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Age Differences in Visuospatial Working Memory

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In two visuospatial working memory (VSWM) span experiments, older and young participants were tested under conditions of either high or low interference, using two different displays: computerized versions of a 3 × 3 matrix or the standard (randomly arrayed) Corsi block task (P. M. Corsi, 1972). Older adults' VSWM estimates were increased in the low-interference, compared with the high-interference, condition, replicating findings with verbal memory span studies. Young adults showed the opposite pattern, and together the findings suggest that typical VSWM span tasks include opposing components (interference and practice) that differentially affect young and older adults.

Keywords: visuospatial working memory, age differences, practice effects, interference effects

Older adults' cognitive abilities are influenced by many factors (e.g., Grady & Craik, 2000), including an increased susceptibility (compared with that of young adults) to the detrimental effects of irrelevant information (Hasher, Lustig, & Zacks, 2007; Hasher, Zacks, & May, 1999). Older adults are more vulnerable than young adults to the disruptive effects of concurrent distraction as can be seen in flanker (e.g., Zeef, Sonke, Kok, Buiten, & Kenemans, 1996), visual search (e.g., Scialfa, Esau, & Joffe, 1998), and basic perceptual speed (Lustig, Hasher, & Tonev, 2006) tasks. In addition to their differential vulnerability to disruption from concurrent distraction, older adults are also more vulnerable than young adults to the disrupting effects of distraction from the recent past (Hasher et al., 2007). This latter effect, descriptively called proactive interference (PI), has been shown in a number of situations, perhaps most dramatically in memory tasks in which previously presented but no-longer-relevant materials disrupt the ability to recall the most recently presented information. Of particular relevance to the current work is the fact that PI is known to differentially lower the memory performance of older adults (e.g., Hasher, Chung, May, & Foong, 2002; Kausler, 1990; Winocur & Moscovitch, 1983).

The impact of PI has long been recognized in list learning and long-term memory tasks (Kausler, 1990; Postman & Underwood, 1973). Earlier work demonstrated the effects of PI on short-term memory tasks (Keppel & Underwood, 1962), and more recent work has highlighted its role in working memory (WM; Bunting, 2006; Lustig, May, & Hasher, 2001; May, Hasher, & Kane, 1999) as well as in implicit memory (Lustig & Hasher, 2001).

With respect to the operation of PI in WM, consider Daneman and Carpenter's (1980) classic reading span task. Participants typically receive between three and five sets of sentences that they read or listen to for comprehension, and then they are asked to recall the final words of each sentence. Investigators typically begin the task by having participants recall the shortest sequence (often two sentences) before moving on to recalling between three and five sets of three sentences. The series continues in that manner to the largest set size, typically four or five sentences in length. Given that a high span score is determined by successful performance on the longer set sizes, the ascending format places at a disadvantage participants who cannot ignore no-longer-relevant materials from previous trials. In that light, it is not surprising that older adults, who are known to have difficulty suppressing no-longer-relevant material and who show greater evidence of PI in a range of tasks (Kausler, 1994; Lustig et al., 2001), typically perform more poorly than young adults on the reading span task. Reversing the conventional order of presentation (so starting with the longest instead of shortest set size) in verbal WM span tasks reduces the effects of irrelevant, prior trial information during recall of the longest set sizes, differentially improving older adults' performance. In fact, age differences in WM span scores have actually been eliminated using this reverse presentation order (Lustig et al., 2001; May et al., 1999).

To date, work on the impact of irrelevant prior information on WM span has involved only verbal materials; to our knowledge,

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nothing is known about the role of PI on memory for visuospatial information. There is a literature, however, suggesting that visuospatial working memory (VSWM) is affected more by age than is performance on verbal tasks. For example, Jenkins, Myerson, Joerding, and Hale (2000) found older adults' performance on VSWM tasks was poorer than their performance on verbal WM tasks, and Myerson, Emery, White, and Hale (2003) found evidence for greater interference on a visuospatial compared with a verbal span task (see also Park, Lautenschlager, Hedden, Davidson, Smith, & Smith, 2002).

In the present study, we investigated whether PI is a contributing factor to age differences in VSWM, as it is in verbal measures of WM. To this end, we followed the procedure of May et al. (1999) and manipulated the presentation sequence, with young and older participants performing the task under either the commonly used ascending format (with the shortest set sizes presented first) or under an interference-reducing descending format (with the longest set sizes presented first).

To assess VSWM, we used the classic nine-location Corsi block task (CBT; Corsi, 1972) in the first study because it is widely used to assess visuospatial memory in both clinical (e.g., Joyce & Robbins, 1991; Vilkki & Holst, 1989) and nonclinical (e.g., Jones, Farrand, Stuart, & Morris, 1995; Smyth & Scholey, 1994) populations. Although the CBT is often considered a short-term memory (STM) task, Miyake, Friedman, Rettinger, Shah, & Hegarty (2001) reported that those factors believed to differentiate verbal WM and STM tasks, such as executive functioning and controlled attention, are as strongly involved in visuospatial STM tasks as in conventional VSWM tasks, and the CBT is now considered to be an excellent measure of VSWM (see also, Berch, Krikorian, & Huha, 1998; Kessels, Kappelle, de Haan, & Postma, 2002; Vecchi & Richardson, 2001).

The CBT consists of a board with 9 or 10 raised blocks arranged in an irregular pattern. The task requires the participant to remember the particular blocks that were tapped on a given trial by the test administrator as well as the order in which they were tapped. Apart from memory for sequential order, the CBT is believed to involve a number of other components important to VSWM: encoding of visual stimuli, maintenance of that information, memory of spatial locations, inhibition of recall of irrelevant information (thus maintenance of attention on the task), and selection of response at retrieval (Bruyer & Scailquin, 1999; Fischer, 2001; Hanley, Young, & Pearson, 1991; Smyth & Scholey, 1994), all factors assessed across multiple trials on the same board. Of course, many of these features (such as its conventional ascending format, recall across multiple trials, and visual similarity of stimuli across all trials) also provide an ideal setting for the build up of PI. On the basis of findings from the reading span task (e.g., May et al., 1999), we reasoned that the CBT may underestimate the true visuospatial abilities of older adults due to age-related differences in susceptibility to interference effects. As we will show, the CBT may also *overestimate* the visuospatial abilities of young adults, perhaps because of practice effects. In a second study, we used a 3 × 3 matrix display to assess the generality of the effects found in Experiment 1.

If PI contributes to age differences in visuospatial span tasks, and if older adults are differentially vulnerable to these effects, we anticipated that they would do significantly better in the descending, compared with ascending, conditions of both the classic CBT and the organized matrix.

Experiment 1

Young and older adults participated in either a conventional ascending span task, or an interference-reducing descending version of the CBT. Our question was whether, by reducing the amount of PI, we could improve the performance of older adults.

Method

Participants. Thirty-six young adults and 36 older adults were randomly assigned to either the ascending or descending span condition. Data were discarded if participants failed to meet criterion on years of education (minimum = high school diploma) or showed evidence of cognitive impairment screening (score >6 on the Short Blessed Test (SBT), Pfeiffer, 1975). Three older adults were excluded on these bases, leaving a sample of 36 young and 33 older adults. Participants were randomly assigned to either the ascending or descending condition and were tested individually. Young adults were members of the University of Toronto's student population and received course credit or monetary remuneration. Older adults were volunteers registered with the University of Toronto's older adult participant pool and received remuneration based on $10 for each hour of participation time.

Materials. The experimental span task was programmed using E-Prime software (Psychology Software Tools, Pittsburgh, PA). We used a computerized version of the CBT with the nine potential target locations presented as two-dimensional gray squares of equal size (3 cm^2) against a white background and arranged in the randomized display of Corsi's (1972) original task (see Figure 1). Stimuli were presented on a touch screen monitor with a display area of 38.10 cm. Target sequences were chosen based on those used in the spatial span task of the Wechsler Memory Scale (3rd ed., Wechsler, 1997b). Time-of-day preferences were determined by Horne and Ostberg's (1976) Morning/Eveningness Questionnaire (MEQ). The SBT screened older adults for early signs of dementia.

Procedure. Older adults were tested in the morning (before 11 a.m.), and younger adults were tested in the afternoon (after 12 p.m.). These times were chosen based on findings that both older and young adults' performance on many cognitive tasks is affected by circadian arousal patterns, with older adults' peak time,

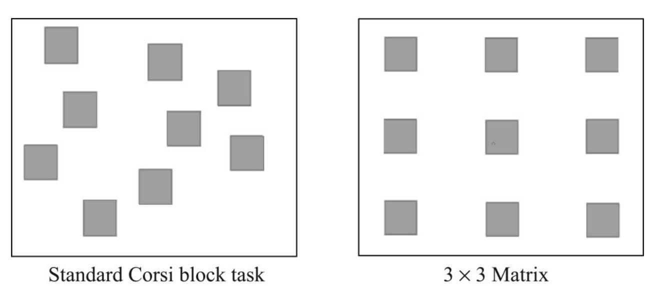

Figure 1. Examples of the two experimental displays. The display on the left was used in Experiment 1. That on the right was used in Experiment 2.

in general, being in the morning and young adults, in general, reaching their peak later in the day (Hasher et al., 1999). Of particular relevance to the present study is the evidence of greater PI effects at off peak than at peak times (Hasher et al., 2002).

Subsequent to reading the task instructions, participants were given one practice trial with a 2-location sequence, after which sequences were presented in either an ascending (starting with set size 4 and progressing to set size 7) order of difficulty, or in a PI-reducing descending (from set size 7 to set size 4) order of difficulty. In both conditions, 3 trials at each of the 4 set sizes were presented for a total of 12 trials. All 3 trials of a set size were presented before experimenters continued to the next set size. Except for the ascending versus descending order of test administration, the exact same spatial sequences were used for all participants.

Each trial began when the participant pressed the keyboard's space bar, following which the display of nine gray squares on a white background was presented for 1,200 ms. A pattern of the required number of target locations was then presented sequentially. Each target location was identified by a 1,500-ms change in color from gray to black. Immediately after presentation of the to-be-remembered sequence, a thin black frame appeared around the entire display as a prompt for the participants to begin serial recall. Participants recalled target items by touching the relevant squares in the order of presentation. Responses were automatically recorded.

Results and Discussion

Older adults (M age = 66.56 years, $SD = 4.77$; range = 60–77 years) had higher scores than young adults (M age = 19.72 years, $SD = 2.19$; range = 18–26 years) on the MEQ ($M = 59.52$, $SD = 10.21$, and $M = 43.18$, $SD = 9.53$, respectively), consistent with their greater trend towards morningness (Yoon, May, & Hasher, 1999). Older adults also had more years of education ($M = 16.06$ years, $SD = 3.80$) than young adults ($M = 13.02$ years, $SD = 1.30$). Within each age group, there were no main effects or interactions with condition (ascending vs. descending) on education or MEQ.

We scored the CBT as the percentage of correctly recalled trials. A 2 (age) × 2 (condition) analysis of variance (ANOVA) on these scores showed young adults had higher span scores than older adults, $F(1, 65) = 38.31$, $MSE = 3.71$, $p < .01$, Ms = 65 and 40, respectively. Age interacted with condition, $F(1, 65) = 5.99$, $p = .02$, with older adults performing significantly better in the descending ($M = 48$, $SD = 22$) than in the ascending ($M = 33$, $SD = 16$) condition, $t(31) = 2.07$, $p < .05$, and, somewhat surprisingly, young adults showing the opposite pattern, that is, marginally poorer span scores in the descending ($M = 57$, $SD = 20$) than in the ascending ($M = 71$, $SD = 16$) condition, $t(34) = 1.94$, $p = .06$ (see Figure 2A). Note that despite the benefit that older adults received from the descending version, their overall scores in that condition were still reliably lower than those of the comparable group of young adults, $t(31) = 2.56$, p .02. If older adults' benefit in the PI-reducing descending condition was indeed due to our manipulation, their span scores on the longest set sizes should be higher in the descending condition than in the ascending condition. With this in mind, we used planned contrasts to examine the percentage of older adults' total correct trials at set sizes 5, 6, and 7. Participants in the descending condition had a higher percentage of correct trials ($M = 39$, $SD = 22$) than did older adults tested in the ascending condition ($M = 23$, $SD = 14$), a difference that was reliable, $t(31) = 2.50$, $p = .02$, and consistent with the conclusion that PI plays a substantial role in determining performance.

These results demonstrate that the detrimental effects of the typical manner of administering WM span tasks generalizes from the verbal span tasks used by Lustig et al. (2001) and May et al. (1999) to at least one version of a VSWM task. Older adults received a substantial benefit when assigned to the PI-reducing descending, compared with standard ascending, condition. These findings are consistent with literature suggesting that older adults

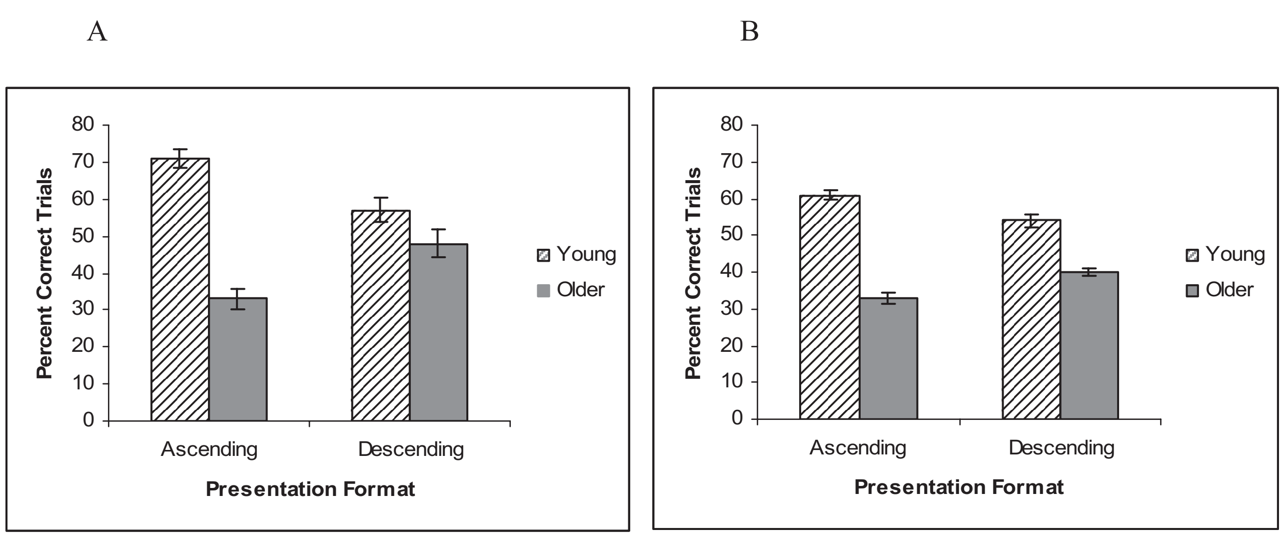

Figure 2. Percentage of correct trials for young and older adults tested in the ascending and descending format in (A) Experiment 1 (Corsi block task; P. M. Corsi, 1972) and (B) Experiment 2 (matrix). Error bars represent standard error of the mean.

are more vulnerable to the effects of PI than are young adults (e.g., Kane & Hasher, 1995; Lustig & Hasher, 2001; Winocur & Moscovitch, 1983) and suggest that conventional WM span tasks, visuospatial as well as verbal, do indeed encourage the build-up of PI, reducing the span scores of those individuals, such as older adults, who have difficulty suppressing previously learned information.

With regard to young adults' advantage in the ascending, compared with the descending, condition, we compared the number of correct trials at the largest set sizes, once again using planned contrasts on these most difficult items. Young adults had reliably higher span scores in the ascending ($M = 67$, $SD = 13$), compared with the descending ($M = 47$, $SD = 17$), format, $t(33) = 3.88$, $p < .001$, consistent with a beneficial practice effect. We discuss these findings further after reporting on a second study.

Experiment 2

As before, young and older adults performed a standard ascending span task or an interference-reducing descending version of the same task. For purposes of generalization, we arranged the nine potential target locations in an organized 3 × 3 matrix. As in Experiment 1, our critical question was whether the descending presentation of a VSWM span task would benefit the performance of older adults. We were also able to assess whether the ascending condition would again benefit the performance of young adults, as we had found in Experiment 1.

Method

Participants. Sixty young adults and 60 older adults were recruited and remunerated as in Experiment 1. Exclusion criteria were identical to those used in Experiment 1 and resulted in a final sample of 59 young adults and 52 older adults.

Materials and procedure. In this experiment, the nine potential target squares were presented as a structured 3 × 3 matrix (see Figure 1). Set sizes varied from 3 to 9, with three sets tested at each set size, for a total of 21 trials. To ensure participants assigned to the ascending or descending span presentation did not differ on basic visuospatial abilities, in this experiment we administered the block design task (BDT) from the Wechsler Adult Intelligence Scale (3rd ed., Wechsler, 1997a). In all other respects, procedures (e.g., task presentation, timing, recall cues) and materials were identical to those used in Experiment 1.

Results and Discussion

Older adults (M age = 69.25 years, $SD = 5.27$; range = 60–76 years) had higher scores than young adults (M age = 20.22 years, $SD = 3.89$; range = 18–30 years) on the MEQ ($M = 59.15$, $SD = 9.86$, and $M = 42.66$, $SD = 10.14$, respectively), reflecting their greater tendencies towards morningness (e.g., Yoon et al., 1999). Older adults also had more years of education ($M = 15.35$ years, $SD = 3.83$) than young adults ($M = 13.91$ years, $SD = 1.52$). There were no main effects or interactions of age, MEQ score, or education with condition, indicating that within each age group, those randomly assigned to the ascending versus descending conditions did not differ on these variables. Older adults performed more poorly than young adults on the BDT ($M = 34.35$, $SD = 7.59$, and $M = 52.61$, $SD = 8.75$, respectively); however, there were no differences in BDT scores within older or young adults assigned to either the ascending or descending task (see Table 1).

A 2 (age) x 2 (condition) ANOVA on proportion of correct trials showed young adults having higher span scores than older adults, $F(1, 107) = 107.10$, $p < .01$, Ms = 58 and 37, respectively. Age again interacted with condition; $F(1, 107) = 9.08$, $p < .01$, with older adults performing significantly better in the descending ($M = 40$, $SD = 8$) than in the ascending ($M = 33$, $SD = 10$) condition, $t(50) = 2.79$, $p = .01$, and with young adults again showing the opposite pattern: reliably poorer span scores in the descending ($M = 54$, $SD = 13$) than in the ascending ($M = 61$, $SD = 10$) condition, $t(57) = 2.03$, $p = .05$ (see Figure 2B). Note that, as in Experiment 1, despite the improvement in the performance of older adults and the decline in the performance of young adults in the descending, as opposed to the ascending, condition, the age difference in the descending condition remained significant, $t(54) = 4.87$, $p < .01$.

Here, as in the first study, older adults received a substantial benefit when assigned to the PI-reducing descending, compared with the ascending, version of a VSWM task. Planned contrasts on the critical longest set sizes (here, sets 6–9) once again showed reliably better performance in the descending condition ($M = 12$, $SD = 12$) than in the ascending condition ($M = 6$, $SD = 9$), $t(50) = 2.17$, $p = .03$. Our results clearly demonstrate that the detrimental effects of the typical sequencing of WM span tasks generalize from the random display of the CBT to the matrix used in Experiment 2. As well, the benefit for young adults in the ascending ($M = 34$, $SD = 16$) compared with the descending

Table 1
Age and Years of Education for Each Group of Participants in Experiments 1 and 2, with Block Design Test Scores for Experiment 2

Demographic data	Young adults				Older adults			
	Ascending		Descending		Ascending		Descending	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Experiment 1 (Corsi block test)								
Age	20.00	2.40	19.41	1.94	67.00	4.65	66.12	4.99
Education	13.26	1.45	12.76	1.09	16.13	3.61	16.00	4.08
Experiment 2 (3 × 3 matrix)								
Age	19.78	2.53	20.47	4.85	69.63	5.10	68.71	5.25
Education	13.75	1.68	14.05	1.37	15.24	4.02	15.46	3.72
Block design	52.11	10.40	53.07	7.10	33.92	7.33	34.79	7.99

($M = 28$, $SD = 18$) format of Experiment 1 was also replicated, although the comparison here on the longest sets did not reach significance ($p > .05$).

General Discussion

We focus first on interference effects, effects we assessed in these studies because earlier work showed that both operation span (Bunting, 2006) and reading span (Lustig et al., 2001; May et al., 1999) are vulnerable to the negative effects of PI, the disruptive effects that earlier information has on the retrieval of the most recent information. Older adults are known to have difficulty suppressing these irrelevant items from the past (e.g., Hartman & Dusek, 1994) and often show larger PI effects than do young adults (Winocur & Moscovitch, 1983). With respect to reading span, two sets of studies (Lustig et al., 2001; May et al., 1999) demonstrated that reducing interference by administering the longest set sizes first rather than last is especially beneficial to older adults. We used that same manipulation and found that older adults do indeed show bigger span scores when tested in a PI-reducing format. Hasher et al., (1999, see also Hasher et al., 2007) attributed this vulnerability to PI to an age-related reduction of attentional processes that otherwise serve to suppress no-longer-relevant information. Effective suppression enables people to recall information from only the most recent trial. Ineffective suppression enables competition between information from prior trials and that from the most recent ones, resulting in lower span scores. Consistent with these observations is other evidence that individuals and groups shown to be vulnerable to interference typically have low span scores (e.g., Butters, Delis, & Lucas, 1995; Chiappe, Hasher, & Siegel, 2000; Gernsbacher, 1997). The present results suggest that the combination of poor attentional control and the procedures used in many VSWM span tasks is particularly disadvantageous to older adults, resulting in lower span scores than might be truly representative of their skills.

We note that not only did young adults not benefit from the descending administration of the VSWM span tasks used in our experiments, they were actually disadvantaged relative to performance in the ascending condition. A careful rereading of those studies with ascending and descending span manipulations suggests that such patterns have been found before for young adults, although they have not been reported as reliable (see Lustig et al., 2001; May et al., 1999). Of central relevance to the present findings, Fischer (2001) reported a borderline advantage ($p < .07$) for young adults in an ascending as compared with a descending VSWM span.

One possible explanation for younger adults' higher span scores in the ascending, relative to descending, condition might be differential benefits from practice effects and strategy use (Voyer, Voyer, & Bryden, 1995) stemming from beginning with the short lists. General practice effects have been found in both verbal (e.g., anagram solving, Gavurin, 1973) and visuospatial (e.g., mental rotation, Lohman & Nichols, 1990) tasks, as well as on subtests of the Wechsler Memory Scale–Revised (Theisen, Rapport, Axelrod, & Brines, 1998), at least for young adults. Indeed, an earlier study on learning to learn (Postman, 1969) confirmed that young adults virtually always show rapid improvement on tasks, no matter how novel, and training or practice under conditions similar to those of a later task facilitates development of task-specific skills. Here, practice effects could be seen in superior performance on longest sets when they were given last rather than first. These practice effects then outweigh the PI effects otherwise found in ascending span procedures.

Although older adults have been shown to benefit from practice under certain circumstances (e.g., Ratcliff, Thapar, & McKoon, 2006), practice effects have been reported to be smaller for older compared with young adults (Monge, 1969). In addition, on occasions when practice is likely to help performance, the effects have been negated by other components of the task that are troublesome to older adults (e.g., task switching, see Maquestiaux, Hartley, & Bertsch, 2004). Since interference effects are greater for older than for young adults, it would not be surprising that, to whatever degree they show practice effects in the ascending version of span tasks, these are more than outweighed by interference stemming from poor suppression regulation. Taken together, these two studies thus suggest the existence of at least two factors that contribute to performance on WM span tasks: practice and interference. Age differences in the benefits of practice and in the costs of interference may lead to an overestimate of span size for young adults and to an underestimate of span size for older adults, at least in the ascending manner in which both reading span and visuospatial span tasks are administered.

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