Journal of the International Neuropsychological Society (2000), **6**, 770–780.

Speed and memory in WAIS–R–NI Digit Symbol performance among healthy older adults

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(RECEIVED December 3, 1998; REVISED July 16, 1999; ACCEPTED November 12, 1999)

Abstract

Although roles have been proposed for both graphomotor speed and learning in the execution of Digit Symbol, few data have been available concerning performance across the adult lifespan on the Symbol Copy, paired associates, or free recall measures derived from Digit Symbol and recommended in the WAIS–R–NI. We report findings on 177 healthy older adults (ages 50–90), providing normative data by age group, education level, and gender. As previously reported, Digit Symbol scores decline steeply with age ($r = -.64$). Symbol Copy speed declines almost as steeply ($r = -.58$). Incidental learning, however, declines only modestly ($r = -.26$ on both measures). Symbol Copy is a far stronger correlate of Digit Symbol ($r = .72$) than are paired associates or free recall ($r = .26$ and $r = .28$, respectively). The 2 incidental learning measures do, however, offer valuable supplementary information as part of a comprehensive individual assessment. When low Digit Symbol scores are produced by slowing on Symbol Copy, further evaluation of perceptual and motor speed and dexterity are indicated. When low incidental learning scores are obtained, further evaluation of memory is warranted. Qualitative analysis of errors (e.g., rotations) made on the incidental learning procedures may also be valuable. (*JINS*, 2000, *6*, 770–780.)

Keywords: Wechsler, Digit Symbol, Aging, Incidental learning, Psychomotor speed

INTRODUCTION

Digit symbol substitution tests have existed since the earliest days of psychological assessment (e.g., Woodworth & Wells, 1911), and a Digit Symbol (or Coding) subtest has been featured on every edition of the Wechsler intelligence scales (e.g., Wechsler, 1981). The concept originally underlying these tests was that learning the symbols (and the associated digits) would determine the number of items correctly completed during the time allotted. Several early studies suggested that speed, not memory, is the prime determinant of Digit Symbol (Burik, 1950; Murstein & Leipold, 1961) or obtained equivocal findings concerning the importance of learning and memory in Digit Symbol performance (Luchins & Luchins, 1953). Recent intellectual assessment texts (e.g., Groth-Marnat, 1990; Kaufman, 1990), however, while acknowledging speed as a key factor in Digit Symbol, continue also to refer to its alleged role as a measure of short-term memory and learning.

The determinants of success (or failure) on Digit Symbol are important for several reasons, including the test's sensitivity to normal age-related cognitive decline. Digit Symbol enjoys (or suffers) the strongest negative relationship with age of all Wechsler subtests (e.g., Birren & Morrison, 1961; Howell, 1955; Kaufman, 1990). In addition, although the weakest IQ predictor on the Wechsler scales, Digit Symbol is also their most sensitive indicator of central nervous system dysfunction (Kaplan et al., 1991; Lezak, 1995). Depressed Digit Symbol scores are associated with a variety of conditions, and tend to correlate with severity of disorder.

Together with this wide-ranging efficacy come two major, and related, problems. First, despite its long history, the actual cognitive processes involved in Digit Symbol are poorly understood. Second, at our present state of knowledge, it contributes little to the differential diagnostic enterprise beyond the likelihood of unspecified neuropathology and cognitive dysfunction. Improved understanding of the cognitive processes contributing to performance would help

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to remedy this, ideally offering a list of diagnostic possibilities and indicating further procedures by which to differentiate among them.

One approach to analyzing Digit Symbol into its constituent elements is to devise analogous tests that differ only in omitting one or more components: an application of Donders' subtraction method (Gottsdanker & Schragg, 1985) to clinical psychometrics. The size of the correlation between scores on Digit Symbol and on such an analog test indicates the extent of their theoretical linkage; the degree to which the tests possess independent variance indicates the importance to Digit Symbol of the cognitive functions omitted on the analog test. Such patterns of relationship should be established not only for healthy young adults, but also in patient groups and aging populations, for a cognitive ability that is necessary in order to perform well, but that is universally intact among healthy young adults, will not appear to be important in any studies limited to that population (Glosser et al., 1977).

Although several authorities allude to the possible importance of visual scanning efficiency (Burik, 1950; Kaplan et al., 1991) or visuoperceptual functions (Glosser et al., 1977; Royer, 1971) in Digit Symbol performance, the contributions of speed and incidental learning/memory have received the most attention, and are the foci of this paper.

Speed in Digit Symbol

One step-down version of Digit Symbol simply omits the code key; instead of substituting symbols for digits, the examinee copies symbols from the upper boxes into the adjacent empty boxes. This retains the test's visuoperceptual and graphomotor elements while removing coding operations, including memory.

Royer (1971) found, as expected, that symbol copying occupied less time than did coding, but as the tasks were completed by different samples, the contribution of copying speed to Digit Symbol was undetermined. Storandt (1976) and Glosser et al. (1977) reported that copying occupied approximately half as much time as coding, but neither reported the correlation between the two measures. Storandt (1976) also noted that Symbol Copy speed mediated most of the age-related decline in Digit Symbol.

LeFever (1985) obtained a correlation of $r = .85$ between Digit Symbol and Symbol Copy in a sample of 108 healthy persons ranging from 20 to 90 years of age, and replicated this finding in a mixed sample of neurological patients (LeFever, 1991). Scores on both tests declined sharply with age; based on these findings, LeFever (1985) proposed that Symbol Copy might reasonably be substituted for the more complex coding measure. Here, he overstated the case; we compared the age correlations LeFever (1985) reported for Digit Symbol (−.76) and Symbol Copy (−.69) using the Williams procedure for testing the difference between nonindependent correlation coefficients and found that they are in fact significantly different [$t(105) = 2.01$, $p < .05$], indicating that the regression slopes are not equal: Digit Symbol is more affected by age than is Symbol Copy. This conforms with Salthouse (1992), but not with Erber et al. (1981), who reported equivalent age differences on the two tests. The issue is an important one, for it bears on the question of whether the higher cognitive functions presumably called for by the coding component of Digit Symbol are adversely affected by aging, or whether Symbol Copy functions like graphomotor speed wholly account for the age-related decline in Digit Symbol scores.

The *temporal pattern* of Digit Symbol performance might also be worth measuring. It might be argued, for example, that examinees whose performance *accelerates* are learning how to do the task more efficiently, whether by mastering the digit–symbol pairs or in some other fashion. Taken as a group, such people would be expected to obtain relatively *high* mean scores on Digit Symbol and the incidental learning measures. At the other extreme, examinees whose performance *decelerates* over time clearly are not mastering the task, whether owing to learning problems, distractibility, neuromotor fatigue, or some other factor. Taken as a group, they would be expected to obtain relatively *low* mean scores on Digit Symbol and the incidental learning measures. It may well be that some cases of slowing are at least partially attributable to fatigability; if so, these would probably be the more obvious or severe cases of slowing, such as individuals whose performance steadily deteriorates over time. Distractibility or a learning problem would probably produce a more variable pattern of performance. If slowing is caused by easy fatigability, then relatively low scores should also be obtained on Symbol Copy; conversely, if Symbol Copy scores are comparable to those for the accelerating group, then fatigue has been ruled out as an explanation of any deficiency in Digit Symbol.

It is predicted that examinees displaying an accelerating pattern of performance on Digit Symbol will obtain higher scores on Digit Symbol and the two incidental learning tests than will examinees displaying a decelerating pattern of performance. Those strongly characterized by slowing may also perform less well on Symbol Copy.

Memory in Digit Symbol

The most direct means of measuring learning and memory relative to Digit Symbol is to test recall of the digit–symbol pairings, and/or free recall of the symbols, after administering the test under standard conditions. In this way, the amount of incidental learning that takes place during completion of the test and the impact of differential learning on scores can be assessed. Given the abiding concern over the magnitude of the role purportedly played by learning and memory in Digit Symbol performance, it is surprising how meager are the available data on this subject.

Burik's (1950) 50 female high school students recalled a mean of 7.1 digit–symbol pairs, while the 15 college students who took the test under standard conditions for Murstein and Leipold (1961) recalled a mean of 6.20 (SD = 1.76). The 19 normal controls (M age = 70.1 years) tested by Hart et al. (1987) recalled a mean of 6.4 digit–symbol pairs and 6.9 symbols. These data imply that aging has little effect on incidental learning in Digit Symbol. Erber (1976), however, found that young adults acquired more paired-associates learning across 10 trials than did older adults. More recently, significant age differences in incidental paired-associate learning on Digit Symbol were obtained in a sample of 131 White South Africans ranging in age from 20 to 89 (Shuttleworth-Jordan & Bode, 1995). As there were only 20 to 30 persons in each age group, these findings should be treated cautiously, but they suggest a marked decline starting at about age 70.

Erber (1976) suggested that the performance of older people might be slowed by frequent consultation of the code key secondary to this memory deficit. Salthouse (1978), however, reduced the number of digit–symbol pairs so as to equalize younger and older examinees on knowledge of the key, and reported that young and old adults benefited equally from the reduction in complexity, implying that age-related memory deficits play no significant role in declining Digit Symbol scores. Also, Erber et al. (1981) trained young and older adults to 100% mastery of the standard code key, and found that only the young improved their scores as a result; age differences were not attributable to unnecessary consultation of the code key by the old.

The clinical relevance of measuring incidental learning in administering Digit Symbol was demonstrated by Hart et al. (1987), who found that the incidental learning measures contribute to the differential diagnosis of depression and dementia; age-matched patients with early dementia or depression were indistinguishable on Digit Symbol, but the depressed group substantially outperformed the dementia group on memory. Interestingly, the depressed group was impaired relative to controls on paired-associate learning, but not on free recall of the symbols, possibly reflecting a passive learning style or selective difficulty in perceiving contingent relations among the depressed. Whether the incidental learning that takes place during Digit Symbol performance contributes useful data to cognitive assessment is, in fact, an issue distinct from that of how far Digit Symbol performance depends upon such learning.

Rationale for the Present Study

While many previous studies have examined age differences in Digit Symbol, few have investigated age differences in Symbol Copy. Only one published report (Shuttleworth-Jordan & Bode, 1995) assessed age differences on incidental paired-associates learning during Digit Symbol. No previous study has examined age differences on free recall of the symbols, nor has any study examined both copying speed and incidental learning in order to evaluate their relative importance to Digit Symbol score or their relative rates of age-associated decline.

Publication of the WAIS–III (Psychological Corporation, 1997), which for the first time includes Symbol Copy and two incidental learning measures as optional procedures following Digit Symbol administration, helps to remedy the first two lacks, providing some normative data for Symbol Copy and incidental learning. However, the Digit Symbol subtest has been modified (e.g., the test form includes fewer items per line, but more items overall, and 120 s are allowed, rather than 90 s), so these norms cannot easily be applied to the WAIS–R or WAIS–R–NI. Also, the WAIS–III *Technical Manual* reports only cumulative percentages of examinees performing at different levels up to the 50th percentile. Higher levels of performance are not described, nor are means and standard deviations provided. Scores are not analyzed by education or gender, and no correlations between the incidental learning measures, Symbol Copy, Digit Symbol, and IQ are reported. Thus, while useful to clinicians utilizing the WAIS–III, the data provided are of limited value in terms of explaining the cognitive dynamics of the tests or helping users of the WAIS–R–NI.

The primary purpose of the present investigation is to provide these data, thus contributing to our theoretical understanding of the information processing characteristics of Digit Symbol; secondarily, we hope to provide approximate norms by which clinicians may judge WAIS–R–NI Digit Symbol, Symbol Copy, and associated incidental learning scores in aging populations.

In a sample of normally aging participants, we expect to replicate previous findings of substantial age-related decline in Digit Symbol and Symbol Copy. We hope to clarify the issue of whether the aging effect on these two measures is equivalent, or whether (as we predict) there is a greater impact on the more cognitively demanding Digit Symbol test.

We will also clarify to what extent age affects incidental learning on Digit Symbol, and whether this effect is similar for the paired-associates and free recall tests. We predict an age-related decline on these measures like that typically obtained in memory research (a correlation in the $r = -.40$ range; Joy & Fein, 1998), perhaps attenuated by the immediacy of the memory measure (some symbols may remain available in short-term memory). Finally, although previous research has been equivocal, we predict that memory will prove to play a significant, if subsidiary, role in Digit Symbol performance.

In addition to the number of correct responses on the paired-associates and free recall tests, the qualitative nature of errors might be informative. Reproducing a one-, two-, or three-line drawing from a visible model demands only elementary visuoconstructional competence, and intact adults rarely make errors during standard Digit Symbol administration (Paolo & Ryan, 1994). Reproducing designs from memory, though, is comparatively difficult, requiring integration of constructional skill and the visuospatial sketchpad. Relatively subtle deficits might yield errors on the incidental learning measures.

No previous study has attempted a qualitative analysis of errors made on the incidental learning measures. These errors may logically be subdivided into (1) incorrect pairings, or mismatches, involving correct symbols (on the paired-associates test), (2) rotations of the original symbols, and (3) intrusions, namely, symbols unlike those in the key.

Incorrect pairings of digit and symbol are relatively mild errors. Examinees making such errors have learned the symbol, that is, mastered the graphomotor representation, but failed to associate digit and symbol. It might be argued that the visuospatial sketchpad has fulfilled its function, but the executive controller has failed effectively to integrate these new visual data with established verbal (numerical) knowledge.

Rotational errors are somewhat less mild, for the mental representation of the symbol itself has been distorted. The degree of distortion is modest; the symbol retains its original contours, but has lost its true orientation. Rotations of designs are often considered to be indicative of diffuse or right parietal deficits on a variety of design copying tasks including the Bender-Gestalt (Billingslea, 1963; Lezak, 1995; Mermelstein, 1983) and the Benton Visual Retention Test (Sivan, 1992), and do assist in discriminating neurological from psychiatric conditions (Heaton et al., 1978). Their frequency increases significantly with advanced age, however (Lacks & Storandt, 1982), so normative base rates must be established for intact members of various age groups.

Intrusions would appear to reflect the most severe impairment, in that even the basic configuration of the original design is lost or distorted. A defensive stance toward failure or a liberal response bias might produce an occasional intrusion, but in general these errors ought only to appear in the protocols of neurologically compromised patients, those whose ability to discriminate between a remembered response and an image generated during task completion is so reduced that superficially plausible responses (confabulations) will not be inhibited.

We predict that the frequency of each form of error will be inversely related to its severity (i.e., mismatching symbol and digit will be common, rotation of symbols less so, and intrusions quite rare) and that the frequency of errors will increase with age.

METHODS

Research Participants

Participants were 177 adults, aged 50 to 90 years ($M = 68.33$), including 126 women and 51 men. All were recruited through advertisements in local newspapers and radio shows, at senior citizen centers, and at other community centers in the metropolitan Toronto area. Participants averaged 13.59 years of school; educational data were unavailable for 11 persons. For purposes of data analysis, the sample was divided into four age groups (50–59, $n = 40$; 60–69, $n = 51$; 70–79, $n = 52$, and 80–90, $n = 34$) and two educational levels (≤ 12 years, $n = 76$; and >12 years, $n = 90$). The latter are referred to as the "high school" group and the "college" group, respectively. The sample was 99% White. Occupations included major professionals and executives (10%), minor professionals (25%), administrative/managerial (17%), clerical (28%), and service, labor, or homemaker (20%). Occupational status and educational level were strongly correlated ($r = .66$), so only education was utilized in data analysis. None were diagnosed with any neurological, psychiatric, or substance abuse disorders, and all reported themselves to be in good health at the time of testing. As expected among an aging population, however, many (62%) were receiving one or more prescription medications; most of these (36%) used only one, but 13% used two, 9% three, and 4% four or more medications. Antihypertensive medications were the most widely used (15% of the sample), followed by treatment for angina and/or arrhythmias (9%), estrogen replacement therapy (9%), thyroid supplements (8%), antihistamines or decongestants (6.5%), soporifics (6.5%), anti-asthma agents (6%), and diabetes treatments (5%). The number of medications used was uncorrelated with age, education, occupation, IQ, or any dependent measure used in the present study. Only antihypertensives were used by enough participants to empower meaningful pairwise comparisons, and the only near-significant effect was a trend for those receiving antihypertensives to be older than those not receiving such medications. Regarding alcohol, 26% of the participants were teetotalers, 24% drank less than 1 ounce of liquor (or the equivalent) per week, 8% had 1 drink per week, 17% had 2 to 4 drinks per week, 8% had 5 to 9 drinks per week, 15% had 10 to 18 drinks per week, and 3% had 19 or more drinks per week. The amount of alcohol consumed was weakly but significantly related to higher educational level ($r = .26$), occupational status ($r = .26$), and IQ ($r = .20$), and males drank slightly more than females ($r = .19$). There were, in short, very few participants who could be described as heavy drinkers and no signs of alcohol-related cognitive impairment.

Instruments and Procedure

Testing was conducted by research assistants, and protocols were scored by a doctoral candidate in clinical psychology, supervised by an experienced clinical neuropsychologist. After an interview in which demographic and health-related data were collected, participants completed the Information, Arithmetic, Picture Completion, Block Design, and Digit Symbol subtests of the WAIS–R. Full-scale IQ was estimated based on the first four subtests. In addition, several WAIS–R–NI (Kaplan et al., 1991) subtests were administered, including the Symbol Copy test and two incidental learning measures.

All participants were allowed to complete the first three rows of the Digit Symbol test form in their entirety. (Position as of 90 s was noted, and the number of items completed at that time was scored.) Immediately afterward, the test sheet was folded so as to conceal all but the final (fourth) row, and participants were instructed to fill in as much of this row as they could, from memory; the number of symbols correctly matched with digits became the paired-associates score. After this, they were instructed to write out as many of the symbols as they could remember, without regard to which number each had been paired with; the number of symbols correctly reproduced was used as the free recall score. Symbol Copy was administered later in the session. All participants were allowed to copy three rows of symbols, and the time required to do so served as the dependent measure. Except for two individuals who did not complete the free recall test, all scores are available for all participants.

Incidental learning test errors were subjected to qualitative analysis as follows. Incorrect responses (errors of commission, or false positives) and items left blank (errors of omission, or misses) were tabulated, and a response bias measure was derived for the paired-associates test: the ratio of incorrect responses to omitted items. Incorrect responses were categorized as (1) mismatches (correct symbols incorrectly paired with digits—this error type applies only to the paired-associates test); (2) rotations (symbols like those in the key, but 90° or 180° deviated from the original); and (3) intrusions (symbols unlike those in the key).

An *accelerated* pattern of performance was defined as one wherein the number of items completed in the last 30 s of the test was greater than the number completed in either the first 30 s or the middle 30 s of the test. A *decelerated* pattern of performance was defined as one wherein the number of items completed in the first 30 s of the test exceeded the number completed in either the middle or final 30 s of the test. A *consistently accelerated* pattern of performance was defined as one wherein the number of items completed in the last 30 s of the test was greater than that completed in the middle 30 s and the number completed in the middle 30 s was greater than that completed in the first 30 s; the opposite pattern was deemed *consistently decelerated*.

Data Analysis

The primary dependent measures (Digit Symbol, Symbol Copy, paired associates and free recall scores) were subjected to 4 × 2 factorial ANOVAs with age group and education level as independent variables. Statistically significant effects were pursued using Tukey's Honestly Significant Difference (HSD), a conservative *post-hoc* procedure that controls for Type I error across all possible pairwise comparisons. Because the ANOVAs were unbalanced, degrees of freedom for the Studentized range statistic were determined using harmonic means. In order to clarify effect sizes, results of correlational analyses are also reported.

Test results and error analyses are reported according to age group and education level in order to provide clinicians and researchers with norms against which to compare findings for individual cases or study cohorts. The frequency of different types of error on the incidental learning measures is also reported, as these data may be useful in individual assessment.

RESULTS

Demographics

Years of education, stratified by age group, were as follows ($M \pm SD$): 50s = 14.94 ± 3.43; 60s = 12.67 ± 2.67; 70s = 13.62 ± 3.50; 80s = 13.58 ± 4.34. Small age difference obtained [$F(3,162) = 2.93$, $p < .04$]; participants in their 50s averaged more education than those in their 60s. Estimated IQ, stratified by age group, was as follows ($M \pm$ SD): 50s = 109.95 ± 14.74; 60s = 106.36 ± 12.99; 70s = 112.56 ± 15.19; 80s = 101.85 ± 13.68. Age differences were also found for IQ [$F(3,173) = 4.38$, $p < .01$]; the oldest cohort obtained lower IQs than did the next-oldest group, presumably owing to the fact that WAIS–R norms end at age 74 and so do not compensate for normal intellectual decline taking place after that age.

Members of the high school and college-educated groups did not differ on age (69.68 ± 9.40 *vs.* 68.51 ± 10.35, respectively, $t < 1$). The expected large IQ difference across levels of education obtained [100.66 ± 12.07 *vs.* 113.52 ± 13.71, $t(165) = 6.36$, $p < .001$]; estimated IQs were very close to expected values at each level of education (Kaufman, 1990).

Male participants averaged 4 years older than female participants [71.49 ± 10.40 *vs.* 67.53 ± 9.62 years, $t(176) = 2.42$, $p < .02$]. Men also averaged 2 more years of formal education [15.06 ± 4.09 *vs.* 13.02 ± 3.08, $t(165) = 3.50$, $p < .01$] and obtained concomitantly higher full-scale IQs [117.96 ± 14.76 *vs.* 104.13 ± 12.56, $t(176) = 6.29$, $p < .01$].

Test Results by Age Group and Education Level

Digit Symbol score (Table 1) showed the expected large main effect for age [$F(3,158) = 36.69$, $p < .001$], a small but statistically significant main effect for education [$F(1,158) = 7.84$, $p < .01$], and no interaction effect ($F < 1$). Digit Symbol scores essentially decrease monotonically with age, with virtually all comparisons significant per Tukey's HSD test; the college group slightly outscores the high school group at every age level.

Symbol Copy time (Table 2) also showed a large main effect for age [$F(3,158) = 28.30$, $p < .001$], a smaller but significant main effect for education [$F(1,158) = 9.28$, $p < .01$], and no interaction effect ($F < 1$). Symbol Copy speed, too, declines steadily with age—with an especially large drop in the 80s—and again, the college group maintains a small advantage across all age levels.

Table 1. Digit Symbol score by age and education

	High school		College		All levels	
Age group	*M*	*SD*	*M*	*SD*	*M*	*SD*
50–59 y.o.	48.09	11.59	52.33	9.70	50.62	8.93
60–69 y.o.	44.68	9.55	50.85	11.02	47.82	10.44
70–79 y.o.	35.13	7.93	40.04	8.86	37.90	8.68
80–90 y.o.	27.64	9.42	29.79	9.70	29.03	9.39
All ages	39.14	11.72	43.56	13.01		

Table 2. Symbol Copy time stratified by age and education

	High school		College		All levels	
Age group	*M*	*SD*	*M*	*SD*	*M*	*SD*
50–59 y.o.	70.55	20.14	55.38	11.97	59.10	15.74
60–69 y.o.	73.11	17.00	64.30	12.62	68.92	15.59
70–79 y.o.	77.65	12.16	72.67	11.38	75.04	12.14
80–90 y.o.	101.71	25.58	96.68	27.10	98.09	26.12
All ages	79.38	20.86	71.27	21.79		

Incidental paired-associates learning (Table 3) showed a significant main effect for age $[F(3,158) = 4.03, p < .01]$, another main effect for education $[F(1,158) = 5.39, p < .05]$, and a trend toward a significant interaction effect $[F(3,158) = 2.41, p < .07]$. Participants in their 50s (and those in their 60s) outperformed those in their 80s, and more highly educated participants outperformed those with less education, but these effects were almost totally moderated by a large decline in paired-associates learning among members of the high school group in their 80s, who scored a standard deviation lower than either their age-mates with higher education or their educational peers in the next-younger age cohort.

Similarly, free recall scores (Table 4) showed significant main effects for age $[F(3,156) = 4.56, p < .01]$ and education $[F(1,156) = 9.36, p < .01]$ and a trend toward a significant interaction effect $[F(3,156) = 2.23, p < .09]$. Once again, differences favoring other age groups over those in their 80s and favoring college-educated over non-college-educated participants were mediated almost entirely by a sharp decline among members of the high school group in their 80s.

In order to assist clinicians in the interpretation of individual test protocols, the percent of participants obtaining different incidental learning scores is given in Table 5.

The coding:copying ratio showed a main effect for age $[F(3,158) = 5.36, p < .01]$, no main effect for education $(F < 1)$, and no interaction effect $[F(3,158) = 1.39, p = .25]$. This ratio declined (meaning that coding operations required more time relative to copying) among participants in their 70s (compared with those in their 60s) and participants in their 80s (relative to those in their 60s or 70s).

Table 3. Incidental learning (paired associates) stratified by age and education

	High school		College		All levels	
Age group	*M*	*SD*	*M*	*SD*	*M*	*SD*
50–59 y.o.	5.00	2.41	5.46	2.58	5.52	2.63
60–69 y.o.	5.18	2.21	5.20	2.50	5.18	2.35
70–79 y.o.	4.52	2.48	4.89	2.12	4.62	2.33
80–90 y.o.	2.07	1.59	4.84	2.85	3.71	2.71
All ages	4.38	2.55	5.10	2.42		

Table 4. Incidental learning (free recall) stratified by age and education

	High school		College		All levels	
Age group	*M*	*SD*	*M*	*SD*	*M*	*SD*
50–59 y.o.	6.82	1.89	7.58	1.18	7.45	1.41
60–69 y.o.	7.19	1.21	7.40	1.31	7.20	1.31
70–79 y.o.	6.86	1.49	7.00	1.27	6.96	1.34
80–90 y.o.	5.43	.85	7.00	1.60	6.35	1.52
All ages	6.70	1.48	7.24	1.34		

Test Results by Gender

Gender differences on the tasks of interest were minor. Women tended to earn slightly higher Digit Symbol scores, though the effect fell short of significance $[43.01 \pm 12.03$ *vs.* $39.27 \pm 12.66; t(176) = 1.84, p < .10]$. Women also completed Symbol Copy more quickly $[71.55 \pm 20.03$ *vs.* $80.41 \pm 24.02; t(176) = 2.51, p < .02]$. These results conform to those of previous studies (Kaufman et al., 1988). The ratio of coding time to copying time was identical across gender ($M = .48$ for both), and female and male participants were indistinguishable on the paired-associate $[4.71 \pm 2.63$ *vs.* $5.06 \pm 2.30; t(176) = .83, p = .40]$ and free recall tasks $[6.91 \pm 1.45$ *vs.* $7.24 \pm 1.35; t(174) = 1.25, p = .21]$.

Correlations Among Age, Digit Symbol Score, and Other Measures

Table 6 shows the correlation matrix of age, education, estimated IQ, Digit Symbol score, Symbol Copy score (the inverse of the time required to complete the test, so as to render the direction of scoring similar across all tests), the code:copy ratio, paired-associate learning, and free recall. The correlation of Digit Symbol with age ($r = -.64$), consistent with prior research, is greater in magnitude than that typical of memory tests. The correlation between Symbol

Table 5. Incidental learning scores: Frequency data

	Paired-Associates		Free Recall	
Score	No. participants	%	No. participants	%
0	11	6.2	0	0.0
1	8	4.5	0	0.0
2	13	7.3	0	0.0
3	23	13.0	2	1.1
4	27	15.3	6	3.4
5	28	15.8	16	9.1
6	20	11.3	40	22.9
7	16	9.0	39	22.3
8	11	6.2	42	24.0
9	20	11.3	30	17.1

Table 6. Correlations among demographics and major test results

	Age	Educ.	FSIQ	DSym	Copy	Ratio	Pairs	Free
Age	1.00	−.12	−.09	*−.64*	*−.58*	.26	−.26	−.26
Education		1.00	*.45*	.19	.23	−.06	.20	.21
IQ (est.)			1.00	.29	.21	−.23	.27	.28
Digit Symbol				1.00	*.72*	*−.51*	.26	.28
Symbol Copy					1.00	.09	.26	.27
Copy:Code ratio						1.00	−.09	−.07
Pairs learned							1.00	*.69*
Free recall								1.00

Note. All values above $r = .20$ are significant ($\alpha = .01$); values shown in italics account for 20% or more of score variance. Symbol Copy is scored as speed, rather than time required. Thus, positive correlations between tests always indicate that superior performance on one is associated with superior performance on the other.

Copy and age ($r = -.58$) is also large. The difference between these correlations ($q = .10$) suggests a small effect, but falls short of significance [$t(174) = 1.15$, $p = .25$], not resolving the issue of whether the two tasks dissociate with advanced age. This is also seen in the significant but weak correlation between the code:copy ratio and age.

Both incidental learning measures show significant, but modest, negative correlations with age. Only 7% of the variance in incidental learning can be accounted for by age, compared with 34% for Symbol Copy and 41% for Digit Symbol. Comparing the correlations with age of each measure, we found that (1) Digit Symbol is more strongly correlated with age than are the paired-associate test [$t(174) = 4.93$, $p < .01$] or the free recall test [$t(172) = 5.09$, $p < .01$]; and (2) Symbol Copy is more strongly correlated with age than are the paired-associate test [$t(174) = 4.07$, $p < .01$] or the free recall test [$t(172) = 4.09$, $p < .01$].

The correlation between Digit Symbol and IQ ($r = .29$) is relatively low, presumably because Digit Symbol was not used to derive IQ. Incidental learning measures correlate as strongly with IQ as does Digit Symbol itself.

By far the strongest predictor of Digit Symbol score is Symbol Copy score; correlations with the incidental learning tests, though statistically significant, are relatively weak. In order to clarify the relationship between Digit Symbol, Symbol Copy, and the incidental learning measures, all these predictors were entered into a hierarchical multiple regression procedure. Results show that Symbol Copy, as expected, accounts for over 50% of Digit Symbol variance. Adding incidental learning (free recall) to the equation results in a significant increment in explanatory power, but only a relatively trivial 1% of additional variance is so explained. When age, gender, and IQ are added to the pool of predictors, Symbol Copy retains its position of primacy, age and IQ each account for significant increments in R^2 (8% and 2%, respectively), and neither incidental learning measure remains in the model. The fact that age influences Digit Symbol scores even after Symbol Copy scores have been controlled also supports the hypothesis that factors other than graphomotor speed are involved in Digit Symbol, and suggests that these factors, too, are adversely affected by age.

Qualitative Analysis of Digit Symbol Recall Errors

Tables 7 and 8 provide details concerning the types of errors made on the incidental learning tests, broken down by age group and education level, respectively.

The mean number of mismatches of symbol and digit on the paired-associates task was 1.03. There was a trend to-

Table 7. Error analysis by age group

	50–59 ($n = 40$)		60–69 ($n = 51$)		70–79 ($n = 52$)		80–90 ($n = 34$)	
Test/error type	*M*	(*SD*)	*M*	(*SD*)	*M*	(*SD*)	*M*	(*SD*)
Paired assoc.								
Mispaired	0.75	(1.00)	0.76	(0.97)	1.33	(1.58)	1.32	(1.93)
Rotations	0.18	(0.45)	0.57	(0.85)	0.67	(0.94)	0.47	(0.83)
Intrusions	0.02	(0.16)	0.02	(0.14)	0.02	(0.14)	0.12	(0.17)
Wrong:omit.	0.83	(0.77)	1.22	(1.13)	1.58	(1.32)	0.59	(0.33)
Free recall								
Rotations	0.68	(0.69)	0.94	(0.77)	0.86	(0.78)	1.12	(1.01)
Intrusions	0.05	(0.22)	0.04	(0.20)	0.02	(0.14)	0.09	(0.38)

Table 8. Error analysis by education

	<10 years ($n = 16$)		10–12 years ($n = 60$)		13–16 years ($n = 52$)		>16 years ($n = 38$)	
Test/error type	*M*	(*SD*)	*M*	(*SD*)	*M*	(*SD*)	*M*	(*SD*)
Paired assoc.								
Mispaired	1.94	(2.17)	1.08	(1.58)	0.63	(0.97)	1.13	(1.14)
Rotated	0.50	(0.63)	0.60	(0.96)	0.50	(0.80)	0.34	(0.75)
Intrusions	0.06	(0.25)	0.03	(0.18)	0.02	(0.14)	0.00	(0.00)
Wrong:omit.	1.57	(1.72)	1.20	(1.18)	0.94	(0.71)	1.07	(1.08)
Free recall								
Rotations	0.88	(0.89)	1.09	(0.84)	0.79	(0.75)	0.74	(0.79)
Intrusions	0.06	(0.25)	0.02	(0.13)	0.08	(0.33)	0.05	(0.22)

ward a main effect for age on this measure [$F(3,158) = 2.35$, $p < .08$], a significant main effect for education [$F(1,158) = 4.28$, $p < .05$], and no interaction effect [$F(3,158) = 1.07$, $p = .36$]. Examinees above age 70 made significantly more such errors than did those below age 70, taken as a group, while members of the college group made significantly fewer of these errors than did members of the high school group.

The mean number of rotational errors (.49) was lower than the number of mismatches [$t(176) = 4.63$, $p < .001$]. This ANOVA also revealed a trend toward a significant main effect of age [$F(3,158) = 2.45$, $p < .07$], but there was no main effect of education ($F < 1$) and no interaction effect ($F < 1$). Participants in their 50s made significantly fewer errors than did those in their 70s, or all the older groups treated as a whole.

The average examinee made only .04 intrusion errors, lower than the number of rotation errors [$t(176) = 5.22$, $p < .001$]. This age ANOVA was insignificant ($F < 1$). Those above age 80 did make an increased number of intrusion errors relative to all younger groups, but although this effect was significant ($\alpha = .05$) in a t test, the rate of intrusion errors was very low at all ages.

Rotational errors were significantly more common on the free recall task ($M = .89$) than on the paired-associates task [$t(171) = 5.94$, $p < .001$]. Here, again, there was a trend toward a main effect for age [$F(3,156) = 2.32$, $p < .08$], a significant main effect of education [$F(1,156) = 4.45$, $p < .05$], and no interaction effect ($F < 1$). Participants in their 50s tended to make fewer such errors than did those in their 80s, but this, too, was only a trend; members of the college group made significantly fewer such rotational errors than did members of the high-school group.

Intrusions were as rare on free recall as on the paired-associates test ($M = .05$), clearly less common than rotation errors [$t(173) = 5.94$, $p < .001$] and once again there was no clear effect for age, though once again it was the oldest cohort that made the most such errors.

Pattern of Performance on Digit Symbol

Thirty-six participants (20.3% of the sample) followed an accelerated pattern, while 70 participants (39.5% of the sample) followed a decelerated pattern. The remaining participants showed neither pattern. The accelerated group obtained higher mean scores on Digit Symbol [47.89 *vs.* 41.27; $t(104) = 2.72$, $p < .01$] and paired associates [5.28 *vs.* 4.09; $t(104) = 2.42$, $p < .02$] but not on Symbol Copy (69.69 s *vs.* 75.39 s; $t(104) = -1.25$, $p = .21$] or free recall [7.03 *vs.* 6.81; $t < 1$]. The two groups did not differ on age [67.42 *vs.* 67.31; $t < 1$] or education [13.18 *vs.* 13.71; $t < 1$].

Only 9 participants (5.1% of the sample) *consistently* accelerated on Digit Symbol; 19 (10.7%) consistently decelerated. Results for these more narrowly defined groups were similar to those for the larger groups from which they were drawn, with one exception. In addition to obtaining higher mean scores on Digit Symbol [50.11 *vs.* 38.05; $t(26) = 2.70$, $p < .02$] and paired associates [5.67 *vs.* 3.47; $t(26) = 2.21$, $p < .05$], the consistently accelerated group tended to obtain higher mean scores on Symbol Copy (63.78 s *vs.* 83.11 s, $t(26) = -2.02$, $p < .06$]. The two groups did not differ on free recall (7.11 *vs.* 6.74; $t < 1$), age [65.00 *vs.* 70.37; $t(26) = -1.32$, $p = .19$], or education (13.38 *vs.* 12.65; $t < 1$).

Differences between the larger "accelerated" and "decelerated" groups were not due solely to the differences between the smaller, more narrowly defined groups that showed consistently accelerating or decelerating patterns. Differences between the more narrowly defined groups were indeed larger, but even after these individuals were removed, examinees who performed best in the latter 30 s of the test obtained notably higher scores on Digit Symbol and paired-associates learning than those who performed best in the first 30 s of the test.

DISCUSSION

Wherever our study replicates previous investigations, our findings are consistent with existing knowledge regarding the Digit Symbol test and its analogs. This increases the likelihood that our more novel findings represent genuine increments in our understanding of the test, rather than merely unique qualities of our sample. Age-related decline accounts for about 40% of score variance on Digit Symbol and about 34% of the variance on Symbol Copy. These two measures are strongly correlated, but the copying task accounts for only about 50% of the variance on the coding task. Incidental learning explains a small fraction of the remaining variance, but speed is clearly far more important than memory to Digit Symbol performance.

Age effects on Digit Symbol and Symbol Copy are similar in magnitude. Digit Symbol may be more adversely affected, but our data on this issue are inconclusive. The ratio of coding speed to copying speed is close to values previously reported and, also consistent with prior research, changes little with age. We did, however, find a small but significant age-related decline in this ratio among those aged 70 and above, implying that the coding process (not solely graphomotor speed) does become more difficult in old age. Still, if age produces a partial dissociation between coding and copying, the effect is a small one, and may not obtain until above age 70. Memory deficits can explain only a fraction of this divergence between coding and copying tests.

Certain limitations of our sample should be acknowledged. Although the total sample was relatively large, it was not evenly distributed across age, education, and gender. The average participant was somewhat more highly educated than the average member of the population, and there was a tendency for older participants to be less well educated, which makes it difficult to disentangle the relative influence of age and education on test performance. We attempted to compensate for this by presenting data stratified by age and by education. On the whole, our results on these dimensions appear clear and straightforward. Probably the most problematic aspect of the sample was the preponderance of female participants combined with the fact that the men were slightly older and better educated. Of course, Wechsler scale norms typically merge male and female respondents, and there were few gender differences on the tests studied—chiefly a slight female superiority on Symbol Copy and Digit Symbol that is consistent with prior research. Still, a more balanced sample would have been preferable, and our gender data should be treated cautiously. Also, the fact that our sample consisted almost wholly of persons of European extraction suggests that clinicians should exercise due caution in generalizing these results to members of other ethnic groups. The failure to obtain independent verification of health status raises the possibility that some volunteers may have concealed neuropsychiatric conditions, perhaps increasing the functional heterogeneity of our sample—but all participants were sufficiently well oriented to make and keep appointments and complete a battery of complex tasks, and scores on the Wechsler subtests administered are consistent with existing norms and free of grossly abnormal protocols.

We offer the following clinical guidelines with respect to Symbol Copy interpretation. Most people will complete Symbol Copy at approximately twice the rate at which they perform on Digit Symbol. (Relative speed may be measured as time/symbol or as symbols/s.) If Symbol Copy speed is much lower than this, the person may not have invested full effort in the task, but if motivational factors are ruled out, further testing of visual acuity, motor speed and dexterity is indicated. If Digit Symbol speed is much lower, higher-order cognitive functions (e.g., memory, visual scanning, or set shifting) may be compromised. Further evaluation of these functions should clarify the nature of the problem. The incidental learning measures administered after Digit Symbol may be useful initial tests of the memory deficit hypothesis, and rotational errors made on these memory tasks may also be relevant to the perceptual deficit hypothesis.

Incidental learning does take place in the course of completing Digit Symbol, and does correlate with Digit Symbol score, but the relationship between these memory measures and raw score is relatively weak ($r = .26$ in the present sample). The fact that the two incidental learning scores correlate, albeit modestly, with IQ supports their validity, though studies involving other memory measures are needed. The increment in Digit Symbol prediction produced by adding incidental learning to graphomotor speed is small, accounting for only a fraction of the additional age-related decline on Digit Symbol.

In our sample, incidental learning declines only modestly with age. The age differences on paired-associates learning obtained in our study is smaller than that reported by Shuttleworth-Jordan and Bode (1995). This is the only substantive discrepancy between their results and ours, and the only age group for which the results differ substantially is the 70-to-79-year-old range. Our participants in this range obtained paired-associates scores slightly lower than those in the two younger age groups, but the decade to decade decline was gradual; Shuttleworth-Jordan and Bode (1995) report a much more dramatic drop for this age cohort. Sample characteristics may have produced this discrepancy. In general, the two studies present highly convergent data on Digit Symbol incidental learning. Perhaps our most interesting finding here was a trend toward interaction effects on both the paired associates and free recall tests. The fact that only the less well educated participants showed a significant age-related decline on these measures is consistent with a protective effect of higher education or greater reserve capacity (identifiable in youth as higher academic ability) on the part of those who pursued higher education. Because these findings were marginal, however, they should be treated cautiously until replicated.

As best we can determine from the cumulative percentages in the WAIS–III *Technical Manual*, our findings are consistent with those for the normative sample for that instrument. On the free recall test (which is practically identical to that in the WAIS–R–NI), the median number of symbols recalled changes very little from age 50 (7) to age 89 (6); a slightly larger age effect apparently obtains for the paired-associates learning test, but as the format has been changed, the results may not be comparable. Except for the small group of controls in Hart et al. (1987) and the cumulative percentage data provided in the WAIS–III *Technical Manual*, we report what we believe to be the first data on free recall of the symbols. On average, older examinees recall approximately two more symbols than they can match correctly with digits.

We offer the following guidelines for interpretation of incidental learning scores obtained in the assessment of middle-aged and older adults (see Table 5). Over 80% of such persons will correctly match at least 3 symbols with digits; scores below three should, therefore, be noted, but only scores of zero may be regarded as definitely abnormal. On the free recall task, over 85% of healthy older examinees will produce at least six correct symbols, and any score below 5 may be treated as abnormal. These scores are lower than Kaplan (1988) predicted based on clinical impressions, and the present data supersede those guidelines.

Low incidental learning scores that are unremarkable in other respects may reflect memory deficits, and warrant further investigation. Given the absence (to date) of validity studies and the brief nature of the tests (implying truncated reliability), they should *not* be treated as independent memory tests, only as screening instruments. The strong correlation between the memory tests suggests that major discrepancies between the two may be clinically significant; such a discrepancy obtained, for example, among Hart et al.'s (1987) depressed patients.

The following criteria are suggested for evaluating the significance of qualitative errors on the incidental learning tests. Here, too, the absence of validity studies should be borne in mind, and unusual findings should be treated as sources of hypotheses to be tested rather than as strong evidence of particular areas of deficit. Matching a symbol with an incorrect number is a common error, but 90% of healthy older examinees make no more than two such errors, and four (conservatively, five) mismatches constitutes an abnormal performance (i.e., characterizes less than 5% of the protocols of healthy older adults). One rotation on the paired-associates task is common, but only 10% of healthy participants produced more than one rotated symbol on this measure, and three such errors is distinctly abnormal. The presence of *any* intrusion errors must be regarded as abnormal.

On free recall, a single rotation is so common as to be expected, and two may be treated as within normal limits, but any score of 3 or above is abnormal. As on the paired-associates task, the presence of any intrusions is abnormal. Producing more than nine symbols also is a noteworthy violation of test parameters, occurring in fewer than 6% of the protocols.

Qualitative analysis of errors made on the incidental learning tasks yields several findings of interest. As predicted, mismatches on the paired-associates test were most frequent, rotations were next in frequency, and intrusions were rare. Mismatches were more common among older and less educated examinees; rotations increased in frequency with age, but not education, on this task. Rotations were more common on free recall, presumably owing to the absence of digit cues or to distortion taking place during the longer interval elapsed since seeing the key. The frequency of rotations on this task increased with age and decreased with education. Intrusion errors were rare on both tasks and at all levels of age and education.

If a low paired-associates score is caused by an excessive number of mismatches, one might wish to rule out thought disorder or learning disability, but a liberal response bias and/or a defensive stance toward failure might also produce such a profile. Low incidental learning scores caused by many rotational errors may indicate a need for further assessment of visuoperceptual and visuoconstructive functions as well as memory. Rotational errors may have diagnostic significance as indicators of CNS dysfunction (probably diffuse or localized to the right parietal area—perhaps localized to the prefrontal regions upon which the visuospatial sketchpad depends), but only if they occur at an elevated rate. Research on clinical populations is needed in order to test this hypothesis. Confabulated symbols would appear to be almost pathognomic of memory dysfunction, though again research on clinical populations is needed.

Once again, we should like to stress that caution should be exercised in the interpretation of incidental learning scores. Although these are face-valid indicators of visuospatial memory, few data are yet available to demonstrate their relationship with better-validated memory tests. Abnormal findings *do* justify further assessment, and in combination with other indicators of dysfunction in these domains, strengthen the inference of deficit, but ought not to be used as "stand-alone" measures of memory or perceptual ability. This is in keeping with the purpose of the WAIS–R–NI as a whole: to suggest and test clinical hypotheses and guide the selection of further assessment procedures. Adding Symbol Copy and the two incidental learning measures to test administration does not invalidate standard scoring, requires only a few minutes of added testing time, and may provide valuable supplementary information. The incidental learning tests themselves are promising tools for research and clinical evaluation, despite their limited degree of relatedness to Digit Symbol score. The greatest need at the present time is for validation of these incidental learning tests as measures of learning and memory.

Different patterns of performance on Digit Symbol are related to success on the task; examinees who improve in the course of test completion obtain higher scores and acquire more incidental paired-associates learning in the process. Individuals who slow down in the course of test completion not only obtain lower scores, but also learn less—thus, it cannot be argued that their slowing is due to unnecessary expenditure of effort to memorize the code key. In extreme cases, this slowing seems to be associated with fatigue (reflected in low Symbol Copy scores), but fatigue alone cannot fully explain the group differences. Presumably a combination of fatigability, distractibility, and failure to learn underlies their poor Digit Symbol performance, but only further investigation can reveal the extent to which each factor contributes.

In summary, Digit Symbol score is evidently determined primarily by speed and only very secondarily by memory. Incidental learning scores may, however, prove to be valuable memory screening instruments. Qualitative analysis of incidental learning errors and temporal pattern of performance on Digit Symbol may also be revealing. It should again be noted that the minor role played by memory in this study may not generalize to patient populations wherein mnestic functions are severely compromised (Glosser et al., 1977).

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