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Age Differences in Learning Serial Patterns: Direct Versus Indirect Measures

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Adult age differences in learning and retention of a nonverbal sequence were examined using the serial reaction-time task of Nissen and Bullemer (1987), with 20 younger and 20 older Ss. An asterisk appeared in one of 4 spatial locations, and the Ss responded with a corresponding key press. The first 4 blocks each contained 10 repetitions of a 10- or 16-element spatial sequence, and the 5th block contained a random sequence. The difference between response time on Blocks 5 and 4 served as an indirect measure of pattern learning. The direct measure was accuracy in a final generation block in which the Ss predicted which location would appear next. Results were similar to those with verbal materials; the indirect measure revealed age similarity for patterns of both lengths, but the direct measure yielded age differences favoring the young. For both ages and types of measures, the long patterns led to poorer learning than did the short patterns.

Typically, memory is tested directly by asking the subject to make an introspective judgment about learning or remembering some past event. Such conscious recollection is required on both recall and recognition tests. However, memory can also be inferred indirectly from patterns of performance on tasks in which the subject is not asked to refer to some past event. For example, even though a person does not report recognizing a word, memory for that word would be revealed indirectly if, in a subsequent naming task, the person read the word aloud more quickly than in a control condition in which the word had not been studied earlier.

Direct and indirect tests usually yield markedly different patterns of results; they often are influenced differently by the same experimental variables (e.g., Graf & Schacter, 1987), stochastically independent of each other (e.g., Tulving, 1985), and affected differently by pathology (e.g., Schacter, 1985). The implications of such dissociations for theories of memory are unclear. Some authors argue that indirect and direct tests reflect the operation of two distinct forms or systems of memory, and others contend that both depend on a single underlying system (cf. Johnson & Hasher, 1987; Richardson-Klavehn & Bjork, 1988; Schacter, 1987; Tulving, 1985). The study reported here was not designed to decide between these alternatives. Following Johnson and Hasher (1987) and Richardson-Klavehn and Bjork (1988), we use the terms *direct* and *indirect* to describe tasks that either do or do not instruct the subject to call upon specific past experience (i.e., recollection). In earlier research (cf. Schacter, 1987), including our own (e.g., D. V. Howard, 1988), the terms *explicit* and *implicit* have often been used instead. However, as Johnson and Hasher (1987) and Richardson-Klavehn and Bjork (1988) have argued, the implicit–explicit dichotomy invites confusion because it is sometimes used to refer to different tasks and other times to different underlying memory systems. To avoid such ambiguity, we adopt the theoretically neutral direct–indirect terminology here, and then, in the discussion, we consider briefly the implications of our findings for questions about underlying memory systems.

What is most important for the present study is that direct and indirect measures show different patterns of aging (see the review by D. V. Howard, 1988). On direct tests, older people typically show significantly and substantially poorer memory than do younger people, but on indirect tests, age differences are either reduced substantially or eliminated (e.g., Chiarello & Hoyer, 1988; D. V. Howard, Heisey, & Shaw, 1986; Light & Singh, 1987; Light, Singh, & Capps, 1986; Moscovitch, 1982; Moscovitch, Winocur, & McLachlan, 1986; Rabbitt, 1982; Rabinowitz, 1986).

The previous evidence for different aging effects on direct and indirect tests has come from research on memory for verbal materials such as lists of words or sentences. The main goal of the present research is to find out whether such differential aging effects also occur for the learning and memory of nonverbal materials. We do so by examining acquisition and retention of a nonverbal spatial sequence, using a task introduced by Nissen and her colleagues (Knopman & Nissen, 1987; Nissen & Bullemer, 1987; Nissen, Knopman, & Schacter, 1987; Nissen, Willingham, & Hartman, in press).

In Nissen et al.'s (1987) serial reaction-time (RT) task, an asterisk appears on each trial in one of four spatial locations. The subject is to respond by pushing the corresponding one of four keys, with a correct response initiating the next trial. Nissen et al.'s subjects are first given a 10-trial repeating sequence. After 4 or more such blocks of 100 trials each (and hence 40 or more

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repetitions of the 10-trial sequence), the sequence becomes random. The presence or absence of a repeating pattern is never pointed out to the subjects; they are told only that they should respond as quickly as possible when the asterisk appears on each trial. Nissen et al. found that response time typically declines over the initial repeating blocks, a decline that could be due to general practice effects or to learning of the repeating pattern, or to both. More important, they also found that response time increases substantially when the switch to the random block occurs. This response-time increase offers an indirect measure of pattern learning. The last repeating block differs from the random block only in the presence of the repeating pattern, so if people had learned nothing about the pattern, its absence should not affect performance at all. The response-time difference is an indirect measure in that the instructions refer only to the task at hand and do not require awareness of the pattern. In some of Nissen et al.'s experiments, a direct measure of pattern learning has been obtained in a generation block, in which the task is to predict where the asterisk will occur next by pushing the corresponding key. This test is direct in that the subject is to use earlier experience with the pattern to predict the asterisk position.

Nissen et al.'s (1987) research has shown that in this nonverbal task, direct and indirect measures yield dissociations similar to those seen in tests of verbal materials. Individuals who show severely impaired pattern learning by the direct measure sometimes show unimpaired pattern learning on the indirect measure. For example, Nissen and Bullemer (1987) and Nissen et al. (in press) have shown that after encountering four repeating blocks, Korsakoff's patients have learned the sequence as well as normal individuals by the indirect measure, even though the patients show no awareness at all of the repeating sequence. Knopman and Nissen (1987) have shown a similar pattern for some Alzheimer's disease patients (although some failed to show learning even on the indirect measure). Nissen et al. (1987) have shown that when college students are given scopolamine (an anticholinergic drug that produces amnesic symptoms), their learning of the sequence is impaired on the direct test, as revealed by a lower percentage correct on the generate task, but shows no deficit at all on the indirect measure. Furthermore, the indirect measure reveals excellent and equal retention for both a saline control and the scopolamine groups when tested after a 30-min filled retention interval. Some earlier research (e.g., Drachman & Leavitt, 1974) has shown that administering scopolamine to a young person mimics the pattern of memory loss seen in normal aging when verbal memory is assessed, and so it is of interest to determine whether this would be the case for this nonverbal task as well (i.e., Would older people show memory for the pattern equal to that of younger people on the indirect test but deficient memory on the direct test?).

In the present experiment, groups of younger and older participants completed a total of eight blocks in Nissen et al.'s (1987) serial reaction-time task. Blocks 1 through 4 contained 10 repetitions of a patterned sequence, and Block 5 contained a random sequence. After a 30-min filled retention interval, Blocks 6, 7, and 8 were presented, each containing 10 more repetitions of the same patterned sequence. Finally, immediately after Block 8, people completed a generation task containing 10 repetitions of the pattern.

This procedure yields three measures of interest for each participant. An indirect measure of pattern learning will consist of response time on Block 5 minus that on Block 4 because this difference score indicates the extent to which the repeating pattern affects performance. Thus, the higher the score, the greater the degree of pattern learning. The direct measure of pattern learning will be the percentage correct on the generation block. Finally, an indirect measure of pattern retention will be obtained by comparing response time on repeating Block 4 with that on repeating Block 6, which occurred immediately after the 30-min retention interval.

Instead of using a single 10-element repeating sequence for all of the subjects, as Nissen and her colleagues (Knopman & Nissen, 1987; Nissen & Bullemer, 1987; Nissen et al., 1987; Nissen et al., in press) have done in their studies to date, we used four different patterns, two 10-element and two 16-element patterns. We did so, not only to test the generality of the findings across patterns, but also to investigate the effect of sequence length on learning and retention. This seemed important because Nissen and Bullemer (1987) have presented some evidence that pattern learning, even when assessed via the indirect test, is capacity demanding. Therefore, we expected that increasing the pattern length would make greater demands on limited capacity and, so, would affect both direct and indirect measures of learning, and we expected any such effects would be magnified in the older group.

Nissen has previously tested older subjects on the serial reaction-time task; 13 people in the 61–78-year-old age range, 8 in the 61–71-year-old age range, and 7 in the 62–72-year-old age range served as age-matched control subjects for the studies of Alzheimer's disease patients (Knopman & Nissen, 1987) and Korsakoff's patients (Nissen & Bullemer, 1987; Nissen et al., in press), respectively. Older people did learn and retain the repeating sequence. All of the older control subjects in all three studies revealed higher response times on a subsequent random block than on the most recent repeating block, and in the study testing long-term retention, they showed no forgetting over a 1-week-long retention interval (Nissen et al., in press). Nonetheless, Nissen's studies were not designed to study aging; the scores of normal young and elderly subjects cannot be compared directly because both groups were never tested in the same experiment and are not necessarily comparable. More important, these studies did not provide direct measures of pattern learning (inasmuch as a generation block was not included) nor of the effects of pattern length (inasmuch as the same 10-element sequence was given to all of the participants).

Method

Subjects

In all, 20 younger and 20 older participants were tested, 5 per age group on each of four patterns. The younger subjects (9 women and 11 men) were students at either The Catholic University of America or Georgetown University. The older participants (12 women and 8 men) were community-dwelling adults, healthy by their own report, who responded to newspaper advertisements seeking volunteers. The mean age of the younger group was 22.20 years (SD = 4.88) and of the older group, 71.25 years (SD = 3.14). The age groups were similar in years of education completed (younger M = 15.30, SD = 1.52; older M = 15.75, SD =

2.75), in Wechsler Adult Intelligence Scale (WAIS, Weschler, 1981) Vocabulary score (younger $M = 62.25$, $SD = 11.15$; older $M = 64.30$, $SD = 5.55$) and in WAIS Digits Backward score (younger $M = 5.65$, $SD = 1.66$; older $M = 5.00$, $SD = 1.26$). As is typical, however, the younger participants scored higher than the older participants on the WAIS Digit-Symbol Substitution task (younger $M = 68.65$, $SD = 13.44$; older $M = 47.40$, $SD = 7.74$), $t(38) = 6.12$, $p < .0001$.

Stimuli and Apparatus

The participant was seated at a CRT on which were displayed four separate squares equally spaced in a row across the bottom of the screen. The response keys ("z", "x", ".", "/") were marked with red felt, and the participant was instructed to rest the index and middle fingers of each hand on these four keys. On each trial the stimulus consisted of a single asterisk that appeared in one of the four boxes. The asterisk remained on the screen until the subject pushed the corresponding key located beneath the asterisk. Four stimulus patterns were produced, two of length 10 and two of length 16. One of the shorter patterns, Pattern 10A, was that used by Nissen and her colleagues (D-B-C-A-C-B-D-C-B-A, with A denoting the left-most position and D the right-most position), whereas the other, 10B, was selected haphazardly to have generally similar characteristics (D-A-C-B-C-B-A-D-A-C). Both 16-element sequences were also assembled haphazardly. These were pattern 16A (B-C-A-C-D-C-D-B-A-D-A-D-A-C-A-D) and 16B (C-A-C-B-A-D-C-D-B-D-B-A-C-B-C-D). No single location was repeated on successive trials in any of these patterns.

Design

There were two between-subjects factors, age and pattern length (10 element vs. 16 element). For the serial reaction-time task, there was an additional within-subjects factor of block (1 through 8).

Procedure

Participants, seated at the CRT display, were asked to position their hands as was previously described. They were told to press the key below the asterisk as quickly as possible without making errors. The participants' correct response turned off the asterisk, and then 500 ms later the next asterisk occurred. A block consisted of 100 or 160 such trials (for the 10-element and 16-element patterns, respectively). Successive blocks were separated by a rest period of at least 2 min, and the subject initiated the next block by pushing any key. There were four such blocks in which the same sequence was presented 10 times in a row, with no pause or other indication being given of the beginning or ending of each repetition of the sequence. Following this exposure to repeating blocks, all of the participants experienced one 100- or 160-trial random block (for the 10-element and 16-element patterns, respectively), identical to those just described, except that the position of the asterisk was determined randomly (with the constraint that the same position could not be used on successive trials).

Next, there was a 30-min retention interval during which the participant completed the WAIS Backward Digit Span, Digit Symbol, and Vocabulary tests in that order. This 30-min period was followed by three more blocks of the repeating sequence described earlier, and then a final block of a generate task. The latter served as a direct test of pattern learning and was identical to the earlier repeating blocks, except that the subject was asked to predict which asterisk would occur by pushing the appropriate key, and the instructions stressed accuracy, not speed. On each trial, the asterisk appeared only after the subject pushed the correct key.

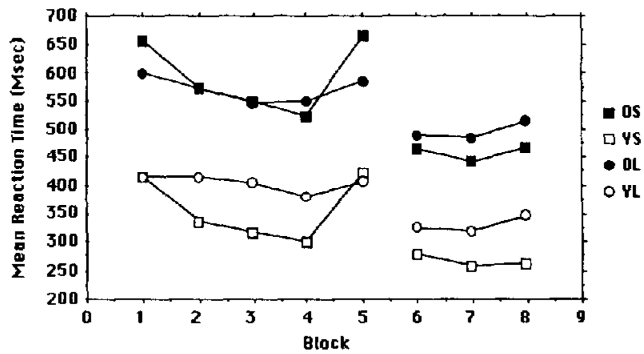

Figure 1. Mean of median response times in milliseconds as a function of block in the serial reaction-time task. (The two upper curves [filled points] are for the older, and the two lower curves [open points] for the younger participants. The short 10-element patterns are marked by squares and the long 16-element patterns by circles. OS = older subjects, short pattern. YS = younger subjects, short pattern. OS = older subjects, long pattern. YL = younger subjects, long pattern.)

Results

Accuracy on the Serial Reaction-Time Task

Both younger and older participants were highly accurate on the serial reaction-time task. The arc sin transformed accuracy scores were submitted to a 2 × 4 × 8 (Age × Pattern × Block) mixed-design analysis of variance (ANOVA), with block a within-subjects factor. The only significant effects were due to age, $F(1, 32) = 26.01$, $p < .0001$, and block, $F(7, 224) = 3.78$, $p < .0007$. The age effect indicates that the older participants (M proportion correct = .98, $SD = .02$) were more accurate than were the younger participants ($M = .92$, $SD = .07$). The block effect, although reliable, was small in magnitude; the highest mean accuracy was .96, obtained on Block 1, and the lowest was .94, obtained on Blocks 4, 5, and 6.

The finding that overall accuracy was high, varying little with block or pattern, and the fact that the age effect did not interact with the other variables (all $ps > .20$) indicate that in subsequent analyses of the serial reaction-time data we would be justified in looking only at RTs on correct trials.

Response Times on the Serial Reaction-Time Task

We calculated the median RT of correct responses in each set of 100 trials (for the 10-element groups) or 160 trials (for the 16-element groups). Then the means of these medians were computed for each block. Because our primary interest was in the effect of pattern length, not individual patterns, we wanted to collapse across the two patterns of each length. In order to make sure that such collapsing would not mask important interactions, we first completed two separate ANOVAS on the correct response times, one on the two short patterns and another on the two long ones. Each was a 2 × 2 × 8 (Age × Pattern × Block) mixed-design ANOVA with block a within-subjects factor. In neither analysis did any interaction with pattern approach significance, so in the RT analyses that followed, we collapsed across the two patterns of a given length.

The group mean RTs are shown in Figure 1, separately for each age group and pattern length. Figure 1 reveals three gen-

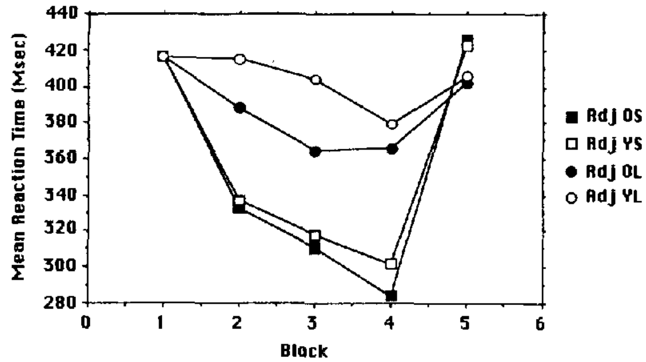

Figure 2. Adjusted mean of median response times in milliseconds as a function of block in the serial reaction-time task. (The filled points show the data for the older participants, and the open points show those for the younger participants. The short 10-element patterns are marked by squares, and the long 16-element patterns by circles. OS = older subjects, short pattern. YS = younger subjects, short pattern. OL = older subjects, long pattern. YL = younger subjects, long pattern.)

eral characteristics of performance on the serial reaction-time task. First, as expected, the response times are longer for older than for younger participants, a difference on the order of 200 ms. Second, the pattern of response times over blocks is similar to that obtained by Nissen; for all groups, response time declines over the first four blocks when the repeating pattern is presented, increases on Block 5 when the random sequence is presented, and returns to the faster level for Blocks 6 through 8, which again contain the repeating pattern. Unexpectedly, RT appears to increase from Block 7 to Block 8, a pattern that did not appear in Nissen and Bullemer's (1987) work. This increase likely reflects fatigue or boredom, or both; the increase is most obvious for the people who received the long patterns and hence had participated in 60% more trials. A third general characteristic of this figure is that the pattern of change in RT over blocks seems less pronounced for the long patterns than for the short patterns.

These observations were confirmed in a $2 \times 2 \times 8$ (Age $\times$ Length $\times$ Block) mixed-design ANOVA in which block was a within-subjects variable. The only significant effects were those due to age, $F(1, 36) = 40.67$, $p < .0001$; block, $F(7, 252) = 73.37$, $p < .0001$; and the interaction of Length $\times$ Block, $F(7, 252) = 9.46$, $p < .0001$. None of the interactions with age even approached significance (for all, $p > .30$).

The absence of any even marginally significant interaction with age suggests that the pattern of change in response time over blocks is similar for both age groups. Furthermore, the lack of age interactions, coupled with the significant Block $\times$ Length interaction, indicates that although pattern length affects performance, it does so similarly for both age groups. It is difficult to appreciate the degree of age similarity in Figure 1, in part because of the large age differences in overall response time and in part because by chance we assigned more fast older subjects to the long than to the short patterns (the two older groups differ from each other in response time on Block 1). To make age and pattern length effects easier to examine, Figure 2 shows adjusted data for Blocks 1 through 5, in which the functions are shifted so that all four groups have equal response time on Block 1. This was accomplished by determining the difference in RT on Block 1 for the different groups and then adding or subtracting this amount to each of the other blocks. This adjusted figure shows that both age groups have almost identical degrees of disruption when the random block is presented (and, hence, identical scores on the indirect test of memory). These adjusted functions also show more clearly the effect of pattern length on learning.

The analyses presented so far point to impressive degrees of age similarity in the pattern of response times. They do not, however, provide specific tests of whether there are age differences in practice effects or in the indirect test of learning or retention, nor do they make clear exactly which of these processes are influenced by pattern length. The following analyses address each of these issues directly.

Practice Effect on Serial Reaction-Time Task

To analyze practice effects over the first four repeating blocks of the experiment, we calculated a practice score for each participant by subtracting mean response time on Block 4 from that on Block 1. These scores and their standard deviations are shown in the left panel of Table 1.

For the short patterns, the mean practice scores were significantly different from zero for both the younger group, $t(9) = 6.62$, $p < .0001$, and the older group, $t(9) = 3.81$, $p < .005$. For the long patterns, this practice score was significantly different from zero for the older group, $t(9) = 2.28$, $p < .05$, but only marginally so for the younger group, $t(9) = 2.11$, $p < .07$.

When the practice scores were submitted to a 2×2 (Age $\times$ Length) between-subjects ANOVA, the only significant effect was due to length, $F(1, 36) = 11.13$, $p < .0001$. (The age effect and the Age $\times$ Length interaction both yielded F values less than 1.0) Thus, the magnitude of the practice effect varies significantly with pattern length (with shorter patterns showing a larger effect), but not with age.

Indirect Test of Pattern Learning

Practice effects represent a combination of improvement due to general experience in the task plus that due to specific pattern learning. To examine pattern-specific learning, we calculated

Table 1
Means and Standard Deviations of Scores in the Serial Reaction-Time Task for Both Ages and Pattern Lengths

Pattern length	Practice score		Indirect score	
	Younger	Older	Younger	Older
Short				
M	113	132	119	142
SD	54	109	65	104
Long				
M	37	49	28	36
SD	56	68	69	42

Note. Practice score = Block 1 response time minus Block 4 response time; Indirect score = Block 5 response time minus Block 4 response time.

an indirect score for each participant, by subtracting Block 4 response time from that on Block 5. These values are shown in the right panel of Table 1.

For the short patterns, these scores were significantly different from zero for both the younger, $t(9) = 5.84$, $p < .0002$, and the older participants, $t(9) = 4.32$, $p < .0019$. However, for the long patterns the score was significantly different from zero for the older participants, $t(9) = 2.72$, $p < .03$, but not for the younger participants, $t(9) = 1.27$, $p > .20$. As Table 1 suggests, the lack of significance for the younger group receiving the long patterns reflects the high variability in that group.

A 2 × 2 (Age × Length) between-subjects ANOVA on the indirect scores yielded only a main effect of length, $F(1, 36) = 18.13$, $p < .0001$. Neither the effect of age, $F(1, 36) = 0.45$, nor the Age × Length interaction, $F(1, 36) = 0.10$, approached significance.

Thus, after 40 repetitions of the patterns, participants of both ages had learned more about the short patterns than the long patterns. The lack of main effects or interactions with age indicates that there was no age-related deficit in the degree of pattern learning for patterns of either length when an indirect measure of learning was used. In fact, the *t* tests previously described indicate that for the long patterns, it was only the older group who showed significant pattern learning.

Indirect Test of Pattern Retention

Between repeating Blocks 4 and 6, there was a random serial reaction-time block plus a 30-min filled retention interval. Figure 1 shows that for all groups, response time on Block 6 was at least as fast as it had been on Block 4, suggesting that there was excellent retention over the delay. To determine whether the degree of retention varied with age or pattern length, we calculated a retention score (Block 4 minus Block 6 response time) for each participant and submitted these to a 2 × 2 (Age × Length) between-subjects ANOVA. There were no significant effects ($p > .10$, in all cases).

The mean Block 6 response time used in the previous analysis could be reflecting relearning of the pattern over the course of the sixth block, rather than memory over the retention interval. To test this possibility, we compared only the first two pattern repetitions in Block 6 with the last two pattern repetitions in Block 4. This subset of the data yielded exactly the same pattern of response times. Thus, by this indirect measure, retention of the patterns is excellent for both pattern lengths for participants of both ages.

Direct Test of Pattern Learning

We calculated the mean proportion correct that each participant earned on the generation task that followed Block 8. To find out whether it would be appropriate to collapse across the two patterns of each length, we first performed two separate 2 × 2 (Age × Pattern) between-subjects ANOVAS, one on the two short patterns and the other on the two long patterns. The analysis of the short patterns did not yield a significant effect or interaction of pattern, but the analysis of the long patterns resulted in a significant effect of pattern, $F(1, 16) = 14.18$, $p < .002$, suggesting that it would be unwise to collapse across patterns in considering the direct measure.

Table 2
Mean Proportion Correct and Standard Deviations in the Generation Task (Direct Score)

	Age group			
	Younger		Older	
Pattern	*M*	*SD*	*M*	*SD*
Short				
10A	.76	.18	.69	.23
10B	.84	.21	.62	.26
Combined	.80	.19	.66	.24
Long				
16A	.69	.22	.54	.14
16B	.46	.13	.28	.11
Combined	.58	.21	.41	.18

Table 2 displays the group means of the subject mean proportion correct by age group and pattern. Most notable is the fact that, unlike the indirect measures, this direct measure reveals a consistent age difference, with the older people scoring lower than the younger people for all four patterns. Furthermore, for both ages, accuracy varies across patterns, performance on Patterns 10A and 10B is better than that on Pattern 16A, and performance on Pattern 16B is notably poorer than on any of the other three patterns.

These observations were confirmed in a 2 × 4 (Age × Pattern) between-subjects ANOVA, which yielded significant effects of both age, $F(1, 32) = 7.60$, $p < .01$, and pattern, $F(3, 32) = 7.43$, $p < .001$, but not their interaction, $F(3, 32) = 0.35$. Post hoc Scheffé tests indicated that the only patterns significantly different from each other were 10A versus 16B, and 10B versus 16B. (An analysis using an arc sin transformation yielded the same results). Thus, the direct measure of pattern learning is similar to the indirect measure in indicating that learning is better for short patterns than for long patterns. However, the direct measure differs from the indirect in varying with age and in being influenced by exactly which longer pattern is presented.

It seemed possible that the older people's poorer performance in the generation task was due to confusion at switching to a new task. To find out, we compared generation accuracy on the first half of the generation trials with that on the second, reasoning that if older people were simply having difficulty in adjusting to the generation task, then the age difference should be smaller on the second half of the trials than on the first. We found the reverse to be the case. Whereas the young people showed evidence of learning during the generation block, with mean accuracy of .65 ($SD = .22$) on the first half and .73 ($SD = .23$) on the second half, the older people performed almost identically on the two halves, with means of .54 ($SD = .23$) and .52 ($SD = .26$), respectively. This observation was confirmed in a 2 × 4 × 2 (Age × Pattern × Half) mixed-design ANOVA with *half* a within-subjects variable. This yielded main effects of age, $F(1, 32) = 6.45$, $p < .02$, and pattern, $F(3, 32) = 7.67$, $p < .0005$, as well as an interaction of Age × Half, $F(1, 32) = 9.21$, $p < .005$.

Discussion

Indirect Versus Direct Tests and Aging

The most important finding is that the dissociative effects of aging on direct versus indirect tests of memory that have been demonstrated for verbal materials also occur for a nonverbal serial sequence. After 40 repetitions, older people show just as much memory for a pattern as do younger people when an indirect test is used. This is evidenced by the fact that the two age groups show equivalent disruption when the pattern is removed. And, as Figure 2 shows, for both ages and both pattern lengths, response time on random Block 5 returns fully to its original Block 1 level. This age constancy, which is apparent in the group means, is also obvious in the data from individual subjects. For the short patterns, all 10 subjects of each age are in the direction of having longer response times on random Block 5 than on repeating Block 4. For the longer patterns, this is true for 6 of the 10 younger and 8 of the 10 older subjects. Furthermore, the indirect test reveals equal and excellent retention of the patterns for both ages over a 30-min long retention interval filled with attention-demanding tasks.

In contrast to the age similarity on the indirect measures of learning and retention of the pattern, there were significant age deficits on the direct measure. In the generation task in which people were asked to anticipate which asterisk would appear next by pushing the button under the expected position, accuracy was consistently and significantly higher for the younger than the older participants. In fact, as Table 2 shows, for one of the long patterns (16B), the older participants' generation accuracy of .28 was not significantly different from chance (which would be .33 if they learned only that repeating items never occur, and .25 if they did not).

The fact that age differences appeared on the direct, but not the indirect, test is particularly striking because the tests were administered after different degrees of exposure to the pattern. Although the indirect test occurred in Block 5 after only 40 repetitions of the pattern, the direct memory test was not given until Block 9 after an additional 30 repetitions of the pattern had occurred. And yet it is only the direct test that shows age differences.

It has been noted (e.g., Chiarello & Hoyer, 1988; Light & Singh, 1987) that in many studies, indirect tests do show a small advantage favoring the younger subjects, even though the age difference does not approach statistical significance. This suggests the possibility that there is a small but real age difference even on indirect measures, which experiments with small sample sizes lack power to detect. This argument does not apply to the present experiment. As Table 1 and Figure 2 show, the magnitude of the practice score and of the indirect score is, for both short and long patterns, in the direction of being greater for the older than the younger participants.

The findings here, then, join earlier studies of memory for words and sentences in indicating that relative to younger people, older individuals have particular difficulty on tasks that require deliberate, conscious recollection of past events. As yet there is no good theoretical account of why this difficulty occurs, but the present study puts constraints on possible explanations. First, our findings indicate that the difficulty older people have on direct tests is *not* limited to those requiring extensive retrieval strategies, such as the strategies used to locate in memory the word that had earlier been presented with another word. In the present generation task, no such extensive search of memory is required, and yet age deficits still appeared.

Second, the older person's difficulties on direct tests are *not* attributable solely to cautiousness. In some direct tests of verbal memory, it can be argued that the age differences reflect the older person's having adopted a higher criterion for recognizing a word or for guessing in a recall task. In the present direct test, however, participants were required to guess on each trial and to keep doing so until they chose the correct answer—a condition that should reduce or eliminate the influence of such cautiousness. And yet still, age deficits appeared on the direct test.

Third, the poor performance on the direct test does *not* mean that the older people were totally unaware of the repeating pattern. Unfortunately, we did not record if and when people mentioned that they noticed a pattern. Nonetheless, we noted that the majority of subjects of both ages reported spontaneously that they noticed some repeating sequences, quite unlike Nissen and Bullemer's (1987) and Nissen et al.'s (in press) Korsakoff's patients who reported no awareness at all of the pattern (despite their normal performance on the indirect test). Even though many of the older participants in the present study were aware that some pattern was present, they were poorer than the younger participants at making conscious, deliberate use of this awareness in the generation task.

Thus, the present findings broaden the range of conditions under which older people have been shown to have difficulty on direct memory tests. Age deficits on direct tests occur even when the test is nonverbal and requires minimal search of memory, and even when the effects of age differences in cautiousness are ruled out.

Indirect Tests and Automaticity

These findings also broaden the range of conditions under which age constancy has been shown on indirect tests. There is some evidence that the pattern learning tapped by indirect tests in this task relies on effortful rather than on automatic processes during study, an important observation in light of Hasher and Zacks's (1979) argument that age constancy is usually observed in automatic, but not in effortful processes.

Nissen and Bullemer (1987) have found that college students show no learning of the repeating pattern on either the direct or the indirect test if they do the serial reaction-time task simultaneously with an attention-demanding task, in which they must discriminate and count tones. In the sense of being disrupted by a dual task, then, the learning tapped by the indirect measure calls upon effortful rather than automatic processes.

This forms an interesting parallel with learning verbal materials. Schacter and Graf (1986) have shown that learning a new association between two previously unassociated words requires attention, in that the person must have formed a meaningful connection between the two words, and this is true even when learning is tapped via an indirect test. Thus, these earlier findings with both verbal and nonverbal materials indicate that the learning tapped by at least some indirect tests is not automatic; it calls upon limited processing capacity, violating one of the widely accepted criteria for automaticity (e.g., Hasher & Zacks, 1979; Shiffrin & Schneider, 1977). Therefore, the present findings suggest that age constancy can occur on indirect tests, even when the learning being assessed requires effortful processing.

One caveat is in order here; there may be age differences in the *rate* of pattern learning, which would not be apparent in the present experiment. The indirect test did not take place until people had experienced 40 repetitions of the pattern. Nissen and Bullemer (1987) have shown that college students show clear evidence of some pattern learning on the indirect measure within the first 10 repetitions. Whether the same is true for older people is a question we are investigating in ongoing experiments. In fact, there is already some evidence for age differences in the rate of acquisition of new verbal associations. Under less than optimal study conditions (e.g., short study time) older persons are sometimes poorer than young persons on indirect tests of memory for a new association between two words (D. V. Howard, 1988; D. V. Howard et al., 1986).

Different Memory Systems?

Nissen and her colleagues (Knopman & Nissen, 1987; Nissen et al., 1987) have argued that the measures used here reflect the operation of two distinct memory systems, with the direct measure tapping declarative memory and the indirect tapping procedural memory (e.g., Cohen, 1984). Their argument for this distinction is based on the dissociations they have observed between these measures in clinical populations, including Alzheimer's patients (Knopman & Nissen, 1987), Korsakoff's patients (Nissen & Bullemer, 1987; Nissen et al., in press), and scopolamine-challenged college students (Nissen et al., 1987).

It is of interest, then, to consider whether the present data provide additional evidence for two distinct memory systems. We do find a dissociation between the direct and indirect measures in yet another special population; our older participants were poorer than our younger participants on the direct, but not on the indirect, test.

Our data also provide one instance of a functional dissociation between the two measures; this concerns the effect of the particular pattern on performance. For the indirect measure of learning, we found no hint of a difference between the two patterns of a given length, and this was also true for the direct measure for the two short patterns. However, the two long patterns differed from each other on the direct measure, with 16B resulting in much poorer generation accuracy than 16A (see Table 2) for both ages. (Our attempts to determine exactly what makes 16A and 16B so different were not particularly successful. It may be important that the easier pattern 16A contains three instances of an A–D sequence, whereas pattern 16B has no pair repeating more than twice.) This differential influence of particular pattern suggests the hypothesis that as patterns get longer and, hence, more difficult to learn, then direct, but not indirect, measures are influenced by specific properties of the pattern. If this hypothesis were supported in future studies using a range of different patterns, it might mean that two different kinds of learning are indeed involved. Thus, one could argue that the form of learning tapped by the direct measure, but not that tapped by the indirect, is sensitive to differences among patterns because only the direct task reflects the operation of learning strategies (such as looking consciously for repeating pairs). Because some patterns are easier to learn by such strategies than others, pattern differences emerge, but only on direct tests.

Although both age and particular pattern show dissociative effects on direct versus indirect measures, other aspects of our data fail to show such dissociations. We found that the variable of pattern length influenced both the direct and indirect measures in the same way. In addition, there is some evidence that subjects who showed good pattern learning by one measure were also relatively good learners by the other. This evidence comes from correlations we conducted between a subject's direct score (proportion correct on the generation task) and that subject's indirect score (Block 5 minus Block 4 response time). Because of the small number of subjects per pattern and the fact that generation performance varied with particular pattern for the longer patterns, we were only able to perform such correlations on the data from the short patterns, combining the data from the groups receiving Patterns 10A and 10B. These correlations were well above zero for both the younger group, $r = .469$, $p < .17$, $n = 10$, and the older group, $r = .561$, $p < .10$, $n = 10$, although they failed to reach statistical significance.

The finding that age shows dissociative effects on direct versus indirect measures, but that nonsubject variables do not, is in keeping with other research using Nissen et al.'s (1987) serial response-time task. As noted earlier, Nissen and Bullemer (1987) have found that both direct and indirect measures are influenced similarly by including a simultaneous attention-demanding task during learning. And in other work, we have found that by both direct and indirect measures, pattern learning occurs even when the subject simply observes the pattern, rather than responding overtly (J. H. Howard & Howard, 1989). Thus, with the notable exception of the dissociations seen in aging and in clinical populations, we find little evidence that the direct and indirect measures used here are tapping two different systems.

Similarities Between Scopolamine Effects and Aging

Our results extend earlier observations (Caine, Weingartner, Ludlow, Cudahy, & Wehry, 1981; Drachman & Leavitt, 1974) that compare the effects of scopolamine and aging. The 10-element conditions in the present experiment are identical to those used in a study by Nissen et al. (1987), except that whereas we varied adult age, Nissen et al. tested only young subjects, one half of whom had been given low doses of scopolamine. Comparisons between the studies indicate that the effects of aging and scopolamine are similar. When compared with the college student control subjects, both older subjects and scopolamine-challenged college students showed overall slowing in the serial reaction-time task and poorer performance on the generation task. The generation scores for the 10-element patterns were quite similar for the younger control groups in both studies, with proportions correct of .80 in our study and .83 in Nissen et al.'s. In contrast, our older group earned a proportion correct of .61, and Nissen's young scopolamine group earned a score of .70. Despite the overall slowing and poor generation scores resulting from aging and from scopolamine, neither of these variables affects indirect memory measures.

Thus, our findings, coupled with those of Nissen and her colleagues, offer further evidence that drug-induced cholinergic blockage in younger people results in a pattern of cognitive savings and loss similar to that which accompanies normal aging. This is the case not only for verbal memory (as Drachman & Leavitt, 1974, had already demonstrated) but also for a nonverbal serial-learning task.

In conclusion, the present study of memory for a nonverbal spatial sequence joins previous studies of verbal memory in showing that whether age deficits appear depends at least in part on how memory and learning are assessed. Even though older adults were significantly poorer than were younger adults on a direct test of how much they had learned about a pattern, they showed as much pattern learning as younger people when an indirect test was used.

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