

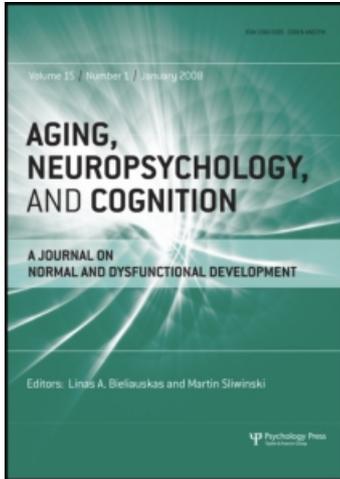
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Are There Age Differences in the Executive Component of Working Memory? Evidence from Domain-General Interference Effects

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ABSTRACT

Young and older adults performed verbal and spatial storage-only and storage-plus-processing working memory tasks while performing a secondary finger tapping task, and the effects on both the maximum capacity (measured as the longest series correct) and the reliability (measured as the proportion of items correct) of working memory were assessed. Tapping tended to produce greater disruption of working memory tasks that place greater demands on executive processes (i.e., storage-plus-processing tasks compared to storage-only span tasks). Moreover, tapping produced domain-general interference, disrupting both verbal and spatial working memory, providing further support for the idea that tapping interferes with the executive component of the working memory system, rather than domain-specific maintenance processes. Nevertheless, tapping generally produced equivalent interference effects in young and older adults. Taken together, these findings are inconsistent with the hypothesis that age-related declines in working memory are primarily attributable to a deficit in the executive component.

Keywords: Working memory; Short-term memory; Aging; Executive; Dual-task; Item-manipulation.

INTRODUCTION

Most models of working memory (e.g., Baddeley, 1986; Engle, Laughlin, Tuholski, & Conway, 1999) assume that there are at least two types of processes composing working memory: domain-general executive processes and domain-specific maintenance processes (e.g., rehearsal). Aging could

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have an effect on either one or both of these types of processes, and it is important to determine whether the well established decline in working memory with age (Bopp & Verhaeghen, 2005; Salthouse, 1994) is part of a more general decline or whether specific working memory processes are particularly age-sensitive. One long-standing proposal in the literature is that executive aspects of working memory may be more affected by aging than is storage capacity (e.g., Babcock & Salthouse, 1990; Craik, 1977; Dempster, 1992; Moscovitch & Winocur, 1992; West, 1996).

One widely used approach to examining the effects of aging on working memory is to compare young and older adults' performance on dual-task procedures that involve a primary memory task and a secondary, non-memory task. Such storage-plus-processing tasks are sometimes termed complex span tasks (Engle et al., 1999) to distinguish them from simple span tasks that require only temporary storage of memory items. Because complex/storage-plus-processing tasks (e.g., operation span) require participants to switch attention back and forth between the primary memory task and the secondary processing task, all the while coordinating the encoding of memory items and the processing of other stimuli which do not have to be remembered, it is thought that they place greater demands on executive processes than simple/storage-only span tasks (Baddeley, 1996; Baddeley & Della Sala, 1996; Engle et al., 1999; Oberauer, Lange, & Engle, 2004).

Working Memory and Aging

Two meta-analyses have reported that age differences in memory span are larger on storage-plus-processing tasks than on tasks that require storage only. In an early meta-analysis, Babcock and Salthouse (1990) found that when they compared performance on storage-only and storage-plus-processing span tasks that involved the same type of information (e.g., digit span vs. computation span, word span vs. reading span), the differences between young and older adults were slightly larger for the storage-plus-processing tasks (complex) span tasks, suggesting that older adults may have a specific deficit in the executive (central-processing) component of working memory. A more recent meta-analysis by Bopp and Verhaeghen (2005) reached similar conclusions. However, another meta-analysis by Jenkins, Myerson, Hale, and Fry (1999), which reviewed a number of studies by Hale and her colleagues, found equivalent age differences on storage-only and storage-plus-processing span tasks.

It should be noted that in addition to their meta-analytic findings, Babcock and Salthouse (1990) also reported the results of three working memory experiments conducted in their own laboratory, two of which compared performance by young and older adults. In both of these experiments, young and older adults performed a storage-only span task (serial recall of digits) and a storage-plus-processing span task (computation span) that

required remembering digits as well as performing a secondary processing component (solving simple arithmetic problems). In both experiments, Babcock and Salthouse found that the age difference on the storage-plus-processing task was no larger than that on the storage-only span task. Based on their own experimental results, the authors concluded that “age differences in memory span seem to be independent of the amount of concurrent processing required in the task” (p. 425).

A number of other studies have also failed to find evidence of greater age differences on storage-plus-processing span tasks. For example, Belleville, Rouleau, and Caza (1998) and McCabe and Hartman (2003) both found that controlling for age differences in simple storage capacity, either experimentally or statistically, eliminated age differences on storage-plus-processing tasks. Moreover, Hale and her colleagues have consistently found that age differences on storage-plus-processing span tasks are no greater than age differences on storage-only span tasks (for a meta-analytic review, see Jenkins et al., 1999). Thus, although some meta-analytic results suggest that older adults' memory spans are more affected by a concurrent secondary task than young adults' spans, there are clearly numerous exceptions to this finding. As a consequence, it appears that the executive deficit account of age differences in working memory is in need of careful reconsideration.

Same-Domain Interference in Working Memory

Not only is there reason to question the reliability of the finding that older adults' memory spans are more affected by secondary tasks, there is also reason to question whether this finding should be attributed to an age-related deficit in the executive component of the working memory system. As noted previously, maintenance processes are domain-specific, whereas executive processes are usually assumed to be domain-general. Nevertheless, most studies of age differences in working memory have used storage-plus-processing span tasks (e.g., reading span and operation span) in which the secondary tasks were from the same domain as the memory items (e.g., verbal or spatial). Under such circumstances, it is unclear whether the interference that results is due to disruption of domain-specific maintenance processes, disruption of domain-general executive processes, or both. This is because representations in working memory appear to be particularly sensitive to similarity-based (same-domain) interference caused by the overwriting of overlapping features (Nairne, 1990; Tehan & Humphreys, 1998). Indeed, Oberauer and Kliegl (2001) have suggested that age differences in working memory may in part be due to differential effects of such similarity-based interference and crosstalk between elements in memory, rather than being the result of an age-related deficit in the executive component (for a related suggestion, see Hale, Myerson, Emery, Lawrence, & Dufault, 2007).

To avoid the ambiguity that results when the stimuli for the primary memory task and the secondary processing task are from the same domain, it might seem that a better approach would be to compare young and older adults' performance on storage-plus-processing tasks that involve primary and secondary task stimuli from different domains. The only two studies to take this approach (Jenkins, Myerson, Joerding, & Hale, 2000; Myerson, Hale, Rhee, Weiss, & Abrams, 1999) combined primary memory span tasks, for which the to-be remembered stimuli were either verbal (digits or letters) or spatial (locations), with verbal and spatial secondary tasks: naming the color of each memory item aloud or pointing to the location of a color that matched the memory item. For both young and older adults, the verbal secondary task interfered with memory for digits and letters but not with memory for locations; the spatial secondary task interfered only with memory for locations and not with memory for digits (Myerson et al., 1999), although there was a slight effect on both young and older adults' memory for letters (Jenkins et al., 2000).

These results replicate and extend previous findings with young adults showing that simply having to coordinate two tasks is not necessarily sufficient to interfere with working memory (Hale, Myerson, Rhee, Weiss, & Abrams, 1996). These findings have two implications: one methodological and one theoretical. Methodologically, they suggest that comparing same-domain interference effects is unlikely to be a useful way to assess whether executive deficits play a role in age-related differences in working memory. Theoretically, they support the view that age differences in same-domain interference, which have been taken as support for age-related executive deficits, may instead reflect disruption of domain-specific maintenance processes (Hale et al., 2007; Nairne, 1990a; Oberauer & Kliegl, 2001; Tehan & Humphreys, 1998).

Domain-General Interference in Working Memory

If performing a secondary task from the same domain as a primary memory task interferes with domain-specific maintenance processes, and not with domain-general executive processes, then previous findings with same-domain memory and secondary tasks may be simply irrelevant to the issue of whether an age-related executive deficit underlies age differences in working memory. In order to better address this issue, what is needed is a secondary task that has two critical characteristics: First, it interferes with both verbal and spatial working memory because this would suggest that it disrupts domain-general executive processes; second, it does not involve processes likely to interfere with domain-specific maintenance processes. Given such a task, one could compare its effects on young and older adults' working memory performance in order to see if older adults show greater interference. If they do, this would provide evidence that older adults have

greater difficulties coordinating different tasks, as predicted by the executive deficit account of age differences in working memory. If they do not, this would cast doubt on the executive deficit account.

What might be an example of such a secondary task? Simple, rhythmic finger tapping has long been used as a concurrent task to study the effects of allocation of attention and task coordination on memory. Importantly, finger tapping does not require production or processing of additional verbal or spatial stimuli of the sort that might disrupt domain-specific maintenance processes. A number of studies have demonstrated that finger tapping disrupts memory for verbal material (e.g., Larsen & Baddeley, 2003; Saito, 1993, 1994), and the two studies that examined performance in both the verbal and spatial domains found that a finger tapping task that consisted of pressing a series of buttons on a keyboard interfered with working memory in both domains (Jones, Farrand, Stuart, & Morris, 1995; Salway & Logie, 1995).

The finding that finger tapping can produce domain-general interference suggests that examining the effect of tapping on verbal and spatial working memory tasks may be a good way to assess potential executive deficits in older adults' working memory system. If adding a tapping task to a memory span task places demands on domain-general executive processes, and if older adults have deficits in these processes, then older adults should show greater interference than young adults on both verbal and spatial working memory tasks.

Memory Span Tasks in the Present Study

In the present study, we not only compared the effects of tapping on both verbal and spatial memory span tasks, but within each domain, we also assessed the effects of tapping on both storage-only and storage-plus-processing tasks. If tapping disrupts executive processes, then it should have a greater effect on storage-plus-processing tasks, and if there are age differences in the executive component of working memory, then these differences should be most apparent when the effects of tapping on the storage-only and the storage-plus processing tasks are compared.

The storage-plus processing tasks used in the present study were item-manipulation span tasks rather than the more traditional dual-task procedures. Like dual-task procedures, item-manipulation tasks require participants to switch their attention back and forth between storage and processing. For example, letter-number sequencing, an item-manipulation span task, involves presentation of a series of alternating letters and numbers, but at recall, the numbers must be reported first, in numerical order, followed by the letters, in alphabetical order. As Emery, Myerson, and Hale (2007) showed, both young and older adults rearrange items online (i.e., while other items are still being presented) when performing this task, switching their attention back and forth between encoding new items, reordering items

already encoded, and maintaining items both prior to and after they are reordered. Unlike the processing portion of traditional storage-plus-processing span tasks, however, the processing portion of item-manipulation tasks does not involve processing new stimuli. Thus, although item-manipulation tasks involve executive coordination processes, they minimize the overwriting of already encoded items by new stimuli. Consequently, interference effects on item-manipulation tasks may be a purer measure of the disruption of executive processes than are interference effects on traditional storage-plus-processing tasks and may provide a better way to address hypotheses regarding age-related deficits of the executive component.

The effects of tapping on working memory were assessed by examining two different aspects of performance hypothesized to reflect the maximum capacity and the reliability of the working memory system: the longest series of items that could be correctly recalled, which measures capacity, and the proportion of items that could be correctly recalled across all series, which reflects not only capacity but also the reliability with which items can be recalled regardless of list length. Unsworth and Engle (2007) recently suggested that measures that focus only on trials where all items are reported correctly may under estimate the contribution of retrieval from secondary memory to working memory function, and they recommended using methods which give partial credit for items reported correctly even if all of the items of a series were not correct. The proportion of items correct measure used here is intended, in part, to accomplish that goal. Taken together, the two measures (longest series correct and proportion of items correct) may provide a fuller assessment of working memory function than would result from focusing on one measure alone (Conway et al., 2005; Unsworth & Engle, 2007).

METHOD

Participants

Participants were 24 Washington University undergraduates (17 female; ages 18–25; $M = 20.3$, $SD = 1.6$) and 24 community-dwelling older adults (15 female; ages 65–85; $M = 75.1$, $SD = 6.1$) recruited from the Washington University Older Adult Subject Pool maintained by the Psychology Department's Aging and Development Program. The older adults reported more years of education ($M = 15.5$, $SD = 2.2$) than the young adults ($M = 14.0$, $SD = 1.1$); $t(46) = 2.96$, $p < .01$. Older adults were screened for history of neurological disorder and uncorrected impairments in vision. In addition, older adult participants with scores on the Mini-Mental State Exam (MMSE) of less than 26 were excluded from participation. The mean MMSE score for the included sample was 28.2 ($SD = 1.2$). Young adults participated in

exchange for either course credit or \$20 in remuneration; all older adults received \$20 in remuneration.

Apparatus

Stimuli were presented on a 17-inch color, touch screen monitor (Planar Systems, Inc., Beaverton, OR) at a comfortable viewing distance of approximately 60 cm. Responses for the spatial working memory tasks were made by touching the monitor to mark the to-be-remembered cells on a grid. Vocal responses were used for the verbal working memory tasks and were recorded using a digital voice recorder with a built-in microphone (Olympus Imaging America Inc., Center Valley, PA). The software for all tasks was developed using E-Prime software (Psychology Software Tools, Inc., Pittsburgh, PA) by the first author.

Tasks

Participants performed both storage-only tasks and storage-plus-processing (item-manipulation) span tasks. One concern when comparing interference effects across storage-only and storage-plus-processing tasks is that task complexity, as defined by the task structure, may be confounded with task difficulty, as reflected in level of performance. To avoid this problem, we selected storage-plus-processing tasks that, according to previous research and pilot testing, were not expected to substantially decrease working memory scores relative to the corresponding storage-only tasks (Emery et al., 2007).

Storage-Only Verbal Span Task (Letter–Number Forward)

Each trial consisted of a series of alternating letters and digits. Participants began each trial of this task by touching a fixation cross at the center of the screen followed by a 1000 ms blank screen. Then a 45 × 45-mm box was presented for 750 ms. Each to-be-remembered letter or digit was presented inside the box for 1750 ms, followed by an inter-stimulus interval of 750 ms during which the box remained on the screen. A set of 9 letters (B, F, H, J, L, N, P, R, X) and 9 digits (1–9) was used. Following presentation of the last item on each trial, the box remained on the screen for 750 ms, after which recall was cued by changing the color of the box to green. Participants were instructed to recall the series of letters and numbers in the same order in which they were presented. Series ranging from 3 to 12 items, with two trials at each series length, were presented in a pseudorandom order. Such a wide range of series lengths was used in order to simultaneously avoid ceiling and floor effects with the young and older adult samples.

Storage-Plus-Processing Verbal Span Task (Letter–Number Sequencing)

The presentation procedure for this task was identical to the letter–number forward task, except that participants were instructed to first recall

all of the numbers in numerical order and then to recall all of the letters in alphabetical order. For example, after seeing the series 'H, 2, B, 5, L, 1,' participants were to say aloud '1, 2, 5, B, H, L'. This task was adapted from a subtest of the third edition of the Wechsler Adult Intelligence Scale (WAIS-III; Psychological Corporation, Wechsler, 1997) but differs from that subtest in that the items were presented visually and the rate at which they were presented was one every 2.5 s (rather than one every second as on the WAIS subtest) so as to facilitate rearranging the items online. It should be noted that prior research on the letter–number sequencing task has shown that having to reorder the items does not result in decreases in working memory span relative to conditions where series of digits and letters are reported in the order presented. In fact, reordering the items actually leads to increases in working memory span compared to forward recall (Emery et al., 2007; Robertson, Myerson, & Hale, 2006).

Of particular relevance for the present study is that both young and older adults have been shown to benefit from the sequenced order of recall in this task but young adults benefit slightly more than older adults (Emery et al., 2007; Robertson et al., 2006), and we expected to replicate this finding. Indeed, this counter-intuitive pattern, in which performance of the storage-plus-processing task is superior to performance of the storage-only span task, makes the letter–number-sequencing span task well suited for the present study. This is because if the interference produced by the secondary tapping task is greater on the storage-plus-processing (item-manipulation) task than on the corresponding storage-only task, as predicted by an executive deficit hypothesis, this cannot be attributed to the greater difficulty of the storage-plus-processing task, rather than to its greater complexity. The series lengths for the letter–number sequencing task ranged from 3 to 12 items, with two trials at each series length, and were presented in a pseudo-random order, just as for the letter–number forward task.

Storage-Only Spatial Span Task (Grid Locations)

In the grid locations span task, a series of Xs were presented, one at a time, in the cells of a 4×5 grid, indicating the locations that were to be remembered. Participants initiated each trial by touching a fixation cross at the center of the screen. This was followed by a 1000-ms blank screen, after which an empty grid measuring 140×165 mm was presented for 750 ms. Each to-be-remembered location was presented in one of the cells of the grid for 1750 ms followed by an inter-stimulus interval of 750 ms during which the empty grid remained on the screen. Following presentation of the final item, the grid remained on the screen for another 750 ms, at which point the grid turned green and a tone prompted recall. At recall, participants were to touch all of the locations in the grid in which an X had appeared. Series ranging from 2 to 11 items, with two trials at each series length, were

presented in a pseudorandom order. Based on previous results and pilot testing with the current procedures showing differences in the level of older adults' performance on spatial and verbal working memory tasks, the length of the series in spatial conditions ranged from 2 to 11, whereas the length of the series in the verbal conditions ranged from 3 to 12. These ranges resulted in equal numbers of trials in both domains while avoiding floor effects in the spatial domain, especially for the older adults, and ceiling effects in the verbal domain, especially for the young adults.

Storage-Plus-Processing Spatial Span Task (Arrow Locations)

The presentation procedure for this task was identical to that of the grid location span task with the exception that reordering of the to-be-remembered items was required. Instead of Xs indicating the location of to-be-remembered locations, leftward or rightward pointing arrows were presented in the cells of the grid. Participants were instructed to remember the adjacent location that each arrow pointed to. The arrows always pointed to locations inside of the grid (i.e., arrows that appeared in the first column always pointed rightward and arrows in the fifth column always pointed leftward). Following presentation of the final item, recall was signaled by the green grid and auditory tone. At recall, participants were to touch all of the locations in the grid to which the arrows had pointed.

Scoring of Working Memory Performance

Previous studies have shown that the pattern of results may differ depending on the way in which working memory data are scored (Conway et al., 2005; Unsworth & Engle, 2007). To obtain a fuller understanding of the way tapping influenced working memory performance in the present study, the data were scored in two ways. First, we determined the longest series at which all items could be correctly recalled in order to assess participants' maximum capacity. Second, we determined the total proportion of items that were correctly recalled in order to assess the reliability with which items could be recalled at all of the series lengths. For the proportion correct measure, we corrected for the difference in the series lengths and total number of items in the verbal and spatial domains by giving credit for the 2-item series and excluding the 12-item series from analysis of the verbal domain data.

Secondary Tapping Task

Each of the four tasks was performed once with a secondary tapping task and once without. The order of tasks and conditions was counterbalanced across participants. As in the Jones et al. (1995) study, which showed interference with both verbal and spatial working memory from a secondary tapping task, the secondary task in the present study required participants to tap a series of keys labeled one, two, three, and four in that order using the

four fingers of their dominant hand. Participants were instructed to tap the sequence repeatedly in time with a metronome that sounded for six seconds prior to, and throughout, the presentation of the to-be-remembered items, but not during recall. The six seconds of finger tapping prior to item presentation allowed participants to synchronize their tapping to the metronome. In addition, prior to the first tapping condition, participants received practice with synchronized finger tapping for 30 s, at which time the experimenter provided feedback as to the accuracy of participants' timing. Feedback was also provided during the practice phase preceding each working memory task condition that involved tapping.

For young adults, the metronome was set at two beats per second; for older adults, the metronome was set at one beat per second. These rates were selected to be just slightly faster than the rates of spontaneous motor tapping in young and older adults, respectively (Baudouin, Vanneste, & Isingrini, 2004). Inspection of the audio recordings revealed that all participants in both groups continued to tap in approximate synchrony with the metronome throughout the experimental conditions.

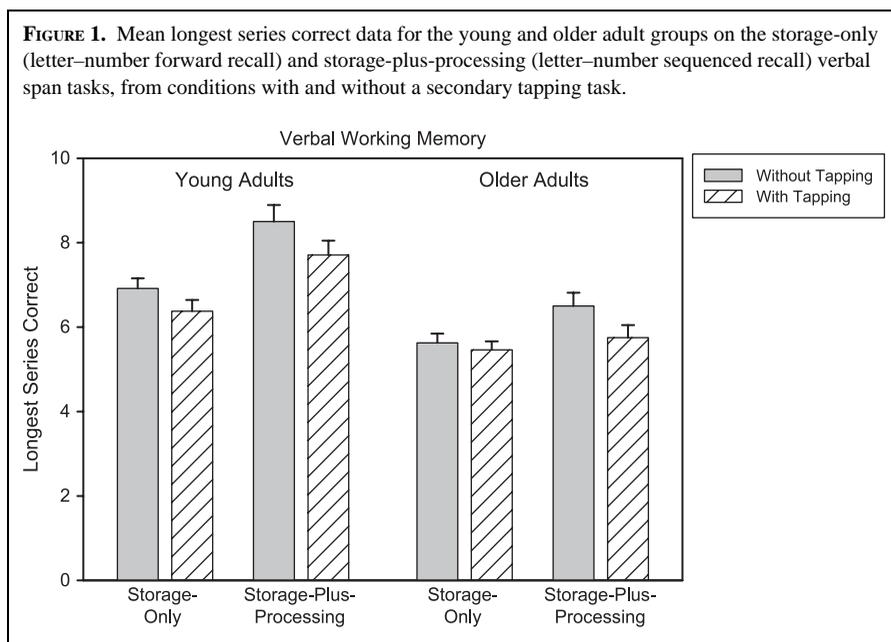
Procedure

Participants completed each of the four working memory span tasks both with and without the secondary tapping task. Tasks were completed in two sessions within approximately one week of one another. The order of tasks was counterbalanced with six participants in each of four pseudorandom orders. Each order began with a different one of the four tasks, and each order alternated verbal and spatial span tasks. For each task, the tapping and no tapping conditions were performed in succession, but in two of the orders, the tapping condition always preceded the no-tapping condition and in two of the orders, it was the other way around. Finally, the first two tasks were either a storage-only span task followed by a storage-plus-processing task or the reverse, a storage-plus-processing task followed by a storage-only task, and whichever order of storage-only and storage-plus-processing tasks was used for the first two tasks, the opposite order was used for the last two tasks. An experimenter delivered detailed instructions and observed participants perform four practice trials before the test trials for each task.

RESULTS

Verbal Working Memory

Figure 1 depicts the mean longest series correct data for the young and older adult groups on the verbal storage-only (forward recall) and storage-plus-processing (letter-number sequencing) span tasks, from conditions both with and without a secondary tapping task. A 2 (Age: young vs. old) \times 2 (Span



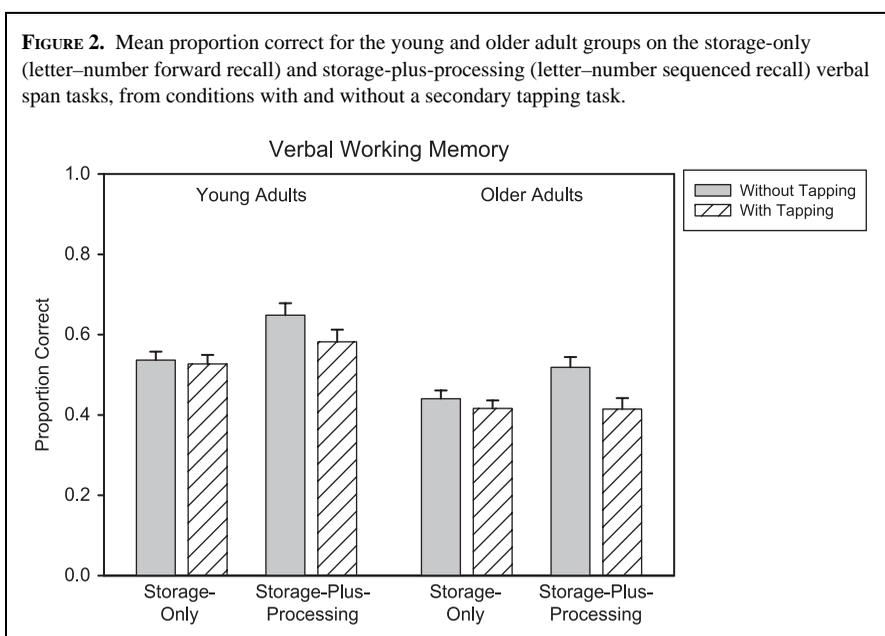
task: forward recall vs. letter–number sequencing) \times 2 (Tapping: with vs. without) repeated measures ANOVA revealed significant main effects of Age, $F(1, 46) = 25.94$, partial $\eta^2 = .361$, $p = .001$, and Tapping, $F(1, 46) = 15.60$, partial $\eta^2 = .253$, $p < .001$. Importantly, the interaction between Age and Tapping was not significant, $F(1, 46) < 1.0$, indicating that tapping did not produce greater interference with older adults' working memory. The interaction between Span task and Tapping did not reach significance, $F(1, 46) = 2.66$, partial $\eta^2 = .055$, $p = .11$. Moreover, there was no three-way interaction between Age, Span task, and Tapping, $F(1, 46) < 1.0$, indicating that tapping affected working memory on both the storage-plus-processing (letter-number sequencing) and the storage-only (letter–number forward) task, and that there was no age difference in the size of this effect.

Additionally, there was a significant main effect of Span task, $F(1, 46) = 32.28$, partial $\eta^2 = .412$, $p = .001$, reflecting the fact that performance was better for the storage-plus-processing task than the storage-only task. Consistent with previous studies using the letter–number sequencing task (Emery et al., 2007; Robertson et al., 2006), the interaction between Age and Span task was also significant, $F(1, 46) = 5.93$, partial $\eta^2 = .114$, $p < .05$, reflecting the fact that the young adults benefited more from reorganizing the memory items than the older adults did.

A slightly different pattern of results was revealed by analysis of the more fine-grained measure of working memory performance: the proportion of correctly recalled items from all of the series lengths presented. As before,

a 2 (Age: young vs. old) \times 2 (Span task: forward recall vs. letter–number sequencing) \times 2 (Tapping: with vs. without) repeated measures ANOVA revealed significant main effects of Age, $F(1, 46) = 24.56$, partial $\eta^2 = .348$, $p = .001$, and Tapping, $F(1, 46) = 34.44$, partial $\eta^2 = .428$, $p < .001$. Also, as with the longest series correct data, there was a significant main effect of Span task, $F(1, 46) = 10.3$, partial $\eta^2 = .183$, $p = .01$, showing that performance was better on the letter–number sequencing task than on the storage-only (forward recall) task. Unlike the longest series correct data, however, the interaction between Age and Span task was not significant, $F(1, 46) = 1.44$, *ns*, suggesting that the effect of reorganizing the memory items was equivalent for young and older adults' in terms of the reliability with which individual items could be recalled (Figure 2).

More importantly, as in the analysis of the longest series correct data, the interaction between Age and Tapping was not significant, $F(1, 46) < 1.0$, indicating that, even with a more fine-grained measure of working memory performance, tapping did not produce a greater interference effect for the older adults. Additionally, the interaction between Span task and Tapping reached significance, $F(1, 46) = 9.84$, partial $\eta^2 = .176$, $p = .01$, indicating that tapping interfered more with the verbal storage-plus-processing span task than with the storage-only task. Finally, the three-way interaction between Age, Span task, and Tapping was not significant, $F(1, 46) < 1.0$, indicating that although tapping tended to affect spans on the storage-plus-processing (letter–number sequencing) task more than it

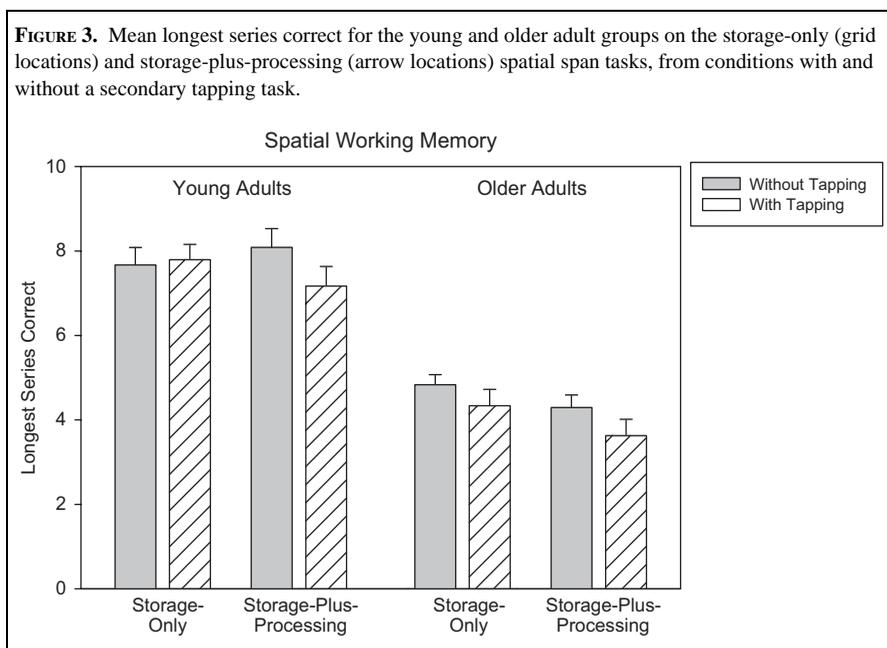


affected the storage-only (forward recall) task, this effect was not larger for older adults.

Spatial Working Memory

Figure 3 depicts the mean longest series correct for the spatial domain for the young and older adult groups in the storage-only and storage-plus-processing span conditions, both with and without a secondary tapping task. For the spatial domain, as was observed for the verbal domain, a 2 (Age: young vs. old) \times 2 (Span task: grid locations vs. arrow locations) \times 2 (Tapping: with vs. without) repeated measures ANOVA revealed significant main effects of Age, $F(1, 46) = 61.78$, partial $\eta^2 = .573$, $p < .001$, Span task, $F(1, 46) = 4.07$, partial $\eta^2 = .081$, $p = .05$, and Tapping, $F(1, 46) = 8.56$, partial $\eta^2 = .157$, $p < .01$. In addition, there was a marginally significant interaction between Span task and Tapping, $F(1, 46) = 2.92$, partial $\eta^2 = .06$, $p = .09$, reflecting the fact that the secondary tapping task tended to produce greater decreases in the longest series correct for the spatial transformation task (i.e., arrow locations) than for the storage-only task (i.e., grid locations).

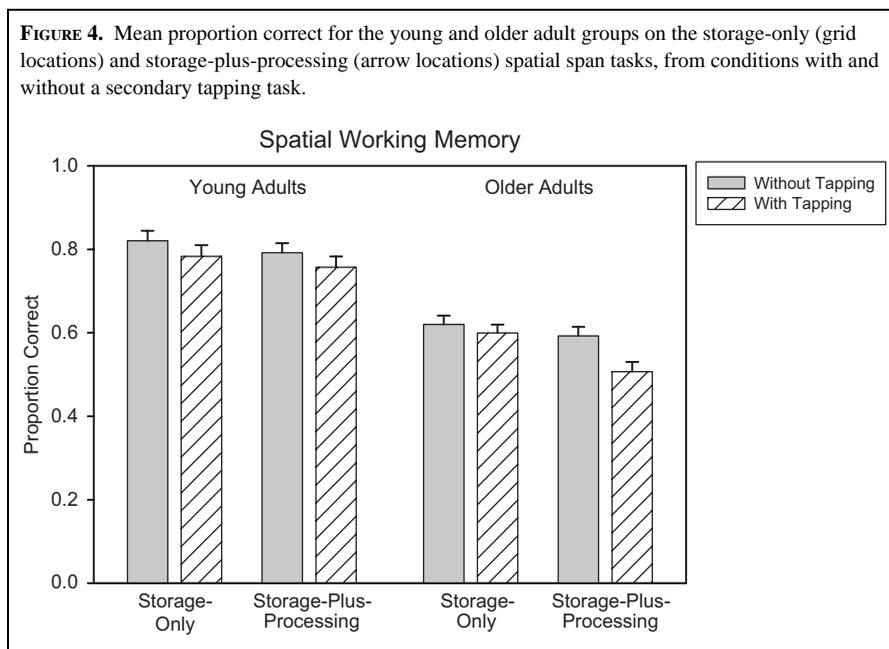
The interaction between Age and Span task was not significant, $F(1, 46) = 2.08$, *ns*, indicating that adding a location transformation component to the storage-only location task did not affect older adults more than young adults. Importantly, just as in the verbal domain, Tapping did not interact with Age, $F(1, 46) < 1.0$, indicating that adding a domain-general secondary task (tapping) produced equivalent amounts of interference in



young and older adults. The three-way interaction between Age, Span task, and Tapping was not significant, $F(1, 46) < 1.0$. Although tapping tended to affect performance on the storage-plus-processing (spatial transformation) task more than it affected the spatial storage-only task, there was no age difference in the size of this effect.

Again, a slightly different pattern of results was revealed by analysis of the more fine-grained measure: the proportion of correctly recalled items from all series lengths (see Figure 4). A 2 (Age: young vs. old) \times 2 (Span task: location storage vs. spatial transformation) \times 2 (Tapping: with vs. without) repeated measures ANOVA again revealed significant main effects of Age, $F(1, 46) = 52.16$, partial $\eta^2 = .531$, $p = .001$, Span task, $F(1, 46) = 17.1$, partial $\eta^2 = .271$, $p < .001$, and Tapping, $F(1, 46) = 34.38$, partial $\eta^2 = .428$, $p < .001$. The interaction between Age and Span task was not significant, $F(1, 46) = 2.42$, *ns*. The interaction between Span task and Tapping, $F(1, 46) = 6.47$, partial $\eta^2 = .123$, $p < .05$, was significant, indicating that tapping interfered with the storage-plus-processing span task more than the storage-only span task. Importantly, the interaction between Age and Tapping was not significant, $F(1, 46) = 1.25$, *ns*, indicating that, collapsing across storage-only and storage-plus-processing tasks, tapping did not produce greater interference for the older adults.

In contrast to the results of our previous analyses, the three-way interaction for proportion of spatial items correct between Age, Span task, and Tapping was significant, $F(1, 46) = 7.43$, partial $\eta^2 = .139$, $p < .01$. Follow-up



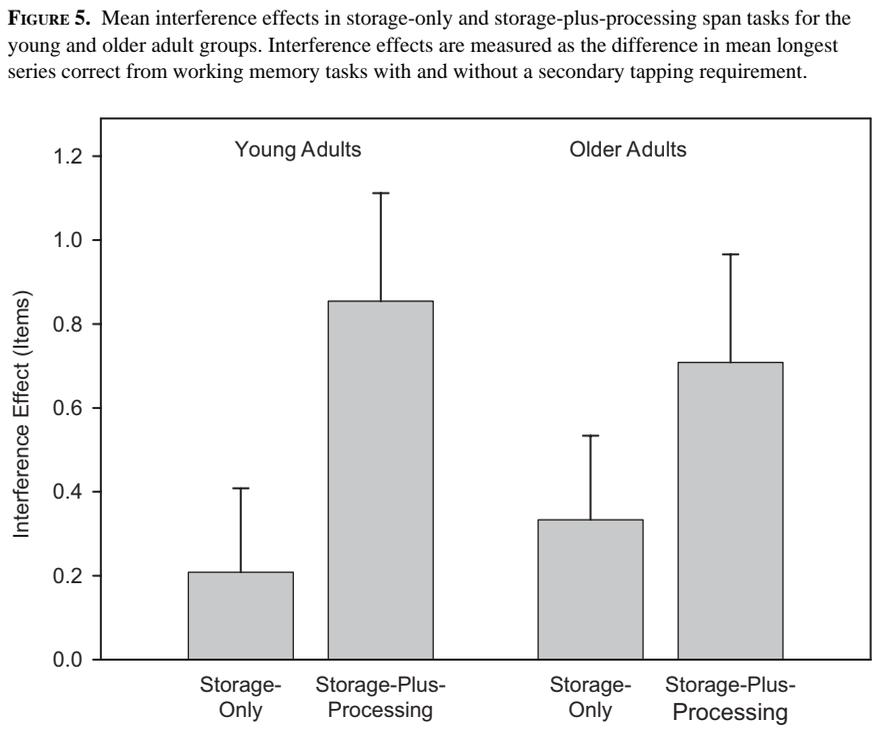
analyses conducted to explicate this result revealed that for the young adults, the effect of tapping was significant for both the storage-only task, $F(1, 23) = 7.89$, partial $\eta^2 = .255$, $p = .01$, and the storage-plus-processing task, $F(1, 23) = 5.41$, partial $\eta^2 = .190$, $p < .05$. For the older adults, the effect of tapping was significant for the storage-plus-processing task as well, $F(1, 23) = 34.99$, partial $\eta^2 = .603$, $p < .001$. However, unlike the young adult group, the effect of tapping was not significant for the storage-only task, $F(1, 23) = 2.69$, *ns*.

DISCUSSION

The present study was designed to test the hypothesis that older adults have deficits in the executive component of working memory. To that end, we compared the effect of a secondary finger tapping task on both storage-only and storage-plus-processing memory span tasks in both the verbal and spatial domains. Given that the executive component is believed to be domain-general in nature, a secondary task that interferes with this component should have similar effects in both domains, whereas a secondary task that interferes with maintenance processes should have domain-specific effects. As expected, rhythmic finger tapping was found to interfere with performance on both verbal and spatial working memory tasks, suggesting that it was disrupting executive processes. Indeed, collapsing across age groups and span tasks, the effects of tapping on verbal and spatial working memory were quite similar, regardless of the measure used. Tapping resulted in a reduction of approximately one-half of an item in the longest series correct in both the verbal and spatial domains (0.56 and 0.49 items, respectively), as well as similar sized decreases in the proportion of items correct (.038 and .036, respectively).

As conceptualized by Baddeley, among others, the executive component of working memory is a limited capacity attentional system (e.g., Baddeley, 2002). Although the attentional demands of repeatedly tapping one's fingers may be relatively low, these demands are presumably higher when tapping must be synchronized with the rhythm of a metronome, as in the present study. Moreover, when tapping must be performed simultaneously with another task whose attentional demands are even higher, such as a memory task, tapping has been shown to disrupt ongoing memory processes, and such results are usually interpreted in terms of interference with executive control (e.g., Kane & Engle, 2000; Larsen & Baddeley, 2003).

In the present study, this interpretation is supported by the finding that combining tapping with a storage-only span task tended to result in less disruption than combining tapping with a storage-plus-processing span task did. Storage-plus-processing tasks are generally assumed to require greater amounts of executive control (e.g., Baddeley, 2002; Engle et al., 1999).



If tapping disrupts such coordination, then the effect of tapping should be more evident for storage-plus-processing span tasks than for storage-only span tasks.

As predicted, tapping had a significantly greater effect on the proportion of items recalled on the item-manipulation span task than on the storage-only task in both domains. This finding is illustrated in Figure 5, which shows that, collapsing across the verbal and spatial domains, tapping had a greater effect on storage-plus-processing span tasks than on storage-only span tasks for both the young and older adult groups, consistent with the view that the secondary tapping task interfered with executive processes.

Aging and Interference Effects in Working Memory

Not unexpectedly, older adults were found to perform more poorly than the young adults in this study on all verbal and spatial working memory tasks, including both storage-only and storage-plus-processing (item-manipulation) tasks, regardless of the measure used to assess their performance. Of primary interest, however, was whether older adults would show greater interference from a secondary finger tapping task that disrupted executive processes in a domain-general fashion. That is, would such a secondary task increase the size of the observed age differences? Contrary to the predictions of the

executive deficit hypothesis, tapping did not produce greater interference for the older adult group. Interference effects were generally equivalent in young and older adults no matter which domain the to-be-remembered items (verbal or spatial) were from, the way in which performance was measured (longest series correct or proportion correct), or the complexity of the span task (storage-only or storage-plus-processing). In the case of the single three-way (Age \times Tapping \times Task) interaction that was observed, tapping interfered with performance (proportion of items correct) on the spatial storage-only span task by young adults, but not older adults.

Although some studies have suggested that older adults have deficits in the executive component of working memory, as evidenced by greater interference from secondary tasks (for a recent review, see Bopp & Verhaeghen, 2005), findings of equivalent interference effects have also been reported (e.g., Babcock & Salthouse, 1990, Experiments 2 and 3; Jenkins et al., 2000; Myerson et al., 1999). As noted in the Introduction, the problem with these earlier studies that compared young and older adults' interference effects in working memory, is that, with one exception (Jenkins et al., 2000), the interference effects in question resulted from pairing primary memory tasks with secondary processing tasks from the same domain. Such pairings are problematic because it is unclear whether such same-domain secondary tasks interfere with domain-specific maintenance processes, domain-general executive processes involved in task coordination, or both.

In contrast to previous studies, participants in the present study performed a secondary finger tapping task, one which is not inherently verbal or spatial, and such tapping interfered with immediate recall of both verbal and spatial memory items, consistent with the view that tapping disrupts domain-general executive processes. Importantly, that disruption was not greater for older adults, as evidenced by the fact that the Age \times Tapping interaction was not significant for either measure in either domain. Indeed, the age differences in working memory were strikingly similar. Collapsing across domains and working memory tasks, the mean age difference in the longest series correct when tapping was not required was 2.48 items, and the age difference when tapping was required was 2.47 items. For the proportion of items correct measure, these differences were .16 and .18, respectively.

Future Directions

Although the present results argue against an executive deficit interpretation of age differences on item-manipulation storage-plus-processing tasks, it is possible that our findings do not generalize to traditional dual-task working memory procedures (e.g., operation span). As already noted, there is reason to believe that interference by same-domain secondary tasks, such as that usually observed on dual-task working memory procedures, may reflect the disruption of maintenance, and not executive processes. It would

seem possible to test this notion using secondary tasks like that used in the present study. That is, adding the requirement to tap out a sequence in a steady rhythm appears to interfere with executive function, as evidenced by the domain-general nature of the interference produced by such tapping as well as the fact that item-manipulation span performance is more disrupted than storage-only performance. Comparing the effects of a finger tapping task on storage-only and dual-task storage-plus-processing procedures would provide a way to determine the degree of executive involvement in such procedures. Importantly, it would also provide a way to test for age differences in the disruption of executive processes in such situations.

Although the finding that performance was better for the letter–number sequencing task (which requires reorganization of the items) than the letter–number forward task (which requires storage only) may seem counterintuitive, a more detailed examination of these effects by Emery et al. (2007) suggests an explanation, one that highlights the fundamental similarity between this and other storage-plus-processing tasks. In addition to examining recall of the items in both their original order (alternating letters and numbers) and their rearranged order (numbers in increasing order followed by letters in alphabetical order), Emery et al. (2007) also examined recall of prearranged items (again, numbers in increasing order and letters in alphabetical order). Memory spans were higher for pre-arranged items than for items that participants rearranged themselves, which were higher than for simple serial recall of alternating letters and numbers.

Based on these findings, Emery et al. (2007) concluded that although item-manipulation has costs similar to those of secondary tasks on more typical dual-task procedures, sequenced items are simply easier to remember than alternating digits and letters, perhaps because of the presence of familiar chunks in alphabetically ordered letters and series of increasing digits. To date, however, relatively few studies have used item-manipulation tasks to examine working memory, and fewer still have compared the performance of younger and older adults on such tasks. The existence of a spatial analog of the letter–number sequencing task would be quite useful in this endeavor, and we are currently working on developing one.

Finally, a review of the audio tapes revealed that both young and older adult participants typically continued to tap as required during the conditions with tapping. However, the quality of the recording was not sufficient to permit us to accurately determine whether taps were omitted because taps on the keyboard that were perfectly synchronized with the metronome (in accordance with the instructions) could be masked by the metronome sound. As a result, it remains possible that the young and older adults differed in the way they divided their attention between the tapping and memory span tasks. Further research that directly examines performance on both kinds of tasks concurrently and that utilizes additional types of working memory tasks is called for.

CONCLUDING REMARKS

As mentioned previously, our finding of equivalent interference effects in young and older adults is not unprecedented. A number of studies using dual-task procedures have failed to find an age difference in interference by secondary tasks (Babcock & Salthouse, 1990, Experiments 2 and 3; Jenkins et al., 1999, 2000; McCabe & Hartman, 2003; Myerson et al., 1999). The present results extend these findings by showing equivalent interference effects in young and older adults using a procedure that we believe directly assesses disruption of the executive component of the working memory system, rather than interference with maintenance processes. Taken together with the results of previous studies that failed to show age differences in interference, the present findings call into question the hypothesis that older adults' deficits in working memory are largely attributable to deficits in the executive component.

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