How RAN Stimulus Type and Repetition Affect RAN's Relation with Decoding Efficiency and Reading Comprehension

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Abstract

Purpose: This study investigated how correlations between rapid automatized naming (RAN) and reading depend on characteristics of the stimuli. RAN tasks using stimuli with high phonological demands were predicted to be the strongest correlates of decoding efficiency, while high semantic demands were predicted to lead to stronger correlations with comprehension.

Method: At two time points, 132 Grade 2 children completed four different RAN versions, two using letter stimuli (low semantic load) and two using object stimuli (high semantic load). Both types of stimuli were used in either a repeated version, where a set of four items were repeated multiple times (low semantic load), or in a unique version, where each item appeared only once (high semantic load). Decoding efficiency and reading comprehension were assessed in Grade 5.

Results: Analyses showed that confirmatory factor models with separate factors for each version provided better fit than grouping factors according to time point. Repetition (lowering semantic load) increased the longitudinal association between RAN objects and decoding efficiency. There was a tendency for conditions with higher semantic load to correlate more strongly with reading comprehension after control for decoding efficiency, but the differences were not significant.

Conclusion: The results indicate that increasing semantic load weakens the relationship with decoding efficiency.

Keywords: Rapid automatized naming, lexical processing, phonological processing, reading comprehension, word reading

There are a number of strong and theoretically fairly well understood predictors of the development of accurate word identification, such as phoneme awareness and letter knowledge (Bowey, 2005; Castles & Nation, 2022). But after children have achieved mostly accurate word identification skills, it is less well established what drives the further development of decoding efficiency besides experience. One of the strongest cognitive predictors of decoding efficiency development across alphabetic orthographies is the speed with which children name series of letters, digits, objects and colors (Juul et al., 2014; Landerl et al., 2019; Landerl & Wimmer, 2008; Moll et al., 2014). This task is known as rapid automatized naming (RAN). Despite the robust statistical correlation with reading, the theoretical reason for this correlation is poorly understood (Kirby et al., 2010). RAN has been proposed to reflect phonological processing (e.g. Wagner et al., 1993), but RAN has also been shown to be distinct from other measures that loosely fit under the heading *phonological processing*, for example phonological awareness tasks and retrieval of phonological codes when naming in a non-serial fashion (Altani et al., 2018; de Jong, 2011; Logan & Schatschneider, 2013; Poulsen et al., 2015; Wagner et al., 1993). Subsequently, several papers have identified individual differences in serial processing of multiple adjacent items as the potential locus of the RAN-reading relationship (Altani et al., 2018; Protopapas et al., 2013; Protopapas et al., 2018), but without clarifying the domain of linguistic processing that is involved (phonological or otherwise).

In this paper, we revisit the role of the linguistic domain in rapid naming tasks by varying the relative weight of phonological and semantic demands of the stimuli. We first investigate whether the demands of the stimuli translate into stable measurements of different sources of individual differences. We then examine whether the difference sources correlate in systematic patterns with different reading measures, namely decoding efficiency and reading comprehension, that presumably draw on phonological and semantic processing to different degrees.

It has been a consistent finding that reading correlates more highly with RAN using alphanumeric symbols (letters or digits) than with RAN using color or object stimuli (cf. Araújo & Faísca, 2019; Araújo et al., 2015 for meta-analyses). However, the reason for this finding is unclear. It may seem obvious that letter naming is a stronger correlate than color or object naming because of the involvement of orthographic knowledge, but this fails to explain why digit naming is also generally a stronger correlate of reading (Araújo et al., 2015). A different explanation is that naming of different item types relies on different subprocesses of naming to different degrees. Psycholinguistic theories of naming generally include two separate domains of subprocesses: first, *semantic* processing in terms of visual identification and matching of a concept to vocabulary items, then *phonological* retrieval and encoding of a phonetic plan (Griffin & Ferreira, 2006; Levelt et al., 1999; Roelofs, 2013). These two stages could be separate sources of individual differences with importance for different aspects of reading, along the lines of the simple view of reading (Gough & Tunmer, 1986; Hoover & Gough, 1990): Phonological processing could be especially important for efficient decoding from letters to sounds and words, while semantic processing could be especially important for meaning retrieval and interpretation in reading comprehension.

Letter naming has been suggested to be mostly dependent on phonological processing, because letters have little or no semantic content, while object naming could be dependent on both phonological and semantic processing (Bowey et al., 2005; Poulsen & Elbro, 2013). If rapid naming relates to reading due to a shared reliance on phonological processing, this could explain the difference between alphanumeric and nonalphanumeric naming in predicting reading. Specifically, letter naming could be a stronger correlate of decoding than object naming because there are few demands on semantic processing to dilute the measurement of phonological processing in naming. Conversely, object naming may be a stronger correlate of reading comprehension because it does require semantic processing in addition to phonological processing. Poulsen and Elbro referred to this as the dual access hypothesis. In support of this idea, they found that isolated picture naming explained unique variance in reading comprehension, while isolated letter naming explained unique variance in decoding. However, these results were obtained with confrontation naming paradigms, where participants name each stimulus presented in isolation (i.e., discrete naming). In the traditional RAN task, all the stimuli are available simultaneously from the start, and the participant has to name the stimuli in a continuous stream (i.e., serial naming). Discrete and serial naming have been shown to have different relationships with decoding (Altani et al., 2018; de Jong, 2011; Logan et al., 2011), so results from discrete naming cannot be generalized to serial naming. The present study investigated whether the dual access hypothesis holds for serial naming as well, that is, whether increasing the semantic load of the stimuli increases the correlation with reading comprehension while decreasing the correlation with decoding.

Set size of the stimuli may also influence the naming task demands with possible consequences for correlations with reading. The Poulsen and Elbro (2013) study also deviated from traditional RAN format by using non-repeated, unique stimuli. Traditional RAN typically repeats the same four or five stimuli about 10 times. In the naming process, repetition probably reduces the demands on conceptual identification and vocabulary matching of the picture (Francis, 2014); identifying the same picture as matching the lexical concept “umbrella” the second time is much easier, both because the picture already has been identified as fitting a particular concept, and because the associated lemma representation is primed from the previous occurrence. When such semantic task demands are reduced, the dual access hypothesis predicts that phonological demands may account for a greater proportion of the total task demands, increasing the correlation with decoding efficiency.

The effect of repetition on phonological processing is less clear. It has been suggested that retrieval from long-term memory of phonological codes might be more demanding in large set sizes (Georgiou et al., 2013). On the other hand, small set sizes with repetition could be phonologically demanding because the same phonological representations have to be activated and disengaged repeatedly (cf. de Jong, 2011; Jones et al., 2008), and it is well established that phonological similarity has a detrimental effect on performance in verbal memory tasks (Oberauer et al., 2018).

In summary, repetition may shift the task demands of naming from semantics to phonology. But the shift may be very limited for alphanumeric stimuli because they have little semantics to begin with: Letters have no semantics; digits may have some semantics, but accessing the semantics is not necessary (and not thought to be involved) in carrying out the naming task. In contrast, accessing the semantics is necessary when the task is to match a picture or a color to the semantic specifications of a lexical entry, as in a naming task. With respect to set size, neither individual studies (e.g. Georgiou & Parrila, 2020; Georgiou et al., 2013) nor meta-analyses have found clear evidence for effects of varying set size (Araújo et al., 2015). Di Filippo et al. (2008) found that dyslexics had disproportionately large naming times on large set-sizes, but this appeared to be a function of larger group differences on more difficult tasks. It should be noted that most studies have made relatively subtle manipulations of set size, with no studies comparing extremes—repeated vs. unique items—where the effects can be expected to be strongest. Furthermore, previous studies have used single indicators of different RAN tasks to test these subtle manipulations with little analysis or correction for measurement error that may have drowned out subtle effects. We believe that subtle manipulations call for particularly strong evidence that the manipulations do in fact shift the make-up of the individual differences that the task draws on. To this end, the present study measured the different RAN versions at two time points to allow modelling of the underlying factor structure.

The Present Study

The present study addressed the hypothesis that the strength of correlations between RAN and reading depends on the semantic load of the RAN task. Semantic load was manipulated through stimulus design: The RAN tests used either objects (high semantic load) or letters (low semantic load), and either unique items (high semantic load) or the traditional repeated items (low semantic load) for a total of four RAN versions. We expected semantic load to have opposite effects on RAN's correlations with decoding efficiency and reading comprehension.

We investigated this in a longitudinal sample of Danish children who in Grade 2 completed the same battery of four versions of RAN at two time points to evaluate the stability of RAN stimuli manipulations. Decoding efficiency and reading comprehension were measured in Grade 5. Grade 5 was chosen because before middle school reading comprehension depends largely on word recognition skills (Florit & Cain, 2011), especially considering that Danish is a relatively opaque orthography (Seymour et al., 2003). More specifically, the research questions were as follows:

1. As a prerequisite to answering the following questions, the first question was whether the within-version correlation between the four different RAN versions was stronger *across* time points (test-retest) than the *within*-time point correlations between different RAN versions. Stronger within-versions than within-timepoint correlations are to be expected if different versions draw on different and stable sources of individual differences. The dual-

timepoint design furthermore allowed us to take retest (un)reliability into account when estimating correlations with later reading outcomes.

2. How does repetition affect the correlations of rapid naming with decoding efficiency? Repetition was expected to lower semantic load, especially in object naming, resulting in higher correlations with decoding efficiency. The effect of repetition on letter naming was expected to be small because letters have no semantics to begin with. Letter items were chosen over digits because there are only 10 digits to choose from, making it impossible to create a unique (i.e., unrepeated) digits task with enough items as in traditional RAN tasks.

3. Do the stimuli with the highest semantic load (i.e., unique objects) yield the strongest correlations between rapid naming and reading comprehension? To address this question we had to control for decoding efficiency, because both letter and object naming can be expected to be substantially correlated with reading comprehension through shared variance with decoding efficiency. This decoding efficiency-related overlap could mask the potential effect of semantic load.

Method

Participants

One hundred sixty six children completed testing at two time points in the spring of Grade 2. The sample was part of a larger longitudinal study that has been reported previously (Elbro et al., 2012; Juul et al., 2014; Nielsen & Juul, 2015; Poulsen & Elbro, 2018; Poulsen et al., 2015; Poulsen et al., 2017). Of these, 132 children also participated in testing in Grade 5, yielding an attrition rate of 19%. Only children who participated in both Grade 2 and 5 were included in the analyses. Of these 132 participants, 66 were girls (50%). The mean age in Grade 5 was 142 months (SD = 4 months). Five percent spoke Danish as a second language. Parental consent was obtained for all participants.

Design and Procedure

As mentioned, the study was a part of a larger five-year longitudinal study with many test points and many variables (see the studies cited above for additional variables). For use in the present study, we selected all available Grade 2 RAN variables, which were designed for this study, and the reasonable minimal set of decoding and reading comprehension variables relevant for answering the research questions while keeping the complexity of models and reporting to a manageable level. We selected word rather than pseudoword list reading measures because we were primarily interested in functional decoding rather than the recoding subskill of decoding. There were no test points in Grades 3-4 and only one test point in Grade 5.

Participants completed RAN tasks in January and March of Grade 2, and decoding efficiency and reading comprehension in September of Grade 5. The order of the RAN versions in each test session was as follows: repeated digits, repeated letters, unique objects, repeated objects, unique letters. Data from repeated digits were left out of the analyses as they have limited bearing on the present research questions, but the digit data and analyses are included in the dataset made available as supplementary materials. The supplementary materials also contain Grade 2 decoding efficiency data.

Materials

Grade 2 Rapid Naming

Participants completed four versions of the rapid naming task. In the *repeated letters* and *repeated objects* versions, the same four letters or pictures (stylized black and white drawings) were presented twice on each of four rows for a total of 32 items. In the *unique letters* version, 27 (of the 29) different Danish letters were presented in four rows of six to seven letters. In the *unique objects* version, 28 unique pictures (stylized colored drawings) were presented in four rows of seven. The score for each version was the number of correctly named items per second.

Grade 5 Decoding Efficiency

The children read aloud three sets of word lists. A set consisted of two lists with 12 words each. Set 1 were lists of 2–3-letter regular words. Set 2 were lists of 4-letter regular words with consonant clusters. Set 3 were lists of 4-letter words with conditional spellings. The test was discontinued if the student misread three or more words from a list or gave up. The children were instructed to read as fast as possible, but that it was also important to be accurate. The study included two additional and more difficult sets, but those sets had a greater number of missing values for efficiency due to stop criteria, and were therefore not included in the present analyses. The responses were recorded and scored for accuracy and speed off-line in Praat (Boersma & Weenink, 2014). The score for each set was the average number of correct words per second across the lists in the set. As a measure of reliability, the correlations between the sets ranged between .81 and .84.

Grade 5 Reading Comprehension

The children completed Tekstlæseprøve 7 ("Text Reading Test 7"; Møller, 2013), which consists of 2110 words and contains 38 maze items (three choices) and 11 short yes-no recall items dispersed throughout the text. The children were given 20 minutes to complete the test. The score was the proportion of correct items. Cronbach’s alpha was .90.

Results

All analyses were conducted in R version 4.1.2 (Team, 2016). Two children had RAN outlier scores above 3.29 SD from the mean (cut-off suggested by Tabachnick & Fidell, 2014). To reduce influence from extreme values, these scores were replaced with the next highest values for that task. One student did not complete the reading comprehension test.

Missing data were handled by listwise deletion in simple correlation analyses and by full information maximum likelihood (FIML) estimation in confirmatory factor analyses. Data and scripts for analyses are available (see supplementary materials).

Descriptive statistics for all the study variables are presented in Table 1. All skewness values were within −1 and 1.

[Insert Table 1 about here]

The first research question was whether the correlations between test points (within the same RAN version) were higher than the correlations between versions (within test points). Table 2 shows that all within-version correlations were high (r's between .66 and .71), and indeed higher than all within-timepoint correlations ($r < .58$). A full correlation matrix of all study variables is available in the online supplementary material.

[Insert Table 2 about here]

Confirmatory factor analyses conducted with the lavaan package v. 0.6-10 (Rosseel, 2012) further supported this observation. All models were computed using FIML to handle the few missing observations. Models with all eight RAN measures loading on one factor or loading on two factors according to time of test provided unsatisfactory fits (see Table 3). A four-factor model that grouped variables according to RAN version provided excellent fits (see Table 3), and significantly better than the one factor-model that loaded all RAN variables on the same factor. The four-factor model also provided significantly better fits than a two-factor model with object/letter factors ($p < .001$), a two-factor model with repeated/unique factors (p

$< .001$), and a three-factor model that grouped both letter versions under one factor ($p < .001$). Thus, both stimulus type (objects vs. letters) and repetition (repeated vs. unique) made a difference for the pattern of individual differences in the RAN tasks.

[Insert Table 3 about here]

In preparation of the next analyses, the four-factor model was expanded to include decoding efficiency (with the three word lists as separate indicators) and reading comprehension (with odd and even items as separate indicators) measures from Grade 5. In this model, non-standardized factor loadings of each pair of RAN indicators were constrained to be equal since there is no reason to think that identical tests should have different loadings. This mitigates the complication that two-indicator latents are underidentified. All latent variables were standardized, to allow interpretation of covariances as correlations. The fit was good, $\chi^2(54) = 62.00$, $p = .21$, *RMSEA* = .033 [90% *C*I .00–.07], *CFI* = .99, *SRMR* = .04. Table 4 presents correlations (covariances) between the standardized factors within the CFA model. We observe the usual pattern that RAN with repeated letters are numerically stronger correlates of decoding efficiency ($r = .65$) than RAN with repeated objects (r = .49).

[Insert Table 4 about here]

The second research question was whether repetition in RAN affects the correlations with decoding efficiency. Specifically, the dual access hypothesis (Poulsen & Elbro, 2013) predicts that repetition increases the correlation between object naming and decoding efficiency, but that repetition has limited effect on correlations with letter naming.

Inspection of the correlations in Table 4 supports this pattern: Repeated objects was a stronger correlate of G5 decoding efficiency than unique objects (*r* = .49 vs. .27). In comparison, the difference between repeated and unique letters was less pronounced (*r* = .65 vs. .57). To test these differences, we imposed equality constraints on the covariances between repeated and unique objects, on the one hand, and decoding efficiency, on the other, in the CFA model. This led to a significant deterioration of model fit, $\Delta\chi^2(1) = 5.94$, $p = .01$. Constraining the correlation of the two RAN tasks with letters and decoding efficiency in the same way did not lead to significant model deterioration, $\Delta\chi^2\ (1) = 1.37$, $p = .24$. In sum, and as predicted, repetition significantly increased the correlation between RAN objects and decoding efficiency, but not the correlation between RAN letters and decoding efficiency.

The third research question was whether RAN with unique objects (highest semantic load) was a stronger correlate of reading comprehension than RAN with repeated letters (lowest sematic load) after controlling for decoding efficiency. As a first observation, the opposite pattern was actually found in the zero-order correlations (unique objects: *r* = .33, repeated letters: *r* = .49) (see Table 4). Note, however, that of all RAN tasks, only unique objects was more highly correlated with comprehension than with decoding efficiency.

To factor decoding efficiency out of reading comprehension in the latent variable model, we modified the model by regressing reading comprehension on decoding and estimated the covariances between the standardized residuals and each of the four RAN latents. This is equivalent to computing semi-partial correlations (cf. Preacher, 2006). Model fit was good, $\chi^2\ (54) = 61.99$, $p = .21$, *CFI* = .99, *RMSEA* = .03, [*CI* .00–.07], *SRMR* = .04. In contrast to the zero-order correlations, unique objects was now the strongest correlate of the reading comprehension residuals, but none of the part correlations were significant (unique objects: *r* = .19, *p* = .06; repeated objects: *r* = .14, *p* = .15; unique letters: *r* = .08, *p* = .40;

repeated letters: $r = .01$, $p = .90$). Imposing equality constraints on the correlations of the two maximally different versions in terms of semantic load, namely unique objects and repeated letters, did not deteriorate model fit significantly, χ^2 (1) = 2.20, $p = .14$. In sum, there was only weak support for the hypothesis that the semantically loaded RAN with unique objects is a stronger correlate of reading comprehension than the semantically empty RAN with repeated letters.

Discussion

The present study investigated the role of semantic load in RAN stimuli by manipulating the type of stimuli, namely letters vs. objects (low vs. high semantic load), and repetition, namely repeated vs. unique items (low vs. high semantic load). We found that what children name in RAN tasks is more important than the time point at which they say it; that is, the within-version correlations across a three-month time span were higher than the within-timepoint across-versions correlations. This is a relatively clear demonstration that the nature of the stimuli influences the source of individual differences that the RAN tasks draw on. Furthermore, the nature of the stimuli influenced the pattern of correlations with different reading measures: As in previous studies, RAN with letter stimuli was a stronger correlate of decoding efficiency than RAN with object stimuli, suggesting that semantic load is a source of noise in the RAN-decoding relationship. The present results provide novel evidence in favor of semantic demands adding noise to the RAN-decoding relationship: RAN with repeated objects was a significantly and substantially stronger correlate of decoding efficiency than RAN with unique objects ($r = .49$ vs. .27). This result sidesteps the difficulties of interpreting the lack of semantics in RAN letters due to confounding with reading experience.

We found weak support for the idea that increased semantic load increases the correlations with reading comprehension: After controlling for decoding efficiency, the correlation between RAN and reading comprehension increased with increases in semantic demands from r = .01 (repeated letters) to r = .19 (unique objects). But the latter correlation was only marginally significant; in addition, no comparison between correlations proved significant, and the difference between unique and repeated letters was small. This opens the possibility that the extra component in unique object naming was visual identification rather than semantic matching of a lexical concept with a visual identity.

Together, the results align to some degree with psycholinguistic models of naming positing that phonological and semantic processing constitute separate stages (Griffin & Ferreira, 2006; Levelt et al., 1999; Roelofs, 2013). The results add to such models by showing that these stages constitute separate sources of individual differences in unselected samples of school-aged children. In the context of reading, Poulsen and Elbro (2013) referred to this as the dual access hypothesis. However, it should be noted that the evidence for the relationship between semantic processing and reading comprehension is weaker than the relationship between phonological processing and decoding efficiency. The result that RAN with unique objects was not a unique correlate of reading comprehension after controlling for decoding efficiency may be taken as a failure to replicate Poulsen & Elbro (2013). However, the significance level was just above .05, and the overall pattern of correlations between reading comprehension and RAN versions was consistent with the predictions, so we are reluctant to consider the hypothesis falsified. Larger samples are needed to settle the issue, especially in a multi-year longitudinal design.

Contrary to present results, previous studies have failed to find clear effects of set size in the RAN-reading relationship even in object naming (e.g. Di Filippo et al., 2008; Georgiou & Parrila, 2020; Georgiou et al., 2013). We believe the important difference is that in the present study we used a strong unique vs. repeated manipulation, where previous studies have contrasted more subtle variations over the number of repetitions. Even one repetition may greatly reduce the need for semantic retrieval and identification in subsequent identical items, making the task more much more dependent on phonological than semantic processing. Furthermore, the present study modelled measurement error by using latent variables with indicators measured at different time points, which may have allowed detecting more subtle differences.

Current explanations for the RAN-reading relationship emphasize the serial nature of the RAN task (Altani et al., 2018; de Jong & van den Boer, 2021; van den Boer & de Jong, 2015). The present findings demonstrate that what is to be named also plays a substantial role for the seriality effects. Protopapas et al. (2018) suggested that predictable, primed phonological representations make items more amenable to efficient cascaded processing, presumably because phonological processing becomes sufficiently automatized—i.e., non-mediated and less resource-demanding—that cascaded processing performance can dominate the task. Conversely, unique semantic identification and retrieval may be too costly to allow parallel processing of upcoming items. The present data are compatible with this view and extend previous studies by showing that the same type of stimuli (objects) become more amenable to cascaded processing when they are repeated.

Limitations

One weakness of the design was that the participants completed the RAN tasks in the same order at both test points in Grade 2. Thus, it cannot be ruled out that task order effects, for example exhaustion or accommodation effects, may have contributed to the high within-task correlations across time points. However, such effects do not appear to dominate the results. For example, the most highly correlated versions were repeated and unique letters, which were separated by the two objects tasks. Nevertheless, future studies should probably counterbalance order of administration.

In contrast to common practice, in the present study we do not focus on the concurrent relationships between RAN and reading but report longitudinal relations instead. This decision was in part guided by the principled concern that reading comprehension is largely a matter of word recognition until middle school, but the decision was also a side effect of practical demands of the overarching longitudinal study in the context of which these data were collected, which did not allow for RAN testing in Grade 5. We do not believe this to be a substantial weakness, as we are not aware of any evidence that there is a change in the processes involved in RAN between Grades 2 and 5. Moreover, one benefit of the longitudinal design is that it protects from short-term transitory accidental fluctuations in individual differences, and thus the results represent the relatively stable, long-term relationship between RAN and reading measures.

A general challenge in interpreting underlying causes of the correlation between RAN letters and reading is that reading experience involves letter access training. As mentioned in the introduction, the choice to use letters instead of digits was motivated by the impossibility of creating a unique digits condition with an sufficient number of items for a RAN task.

Conclusion

To conclude, the present findings provide additional evidence that naming tasks draw on two separable sources of individual differences, namely phonological and semantic processing, and that these sources are relevant for reading in different ways. Phonological processing is directly associated with decoding efficiency, and indirectly with text comprehension. Semantic processing, on the other hand, may be primarily relevant for text comprehension.

Supplementary materials

Data and scripts for analyses are available at:

https://osf.io/wsbj2/?view_only=b282e6fd831e461b96dd6a72f3f3ae87

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Tables

Table 1

Descriptive Statistics

Variable	*n*	*M*	*SD*	Range	Skew
G2 January					
RAN - Repeated objects	132	0.98	0.17	0.57-1.41	0.42
RAN - Unique objects	132	0.92	0.17	0.48-1.39	0.25
RAN - Repeated letter	132	1.65	0.30	0.83-2.39	0.03
RAN - Unique letters	132	1.52	0.30	0.90-2.50	0.45
G2 March					
RAN - Repeated objects	132	1.00	0.19	0.51-1.54	0.30
RAN - Unique objects	132	0.95	0.19	0.47-1.61	0.46
RAN - Repeated letter	132	1.69	0.30	1.08-2.33	0.09
RAN - Unique letters	132	1.56	0.31	0.80-2.41	0.26
G5 May					
Decoding efficiency - list 1	132	1.71	0.42	0.69-2.74	0.12
Decoding efficiency - list 2	132	1.42	0.43	0.19-2.39	-0.16
Decoding efficiency - list 2	132	1.52	0.46	0.30-2.49	-0.16
Reading comprehension	131	.69	.20	0.14-0.96	-0.51

Note. RAN scores are measured in correct items per second, decoding scores in correct words per second, and reading comprehension in proportion correct items.

Table 2

Correlations Between RAN Measures

Variable	1	2	3	4	5	6	7
1. Repeated objects, January G2	-						
2. Unique objects, January G2	.46	-					
3. Repeated letter, January G2	.44	.22	-				
4. Unique letters, January G2	.32	.23	.58	-			
5. Repeated objects, March G2	**.66**	.44	.43	.36	-		
6. Unique objects, March G2	.42	**.71**	.22	.28	.46	-	
7. Repeated letter, March G2	.40	.29	**.71**	.58	.52	.32	-
8. Unique letters, March G2	.31	.23	.57	**.68**	.33	.31	.56

Note. Autocorrelations are marked in bold. Listwise deletion of cases missing data (N = 131).

Table 3

Factor Model Comparisons

Model	χ^2	*df*	*p*	*RMSEA* [90% *CI*]	*CFI*	*SRMR*
One factor	167.21	20	< .001	.24 [.20, .27]	.71	.12
Two factor - time	159.86	19	< .001	.24 [.20, .27]	.72	.11
Two factor - stimtype	80.28	19	< .001	.16 [.12, .19]	.88	.06
Two factor - repetition	153.95	19	< .001	.23 [.20, .27]	.73	.12
Three factor	33.46	17	0.01	.09 [.04, .13]	.97	.04
Four factor	11.76	14	0.63	0 [0, .07]	1	.02

Note. *RMSEA* = root mean square error of approximation, *CFI* = comparative fit index, *SRMR* = standardized root mean square residual. Stimtype = stimulus type.

Table 4

Correlations Between Latent Variables

Latent variables	1	2	3	4	5
1. Repeated objects	-				
2. Unique objects	.65	-			
3. Repeated letters	.65	.36	-		
4. Unique letters	.49	.37	.82	-	
5. G5 decoding efficiency	.49	.27	.65	.57	-
6. G5 reading comprehension	.46	.33	.49	.48	.74