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A Decomposition of Age-Related Differences in Multitrial Free Recall*

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ABSTRACT

The relative roles of acquisition and forgetting in mediating age-related differences in multitrial learning were evaluated by having 258 adults (18 to 94 years of age) complete five study and free-recall test trials of 15 words. Performance across trials was decomposed into (a) gained access, corresponding to the proportion of items recalled on trial n+1 of those that were not recalled on trial n (hence tapping processes related to acquisition), and (b) lost access, corresponding to the proportion of items not recalled on trial n+1 of those that were recalled on trial n (hence tapping intertrial forgetting). Age-related differences occurred both in gained access and in lost access, although acquisition seemed to play a larger role in mediating age-related differences in learning than did forgetting. Also, a composite measure of processing speed shared 63% or more of the age-related variance in measures of free recall. The overall pattern of results is consistent with the view that age-related decreases in the speed of completing elementary encoding operations contribute to poorer learning by leading to weaker representations of the to-be-remembered items.

Learning is essential to accomplishing numerous goals in everyday life. As an individual attempts to learn new material, he or she may require multiple study-test trials to attain mastery. For instance, a musician will repeatedly practice a short pattern of notes to learn a new chord progression, and a student will recite a list of vocabulary items multiple times so as to recall the items on a later test. Even though such learning is important throughout the life span, the nearly universal finding is that more trials are required to reach the same level of performance for older adults than for younger adults (e.g., Delbecq-Derouesné & Beauvois, 1989; Salthouse, 1994; Salthouse & Dunlosky, in press; Witte, Freund, & Sebby, 1990; for a review see Kausler, 1994, pp. 72-77). For one recent example, Salthouse and Dunlosky (in press, Study 2) found that after nine presentations of the to-be-learned items, older adults did not reach the same level of performance as did younger adults after only one presentation.

To improve performance in learning tasks involving multiple trials, an individual must at minimum (a) acquire items that have not yet been learned well enough to be retrieved, and (b) retain items that have already been acquired. These factors suggest two proximal mediators of age-related differences in trial-by-trial performance. Namely, compared to younger adults, older adults may be more likely to forget items that had been retrieved on previous trials, and they may be less effective at acquiring items from one trial to the next. Such an age-related

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decline in acquisition may be partially caused by a related decline in speed of processing, with slower speed of processing resulting in fewer relevant processing operations during study (e.g., Salthouse, 1994, in press; for further review and discussion see Kausler, 1991). Although many studies have described age-related declines in multitrial learning, the relative roles of acquisition and forgetting in producing these effects have not been fully examined.

A primary goal of the present study was to evaluate the relative roles of intertrial acquisition and intertrial forgetting in producing age-related differences in learning. This issue was addressed with data from 258 adults ranging from 18 to 94 years of age (the data presented here were collected during a larger project reported by Salthouse, Fristoe, & Rhee, in press). The data were collected using the Rey Auditory Verbal Learning Test (AVLT), which includes five critical study-test trials of a 15-word list. The AVLT is well suited to our present aims for at least two reasons. First, performance on the AVLT is sensitive to age-related differences in learning, with increasing age linked with less improvement in performance across trials (e.g., Bolla-Wilson & Bleecker, 1986; Geffen, Moar, O'Hanlon, Clark, & Geffen, 1990; Mitrushina, Satz, Chervinsky, & D'elia, 1991; Query & Megran, 1983; Wiens, McMinn, & Crossen, 1988). Although age-related differences in performance have been described in these investigations, they are relatively uninformative concerning the degree to which these age-related differences are mediated by acquisition compared to forgetting. In particular, perhaps because these investigations have mainly focused on different issues than those examined here, none have examined age-related differences by decomposing performance across trials into measures that reflect acquisition and forgetting.

Second, such a decomposition of trial-by-trial performance is afforded by the AVLT, because performance can be analyzed in terms of a measure of gains in access to items from one trial to the next (*gained access*), as well as a measure of losses in access to items from one trial to the next (*lost access*). Gained access and lost access are assumed to measure the effectiveness of acquisition and intertrial forgetting, respectively, and are derived as follows: Gained access is the proportion of items recalled on trial n+1 of those that were not recalled on trial n, whereas lost access is the proportion of items not recalled on trial n+1 of those that had been recalled on trial n (cf. Blachstein, Vakil, & Hoofien, 1993; Salthouse & Dunlosky, in press; Tulving, 1964).

To address our primary goal, we evaluated whether age-related differences occurred in these measures of gained access and lost access. Examination of these measures was assumed to be informative with respect to whether processes related to acquisition or to forgetting mediate the age-related differences in trial-by-trial performance. For instance, if age-related differences occur in trial-by-trial improvements on performance, without concomitant differences in lost access, it might be inferred that intertrial forgetting is not responsible for age-related differences in performance. Based on other research investigating both acquisition and forgetting (but not in the context of multitrial free recall), we expected that age-related differences would occur both in gained access and in lost access (Salthouse, 1994), but that these age-related effects would be larger for gained access than for lost access (cf. Kliegl & Lindenberger, 1993).

The secondary goal of this research was to examine the relations among a measure of speed of processing and various measures of AVLT performance. Previous research has shown that measures of processing speed account for a substantial proportion of the age-related variance in overall performance on tasks of memory (e.g., Bieman-Copland & Charness, 1994; Salthouse, 1994; Salthouse & Coon, 1993). We therefore used hierarchical regression to evaluate the degree to which age-related differences in task-specific components of learning (e.g., gained access that is assumed to measure the effectiveness of acquisition) could be mediated by speed of processing.

The tertiary goal was to further describe age-related differences in terms of serial position effects across trials. Previous investigations of serial position effects have typically involved a single study-test trial of a given list, with robust

age-related differences occurring in recall of words presented at the beginning and middle of the list (primacy and asymptote positions, respectively). The focus of the present research is on performance across *multiple* study trials of the same list. Perhaps even after multiple trials, older adults will not overcome initial differences in performance that occur after the first study trial. By contrast, initial age-related differences in recall of words from these serial positions may diminish across trials, which could occur if practice here yields greater improvement in memory performance for older than younger adults (for evidence that older adults improve with practice – and sometimes more so than younger adults – see Hultsch, 1974; Luszcz & Hinton, 1993; Treat, Poon, & Fozard, 1981). Mitrushina et al. (1991) reported that multiple study trials did not diminish age-related differences in performance across serial positions, but this lack of an effect may have been in part due to a restricted age range (the youngest participant was 57). Thus, we examined these issues using participants from a wider range of ages, although our analyses were mainly exploratory given that currently little is known about the joint effects of age and multitrial learning on serial position functions.

METHOD

Subjects

Two-hundred and fifty-eight adults served as participants and were divided into six age groups: 18-29 (M = 25, n = 41), 30-39 (M = 34, n = 40), 40-49 (M = 44, n = 29), 50-59 (M = 54, n = 58), 60-69 (M = 64, n = 43), and 70-94 (M = 78, n = 47). The oldest group here had a larger range of ages so as to approximately equate groups on sample size – the majority of participants (32) in this group were younger than 81 years of age. Also, one individual who had participated in the larger project reported by Salthouse et al. (in press) had missing data from one trial on the AVLT and hence was deleted from this sample. The percentage of females was approximately the same in each group, with percentages from each group deviating no more than 7% from the overall mean of 63%. Amount of education was also approximately the same across groups: 3.9 (20s), 3.8 (30s), 4.1 (40s), 3.9 (50s), 3.7 (60s), and 3.5 (70+), where 1 = less than 12 years, 2 = high school graduate, 3 = 13-15 years, 4 = college graduate, and 5 = more than 16 years. Further details on these and other demographic characteristics of the groups are presented in Salthouse et al. (in press).

Materials and Procedure

The AVLT was administered with the materials and procedures described in Spreen and Strauss (1991, pp. 149-152). It consists of two 15-word lists (one critical list and one distractor list), with all words being concrete nouns. Stimulus words were read by the experimenter at a rate of approximately one word per second. Immediately after the presentation of the last word of the list, participants were instructed to try to recall aloud as many words as possible, and to recall them in any order. Recall continued until the participant could not recall any more words. All responses (but not the order of response output) were recorded by the experimenter on a scoring sheet.

Words on the critical list were presented in the same order for five study-test trials. After the fifth test trial of the critical list, the distractor list was presented for one study-test trial. Immediately following this study-test trial of the distractor list, participants were asked to recall all of the words from the critical list. Finally, participants completed 20 min of filler activities (the Shipley Vocabulary and Abstraction tests; for details see Salthouse et al., in press) and were then asked to recall all of the words from the critical list. Hence, the sixth (immediate, postdistractor trial) and the seventh (delayed-recall trial) trials involved tests of the critical list without further presentation of the items for study.

Two paper-and-pencil tasks were also administered (letter comparison and pattern comparison) to measure perceptual comparison speed (as in Salthouse et al., in press). For letter comparison, participants determined whether two strings of letters (from 3 to 9 letters long) were the same or different. Each participant wrote either an S (for same) or D (for different) on the line that separated each pair of letter strings. Participants had 30 s to complete as many of the 21 pairs as possible. This procedure was done twice, with different strings appearing on each form. Pattern comparison was identical, except 30 pairs of simple line patterns were used instead of the letter strings.

RESULTS AND DISCUSSION

The primary performance measure is the proportion of words correctly recalled, which is plotted separately for the six age groups as a function of trials in Figure 1. Age (6 between-subject levels) x Trial (either 5 or 2 within-subject levels) anal-

yses of variance (ANOVAs) were conducted[1] on the data represented in Figure 1. These analyses were designed to assess (a) learning across the five study-test trials, (b) forgetting from Trial 5 to Trial 6 (the immediate, postdistractor trial), and (c) retention from Trial 6 to Trial 7 (the delayed-recall trial). The initial analysis on Trials 1 through 5 revealed main effects of age, $F(5, 252) = 17.2$, $MSE = .061$, and trial, $F(4, 1008) = 803.3$, $MSE = .007$, but the Age x Trial interaction was not statistically significant, $F(20, 1008) = 1.49$.[2] Note that the relatively lower performance of the 30s group may be anomalous, because this group had somewhat below-average scores on several typical psychometric tests, such as digit-symbol substitution and object assembly (reported in Salthouse et al., in press). Thus, as in previous research, all age groups improved with additional trials, and the age-related differences in performance persisted across all five trials.

All three effects were significant in the ANOVA contrasting Trials 5 and 6: age, $F(5, 252) = 13.58$, $MSE = .046$; trial, $F(1, 252) = 253.56$, $MSE = .009$; and their interaction, $F(5, 252) = 4.37$. As is apparent from inspection of Figure 1, the interaction is due to greater decline in performance from Trial 5 to Trial 6 with increased age. Finally, the ANOVA examining retention (i.e., contrasting Trials 6 and 7) revealed a main effect of age, $F(5, 252) = 12.63$, $MSE = .079$, but neither the main effect of trial, $F(1, 252) = 0.11$, $MSE = .006$, nor the Age x Trial interaction, $F(5, 252) = 0.22$, was statistically significant. This pattern suggests that little, if any, forgetting occurred across the 20 min retention interval.

A major goal of the present study was to decompose various aspects of these performance curves to understand better how the age-related differences in Figure 1 are mediated. This decomposition was accomplished in three ways: (a) analysis of serial position curves across the five learning trials; (b) examination of fluctuations in recall of individual words across the seven trials; and (c) path analyses and regression analyses to characterize the relations among age, a composite measure of speed of processing, and various aspects of performance.

Serial Position Curves

Figure 2 illustrates the relations between age, trial, and recall performance for three segments of the serial position curve, with performance being plotted as a function of the mean age of each group. Because the focus here was on whether older adults would overcome initial differences in recall across multiple study trials, we present analyses of only the five critical study-test trials. For analyses involving these curves, the individual positions of the curve were collapsed into three segments: Primacy refers to performance collapsed across serial positions 1-3; asymptote refers to performance collapsed across positions 5-11; and recency refers to performance collapsed across serial positions 13-15. Positions 4 and 12 were more ambiguous as to whether they should be included as part of the asymptote and hence were omitted from these analyses.

[1] Because of the relatively large number of statistical comparisons and the moderately large sample sizes, a given comparison was declared as statistically significant if $p \leq .01$. Accordingly, critical t values when evaluating coefficients for path analyses were set at 2.58, instead of the less conservative 2.00.

[2] Because initial levels of performance were not equated across age groups, the nonsignificant interaction does not necessarily indicate that age-related differences did not occur in the rate of learning (Loftus, 1978). To address more fully the possibility of age-related differences in learning rates, we (a) matched the average level of performance on a given trial for a younger group with the average level of performance on that or another trial for an older group, and then (b) compared performance between those groups on the next trials. We used this procedure (including comparisons between age groups that differed by two decades or more) by finding dyads of trials where the difference in mean recall performance between two age groups did not exceed ± .02, and then comparing the mean level of performance for the next trials. Out of the 12 cases where mean performance between two groups matched, mean performance on the next trial for the younger group (vs. the older group) was greater in 11 cases and was tied in 1 case ($p = .006$, via a sign test). Thus, when age groups are matched on mean performance, a trend occurs in which performance on subsequent trials is greater for younger than older adults.

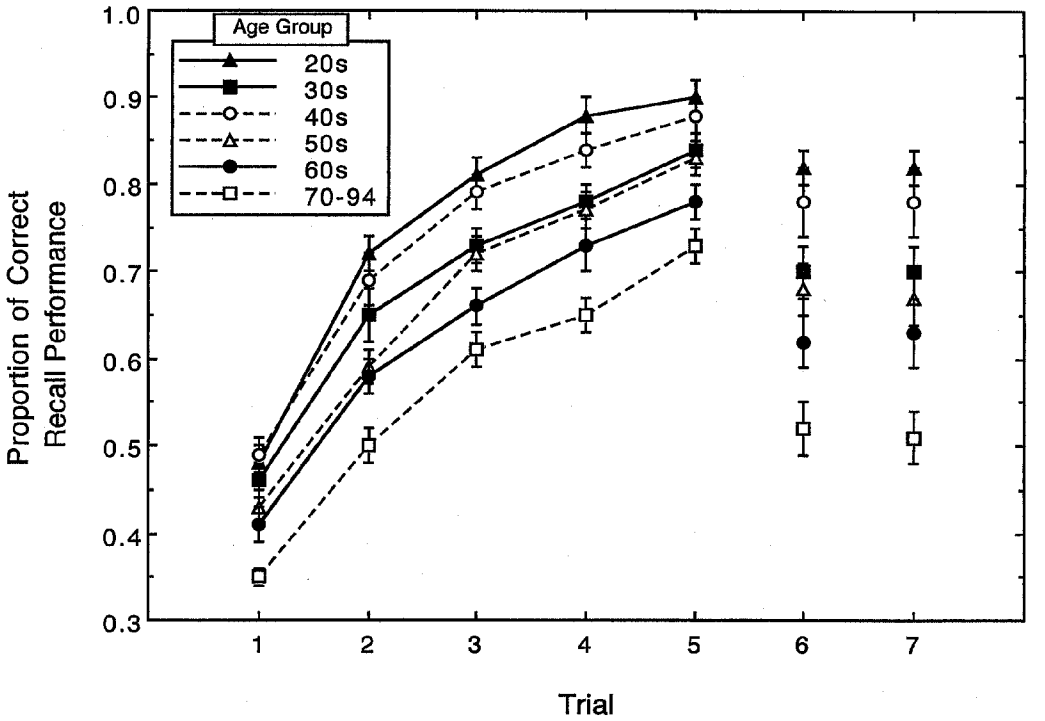

Fig. 1. For each of the 6 age groups, the mean (across individuals) proportion of correctly recalled items on the critical list is plotted as a function of the five study-test trials and for test Trial 6 (which occurred after a study-test trial of a different list) and test Trial 7 (which occurred about 20 min after Trial 6). Trials 6 and 7 did not include a study trial. Bars represent standard errors of the corresponding mean.

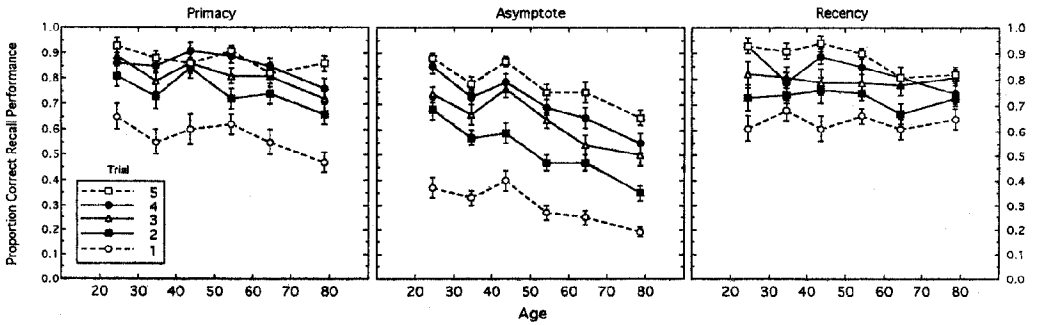

Fig. 2. Mean proportion of correctly recalled items plotted as a function of age group, trial, and segment of the serial position curve. The figure illustrates the age-related effects on performance for the primacy segment (serial positions 1-3, left-most panel) and for the asymptote segment (positions 5-11, middle panel), and the relatively negligible effect of age on performance for the recency segment (positions 13-15, right-most panel).

The following points should be noted about the data in this figure: (a) For each of the trials and across all age groups, performance at the asymptote is lower than performance at the primacy segment or recency segment, which represent the standard primacy effect and recency effect, respectively; (b) across the five trials, performance increased across all serial positions, with performance at the primacy segment and the recency segment being close to the ceiling by the fifth trial; and (c) finally, when performance was below the ceiling (e.g., for the first 3 trials), age-related differences are evident both in the primacy segment and in the asymptote but not in the recency segment.

An Age (6 decades) x Trial (1-5) x Segment (Primacy, Asymptote, Recency) ANOVA was conducted. Consistent with the observations above, a main effect of trial occurred, $F(4, 1004) = 450.20$, $MSE = .03$, and the effect of trial differed somewhat across the three segments as indicated by a significant Trial x Segment interaction, $F(8, 2008) = 13.13$, $MSE = .044$. Although main effects occurred both for age, $F(5, 251) = 11.35$, $MSE = .17$, and for segment, $F(2, 502) = 138.30$, $MSE = .099$, the Age x Segment interaction was also significant, $F(10, 502) = 3.48$. This interaction reflects the negligible effect of age on performance in the recency segment, post hoc $F(5, 252) = 1.54$, $MSE = .098$, but significant age-related differences in performance at the primacy segment and asymptote, post hoc Fs > 3.60, MSEs $< .14$. Neither the Age x Trial interaction nor the three-way interaction were statistically significant, Fs < 1.20. Thus, as is evident from inspection of the left-hand panel and middle panel of Figure 2, age-related effects on performance of words presented at the beginning and middle of the list did not diminish across trials.

To summarize the preceding analyses of recall performance, we briefly highlight several central findings. First, age-related declines in recall performance occurred on Trial 1 and persisted across the next four critical study-test trials. Whether age differences in learning during trials after the first can be fully accounted for by age differences in Trial 1 performance is evaluated further below. Second, age-related differences in forgetting appeared when a distractor list was studied between successive test trials (Trial 5 vs. Trial 6), but forgetting was negligible when unrelated filler tests were performed between Trials 6 and 7. Third, age-related differences in performance across the first five trials (Figure 1) appear to be due more to differences in learning items in the middle-to-first serial positions of the list than in learning items in the recency positions (Figure 2). These results demonstrate consistency of age-related differences in performance for the three segments of the serial position curve *across multiple trials*, which to our knowledge has not been previously reported. Whether such consistency in learning will also be apparent at the level of individuals is a central topic of analyses below.

Gained Access and Lost Access

As discussed above, finer grained analyses of performance consisted of examining two kinds of item fluctuation that could occur from one trial to the next. In particular, we evaluated the proportion of items recalled on a given trial of those that were not recalled on the previous trial (i.e., gained access) and the proportion of items not recalled on a given trial of those that were recalled on the previous trial (lost access) (cf. additions vs. omissions in Blachstein et al., 1993; intratrial retention vs. intertrial forgetting in Tulving, 1964). Thus, each data point on Figure 3 represents values across a pair of trials.

Age x Trial x Kind of Fluctuation (gained access vs. lost access) ANOVAs were conducted for performance on the five study-test trials (left-hand panel of Figure 3) and for performance across the retention trials (right-hand panel), with post hoc ANOVAs conducted where appropriate. Note that the conditional probabilities for a given trial (e.g., mean proportion gained and lost for 20s group on Trial 1) do not necessarily add to 1.0 because all words did not fluctuate from one trial to the next (i.e., some words were not lost or gained across a given pair of adjacent trials).

For performance changes within the first five trials, there was a significant main effect of age, $F(5, 222) = 6.82$, $MSE = .07$, a significant main effect of kind of fluctuation (i.e., gained access

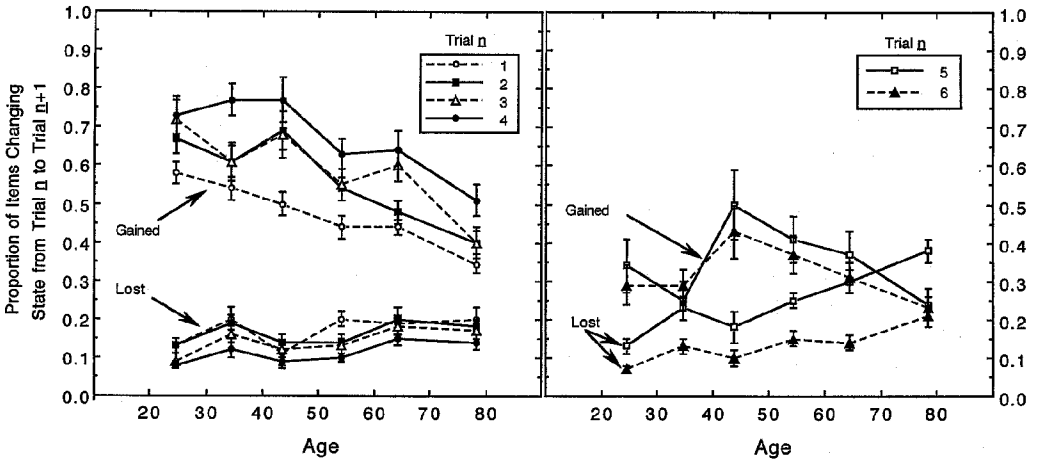

Fig. 3. Gained access and lost access plotted as a function of age group and trial, where gained access is the mean proportion of recalled items on trial n+1 of those that were not recalled on trial n, and lost access is the mean proportion of items not recalled on trial n+1 of those that were recalled on trial n. These measures are shown separately across the five study-test trials (left panel) and across the last three trials (right panel), illustrating gains and losses across the distractor trial and the retention trial (curves labeled 5 and 6, respectively).

was greater than lost access), $F(1, 222) = 836.17$, $MSE = .08$, and a significant Age x Fluctuation interaction, $F(5, 222) = 10.69$. Age-related effects were statistically significant for both kinds of fluctuation (Fs of 4.28 and 10.77 for the effect of age on lost access and gained access, respectively), with the crossover interaction of age and kind of fluctuation indicating that gained access significantly decreased with age (r between chronological age and gained access = −.43) but lost access significantly increased with age (r between chronological age and lost access = +.24; the absolute values of these correlations differ significantly, $t = 2.66$).[3] Significant effects also occurred for trial, $F(3, 666) = 13.44$, $MSE = .04$, and the interaction between trial and the kind of fluctuation, $F(3, 666) = 58.19$. This interaction indicates that as participants had more study-test trials, the proportion of remaining items gained per trial increased (perhaps because fewer items were left to be acquired in the latter trials), whereas the proportion of items lost per trial decreased. (Neither the Age x Trial interaction nor the three-way interaction were significant, Fs < 1.0.)

The ANOVA on data from Trials 5 and 6 (right-hand panel of Figure 3) revealed main effects for age, trial, and the kind of fluctuation, all Fs > 3.75. (The Age x Trial interaction and the three-way interaction were not significant, Fs < 1.0, but the Trial x Kind of Fluctuation interaction was significant, $F(1, 200) = 7.80$, $MSE = .05$.) Age also interacted with the kind of fluctuation, $F(5, 200) = 3.38$, $MSE = .10$: Across the retention trials there was a clear age-related increase in lost access, $F(5, 250) = 10.40$, $MSE = .03$, $r = +.41$, whereas the age differences in

[3] Initial age-related differences in recall performance may propagate subsequent differences in gained access and in lost access. Accordingly, the procedure described in Footnote 2 was used to assess whether age-related differences in these measures still occur when age groups are matched on mean recall performance. Out of the 12 cases where two age groups matched, in 11 cases gained access was greater for younger than older adults, $p < .001$, whereas in only 5 of the 12 cases was lost access greater for younger adults, $p = 1.0$. Thus, when age groups are matched on mean performance, age-related differences remained in gained access but were diminished in lost access.

gained access were less systematic, $F(5, 202) = 2.92$, $MSE = .13$, $p = .015$, $r = -.03$.

In sum, substantial age-related declines occurred in gained access across the five study-test trials. By contrast, negligible age-related effects occurred in gained access across the retention trials, which did not include re-presentation of words for study. Age-related effects were also relatively small on lost access across the first five trials, with somewhat larger age-related effects across the retention trials. Although we have chosen to emphasize interpretations based on the measures of gained access versus lost access, complementary interpretations exist for both measures because each is related to another probability. For instance, the negligible age differences in loss across trials could instead be interpreted as negligible differences in retaining items across trials (cf. Tulving, 1964). Such alternatives can be interchanged with and do not seem at odds with conclusions developed in the present research.

Path Analyses

Path analyses were conducted to examine further the relations among age, gained access, and performance across the five study-test trials. Because age-related effects on the measure of lost access were relatively small compared to the age-related effects on gained access (left panel of Figure 3), the variable of lost access was omitted to simplify analyses. Goals of the path analyses included evaluating (a) the degree to which age-related differences in performance on trial n accounted for age-related differences in performance on trial $n+1$, and (b) the degree to which gained access mediated age-related differences in trial-by-trial performance. To accomplish these goals, we conducted two path analyses using LISREL 8 (Jöreskog & Sörbom, 1993). The first analysis examined the relations among age and performance across successive trials, and the second analysis included these measures along with the measure of gained access.

The outcome of these analyses, with all significant path coefficients reported in standardized units, is shown in Figure 4. The boxes in the row Gained Access were labeled as in Figure 3, with a 1 referring to gained access from Trial 1 to Trial 2, a 2 referring to gained access from Trial 2 to Trial 3, and so on. The models excluded paths in which we had no a priori substantive interpretation (e.g., paths from nonadjacent trials were excluded). The fit of both models was relatively good as revealed by several indexes: For the top panel of Figure 4, $\chi^2(8) = 42.62$, standardized root mean residual = .064, Adjusted Goodness of Fit Index = 0.87, and Comparative Fit Index = .96; for the bottom panel the fit indexes were $\chi^2(31) = 109.28$, standardized root mean residual = .094, Adjusted Goodness of Fit Index = 0.87, and Comparative Fit Index = 0.95.

The top panel of Figure 4 indicates that the age-related effects on performance on later trials cannot be solely accounted for by age-related differences in performance on earlier trials. That is, independent age-related effects on Trials 2 and 4 indicate that there were unique age-related influences on these trials after taking performance on earlier trials (e.g., Trial 1 performance) into consideration. This finding is in apparent conflict with the nonsignificant Age x Trial interaction in the ANOVA (but see Footnote 2), but the pattern is consistent with the recent argument by Salthouse and Coon (1994) that analyses of mean level and of proportions of shared variance yield different kinds of information, and consequently both analytical methods should be used to obtain maximal information.

When the measure of gained access is added to the model, the relations between age and trial-by-trial recall performance change substantially. As illustrated in the bottom panel of Figure 4, no direct links between age and the measures of proportion recall remain, except for the age-related effect on Trial 1.[4] Significant age-related

[4]Two other factors may have affected outcomes in Figure 4. First, because recall was approaching the ceiling on later trials, restriction of variance may have occurred. This would be problematic to the extent that the values were attenuated on later trials; however, the values between successive trials were increasing rather than decreasing. Also, the more interesting age-related effects are evident even during earlier trials when recall is far from the ceiling. Second, proportion correct and gained access are computationally related (Tulving, 1964), and there is currently no way to

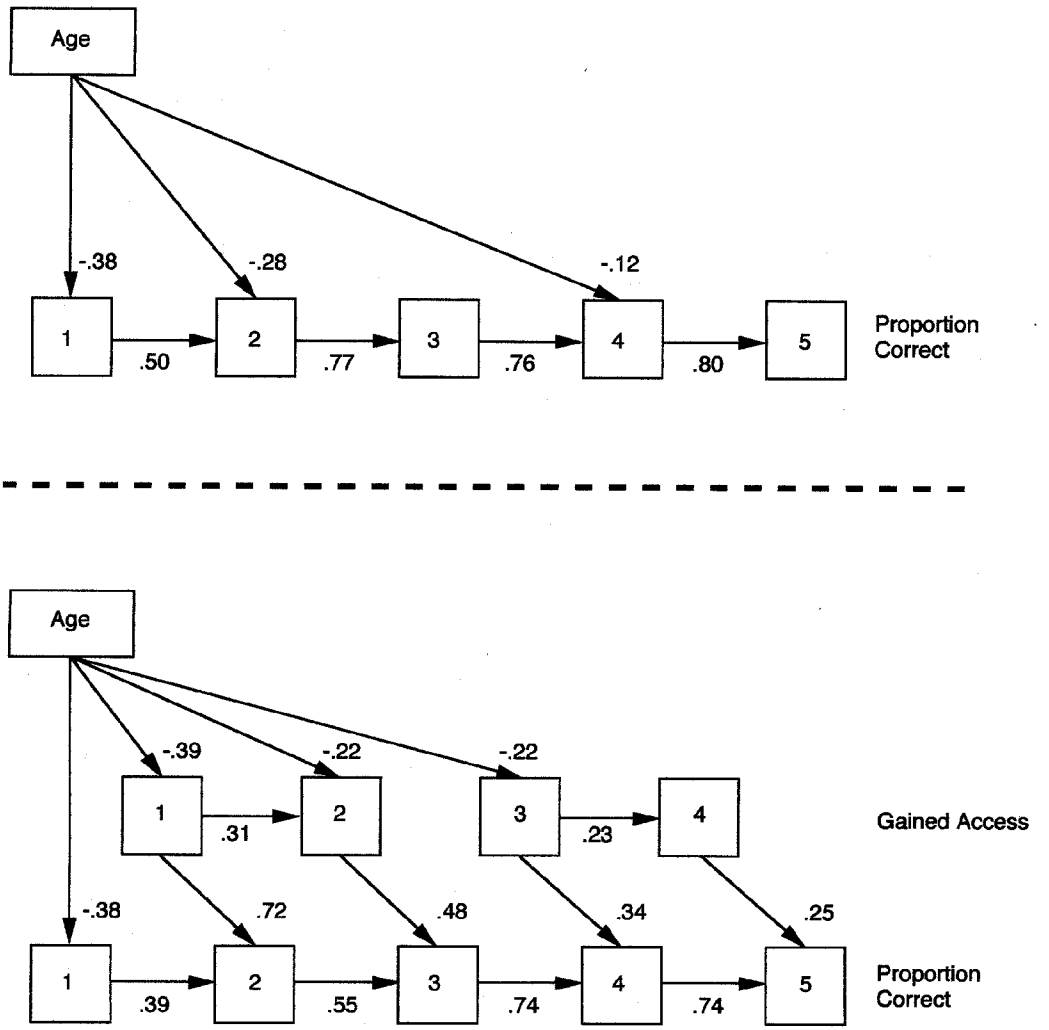

Fig. 4. The relations between chronological age and proportion of correctly recalled items across the five study-test trials (model shown in top panel) and the relations between these two variables with the proportion of gained access as a possible mediator of the age-related effects on trial-by-trial performance (bottom panel). Significant path coefficients are reported in standardized units.

determine how such mathematical dependency would impact the model. However, although conclusions may be partially compromised by the relations between measures and restriction in variance, the models suggest conclusions that converge with those based on other analyses in the present research.

effects occurred on the measure of gained access from Trials 1 to 2, 2 to 3, and 3 to 4, which extend the previous results that distinct age-related influences occur at several phases in learning by indicating that most of these effects are mediated through measures of gained access.

Regression Analyses

To evaluate the degree to which speed of processing might mediate age-related differences in performance (for detailed discussion of this kind of analysis see Salthouse, 1992), we examined the relations among age, a composite measure of processing speed, and two measures of recall performance (trial-by-trial recall performance and gained access) with regression analyses. As in the path analyses, we focused on accounting for age-related effects involving recall performance and gained access, with separate regression analyses for the two measures. A composite measure of processing speed was derived from two paper-and-pencil measures of perceptual comparison speed (letter comparison and pattern comparison) as in Salthouse et al. (in press). In these tests, the participant is asked to make same/different decisions about pairs of letters (or line patterns) as rapidly as possible.

Two values were central to these analyses: (a) the total amount of variance in performance associated with age (i.e., R^2 for age without consideration of speed of processing) and (b) the amount of variance associated with age after partialling the measure of processing speed (i.e., increment in R^2 associated with age after controlling for speed). For each of the two measures (proportion of recall and gained access), the two R^2 values are reported in Table 1. The far-right column of Table 1 indicates the percentage of reduction in the age-related variance associated with speed (i.e., [R^2 with age alone – R^2 change]/R^2 with age alone).

Consider the following points regarding Table 1. First, consistent with the analyses described above, the age-related effects were nearly constant on the proportion correct measures across successive trials. Second, for gained access, significant age-related effects occurred across the first four trials, with age effects diminishing across the last three trials, and particularly across the distractor trial and the retention interval. Finally, although in most cases significant age-related effects were evident after the speed measure had been partialled, in all cases the age-related variance was reduced after partialling speed, and in one case the age-related effects were in the opposite direction after control of speed. These results are therefore consistent with the notion that speed of processing plays a central role in mediating age-related effects on free-recall performance, but that it is not the only factor contributing to those effects.

Table 1. *R*-Squared Associated with Prediction of Various Measures Both with Age Alone and with Age after Statistical Control of Processing Speed.

		Age alone		After speed		
Measure	Trial	R^2	b	R^2 change	b	% Attenuation
Proportion recalled	1	.146*	–.380	.044*	–.271	69.9
Proportion recalled	2	.219*	–.468	.081*	–.368	63.0
Proportion recalled	3	.187*	–.432	.046*	–.279	75.4
Proportion recalled	4	.200*	–.447	.042*	–.266	79.0
Proportion recalled	5	.165*	–.407	.026**	–.211	84.2
Proportion recalled	6	.198*	–.445	.040**	–.257	79.8
Proportion recalled	7	.177*	–.420	.037*	–.248	79.1
Gained access	1	.149*	–.386	.062*	–.321	58.4
Gained access	2	.143*	–.379	.062*	–.322	56.6
Gained access	3	.096*	–.310	.031**	–.226	67.7
Gained access	4	.085*	–.292	.028**	–.214	67.1
Gained access	5	.003	–.058	.000	.003	100
Gained access	6	.007	–.086	.001	–.033	85.7

Note. b = standardized beta coefficient for age; see text for details of % Attenuation.
For tests of R^2 values greater than 0, * $p < .001$, ** $p < .01$.

GENERAL DISCUSSION

The results of this study are consistent with those of other investigations in indicating that multitrial recall performance of simple verbal material is often substantially less for older than younger adults. To illustrate, it is apparent in Figure 1 that twice as many trials were needed by the 60s age group to achieve a level of 70% recall performance compared to the 20s age group. Furthermore, analyses from the present study were inconsistent with the view that such age-related differences in performance across trials were completely attributable to differences in performance on earlier trials that were propagated to later ones. That is, not only did differences occur in performance on later trials when the mean level of performance was matched between younger and older groups on earlier trials, but path analyses revealed that significant age-related effects occurred on later trials both for the proportion of recall and for the measure of gained access. What age-sensitive processes may produce these age-related differences in trial-by-trial performance?

A major aim of the present research was to answer this question in relation to two possible mediators of age-related differences in learning: intertrial acquisition and intertrial forgetting. Acquisition and forgetting were operationalized in terms of measures of gained access and lost access, respectively. One prediction was that age-related differences would occur both in gained and lost access, because findings from previous studies indicated that older adults (as compared to younger adults) have more difficulty in acquiring new items (e.g., Salthouse, 1994) and are more likely to forget previously acquired items (Giambra & Arenberg, 1993).

Results shown in the left panel of Figure 3 are consistent with this prediction, indicating that both acquisition and forgetting mediate age-related differences in learning. However, several findings also imply that acquisition may play a relatively larger role in producing these differences than does forgetting. First, age-related differences were substantial in the measure of gained access and relatively smaller in the measure of lost access, with corresponding correlations between age and gained access ($r = -.43$) and between age and lost access ($r = +.24$) illustrating the differences in effect size. Second, when the mean level of performance was matched between younger and older groups, age-related differences in gained access remained, whereas age-related differences in lost access were minimal (Footnote 3). Although conclusions drawn from these analyses have several limitations (e.g., possible differences in the reliability of gained access vs. lost access, and the post hoc nature of the matching analyses), path analyses provided converging evidence for the central role of acquisition in mediating age-related differences in learning. Namely, age-related effects do not influence the level of recall performance directly, but instead indirectly affect recall via influences on the effectiveness of acquisition during study trials.

These results provide a more precise specification of age-related differences in trial-by-trial performance, although the reason for the age-related differences in the measure of acquisition still remains to be explained. One possibility is that the measure of acquisition taps individual differences in the effectiveness of encoding processes, with effectiveness of encoding being lower with increased age. For example, results from the serial position analyses can be viewed as consistent with an encoding deficit. Although all age groups showed both a primacy effect and a recency effect on the AVLT (replicating Geffen et al., 1990; Mitrushina et al., 1991; Tierney et al., 1994), age-related differences in performance were moderate to substantial at the primacy and asymptote segments of the serial position curve, but they were negligible at the recency segment. This pattern of age-related effects was found across the five study-test trials and implies that most of the age-related differences in improvements across trials are attributable to differences in performance at the beginning-to-middle portions of the list. In other words, differences in trial-by-trial performance may be due more to age-related deficits in transferring information about to-be-learned items to long-term memory than to deficits in retrieving items from primary memory (cf. Delbecq-Derouesné & Beauvois, 1989, who offered a

similar conclusion for age-related performance on a single-trial task of memory).

Other evidence from previous research also indicates that storage processes play a role in producing age-related differences in learning. For instance, Howe (1988) investigated the multitrial learning of younger adults and older adults. An important aspect of his work was fitting the performance data to a two-stage stochastic model so as to estimate parameters signifying various storage processes (3 parameters) and retrieval processes (8 parameters). Although age-related differences were found in parameters related to storage and retrieval, age differences were localized to specific aspects of these processes. Most relevant to the present discussion, Howe (1988) concluded that "age differences at storage were confined to processes involved in *establishing a trace in long-term memory* and did not extend to processes involved in maintaining a stored trace early in memorization" (p. 53, italics added; see Howe & Hunter, 1985, for converging evidence).

Such ineffectiveness of initial encoding may be mediated by a variety of underlying age-related differences, such as differences in the speed of completing elementary encoding operations (Salthouse, 1994) or the degree to which younger versus older adults utilize study activities (e.g., interactive imagery, relational processing, and so forth) that produce higher versus lower levels of memory performance (Verhaeghen & Marcoen, 1994). Although independent measures of study activities were not examined in the present research, results involving the composite measure of processing speed are compatible with the speculation that age-related differences in the effectiveness of encoding mediate differences in multitrial performance. In particular, a majority of the age-related variance in the measure of gained access was shared with the measure of processing speed (Table 1), and age-related differences in the measure of recall were largely mediated by differences in the measure of gained access (Figure 4). This pattern could be due to age-related reductions in processing speed resulting in fewer encoding operations at the time of study, which in turn provide a weaker initial representation of the to-be-learned items in memory that subsequently produces poorer learning (e.g., Salthouse, 1994; Salthouse, in press).

Although slower processing speed appears to mediate a substantial proportion of the age-related decline in learning via affecting some process of acquisition, it is important to note that the present findings indicate that processing speed does not mediate all of the age-related variance in learning. As shown in Table 1, the measure of processing speed accounted for a substantial amount of the age-related variance both in total proportion of recall performance and in the measure of gained access. On average, however, 25% of the age-related variance was not accounted for by the current measure of processing speed. Although this may be partially attributable to the less-than-perfect reliability of these measures, findings from several recent studies provide converging evidence for the conclusion that factors other than processing speed will be required to fully account for age-related differences in simple learning (Salthouse, 1994, in press; Salthouse & Dunlosky, in press). A challenge for future research will be to discover what other factor mediates age differences in learning independently of the speed with which people complete elementary mental operations.

In summary, findings from the present study lead to the following substantive conclusions. Age-related differences found in multitrial free recall do not appear to be propagated solely by differences in performance on earlier trials, and hence seem to reflect true age-related differences in the rate of learning. Processes of acquisition play a central role in mediating these age differences in learning, with at least some evidence suggesting that age declines in learning are due more to differences in acquisition than in forgetting. Finally, although further research is required to provide a complete characterization of the nature of this age-related deficit, age-related reductions in constructs related to processing speed, which may contribute to a weaker representation of the items at the time of study, appear to be involved in the age-related declines in learning.

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