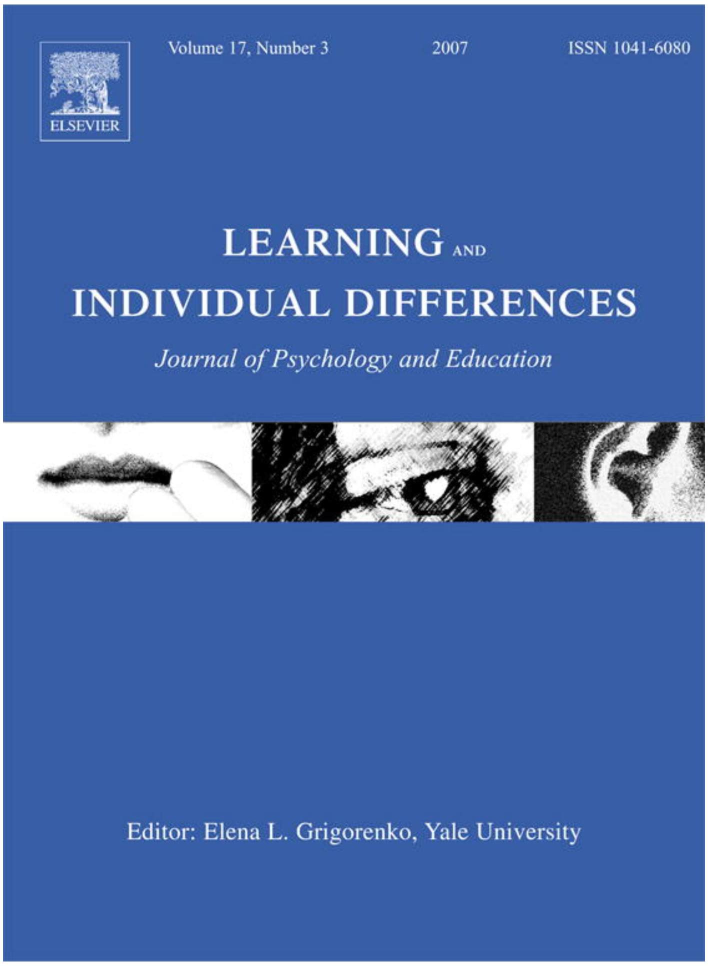
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Correlates of individual, and age-related, differences in short-term learning ☆

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Abstract

Latent growth models were applied to data on multitrial verbal and spatial learning tasks from two independent studies. Although significant individual differences in both initial level of performance and subsequent learning were found in both tasks, age differences were found only in mean initial level, and not in mean learning. In neither task was fluid or crystallized intelligence associated with learning. Although there were moderate correlations among the level parameters across the verbal and spatial tasks, the learning parameters were not significantly correlated with one another across task modalities. These results are inconsistent with the existence of a general (e.g., material-independent) learning ability.

Keywords: Verbal learning; Spatial learning; General learning ability; Intelligence; Growth curve models

Understanding individual differences in learning has been a major focus for research, and has concerned both psychologists and educationists for many years (e.g., Ackerman, Kyllonen, & Roberts, 1999; Ackerman, Sternberg, & Glaser, 1989; Gagné, 1967; Jonassen & Grabowski, 1993; Sternberg, 1984). Learning is commonly defined as the difference between initial and final levels of performance on a cognitive task (Glaser, 1967; McGeoch, 1942; Woodrow, 1946). Individual differences in learning have been found in a wide range of cognitive tasks, including verbal learning (Jenkins, 1967), motor learning (Fleishman, 1967), problem solving (Anderson, 1967), and so on. There have also been many attempts to investigate relationships between learning and intelligence (Ackerman et al., 1989; Duncanson, 1964; Gagné, 1967; Glaser, 1972, 1976; Jonassen & Grabowski, 1993; Stake, 1961; Woodrow, 1946). Correlations between learning and intelligence have generally been positive, but often not statistically significant. Similar to the study of general intelligence (e.g., Cattel, 1971; Herrnstein & Murray, 1994), there have been attempts to investigate general learning ability (e.g., Duncanson, 1964; Horn, 1989; Matzel et al., 2003; Snow, Kyllonen, & Marshalek, 1984; Stake, 1961; Woodrow, 1946). Factor analyses of intercorrelations among measure of

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learning from different tasks have revealed that no general learning ability existed, and rather that learning was specific to a particular type of task (e.g., Duncanson, 1964; Snow et al., 1984; Stake, 1961).

Although results from previous studies have generally been consistent, there is still controversy concerning the relation between intelligence and learning and the existence of a general learning ability. Because intelligence is sometimes defined as “the ability to learn” (Thorndike, 1924), and because Cattel’s (1971) investment theory of fluid and crystallized intelligence is based on the hypothesis that learning is the result of the investment of ability, it seems that intelligence and learning should be correlated. Furthermore, recent studies based on new analytic techniques found that learning was related to several measures of intelligence for older adults (e.g., Jones et al., 2005). One of the major critiques of the previous findings is the use of difference scores to measure learning. The major limitations of difference scores include: (1) difference scores ignore performance on intermediate trials and only utilize the information from the first and last trials, (2) difference scores tend to be highly correlated with the initial scores, and (3) difference scores often have low reliability which could attenuate relationships with other variables. These limitations restrict the value of difference scores in research on individual differences (e.g., Cronbach & Snow, 1997; Lohman, 1999; Snow et al., 1984).

Growth curve models have been recommended as an alternative to difference scores for both theoretical and methodological reasons (e.g., Bock, 1991; McArdle & Andeson, 1990; Rogosa, Brandt, & Zimowski, 1982). Several recent studies have attempted to model short-term learning in a multiple-trial word recall task using contemporary growth curve modeling techniques (e.g., Jones et al., 2005; Poreh, 2005; Nettelbeck, Rabbitt, Wilson, & Batt, 1996; Royall, Palmer, Chiodo, & Polk, 2003; Royall, Palmer, Chiodo, & Polk, 2005; Warschausky, Kay, Chi, & Donders, 2005). Among the results of these studies were significant relations between the learning parameters in these models and age, race/ethnicity, speed of processing, verbal knowledge, and global cognitive ability level. However, growth curve models have only been applied to one type of learning task, and the examination of relations between learning and intelligence, especially fluid and crystallized intelligences, are still rare. Furthermore, to our knowledge, there is no study investigating the existence of a general learning ability across different types of materials using sophisticated growth curve modeling techniques. Finally, the reliability of learning measure derived from growth curve models also needs to be investigated because measures of learning could not be expected to be correlated if they are not reliable.

The current study aims to address these issues with growth curve analyses of two data sets. First, we examine correlations among the growth curve parameters for tasks involving verbal and spatial information to determine the plausibility of a general (i.e., material-independent) learning ability. Second, we examine relations between measures of fluid and crystallized abilities and the growth curve parameters to determine whether, as often hypothesized, higher levels of intelligence are associated with faster learning. Third, we examine correlations of the growth curve parameters derived from parallel forms of a verbal learning task on three separate sessions to estimate the reliability of the parameters. Finally, we examine whether the above described relations varied across different age groups.

1. Growth curve models

Fig. 1 depicts a path diagram for the basic growth curve model used in the analyses. The observed variables are drawn as squares, unobserved or latent variables are drawn as circles, and constants are represented by the triangle. The squares labeled y1 through y5 are the observed scores on trials 1 through 5, respectively. L in the circle is the initial level of performance, and μ_L is mean of the initial level across all the participants. σ_L^2 is the variability around the initial level which represents the inter-individual differences. S in the circle corresponds to the slope, and μ_S is mean of the slope across all the participants. σ_S^2 represents the variability, or individual differences, around the slope, and σ_{LS} on the double headed line represents the covariance between initial level and slope. The circles labeled e1 through e5 are random errors, and their variances (σ_e^2) are assumed to be equal. L and S are random-effects parameters which are different for each individual, whereas μ_L and μ_S are fixed-effects parameters which are the same for all the participants.

The model indicates that the observed variables y1−y5 can be viewed as determined by the initial level (L), the slope (S), and the error (e). Different shapes of the growth curve can be produced by adjusting the weights of α_1 through α_5. For example, assigning them the values 1 through 5 would result in a linear growth curve. In our analyses the value of α_1 was fixed to 0, the value of α_5 was fixed to 1, and the values of α_2, α_3, and α_4 were estimated. This particular model, in which the weights or basis coefficients determine the shape of the growth curve, is known as a latent growth model, and it has the advantage that the form of the function is determined by the data rather than specified a priori. The S parameter in this model can be interpreted as the estimate of learning.

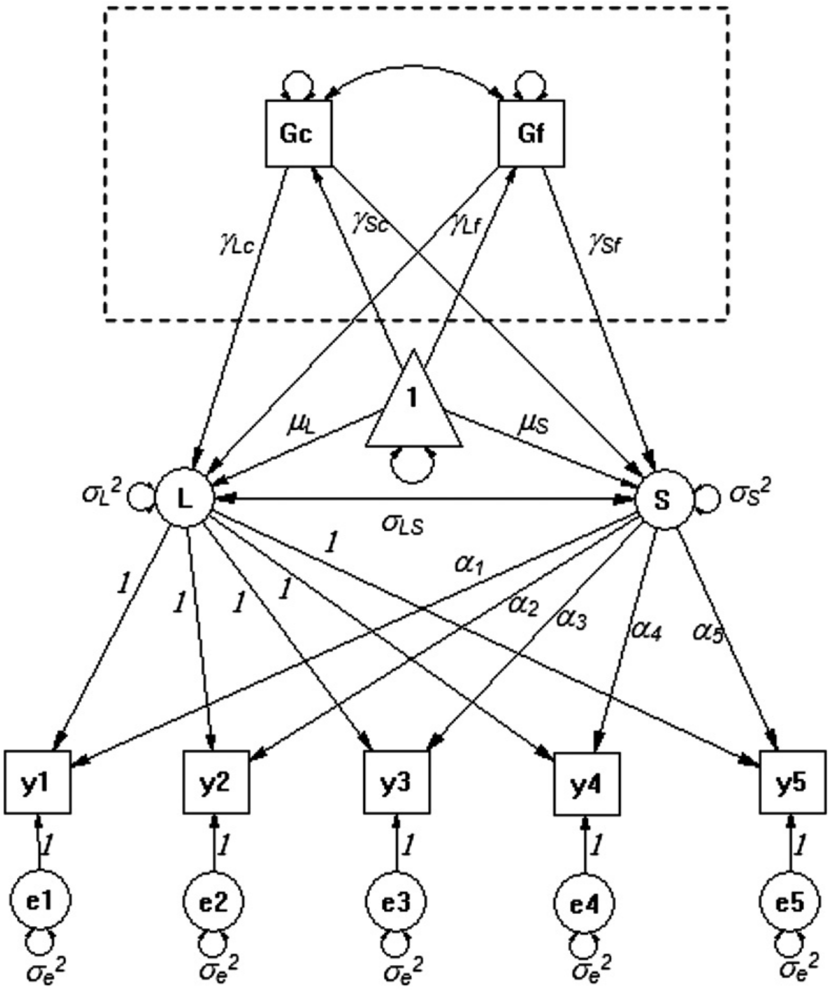

Fig. 1. Illustration of the path diagram for the basic growth curve model used in the analyses. Extensions of the model consisted of incorporating covariates in the analyses as represented in the dashed square, and using the same model with multiple age groups and multiple variables.

We also examined three extensions of the basic model. First, the relations between estimates of crystallized intelligence (Gc) and fluid intelligence (Gf) and the growth curve parameters were investigated by adding them into the growth model as covariates (e.g., McArdle & Nesselroade, 2003). These covariates are portrayed in the dashed square portion of Fig. 1, where it can be seen that the level and slope parameters of the growth curve model are regressed on both Gc and Gf.

A second extension of the basic model consisted of simultaneously estimating growth curve parameters for different age groups. Possible differences in the parameters across groups were investigated by constraining the parameters to be equal, and then determining whether allowing the parameters to be freely estimated resulted in a significant improvement of the fit of the model to the data (e.g., McArdle & Nesselroade, 2003).

The third extension of the model consisted of simultaneously estimating growth curve parameters for either two or three variables, which is known as a multivariate growth curve model (e.g., McArdle & Nesselroade, 2003). Of particular interest in this type of multivariate model are the correlations among the level and slope parameters across different tasks, such as the verbal and spatial learning tasks, or three parallel versions of the verbal learning task.

2. Data set 1

2.1. Participants and measures

The data in this data set were collected by Davis and colleagues (see Salthouse & Davis, 2006, for a recent report of this project). There were a total of 2453 participants ranging from 5 to 92 years of age (M=32.6, SD=22.4), 2124 of

Table 1
Summary of the age and cognitive measures of the participants in Data Set 1

	Age group				
	5–12	13–18	19–39	40–59	60–92
Age					
N	382	379	987	360	435
Mean	8.44	16.36	24.47	48.34	73.43
SD	2.26	1.92	5.78	5.35	7.63
Verbal learning					
N	277	281	855	320	391
Spatial learning					
N	363	334	740	247	313
Both verbal and spatial learning					
N	253	243	608	207	268
Gc					
N	86	63	90	54	105
Mean	−2.69	.11	.82	1.49	.77
SD	1.93	.98	.70	.60	1.28
Gf					
N	86	63	90	54	105
Mean	−1.75	1.14	1.33	.82	−.82
SD	1.97	1.20	1.04	.91	1.57
Correlations					
Age * Gc	.85*	.19*	.20*	.18*	−.22*
Age * Gf	.76*	−.06	−.01	−.18*	−.40*
Gc * Gf	.82*	.63*	.29*	.33*	.59*

Note. *$p < .01$.

whom performed the Rey Auditory Verbal Learning Test (Schmidt, 1996), 1997 of whom performed a picture-matching spatial learning test, and 1579 of whom performed both tests. Because of the wide age range and the interests to investigate the observed relations in different age groups, the sample was divided into five groups for subsequent analyses. Descriptive statistics for this sample are presented in Table 1.

For the verbal learning test, a list of 15 unrelated words was presented followed by an attempt to recall as many of the words as possible. This procedure was repeated five times with the same words presented in a different order each time. The primary measure of performance was the number of words recalled correctly on each trial.

The spatial learning test was a modified version of a game known as Concentration or Memory. It consisted of a display of a matrix of 24 cells, with the participant attempting to find matching pictures by selecting two cells on each trial. If the pictures in the selected cells matched, they were grayed out and removed from play for the rest of the trial. If they did not match, the pictures were again concealed and the participant made another selection of two cells. This procedure continued until all of the matching pictures were selected on a given trial. The trials were repeated five times with the same pictures in the same locations. The primary measure of performance was the percentage of selections on each trial that were optimal in terms of minimizing redundancy and maximizing information gain.

Some of the participants performed the four subtests of the Wechsler Abbreviated Scale of Intelligence (WASI, 1999); Vocabulary, Similarities, Block Design, and Matrix Reasoning. The correlation between the scores on the Vocabulary and Similarities tests was .84, and that between the Block Design and Matrix Reasoning test scores was .73, with the other correlations ranging from .52 to .65. An estimate of crystallized intelligence (Gc) was derived by adding the standardized scores of the Vocabulary and Similarities variables, and an estimate of fluid intelligence (Gf) was derived by adding the standardized scores of the Block Design and Matrix Reasoning variables. Confirmatory factor analyses suggested that the four subtests reliably formed the two factors of Gc and Gf (Salthouse & Davis, 2006). Gc and Gf were positively correlated with one another and the mean level of both Gc and Gf increased and then decreased with age.

2.2. Results

The average trajectories for verbal learning and spatial learning are plotted in Fig. 2. The latent growth model was first fitted to the data for each task separately. The model parameters indicated that after listening to the word list for the

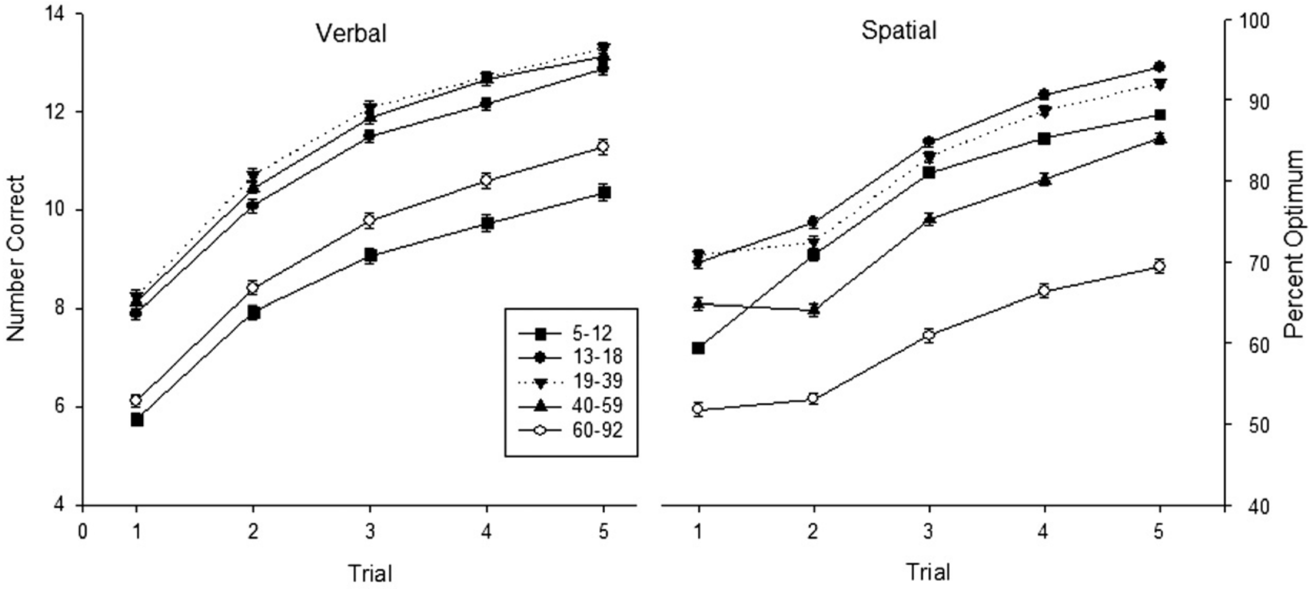

Fig. 2. Plot of the average trajectories, with standard errors, of the verbal learning task and the picture-matching task across age groups in Data Set 1.

first time in the verbal learning task, participants recalled an average of 7.48 words, and after five trials the average recall was 12.47 words, for a gain of 4.99. The variances for the level and slope parameters were significantly different from 0, which indicates that there were significant individual differences in both growth curve parameters.

In the spatial learning task the average optimal selection percentage on the first trial was 64.6, and after five trials it was 87.1, for a gain of 22.5. There were also significant individual differences in both learning measures in this task. However, the shapes of the growth curves were different for the verbal and spatial tasks, as indicated by different basis coefficients α_2, α_3, and α_4 (i.e., .46, .74, .88 for verbal learning and .18, .62, .86 for spatial learning).

Negative correlations between the level and slope parameters (i.e.,−.23 and −.15 for verbal and spatial learning, respectively) raises the possibility that a ceiling effect might have restricted the amount of gain. However, the correlations were still negative (i.e., −.15 and −.07) when the analyses were repeated after deleting participants who reached the maximum score before the final trial. The complete data were therefore used in all subsequent analyses.

Multiple group growth curve models were next conducted on the data from five age groups. A series of models were examined in which all parameters were initially constrained to be equal, and then it was determined whether the fits were improved when sets of parameters were freely estimated based on several fit statistics; the model chi-square, Akaike information criterion (AIC; Akaike, 1973), and the root mean squared error of approximation (RMSEA; Browne & Cudeck, 1993).

The means of the level and slope parameters from the best-fitting model are reported in Table 2. The mean level for both verbal and spatial learning increased across childhood, peaked at the 19–39 age group, and then decreased across adulthood. The mean verbal learning slope increased with age, but there was a slight decrease with age for the mean of spatial learning slope.

The intelligence variables, Gc and Gf, were next considered as predictors of level and slope, first individually, and then simultaneously. When only Gc was present in model for the verbal learning task, it had a positive influence on the level parameters for all age groups except for the 60–93 group, and it was only related to the slope parameters for the 5–12 group. When only Gc was present in the model for the spatial learning task, it was not related to either the level or slope parameters for any group, except for adults between 60 and 93, in which it was related to level. When only Gf was present in the model for the verbal learning task, it had a positive influence on the level parameters for all age groups except for the 40–59 age group, and was only related to the slope parameter in the 5–12 age group. When only Gf was present in the model for the spatial learning task, it had a positive influence on the level parameters in the 19–39 age group and 60–93 age group, and was not related to the slope parameter in any age group. When both Gc and Gf were present in the models, there were no relations of Gc with either the level or slope parameters for the verbal and spatial learning tasks, with the exception of a positive influence on the level parameter of verbal learning in the 19–39 age group. Gf was significantly related to the level parameter in both tasks in the 19–39 and 60–93 groups, and to the

Table 2
Mean, standardized regression coefficients, and across material correlations from the latent growth model by age group, Data Set 1

	Verbal		Spatial		Across material correlations: Verbal–spatial	
	Level	Slope	Level	Slope	Level–level	Slope–slope
Mean (μ_L and μ_S)						
5–12	5.76	4.56	59.40	28.70	.43*	.73
13–18	7.85	4.95	69.82	24.28	.07	−.02
19–39	8.31	5.05	70.67	21.41	.24*	.02
40–59	8.13	5.08	64.47	20.63	.25*	.10
60–93	6.08	5.12	51.68	17.53	.40*	.11
Gc regression coefficients (γ_{Lc} and γ_{Sc})						
5–12	.24(.45*)	.05(.55*)	−.24(.08)	.44(.49)		
13–18	.34(.39*)	−.18(−.10)	−.10(.03)	.26(.16)		
19–39	.34*(.44*)	−.34(−.29)	.09(.24)	−.22(−.25)		
40–59	.40(.37*)	−.39(−.31)	−.03(.05)	.20(.21)		
60–93	.16(.36)	−.22(−.02)	.08(.36*)	−.17(−.05)		
Gf regression coefficients (γ_{Lf} and γ_{Sf})						
5–12	.26(.45*)	.58*(.62*)	.39(.20)	.07(.43)		
13–18	.09(.30*)	.13(.02)	.21(.15)	−.16(.01)		
19–39	.29*(.40*)	.12(.02)	.46*(.49*)	−.10(−.16)		
40–59	−.05(.08)	.25(.13)	.27(.26)	.24(.10)		
60–93	.33*(.42*)	.34(.21)	.46*(.51*)	.21(.10)		

Note. *p<.01. The numbers in parentheses are standardized coefficients when only Gc or Gf was present in the analysis.

verbal learning slope parameter in the 5–12 group. These results indicate that Gc and Gf were generally not related to learning in either the verbal and spatial learning tasks but was related to the initial level of performance in the verbal learning task.

Finally, the correlations between the level parameters and the slope parameters in verbal and spatial learning were estimated by a simultaneous bivariate growth model. These correlations are presented in Table 2, where it can be seen that the level parameters were significantly correlated in each age group except for the 13–18 group. However, the slope parameters were not correlated significantly with each other. These results indicate there may exist a general ability that influences the initial level of performance for the verbal and spatial learning tasks, but there does not appear to be a material-independent learning ability that influences rate of learning.

3. Data set 2

3.1. Participants and measures

The data in Data Set 2 were collected by Salthouse and colleagues (e.g., Salthouse, 2004). There were a total of 583 individuals ranging from 19 to 97 years of age (M=51.5, SD=19.7) who were administered variants of the Wechsler Memory Scale III Word Lists subtest across three separate sessions, with an average time interval from the first to the third session of 10.5 days. On each session a list of 12 unrelated words was presented to the participants followed immediately by an attempt to recall as many of the words as possible. This procedure was repeated four times with the same words in the same order. However, each session involved different words. The primary measure of performance was the number of words recalled correctly on each trial.

All of the participants also completed six tests (see Salthouse, 2004 for detailed descriptions of the tests) that yielded three measures of crystallized intelligence (WAIS III Vocabulary, Woodock Johnson-R Picture Vocabulary, Synonym Vocabulary) and three measures of fluid intelligence (Raven's Progressive Matrices, Paper Folding, Spatial Relations). Confirmatory factor analyses have been used to establish that the measures represented Gc and Gf (Salthouse, 2004; Salthouse & Berish, 2005). The median correlation of the Gf variables was .60, the median correlation of the Gc variables was .69, and the median of the remaining correlations was .25.

Table 3
Descriptive statistics for research participants in Data Set 2

	Age group		
	19–39	40–59	60–97
N	129	228	226
Age			
Mean	26.58	50.40	72.21
SD	6.32	5.29	8.15
Gc			
Mean	−0.92	0.25	0.50
SD	2.50	2.58	2.45
Gf			
Mean	2.05	0.31	−1.38
SD	2.43	2.34	2.20
Correlations			
Age*Gc	.42*	.34*	.35*
Age*Gf	.45*	.31*	.37*
Gc*Gf	.57*	.58*	.53*

Note. *$p<.01$.

The data were divided into three age groups and descriptive characteristics of the sample are presented in Table 3. Gc and Gf were calculated by adding the standardized scores of the intelligence measures. Gc and Gf were positively correlated with one another, and Gc increased with age whereas Gf decreased across successive age groups.

3.2. Results

Fig. 3 portrays mean performance on each trial for the three age groups in each session. Latent growth models were fitted to the data from each session. Parameter estimates for the growth curve model across the three sessions were very similar, and a multiple-group analysis revealed no significant differences in the parameter estimates across the three sessions. The initial recall averaged 6.30 words and by the fourth trial it had increased by 3.73 words. The individual differences in the level and slope parameters were both significantly greater than zero, indicating that people varied in both their initial level of performance and learning.

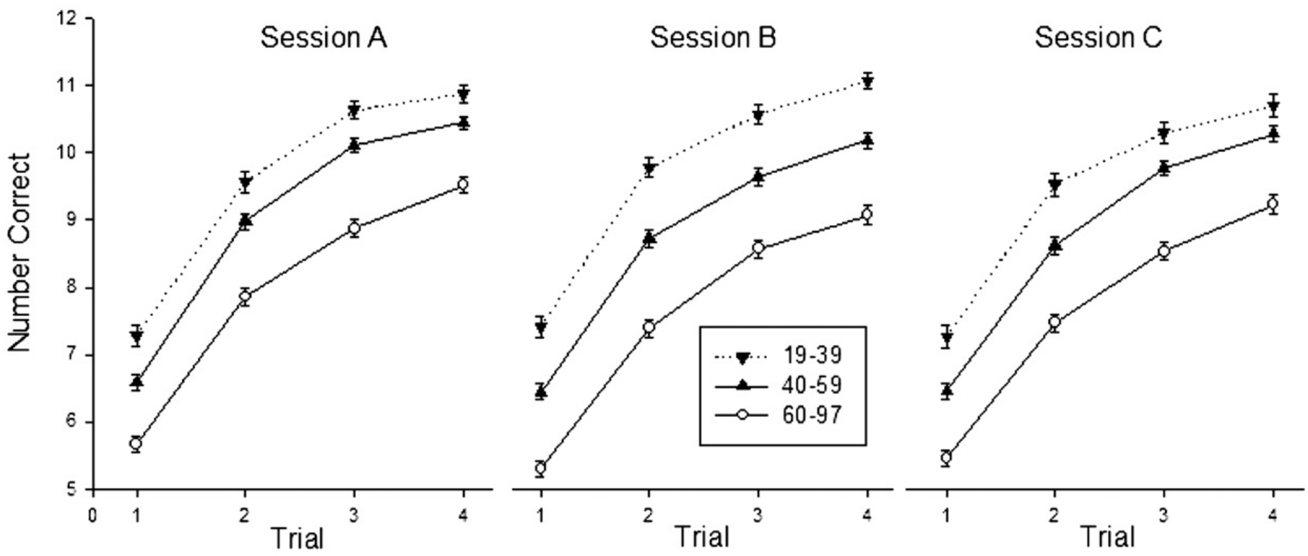

Fig. 3. Average trajectories of verbal learning, with standard errors, across age groups for the three session data in Data Set 2.

Table 4
Mean, standardized regression coefficients, and across session correlation from the latent growth model by age group, Data Set 2

	Session A		Session B		Session C		Across session correlations					
							A–B		A–C		B–C	
	Level	Slope	Level	Slope	Level	Slope	L–L	S–S	L–L	S–S	L–L	S–S
Mean (μ_L and μ_S)												
19–39	7.35	3.65	7.51	3.63	7.41	3.44	.40*	.34*	.50*	.24	.51*	.18
40–59	6.60	3.90	6.44	3.75	6.43	3.86	.53*	.34*	.49*	.21*	.67*	.32*
60–97	5.61	3.74	5.21	3.77	5.38	3.73	.63*	.42*	.70*	.54*	.69*	.79*
Gc regression coefficients (γ_{Lc} and γ_{Sc})												
19–39	.27 (.38*)	−.19 (−.08)	.40* (.56*)	−.40* (−.38*)	.29* (.52*)	−.11 (−.19)						
40–59	.20 (.38*)	−.05 (−.21)	.27* (.40*)	.05 (.07)	.26* (.39*)	.08 (.13)						
60–97	.27* (.39*)	.06 (.13)	.36* (.44*)	.13 (.20*)	.23* (.38*)	.18 (.28)						
Gf regression coefficients (γ_{Lf} and γ_{Sf})												
19–39	.19 (.35*)	.18 (.07)	.27* (.50*)	.04 (−.20*)	.37* (.54*)	−.13 (−.20)						
40–59	.29* (.41*)	−.27 (−.30*)	.23* (.38*)	.03 (.06)	.23* (.38*)	.09 (.13)						
60–97	.22* (.37*)	.14 (.18)	.17 (.35*)	.13 (.20)	.28* (.40*)	.18 (.28)						

Note. *p<.01. The numbers in parentheses are standardized coefficients when only Gc or Gf was present in the analysis.

A multiple-group analysis was then conducted on three age groups for each session. The results of this analysis are summarized in Table 4, where it can be seen that means of the level parameters increased with age, while the means of the slope parameters were not significantly different from each other.

The intelligence variables, Gc and Gf, were next added to the multiple groups model as predictors of the level and slope parameters, first individually and then simultaneously. When only Gc was present in the analysis, it had a positive influence on the level parameter in every group, but it was only related to the slope parameter in the 19–39 and 60–97 age groups in Session B. When only Gf was present in the analysis, it also had a positive influence on all the level parameters, but it was only related to the slope parameter in the 40–59 age group in Session A and the 60–97 age group in Session B. When both Gc and Gf were present, the positive relations of both Gc and Gf with the level parameters held for almost all parameters in each group. However, only one slope parameter was significantly related to either of the intelligence variables. This was in session B, for the 19–39 age group, in which the slope parameter was significantly related to Gc. These results were consistent with those from the Data Set 1, and replicated the finding that Gc and Gf were only related to the initial level of performance in the verbal learning task.

Of particular interest in this data set were the correlations between the level and slope parameters across sessions, which were estimated from a trivariate growth model. The estimated correlations are summarized in Table 4. Notice that all of the correlations among the level parameters were significantly greater than 0, with a median of .53. The correlations among the slope parameters were smaller than those among level parameters, with a median .34. Although the slope correlations were somewhat smaller, they were all significantly different from zero, indicating that the slope parameters are not completely lacking in reliability.

4. Discussion

In this study, we evaluated individual differences in learning on two short-term learning tasks from two data sets using contemporary growth curve models. In both data sets, age differences in short-term verbal learning were primarily related to the level parameter and not to the slope parameter, which is consistent with the impression in Figs. 2 and 3. A similar pattern was recently reported in a meta-analysis by Poreh (2005), and in an article by Van Der Elst, Van Boxtel, Van Breukelen, and Jolles (2005). Studies with only older adults have found shallower rates of learning with increased age (Jones et al., 2005; Royall et al., 2005), but it is possible that some of those differences may be associated with preclinical dementia in the older samples.

We are only aware of one other attempt to study short-term spatial learning. Glahn, Gur, Ragland, Censits, and Gur (1997) used a visual object learning test and found that learning was not significantly different between younger and older participants as assessed with a simple difference score measure of learning. This finding is consistent with the results of the current study, in which the age effects were primarily on the level parameter and not on the slope parameter.

There have been several prior reports of correlations of learning parameters with various cognitive variables, but the cognitive variables were usually treated as though they were independent, and were not considered at the level of cognitive abilities rather than individual variables (Jones et al., 2005; Nettelbeck et al., 1996; Royall et al., 2005). Here we used composite scores to represent fluid and crystallized aspects of intelligence. We found that those measures of cognitive ability were significantly related only to the level parameters and not to the slope parameters. We also found little evidence that either fluid or crystallized intelligence was associated with faster learning in either verbal or spatial learning task. Furthermore, the rates of learning were not significantly correlated across the verbal and spatial tasks. The results from Data Set 2 indicate that slopes of verbal learning were moderately correlated across sessions, and thus there was sufficient reliability for verbal and spatial slope parameters and the slope parameters should have been correlated with one another if a true relation existed.

Our results therefore suggest that it is reasonable to distinguish between general cognitive ability and general learning ability. Participants with higher performance on the initial level of the verbal learning task also performed better on the initial level of the spatial learning task, whereas participants who learned faster on the verbal task did not necessarily learn faster on the spatial task. We conclude that there may be a general (e.g., material-independent) ability associated with initial level of performance in different types of tasks, and that this general ability is related to both Gc and Gf. However, there was no general learning ability (Woodrow, 1946) corresponding to the rate of improvement or learning across different types of tasks. Instead, for each type of material, there appears to be a unique ability associated with learning on that particular task. The finding that verbal learning was moderately correlated across three separate sessions of testing further suggests that these material-specific abilities were stable and enduring traits, at least over the course of approximately two weeks.

Given the significant variability in learning on both verbal and spatial tasks, we can conclude that individual differences in learning do exist, and people vary with respect to efficiency of learning. Educators should therefore recognize that individuals may not learn at the same rate. The low and non-significant correlations between learning and intelligence measures is inconsistent with the claims that intelligence is synonymous with learning ability, and implies that educators must rely on more than global intelligence measures when assessing on individual's potential to learn. Finally, the finding that no general learning ability existed further implies that educators need to pay attention to individual's specific learning ability as well when assessing an individual's potential to learn.

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