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Cognitive correlates of cross-sectional differences and longitudinal changes in trail making performance

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Abstract

A total of 1,576 adults between 18 and 95 years of age performed a battery of cognitive tests and the Connections version of the trail making test twice, with an average interval between assessments of 2.5 years. Consistent with previous results, speed ability and fluid cognitive ability were strongly correlated with trail making performance. Neither speed nor fluid cognitive ability at the first occasion predicted longitudinal changes in trail making performance, but there were significant correlations between the changes in these abilities and the changes in trail making performance. These results indicate that individual differences in speed and fluid cognitive abilities are associated with individual differences in trail making performance both at a single point in time (cross-sectional differences), and in the changes over time (longitudinal changes).

Keywords

longitudinal change; cognitive abilities; age differences and changes

Salthouse (under review) recently found that performance in the Connections version of the trail making task (Salthouse, Toth, Daniels, Parks, Pak, Wolbrette & Hocking, 2000) was strongly related to speed and fluid (Gf) cognitive abilities. Furthermore, the pattern of relations was robust because it was nearly constant from 20 to 90 years of age, and when additional predictors (i.e., measures of working memory) were examined simultaneously. The question in the current study was whether similar patterns of cognitive ability relations are evident on the longitudinal changes in trail making performance. That is, do the same cognitive abilities which predict individual differences in the average level of trail making performance at a single point in time also predict individual differences in the longitudinal changes in trail making performance.

Although it is tempting to assume that some of the same factors involved in the differences between people also contribute to the changes within an individual, it is important to recognize that there is no necessary connection between correlates of between-person differences and correlates of within-person changes. Consider the variable of brain volume. At any given age there are large individual differences in brain volume related to body size, gender, and genetics (e.g., Allen, Damasio, & Grabowski, 2002; Carne, Vogrin, Litewka & Cook, 2006; Peper, Brouwer, Boomsma, Kahn & Pol, 2007). However, within-person changes over time in brain volume have been associated with factors such as amount and type of experience (e.g., Draganski, Gaser, Busch, Schuierer, Bogdahn, & May, 2004; Draganski, Gaser, Kempermann, Kuhn, Winkler, Buchel, & May, 2006; Ilg, Wohlschlager, Gaser, Liebau, Dauner, Woller, Zimmer, Zihl & Muhlau, 2008), presence or absence of neurodegenerative disease (e.g., Baron, Chetelat, Desgranges, Perchey, Landeau, de la Sayette & Eustache, 2001; Jack, Weigand, Shiung, Przybelksi, O'Brien, Gunter, Knopman, Boeve, Smith, & Petersen, 2008), and normal aging (e.g., Fotenos, Snyder, Girton, Morris &

Buckner, 2005; Raz, Lindenberger, Rodrigue, Kennedy, Head, Williamson, Dahle, Gerstorf & Acker, 2005). The comparability of correlates of differences and correlates of changes is therefore an empirical question rather than a logical necessity.

Correlates of change have been difficult to investigate because longitudinal change measures are often not very reliable, and thus have little systematic variance that can be shared with other variables. A major reason for the low reliability of change scores is that there is little variance in the measures of change because the values across the two occasions are typically highly correlated, which means that only a small amount of the variance in the score at the second occasion is not predicted by the score at the first occasion. One methodological solution to the problem of low reliability of longitudinal changes is to use a latent change model in which change is represented by a latent construct determined by the variance shared across multiple variables at each occasion. Because any variance that is shared is necessarily systematic and reliable, latent change models have the potential of increasing the reliability of change by minimizing measurement error (e.g., McArdle, 2009).

A latent change model was used in the current study to examine predictors of longitudinal change in trail making performance. The initial analyses examined relations of the reference cognitive abilities with parameters representing level and change in trail making performance, and subsequent analyses examined relations of changes in the reference cognitive abilities with changes in trail making performance. Three different types of relations of cognitive ability to trail making performance were therefore investigated in the current report: level with level, level with change, and change with change.

The data were obtained from a sample of 1,576 adults who had two assessments of the Connections version of the trail making test and of a cognitive battery with an average interval of 2.5 years between assessments. In addition to analyses of the total sample, the analyses were repeated in subsamples from two age groups, formed by dividing the sample at the median age, to examine the possibility of age-related shifts in the cognitive ability relations.

Method

Sample

Demographic information for the total sample of 1,576 adults, and for the subsamples in two age groups, is presented in Table 1. It can be seen that, on average, the participants had a high level of education, with a higher mean level at older ages. The older adults also had somewhat higher scaled scores on standardized tests from two commercial batteries (Wechsler, 1997a;1997b), and therefore they can be inferred to be functioning at higher levels than the young adults relative to their age peers in the nationally representative normative sample.

Procedure

The procedure in the Connections test will only be briefly summarized here because it has been fully described in Salthouse, et al. (2000) and Salthouse (under review). The test consists of 8 pages containing circled numbers and letters, with the research participants instructed to connect the elements in either a simple sequence (i.e., numeric or alphabetic), or in an alternating sequence (i.e., numerical and alphabetical), as quickly as possible. The measures of performance in the current report were the average number of elements correctly connected in 20 seconds across the two numbers and two letters pages in the simple (A) condition, and the average across the two numbers-letters and the two letters-numbers pages in the alternating (B) condition.

The reference cognitive battery consisted of 16 tests selected to assess four broad cognitive abilities. The abilities (and relevant tests) were: fluid (Gf) cognitive ability (Matrix Reasoning, Shipley Abstraction, Letter Sets, Spatial Relations, Paper Folding, Form Boards), Memory (Word Recall, Paired Associates, Logical Memory), Speed (Digit Symbol Substitution, Pattern Comparison, Letter Comparison), and Vocabulary (WAIS Vocabulary, Picture Vocabulary, Synonym Vocabulary, and Antonym Vocabulary). The tests are briefly described in the appendix, and more details about the tests, and their reliabilities and validities (i.e., factor loadings) are contained in Salthouse (2010b; under review) and in Salthouse, Pink and Tucker-Drob (2008). Correlations among the longitudinal changes in these cognitive abilities have been reported in Salthouse (2010b,[c]).

Results

Figure 1 portrays the means and standard errors of the raw scores for the simple (A) and alternating (B) conditions in trail making performance at the first (T1), and second (T2), occasion as a function of age. Mean performance on the second T2 occasion was significantly ($p<.01$) better than T1 performance for adults in their 20s, but mean T2 performance was significantly worse than T1 performance for adults in their 70s (simple condition only) and in their 80s (both simple and alternating conditions).

In order to express values at the two time points in the same units, the simple and alternating scores were converted to z-score units based on the mean and standard deviation of the respective (i.e., simple or alternating) T1 distribution. Longitudinal change was then computed by subtracting the T1 score from the T2 score, and the resulting mean changes plotted for each decade in Figure 2. Each point in this figure corresponds to the difference between the T1 and T2 scores at that age in Figure 1, after the variables had been converted to z-score units. Correlations of age with the T2–T1 change score were −.18 for the simple (A) condition, and −.12 for alternating (B) condition (both $p<.01$). Furthermore, the age relations in the changes were primarily linear because the quadratic age relations were not significant after the age variable was centered and the age-centered and the squared (quadratic) age-centered variables were included as simultaneous predictors of the T2–T1 changes.

The implication of the results in Figure 2 is that there is a continuous relation between age and longitudinal change, although the direction of the change shifts from positive to negative with increasing age. This pattern is similar to that apparent in other longitudinal studies (see Figure 2.2 in Salthouse, 2010a), and in other cognitive variables in this sample of individuals (see Salthouse, 2010b,c,d).

The contextual analysis model in Figure 3 was used to identify the pattern of cognitive ability relations on the changes in trail making performance from T1 to T2. The initial plan was to analyze the simple (A) and alternating (B) conditions in the same model to investigate relations among the longitudinal changes in the two conditions. However, the correlations between the longitudinal change estimates in the simple and alternating conditions were very close to 1, which indicates that changes in performance in the simple and alternating conditions were not distinct in terms of individual differences. Because the almost complete overlap of the individual differences in the two conditions precluded simultaneous examination of changes in the two conditions, separate analyses were conducted on the simple and alternating variables.

The top portion of Figure 3 indicates that age and the cognitive ability constructs at T1 were used as simultaneous predictors of the level and change in the target trail making variables. The bottom portion of the figure corresponds to the latent change model in which the latent level (Lvl) construct is defined by the variance shared among variables at both occasions, and the latent change (Chng) construct is defined by the variance shared among variables at the second occasion after partialling the variance shared by all variables across both occasions. Estimates for the model were obtained from the AMOS (Arbuckle, 2007) statistical package using the full-information maximum likelihood estimation algorithm to deal with missing data. Because some of the reference cognitive tasks were not administered to all participants, a few variables had up to 28% missing data. However, less than 3% of the data were missing for the two primary connections variables.

Results of the contextual analyses with cognitive abilities at T1 predicting the level and change in trail making performance are reported in Table 2. As one might expect because the level parameter corresponds to the average performance across the two occasions, the pattern of relations on the parameter representing level of functioning was very similar to that with cross-sectional data in the other report (Salthouse, under review). Specifically, there were large influences of speed and Gf abilities on both the simple and alternating measures of trail making performance. However, in contrast to the pattern with the level parameter, there were no significant relations of the reference cognitive abilities on the change parameters. Moreover, this is not because the change parameter lacked reliable variance because the between-person variance in change was significantly different from zero in both the simple (A) and alternating (B) conditions, and there were significant relations of age with the change parameters. These results indicate that although there were significant relations between the level of cognitive abilities and the average level of trail making performance, longitudinal changes in trail making performance were independent of the initial level of performance in the reference cognitive abilities.

One factor that is likely contributing to the different patterns of relations with measures of level and change in trail making is that the estimated correlations between the level and change parameters in the latent change models were .00 for the simple (A) variable and .11 for the alternating (B) variable. These weak correlations indicate that, at least from the perspective of individual differences, the two parameters reflect independent characteristics.

The possibility that the cognitive ability relations varied as a function of age was investigated by repeating the analyses in sub-samples of participants between 18 and 53 years of age and between 54 and 95 years of age. The results of these analyses are also reported in Table 2. Notice that although the age relations were slightly weaker in the samples with restricted age ranges, the major results were very similar with respect to the significant relations of the reference cognitive abilities on the level parameter, and the absence of significant relations of the reference abilities on the change parameter. Independent groups t-tests comparing the unstandardized regression coefficients revealed that none of the differences between the coefficients in the two groups was significant (i.e., all t-values less than 1.4).

Relations between changes in the cognitive ability constructs and changes in the trail making constructs were next examined in a model in which latent level and latent change estimates were simultaneously obtained for each cognitive ability, as well as for the trail making variables. Covariances were estimated between all level and change parameters, but only the change-change correlations are considered here because they are of primary interest in this context. All of the estimated changes had significant individual difference variance, indicating that people differed in the magnitude of each type of longitudinal change. The relevant change correlations are reported in Table 3, where it can be seen that changes in both trail making measures were significantly correlated with changes in speed and changes in Gf. Very similar estimates were obtained when the analyses were repeated in subsamples of young and older adults, and independent-groups t-tests on the covariances revealed that all t-values were less than 1.6, and not significantly different from 0.

The results in Table 3 indicate that people with the greatest changes in trail making performance also tended to have the greatest changes in speed and Gf. Although there was a significant correlation between changes in the simple version of the trail making task and changes in vocabulary only in the older adults, that correlation was not significantly different from the corresponding correlation in the younger adults.

Discussion

Before discussing the specific results, it is worth noting that the magnitude of the longitudinal change in trail making performance in this study was similar to that in other studies with participants of comparable age ranges. For example, Ratcliff, Dodge, Birzescu and Ganguli (2003) found significant longitudinal decline over 2 years for adults 65 to 74 years of age, and Chen, Ratcliff, Belle, Cauley, DeKoskey and Ganguli (2001) reported 2-year longitudinal changes of between .07 and .10 standard deviation units in adults 65 and over, which are comparable to the values in Figure 2.

The major findings of this study were that: (1) individual differences in trail making performance were related to individual differences in speed and Gf abilities, (2) longitudinal changes in trail making performance were not related to the initial level of the reference cognitive abilities, but (3) longitudinal changes in trail making performance were significantly correlated with longitudinal changes in speed and in Gf. Stated somewhat differently, people with high levels of speed and high levels of Gf tended to have the highest level of trail making performance, and people who changed the most in speed and Gf also tended to change the most in trail making performance, but it was not the case that people highest in speed and Gf had the greatest change in the trail making variables.

Although there was some specificity in the relations because level of cognitive ability was not correlated with change in trail making performance, it is important to note that, with the exception of inconsistent relations with vocabulary, the same abilities were involved in the differences and changes. That is, there was little or no relation of memory ability in either the cross-sectional or longitudinal analyses, but in each case there were significant relations of speed and Gf abilities. These results suggest that the same dimensions of individual differences among speed, Gf, and trail making are apparent at a single point in time and in the changes over time. Moreover, the relevant change is not simply global cognitive change because the relations of trail making change to memory change were very weak.

Although seldom examined across a wide age range, the results in Figure 2 indicate that longitudinal change in trail making performance occurs continuously across adulthood, with the direction of the change becoming more negative with increasing age. A very similar pattern has been reported in other cognitive variables (i.e., Salthouse, 2010b,c), and thus it appears that longitudinal change does not abruptly begin at a particular age, but instead occurs continuously throughout adulthood.

The similar pattern of correlations among the changes in the two age groups is also interesting in that it suggests that the determinants of the changes may be similar at different ages. These findings are consistent with results of other analyses (Salthouse, 2010b,c) that longitudinal changes in cognitive abilities have similar variance, reliability, and correlations with other variables throughout adulthood. Cognitive changes may therefore have the same meaning at different ages even though the direction and magnitude of change varies systematically with increased age.

In summary, although it is not logically necessary that the cognitive abilities correlated with individual differences in a variable at a single point in time are also correlated with longitudinal changes in that variable over time, this pattern was evident in the current study. That is, level of speed and level of fluid cognitive ability were significantly correlated with level of trail making performance, and changes in speed and changes in fluid cognitive ability were significantly correlated with changes in trail making performance. However, perhaps because of the weak relations between level and change in trail making performance, there were no significant correlations between the level of cognitive abilities and changes in trail making performance. These results suggest that trail making performance and performance in speed and fluid cognitive ability tests reflect the same dimensions of individual differences both at a single point in time, and in changes over time.

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Appendix

Description of variables

Fluid cognitive ability (Gf)

Matrix Reasoning: Determine which pattern best completes the missing cell in a matrix.

Shipley Abstraction: Determine the words or numbers that are the best continuation of a sequence.

Letter Sets: Identify which of five groups of letters is different from the others.

Spatial Relations: Determine the correspondence between a 3-D figure and alternative 2-D figures.

Paper Folding: Determine the pattern of holes that would result from a sequence of folds and a punch through the folded paper.

Form Boards: Determine which combinations of shapes are needed to fill a larger shape.

Memory

Logical Memory: Number of idea units recalled across three stories.

Word Recall: Number of words recalled across trials 1 to 4 of the same word list.

Paired Associates: Number of response terms recalled when presented with a stimulus item.

Speed

Digit Symbol: Use a code table to write the correct symbol below each digit.

Letter Comparison: Same/different comparison of pairs of letter strings.

Pattern Comparison: Same/different comparison of pairs of line patterns.

Vocabulary

WAIS Vocabulary: Provide definitions of words

WJ-R Picture Vocabulary: Name the pictured object

Antonym Vocabulary: Select the best antonym of the target word

Synonym Vocabulary: Select the best synonym of the target word

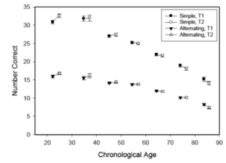

Figure 1.
Means (and standard errors) for the number of connections items completed in simple (A) and alternating (B) conditions at the first (T1) and second (T2) occasion as a function of age. Sample sizes ranged from 80 to 371 across decades.

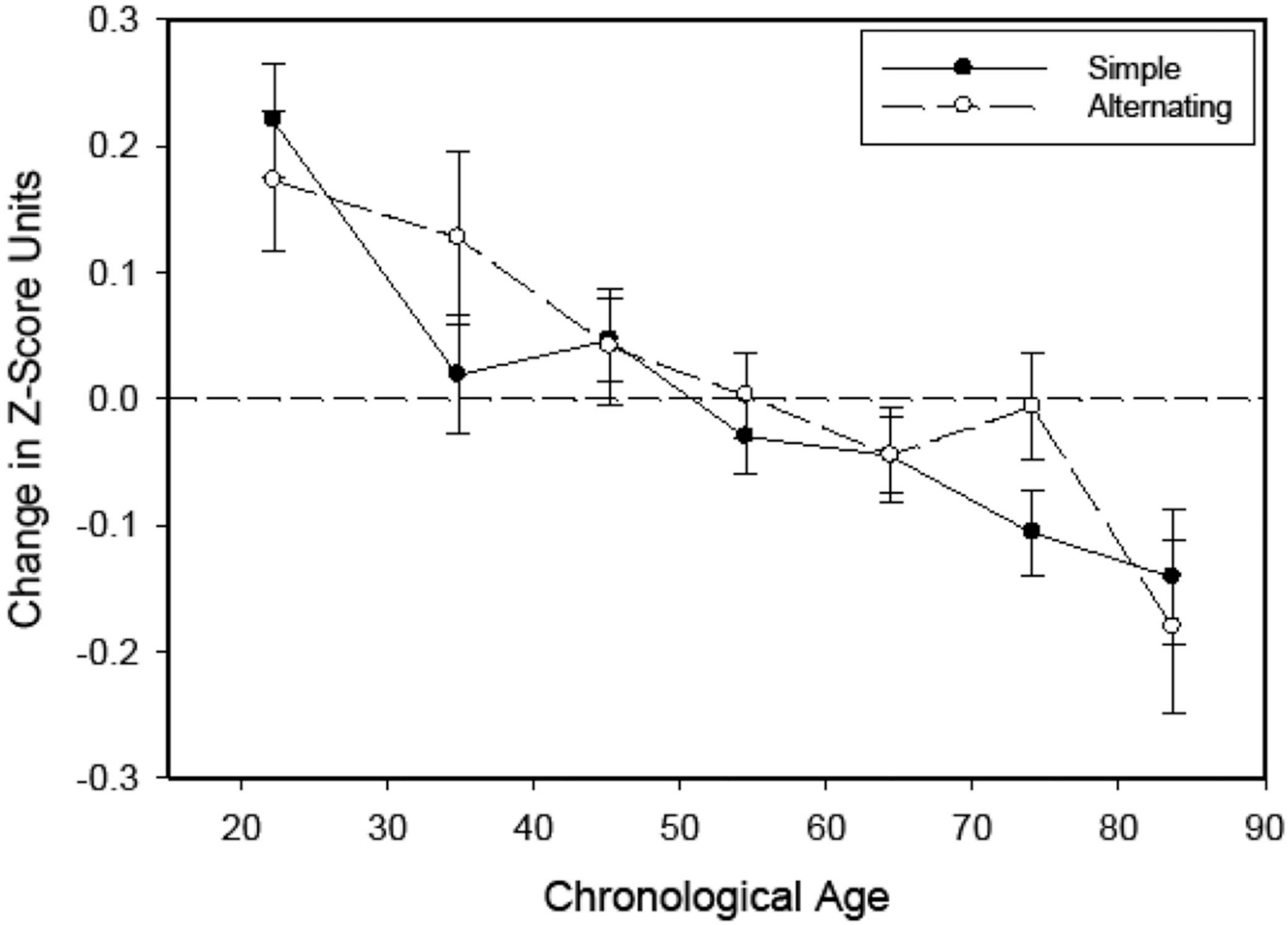

Figure 2.
Means (and standard errors) for longitudinal changes in simple (A) and alternating (B) conditions in T1 z-score units as a function of age. Sample sizes ranged from 80 to 371 across decades.

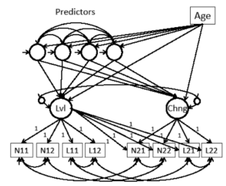

Figure 3.
Contextual analysis model with latent change parameters (Lvl = level; Chng = change) as target variables. Circles correspond to latent constructs representing the variance common to several observed (manifest) variables, which are portrayed as squares. Single-headed arrows represent directed (regression) relations and double-headed arrows represent correlations. Arrows with numbers adjacent to them had their coefficients were fixed to 1, and arrows without a source represent variances. The cognitive variables used to define the latent predictor constructs are not portrayed in the figure, but are briefly described in the appendix. The model is illustrated with variables in the simple (A) condition (i.e., N11 = first test of numbers on the first occasion; L22 = second test of letters on the second occasion), but a comparable model was used with variables in the alternating (B) condition.

Table 1

Sample characteristics

	Mean (SD)	Correlation with Age	Young Mean (SD)	Old Mean (SD)
N	1576	NA	765	851
Age	53.6 (17.2)	NA	39.0 (11.2)	66.9 (9.1)
Sex (prop. female)	.65	−.04	.68	.62
Years of Education	15.7 (2.7)	.22*	15.2 (2.4)	16.2 (2.8)
Self-Rated Health	2.2 (0.9)	.13*	2.1 (0.9)	2.2 (0.9)
Vision	50.9 (37.3)	.35*	39.6 (28.2)	61.7 (42.6)
Scaled Scores				
Vocabulary	12.8 (2.9)	.15*	12.1 (3.1)	13.4 (2.7)
Digit Symbol	11.5 (2.8)	.13*	11.1 (2.9)	11.9 (2.7)
Word Recall	12.5 (3.3)	.09*	12.1 (3.4)	12.8 (3.1)
Logical Memory	12.1 (2.8)	.18*	11.5 (2.8)	12.6 (2.8)
T1–T2 Interval (years)	2.5 (1.1)	−.02	2.6 (1.1)	2.5 (1.0)

*$p<.01$

Note: NA indicates that the value was not applicable. Health was rated on a 5-point scale in which 1 represented "excellent" and 5 represented "poor." Vision was measured at reading distance and corresponds to the denominator of the Snellen ratio averaged across the two eyes. Scaled scores have means of 10 and standard deviations of 3 in the normative samples (i.e., Wechsler, 1997a, 1997b).

Table 2

Standardized coefficients for the contextual analysis results on latent change parameters

	Age		Predictors			
	Total	**Unique**	**Gf**	**Mem**	**Speed**	**Vocab**
Simple (A)						
All						
Level	−.58*	0.02	.32*	−0.01	.67*	−.11*
Change	−.23*	−0.16	.07	−0.03	.07	−0.03
Young (18–53)						
Level	−.29*	0.03	.36*	−0.04	.65*	−0.12
Change	−.19*	−.18*	−0.03	−0.01	0.15	0.06
Old (54–95)						
Level	−.52*	0.03	.33*	.04	.65*	−.13*
Change	−0.08	−0.03	.15	−.04	−.00	−0.07
Alternating (B)						
All						
Level	−.49*	.14*	.60*	0.02	.49*	−0.09
Change	−.33*	−.53*	.03	−0.06	−0.21	0.17
Young (18–53)						
Level	−.22*	0.08	.59*	.03	.45*	−0.07
Change	−0.2	−.34*	−0.13	.02	−0.11	0.21
Old (54–95)						
Level	−.47*	0.08	.62*	.02	.45*	−.12
Change	−0.14	−0.25	.22	−.14	−.30	.14

Note: The values in the “Total” column are simple correlation coefficients, and values in the other columns are standardized regression coefficients predicting the target variable from age and the reference constructs. CFI is the Comparative Fit Index and RMSEA is the Root Mean Squared Error of Approximation. CFI values greater than .92 and RMSEA values less than .10 are often considered to represent a good fit (Kline, 2005). Fit statistics for the models with the total sample were: Simple, CFI = .96, and RMSEA = .06; Alternating: CFI = .95, and RMSEA = .05.

*p<.01

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Table 3

Correlations of latent changes in cognitive abilities with latent changes in simple (A) and alternating (B) trial making performance

	All	Young (18–53)	Old (54–95)
Gf-Simple (A)	.38*	.33*	.34*
Gf-Alternating (B)	.67*	.50	.70*
Memory-Simple (A)	.02	.05	−.04
Memory-Alternating (B)	.02	.10	−.10
Speed-Simple (A)	.35*	.36*	.29*
Speed-Alternating (B)	.60*	.69*	.42*
Vocabulary-Simple (A)	.36*	.24	.44*
Vocabulary-Alternating (B)	.30	.18	.24

* p<.01