMed: 16523997]

Daneman M, Carpenter PA. Individual differences in working memory and reading. Journal of Verbal Learning and Verbal Behavior 1980;19:450–466.

Dunlosky J, Hertzog C. Aging and deficits in associative memory: What is the role of strategy production? Psychology and Aging 1998;13:597–607. [PubMed: 9883460]

Dunlosky J, Hertzog C. Measuring strategy production during associative learning: The Relative Utility of Concurrent versus Retrospective Reports. Memory & Cognition 2001;29:247–253.

Dunlosky J, Hertzog C, Powell-Moman A. The contribution of mediator-based deficiencies to age differences in associative learning. Developmental Psychology 2005;41:389–400. [PubMed: 15769194]

Dunlosky J, Kane MJ. The contributions of strategy use to working memory span: A comparison of strategy assessment methods. The Quarterly Journal of Experimental Psychology 2007;60:1227–1245. [PubMed: 17676555]

Engle RW, Tuholski SW, Laughlin JE, Conway ARA. Working memory, short-term memory, and general fluid intelligence: A latent-variable approach. Journal of Experimental Psychology: General 1999;128:309–331. [PubMed: 10513398]

Faul F, Erdfelder E, Lang A-G, Buchner A. G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behavior Research Methods 2007;39:175–191. [PubMed: 17695343]

Friedman NP, Miyake A. The reading span test and its predictive power for reading comprehension ability. Journal of Memory and Language 2004;51:136–158.

Hasher L, Zacks RT. Working memory, comprehension, and aging: A review and a new view. The Psychology of Learning and Motivation 1988;22:193–225.

Hertzog C. Influences of cognitive slowing on age differences in intelligence. Developmental Psychology 1989;25:636–651.

Hertzog C, Dunlosky J, Robinson AE. Intellectual abilities and metacognitive beliefs influence spontaneous use of effective encoding strategies. 2008Unpublished manuscript

Hertzog C, McGuire CL, Lineweaver TT. Aging, attributions, perceived control, and strategy use in a free recall task. Aging, Neuropsychology, and Cognition 1998;5:85–106.

Jenkins L, Myerson J, Hale S, Fry AF. Individual and developmental differences in working memory across the life span. Psychonomic Bulletin & Review 1999;6:28–40. [PubMed: 12199312]

Kaakinen JK, Hyona J. Strategy use in the reading span test: An analysis of eye movements and reported encoding strategies. Memory. (in press)

Kausler, DH. Learning and memory in normal aging. San Diego, CA: Academic Press; 1994.

Lindenberger U, Baltes PB. Intellectual functioning in old and very old age: Cross-sectional results from the Berlin Aging Study. Psychology and Aging 1997;12:410–432. [PubMed: 9308090]

May CP, Hasher L, Kane MJ. The role of interference in memory span. Memory and Cognition 1999;27:759–767.

McNamara DS, Scott JL. Working memory capacity and strategy use. Memory and Cognition 2001;29:10–17.

Miller PH. Individual differences in children's strategic behavior: Utilization deficiencies. Learning and Individual Differences 1994;6:285–307.

Miller PH, Seier WL, Barron KL, Probert JS. What causes a utilization deficiency? Cognitive Development 1994;9:77–102.

Naveh-Benjamin M, Craik FIM, Guez J, Kreuger S. 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 and Cognition 2005;31:520–537.

Richardson JTE. The availability and effectiveness of reported mediators in associative learning: A historical review and an experimental investigation. Psychonomic Bulletin & Review 1998;5:597–614.

Salthouse TA. Mediation of adult age differences in cognition by reductions in working memory and speed of processing. Psychological Science 1991;2:179–183.

Salthouse TA. Influences of processing speed on adult age differences in working memory. Acta Psychologica 1992;79:155–170. [PubMed: 1598844]

Salthouse TA. The aging of working memory. Neuropsychology 1994;8:535–543.

Salthouse TA. The processing-speed theory of adult age differences in cognition. Psychological Review 1996;103:403–428. [PubMed: 8759042]

Salthouse TA, Babcock RL. Decomposing adult age differences in working memory. Developmental Psychology 1991;27:763–776.

Touron, DR.; Oransky, N.; Meier, ME.; Hines, JC. Poster presented at the 2007 Meeting of the Psychonomic Society. Long Beach, CA: 2007. Does metacognitive monitoring influence age differences in working memory performance?.

Turley-Ames KJ, Whitfield MM. Strategy training and working memory task performance. Journal of Memory and Language 2003;49:446–468.

Verhaeghen P, Marcoen A. Production deficiency hypothesis revisited: Adult age differences in strategy use as a function of processing resources. Aging and Cognition 1994;1:323–338.

Zivian MT, Darjes RW. Free recall by in-school and out-of-school adults: Performance and metamemory. Developmental Psychology 1983;19:513–520.

Acknowledgements

This research was supported by a grant from the National Institute on Aging, one of the National Institutes of Health (R37 AG13148).

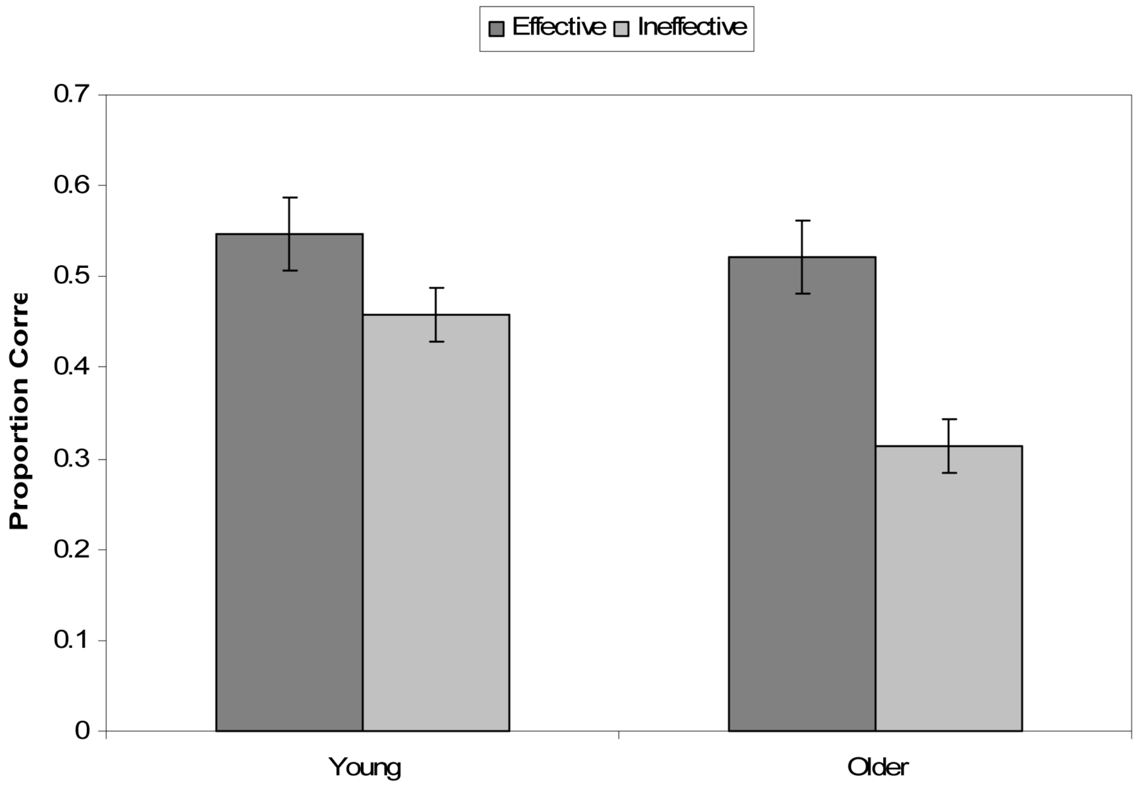

Figure 1.
Mean proportion correct on the RSPAN task as a function of normatively effective strategies (Effective) and less effective strategies (Ineffective) for young and older adults in Experiment 1. Error bars represent the standard errors of each mean.

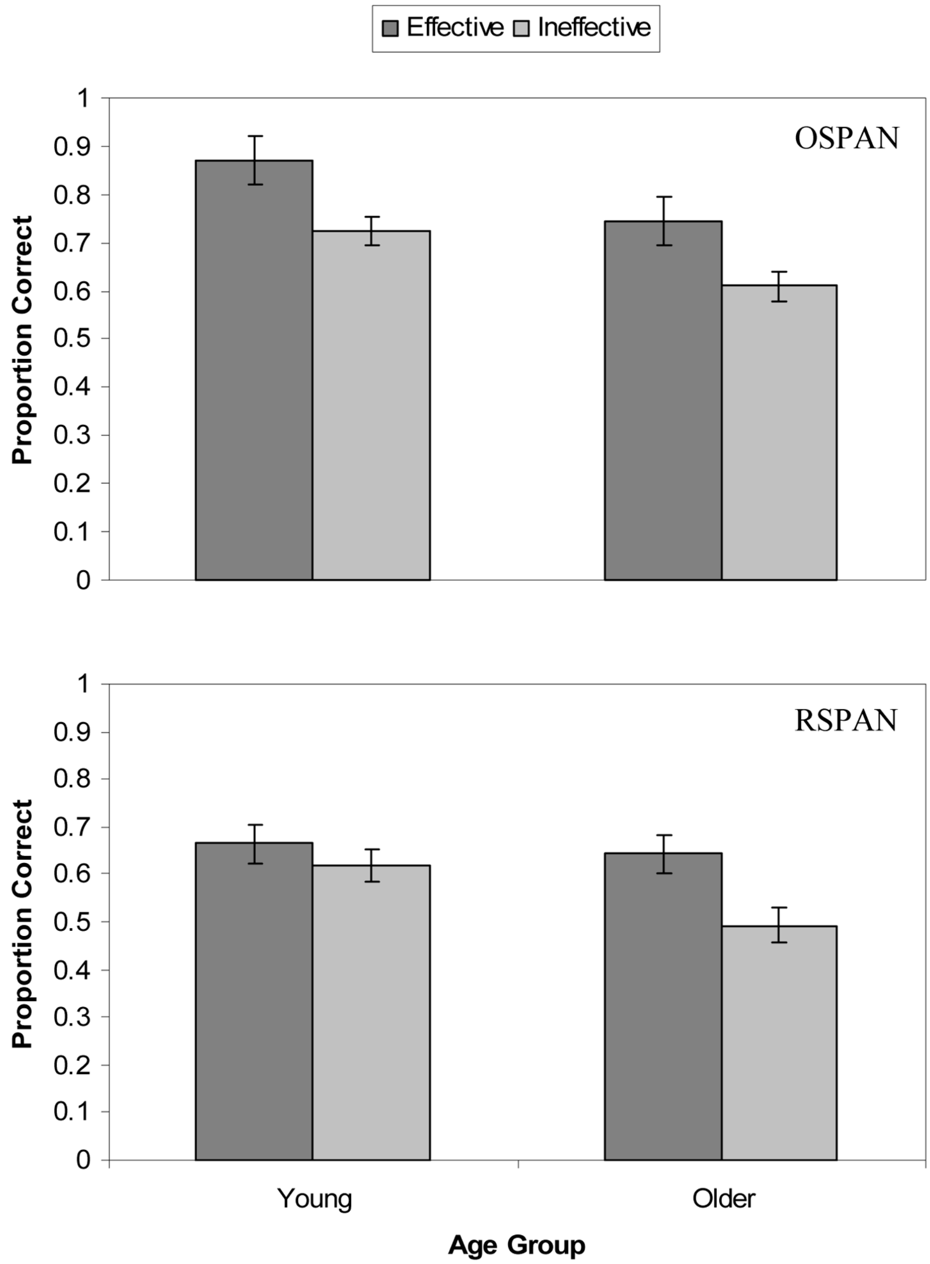

Figure 2.

Mean proportion correct on the OSPAN task (top panel) and the RSPAN task (bottom panel) as a function of normatively effective strategies (Effective) and less effective strategies (Ineffective) for young and older adults in Experiment 2. Error bars represent the standard errors of each mean.

Table 1

Demographics

	Young	**Older**	***t*-values**	***d***
		Experiment 1		
Letter Comparison	21.4 (0.8)	17.4 (0.9)	3.36	0.95
Pattern Comparison	40.5 (1.2)	32.1 (1.3)	4.72	1.34
Vocabulary	12.2 (0.5)	20.1 (1.2)	−6.25	1.76
Years of Education	12.2 (0.2)	15.4 (0.6)	−5.16	1.46
		Experiment 2		
Letter Comparison	21.5 (0.7)	18.5 (0.8)	2.62	0.64
Pattern Comparison	41.4 (1.2)	30.5 (1.2)	6.38	1.57
Vocabulary	13.5 (0.7)	21.2 (1.3)	−5.53	1.36
Years of Education	12.1 (0.4)	15.9 (2.5)	−8.80	2.19

Note. Maximum Vocabulary score = 36; maximum Letter Comparison = 42 and maximum Pattern Comparison = 60. Standard errors for the corresponding means are in parentheses.

Table 2

RSPAN Performance as a Function of Strategy Use for Experiment 1

	Read	Repeat	Imagery	Sentence	Group	Other
Young	.36 (.03)	.51 (.03)	.58 (.04)	.50 (.06)	.53 (.11)	.47 (.11)
Old	.25 (.05)	.37 (.04)	.48 (.06)	.41 (.08)	.59 (.09)	.24 (.05)

Note. Standard errors of the means are reported in parentheses.

NIH-PA Author Manuscript
NIH-PA Author Manuscript

Table 3

Proportion of Reported Strategy Use on the RSPAN Task for Experiment 1

	Read	Repeat	Imagery	Sentence	Group	Other
Young	.21 (.07)	.47 (.07)	.14 (.02)	.08 (.04)	.05 (.02)	.05 (.02)
Old	.17 (.05)	.40 (.07)	.11 (.04)	.12 (.04)	.11 (.03)	.09 (.03)

Note. Standard errors of the means are reported in parentheses.

NIH-PA Author Manuscript
NIH-PA Author Manuscript

Table 4

Number of Participants Using a Given Number of Different Strategies

	1	2	3	4	5
Experiment 1					
RSPAN					
Young	5	5	8	6	3
Old	4	5	8	4	4
Experiment 2					
RSPAN					
Young	1	12	14	6	2
Old	5	9	11	5	3
OSPAN					
Young	11	12	9	3	0
Old	8	13	7	5	0

Note. In Experiment 1, we used only the RSPAN task. “1” means that these participants used only one strategy on the particular task. The number of different strategies does not include the “other” strategy.

Table 5

Recall Performance for Experiment 2

	Young	**Old**
RSPAN	.66 (.02)	.53 (.03)
OSPAN	.75 (.03)	.65 (.04)
PA Recall	.57 (.05)	.35 (.05)
Free Recall	.46 (.03)	.34 (.03)

Note. Standard errors of the means are reported in parentheses.

NIH-PA Author Manuscript
NIH-PA Author Manuscript

Table 6

WM Performance as a Function of Reported Strategy Use for Experiment 2

	Read	**Repeat**	**Imagery**	**Sentence**	**Group**	**Other**
RSPAN						
Young	.51 (.05)	.66 (.03)	.66 (.05)	.70 (.04)	.69 (.08)	.58 (.08)
Old	.43 (.05)	.52 (.04)	.58 (.08)	.65 (.05)	.74 (.04)	.37 (.10)
OSPAN						
Young	.65 (.08)	.75 (.04)	.92 (.04)	.78 (.06)	.86 (.06)	.55 (.19)
Old	.57 (.06)	.65 (.05)	.62 (.10)	.76 (.07)	.76 (.08)	.63 (.09)

Note. Standard errors of the means are reported in parentheses.

Table 7

Proportion of Reported Strategy Use in Memory Tasks for Experiment 2

	Read	Repeat	Imagery	Sentence	Group	Other
RSPAN						
Young	.13 (.03)	.47 (.05)	.14 (.03)	.18 (.04)	.04 (.01)	.04 (.01)
Old	.19 (.05)	.45 (.07)	.05 (.02)	.20 (.05)	.09 (.03)	.02 (.01)
OSPAN						
Young	.14 (.05)	.56 (.06)	.08 (.03)	.16 (.05)	.05 (.02)	.01 (.01)
Old	.28 (.06)	.40 (.07)	.08 (.03)	.10 (.04)	.10 (.04)	.04 (.01)
Paired-Associate Recall						
Young	.12 (.04)	.22 (.05)	.34 (.06)	.19 (.05)	N/A	.11 (.05)
Old	.25 (.05)	.24 (.06)	.38 (.06)	.10 (.04)	N/A	.03 (.01)
Free Recall						
Young	.01 (.01)	.71 (.05)	.17 (.05)	.21 (.05)	.26 (.05)	.19 (.05)
Old	.01 (.01)	.42 (.06)	.21 (.05)	.19 (.05)	.15 (.04)	.36 (.06)

Note. Standard errors of the means are reported in parentheses. Given that reported strategy use for free recall was at the task level (versus item level), proportion of strategy use does not add to 1.0 because participants could report using more than one strategy on the task.