Effects of Age, Domain, and Processing Demands on Memory Span: Evidence for Differential Decline

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ABSTRACT

Analysis of cross-sectional data from the normative sample of the Wechsler Memory Scale – Third Edition (WMS-III) revealed different patterns of age-related differences in memory span measures depending on the type of memory item, processing demands, and the age of the older adult group. Regression of memory span on age revealed that the slope for Spatial Span raw scores was significantly more negative than the slope for Digit Span raw scores. There was no significant difference, however, either between the slopes for forward and backward Digit Span or between the slopes for forward and backward Spatial Span. Regression of Letter-Number Sequencing raw scores on age showed a distinctive, curvilinear pattern. Taken together, the present findings suggest that at least two mechanisms are involved in age-related differences in memory span. One mechanism, associated with a relatively linear decrease in memory span as a function of age, may differentially affect the storage of different types of information (e.g., sequences of digits vs. spatial locations). The other mechanism, evidenced by the curvilinear trend in Letter-Number Sequencing scores, may be tentatively attributed to a decline in executive aspects of working memory that becomes increasingly pronounced with age.

It is well established that older adults perform more poorly on measures of working memory than do younger adults (Salthouse, 1994; Verhaeghen, Marcoen, & Goossens, 1993). There is no consensus, however, regarding which aspects of the working memory system are most affected by aging. Most models of working memory assume two types of components (e.g., Baddeley, 1986; Engle, Laughlin, Tuholski, & Conway, 1999): storage components that may be specific to the type of information (e.g., verbal and visuospatial) and processing or executive function components that are used for selecting, manipulating, and coordinating information in the storage components. Aging could have an effect on any or all of these components. For example, spatial storage may be more affected by aging than verbal storage (e.g., Jenkins, Myerson, Joerding, & Hale, 2000; Myerson, Hale, Rhee, & Jenkins, 1999), or executive aspects of working memory may be more affected than storage capacity (e.g., Dempster, 1992; Moscovitch & Winocur, 1992; West, 1996).

It is commonly believed that older adults show a greater discrepancy between forward and backward digit span than young adults, and such a differential deficit could be a consequence of a specific age-related decline in executive or processing aspects of working memory. This is because forward digit span may primarily measure storage, whereas backward digit span may reflect both storage and processing because it requires that a person must maintain numbers in memory and also manipulate those numbers.

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Alternatively, if the additional processing required by backward span tasks is spatial in nature (Costa, 1975; Hoshi et al., 2000; Rapport, Webster, & Dutra, 1994; Weinberg, Diller, Gertsmann, & Schulman, 1972), then an age deficit in spatial processing could result in backward span being more age-sensitive than forward span.

All of this, however, proceeds from the premise that backward span actually is more affected by aging than forward span. According to the technical manual for the Wechsler Adult Intelligence Scale – Third Edition (WAIS-III; Psychological Corporation, 1997a):

The ability to repeat digits in the order of verbal (forward) presentation...tends to remain relatively stable with aging in normally functioning men and women...Digit Span Backward, however, is more affected by aging and by impairment...[N]ormally functioning adults over 70 years old show a greater discrepancy [than younger adults], with a significantly shortened backward span. (pp. 187–188)

The experimental literature, however, presents conflicting evidence on this point. On the one hand, Babcock and Salthouse (1990) reported a meta-analysis that indicated a greater effect of age on backward than forward digit span. On the other hand, a meta-analysis by Verhaeghen et al. (1993) showed that the effect size for backward digit span did not differ from that for forward digit span. Moreover, Gregoire and Van der Linden (1997) analyzed data from the standardization sample for the French adaptation of the Wechsler Adult Intelligence Scale – Revised (WAIS-R) and found that the slope of the age-related decrease in forward digit span was the same as that for backward digit span.

The evidence regarding a differential age-related decline in verbal and visuospatial memory span is also conflicting. For example, a recent study by Myerson et al. (1999) showed that although young adults and older adults had similar digit spans, the older adults had much lower spatial spans than young adults. Other studies (e.g., Dolman, Roy, Dimeck, & Hall, 2000; Jenkins et al., 2000) have also reported greater age differences in memory span for visuospatial stimuli (e.g., locations and gestures) than for verbal stimuli (e.g., digits and words).

In contrast, Salthouse, Kausler, and Saults (1988) reported evidence against a differential age-related decline in spatial memory span. Salt-house et al. presented participants with a matrix of letters, with certain letters highlighted, and instructed them to remember either the locations of these highlighted letters or the letters themselves. Regression analyses indicated that the rate of decrease in memory performance with age was similar for both verbal (letters) and spatial (locations) materials. A second study (Salthouse, 1995) examined parallel verbal and visuospatial versions of three different working memory tasks, and this study also failed to find evidence that the visuospatial memory abilities of older adults are differentially affected relative to their verbal memory abilities.

Given the mixed evidence with respect to both forward versus backward span and verbal versus visuospatial memory span, a large scale study is needed to resolve these issues. The data from the standardization tables of the Wechsler Memory Scale – Third Edition (WMS-III) and the WAIS-III (Psychological Corporation, 1997b) afford the opportunity for such a study. The standardization sample included more than a thousand adults of various ages, and each age group was selected to be representative of the United States population with respect to sex, level of education, race/ethnicity, and geographic region. The WMS-III includes measures of forward and backward digit span as well as forward and backward spatial span (Psychological Corporation, 1997a). The WMS-III also includes a new measure of working memory, the Letter-Number Sequencing subtest, in which a person is presented with a series of numbers and letters, and then must recall the numbers in numerical order followed by the letters in alphabetical order. Because Letter-Number Sequencing presumably places an even higher load on the ability to manipulate information online than either forward or backward digit span, it may provide a more sensitive test of the effects of age on the processing or executive aspects of working memory.
METHOD

Sample
All data were obtained from the standardization tables in the WMS-III Administration and Scoring Manual (Psychological Corporation, 1997b). As described in the WAIS-III – WMS-III Technical Manual (1997a), the WMS-III standardization sample consists of 1,250 adults partitioned into 13 groups (ages 16–17, 18–19, 20–24, 25–29, 30–34, 35–44, 45–54, 55–64, 65–69, 70–74, 80–84, 85–89). Each of the first 11 groups (through age 74 years) contains data from 100 participants, whereas the last two age groups contain data from 75 participants each. For the following analyses, the first two age groups (ages 16–19 years) were excluded, leaving a total sample size of 1,050 (ages 20–89 years) partitioned into 11 groups. Potential participants were screened with a medical and psychiatric self-report questionnaire (see Table 2.1 in the WAIS-III technical manual; Psychological Corporation, 1997a).

Each age group was selected to be representative of the United States population with respect to sex, level of education, race/ethnicity (White, African-American, Hispanic, or Other), and geographic region (Northeast, North Central, South, and West). A stratified sampling plan, based on 1995 data from the United States Bureau of Census, was used to ensure representativeness (Psychological Corporation, 1997a). For example, in the population at large, 50.1% of young adults aged 25–29 years and 58.0% of older adults aged 75–79 years were female, whereas, in the WMS-III sample the percentages for the corresponding age groups were 50.0 and 58.0%. More specifically, all of the age groups in the WMS-III sample were 50% female except for those participants 65 years or older. For those older age groups, the percentage of female participants was based on corresponding census data. Similarly, for each age group the percentages of participants with different levels of education (i.e., 8 or less, 9–11, 12, 13–15, and 16 or more years of education) in the WMS-III sample closely approximated the corresponding percentages in the United States population (compare Tables 2.5 and 2.7 in the WAIS-III technical manual; Psychological Corporation, 1997a). Notably, age differences in the distribution of levels of education reflect historical trends in educational access (Snyder, 1993).

Subtests
The Digit Span subtest of the WMS-III consists of two parts: Digits Forward and Digits Backward. For each part, the test administrator says a series of numbers at the rate of about one per second. Following presentation, the examinee either repeats the numbers in the order they were presented (Digits Forward) or in reverse order (Digits Backward). For both Digits Forward and Digits Backward, the test begins with series of two numbers. For Digits Forward, the test continues to a maximum of eight numbers, and for Digits Backward the test continues to a maximum of seven numbers. Examinees are given two trials at each series length, and the test continues until both trials of a series length are failed. One point is awarded for each trial that the examinee answers correctly. The total raw score for Digit Span is the sum of the trials answered correctly for both Digits Forward and Digits Backward. The maximum possible score for the Digit Span subtest is 30 (16 points for Digits Forward and 14 points for Digits Backward).

The Spatial Span subtest also consists of two parts: Spatial Span Forward and Spatial Span Backward. For each part, the examiner taps a series of cubes at the rate of about one cube per second. Following presentation, the examinee either taps the cubes in the same order as the examiner (Spatial Span Forward) or in reverse order (Spatial Span Backward). For both Spatial Span Forward and Spatial Span Backward, the test begins with series of two cubes and continues to a maximum of eight cubes. Examinees are given two trials at each series length, and the test continues until both trials of a series length are failed. One point is awarded for each trial that the examinee answers correctly. The maximum possible score for the Spatial Span subtest is 32 (16 points each for Spatial Span Forward and Backward).

In Letter-Number Sequencing, the test administrator says a series of alternating numbers and letters at the rate of about one per second. Following presentation, the examinee first reports the numbers in ascending numerical order, then reports the letters in alphabetical order. The test begins with series of two items (one number and one letter) and continues to a maximum of eight items (four numbers and four letters). Examinees are given three trials at each series length, and continue until all three trials of a series length are failed. Because of differences in administration, the maximum possible raw score for Letter-Number Sequencing is lower than that for either Digit or Spatial Span. The maximum possible score for Letter-Number Sequencing is 21.

Analysis
For the total Digit Span, total Spatial Span, Spatial Span Forward, Spatial Span Backward, and Letter-Number Sequencing subtests, weighted regression analyses were based on reconstructed distributions of raw scores for each age group calculated from the WMS-III standardization tables (Psychological Corporation, 1997b). For Digits Forward and Backward, separate scaled scores are not included in the standardization tables. The tables, however, do provide the cumulative distributions of the longest sequence of digits that participants could recall both forwards and backwards, as well as the cumulative distributions for each age
group of the within-subject difference between the longest span forward and longest span backward. These data were used to compare forward and backward digit spans. Because the present analyses were based on standardization tables rather than the raw data, regression analyses treated the data from each measure as independent.

The WMS-III standardization tables (Psychological Corporation, 1997b) for the total Digit Span, total Spatial Span, Spatial Span Forward, Spatial Span Backward, and Letter-Number Sequencing subtests present the scaled score equivalents of subtest raw scores normalized for each age group. The scaled scores are normalized so that, for each age group, the mean equals 10 and the standard deviation equals 3. In order to reconstruct the original distribution of raw scores for each age group, we first matched each scaled score to its corresponding raw score(s) and then determined the probability of each range of raw scores using a cumulative probability table for a normal distribution. The midpoint of each range of raw scores (or the corresponding range of z scores) was used as the dependent variable in the regression equations, and the product of the probability of each range and the number of people in the age group was used as the regression weight. The independent variable was the midpoint of the age range for each of the 11 groups described above (e.g., the 20–24 group had ages ranging from 20 years and 0 days to 24 years and 364 days with a midpoint of 22.5 years).

The maximum and mean scores for the Letter-Number Sequencing subtest are markedly different from those for the Digit Span and Spatial Span subtests. Therefore, analyses comparing Letter-Number Sequencing with Digit Span and Spatial Span were conducted using z scores rather than raw scores as the independent variable. For each subtest, the distributions of z scores for the various age groups were computed using the mean and standard deviation of the 20–24-year-old age group (estimated from the reconstructed raw score distribution) as a reference.

RESULTS

Means for the various measures at each age, estimated from the reconstructed raw score distributions, are pictured in Figures 1–3, and regression equations and correlation coefficients are reported in Table 1. As may be seen in Figure 1, there is no evidence suggestive of a differential decrease in forward versus backward digit span with age for either Digit Span (top panel) or Spatial Span (bottom panel). There was no significant difference between the slopes for Digit Span Forward and Digit Span Backward, $t(2096) = 0.30, p > .05$. Similarly, there was no significant difference in the slope of the regression lines for Spatial Span Forward and Spatial Span Backward, $t(2096) = 1.21, p > .05$. In addition, regressing the Forward-Backward difference for Digit Span on age indicated that none of the

![Fig. 1. Forward and backward memory spans across all age groups. The top panel shows the mean longest series recalled for Digit Span Forward and Backward. The bottom panel shows the mean raw scores for Spatial Span Forward and Backward. In both panels, the error bars indicate standard errors.](image-url)
variance in the difference scores could be accounted for by age ($r^2 = .00$).

Some of the subtests, however, do show evidence suggestive of a differential decrease. Notably, Spatial Span appears to decrease more as a function of age than does Digit Span, as may be seen in Figure 2. The slope of the regression for the total raw Spatial Span score (0.085 points per decade) was significantly steeper than the slope of the regression for the total raw Digit Span score (0.054 points per decade), $t(2096) = 5.09, p < .001$. Similar results were obtained when age groups that had more females than males were not included in the analysis (i.e., when the age range was restricted to 20–64 years).

Finally, Letter-Number Sequencing scores appear to show a pattern of decrease different from that of either Digit Span or Spatial Span, as may be seen in Figure 3. As noted previously, $z$ scores based on the 20–24-year-old age group were used to compare Letter-Number Sequencing to the other tests. Therefore, constrained

Table 1. Regression Equations and Correlation Coefficients for Memory Span Measures.

<table>
<thead>
<tr>
<th>Equation</th>
<th>$r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digit Span total raw score</td>
<td>$y = -0.054x + 19.18$</td>
</tr>
<tr>
<td>Spatial Span total raw score</td>
<td>$y = -0.085x + 19.18$</td>
</tr>
<tr>
<td>Digits Forward longest series</td>
<td>$y = -0.014x + 7.16$</td>
</tr>
<tr>
<td>Digits Backward longest series</td>
<td>$y = -0.015x + 5.44$</td>
</tr>
<tr>
<td>Spatial Forward raw score</td>
<td>$y = -0.040x + 10.04$</td>
</tr>
<tr>
<td>Spatial Backward raw score</td>
<td>$y = -0.044x + 8.94$</td>
</tr>
<tr>
<td>Digit Span $z$ score</td>
<td>$y = -0.011(x - 22.5)$</td>
</tr>
<tr>
<td>Spatial Span $z$ score</td>
<td>$y = -0.022(x - 22.5)$</td>
</tr>
<tr>
<td>Letter-Number $z$ score</td>
<td>$y = -0.019(x - 22.5)$</td>
</tr>
</tbody>
</table>

*Note.* All reported correlations are significantly different from zero ($p < .05$).
regression analyses (that excluded the 20–24-year-old data) were conducted to determine if the slope of the decrease in Letter-Number Sequencing was different from that of either Digit Span or Spatial Span. That is, all regressions were forced through the point at which age = 22.5, z = 0.0. The slopes for Digit Span, Spatial Span, and Letter-Number Sequencing were, respectively, 0.011, 0.022, and 0.019 z score units per decade. Results indicated that the slope of the Letter-Number Sequencing regression line was significantly steeper than that for Digit Span, t(1896) = 7.26, p < .001, and slightly less steep than that for Spatial Span, t(1896) = 2.11, p < .05.

The graph in Figure 3 reveals some curvature in the relationship between Letter-Number Sequencing and age. This pattern was confirmed by polynomial regression, which indicated that the regression of Letter-Number Sequencing on age has a significant quadratic component, F(1,947) = 32.08, p < .001. Digit Span also shows a significant quadratic component, F(1,947) = 6.69, p < .001; Spatial Span, however, does not, F(1,947) = 1.22, p > .05.

DISCUSSION

To summarize, analyses of cross-sectional data from the WMS-III (Psychological Corporation, 1997b) provided no support for the common belief that backward spans show greater age-related declines than forward spans: There was no evidence of a specific age-related deficit in backward memory span for either verbal material (Digit Span) or visuospatial material (Spatial Span). However, the slope of the regression of Spatial Span on age was significantly more negative than the slope for Digit Span. Scores on the Letter-Number Sequencing subtest also decreased more as a function of age than scores on the Digit Span subtest, but scores on the Spatial Span subtest showed the largest decrease.

The present findings regarding a lack of a specific age-related deficit in backward digit span, relative to forward digit span, are consistent with those reported by Gregoire and Van der Linden (1997) for the French WAIS-R normative sample. In addition, our findings reveal no evidence of a specific age-related deficit in backward spatial span relative to forward spatial span. The results of a meta-analysis of experimental studies reported by Babcock and Salthouse (1990) are sometimes taken as indicating greater age-sensitivity of backward spans. However, the two studies examining cross-sectional data from large, representative samples of people (i.e., the current study and that of Gregoire and Van der Linden) provide no evidence that older adults show a specific deficit in backward spans compared to forward spans. These results are of particular interest because they contradict the established belief – exemplified by the quote in the introduction – that older adults are differentially impaired in backward span.

The present findings regarding Digit and Spatial Span are consistent with the results of several previous studies which reported that older adults are differentially impaired in visuospatial memory span compared with verbal memory span (Dolman et al., 1997; Jenkins et al., 2000; Myerson et al., 1999). They differ, however, from the results of other studies (Salthouse, 1995; Salthouse et al., 1988). Procedural and sampling differences may be responsible for the conflicting nature of previous evidence. Regardless of the correct interpretation of past discrepancies, however, the present findings based on a large normative sample may help resolve the question of whether aging affects visuospatial memory span more than verbal memory span. Comparisons based on raw scores and those based on z scores (in young adult standard deviation units) both revealed that slopes for the regression of spatial span measures on age were significantly more negative than slopes for corresponding digit span measures.

Park et al. (2002) recently reported the results of a study of 345 adults aged 20–92 years that examined age-related differences in various aspects of verbal and visuospatial memory including short-term memory, working memory, and long-term memory. Of particular relevance to the present study are Park et al.’s results for short-term memory, which was represented in their study by Digit Span Forward and Backward and Spatial Span Forward and Backward (which they referred to as Corsi Blocks although they
note that it was taken from the WMS-III). They converted each of these measures to \( z \) scores based on the \( SD \) of the entire sample and then regressed these scores on age.

The Park et al. (2002) regression results were similar to those of the present study in that for both digits and spatial locations, the slopes for the forward and backward scores were approximately equal. In both studies, moreover, the slopes for the spatial span measures were nearly twice as steep as those for the digit span measures. Specifically, Park et al. reported that the slopes for Spatial Span Forward and Backward were \(-0.025\) and \(-0.021\) (both standard errors \(= 0.002\)) whereas the slopes for Digit Span Forward and Backward were \(-0.013\) and \(-0.012\) (both standard errors \(= 0.003\)). Although they reported no significant differences in slope between any of their digit span and spatial span measures, this may be because of the family-wise correction for the number of statistical tests performed, given the size of the difference and the relatively small standard errors.

To facilitate comparison with the Park et al. (2002) findings, we converted the WMS-III data to \( z \) scores based on the \( SD \) of the entire WMS-III sample. Regression analyses based on these transformed data yielded values for the slopes that were very similar to those reported by Park et al. Specifically, the slopes for the transformed WMS-III data were \(-0.025\) for Spatial Span (Forward plus Backward) and \(-0.013\) for Digit Span (Forward plus Backward). The difference between these Digit and Spatial Span slopes was statistically significant: \( t(2096) = 8.08, p > .001\). Moreover, the similarity of these slopes to those reported by Park et al. clearly demonstrates the replicability of the finding that spatial spans decrease more with age than digit spans.

It has been suggested that the extra processing involved in backward digit span is spatial in nature (e.g., Costa, 1975; Hoshi et al., 2000; Rapport et al., 1994; Weinberg et al., 1972), but the normative WMS-III data analyzed here provide little support for the hypothesis. Aging affects visuospatial processing more than verbal processing (e.g., Hale & Myerson, 1996; Jenkins et al., 1999; Lawrence, Myerson, & Hale, 1998), and thus one might expect that adding spatial processing to a verbal task (e.g., digit span) would result in an increased age deficit. Nevertheless, the present results failed to provide evidence suggestive of a differential decline in Digits Backward relative to Digits Forward.

The present results regarding age-related differences in Letter-Number Sequencing may be contrasted with those for Digits Forward and Digits Backward. Letter-Number Sequencing performance clearly decreased at a greater rate, particularly after age 60, than either forward or backward digit span. Some researchers (e.g., Dobbs & Rule, 1989; Engle et al., 1999) have suggested that backward span tasks require relatively little executive processing. Arguably, categorizing items as digits and letters and then reordering them (i.e., numerically and alphabetically) does require substantial executive processing. If so, the present findings are consistent with the hypothesis of specific age-related deficits in executive functions (e.g., Moscovitch & Winocur, 1992; West, 1996). Relatively little research, however, has been done on the Letter-Number Sequencing task since it was recently introduced (Psychological Corporation, 1997a, 1997b), and tests of the hypothesis that this task makes special demands on the ability to manipulate information online are needed.

In conclusion, a single mechanism account does not appear to be sufficient to explain the overall pattern of age-related differences in memory span performance on the WMS-III. Digit Span and Spatial Span both require recalling items in the original and reverse order, yet Spatial Span decreases more with age than Digit Span. Moreover, although both Digit Span and Letter-Number Sequencing use verbal material, the latter decreases more with age than the former. With respect to the two more age-sensitive subtests, Spatial Span showed a linear decrease with age whereas the decrease in Letter-Number Sequencing was significantly curvilinear. Taken together, these findings suggest that at least two mechanisms may be involved in determining the time course of age-related decline in memory span. One of these mechanisms differentially affects the storage of spatial information and may begin affecting working memory performance relatively early in adulthood; the other mechanism, which
has pronounced effects only in later adulthood, may be tentatively attributed to a decline in executive aspects of working memory.

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REFERENCES


