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1 The Effects of Visual Attention Span and Phonological Decoding in Reading
2 Comprehension in Dyslexia: A Path Analysis

3 [Key Words]: Visual Attention Span; Dyslexia; Reading Comprehension

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17 Abstract: Increasing evidence has shown visual attention span to be a factor, distinct from
18 phonological skills, that explains single word identification (pseudo-word/ word reading)
19 performance in dyslexia. Yet, little is known about how well visual attention span explains text
20 comprehension. Observing reading comprehension in a sample of 105 high school students with
21 dyslexia, we used a pathway analysis to examine the direct and indirect path between visual
22 attention span and reading comprehension while controlling for other factors such as
23 phonological awareness, letter identification, short term memory, IQ and age. Integrating
24 phonemic-decoding-efficiency skills in the analytic model, this study aimed to disentangle how
25 visual attention span and phonological skills work together in reading comprehension for readers
26 with dyslexia. We found visual attention span to have a significant direct effect on more difficult
27 reading comprehension, but not on an easier level. It also had a significant direct effect on
28 pseudo-word identification, but not on word identification. In addition, we found that visual
29 attention span indirectly explains reading comprehension through pseudo-word reading and
30 word reading skills. This study supports the hypothesis that at least part of the dyslexic profile
31 can be explained by visual attention abilities.

32

33 Developmental dyslexia is estimated to occur in 10% to 15% of the population in
34 English speaking countries (Lyon, Fletcher, & Barnes, 2002; Shaywitz, et al., 1992). An
35 impairment in phonological processing, namely a deficit in the ability to identify, reflect
36 upon, and store or retrieve the individual sounds in words, is predominantly accepted as
37 the core mechanism of dyslexia (Vellutino et al., 2004; Olson et al., 1994). This
38 explanation has been supported by (1) convergent reports that people with dyslexia
39 perform below average in phonological awareness and auditory discrimination tasks
40 (Bradley & Bryant 1978; Fletcher et al., 1994; Katz, 1986; Thomson & Goswami, 2009),
41 (2) evidence that phonological awareness measured at preschool age can effectively
42 predict future reading performance (Bradley & Bryant, 1983; Torgesen, Wagner &
43 Rashotte, 1994), and (3) evidence that intervention studies training people with dyslexia
44 on phonological awareness and rhythmic processing can effectively improve their word-
45 identification and reading performance (Bradley & Bryant, 1983; Fox & Routh 1976;
46 Thomson, Leong & Goswami, 2012). Phonological processing deficits are believed to
47 result in difficulties in phonemic or letter-sound decoding (Blau et al, 2009), which in
48 turn, impact word identification performance and subsequent reading comprehension
49 (Vellutino et al., 1991, 1994; Snowling, 2000; Blachman, 2000; Stanovich, 1991).

50 Alternative explanations of dyslexia have proposed that visual processing plays a
51 key role, and these models have been hotly debated since the first definitions of dyslexia
52 in the early 1900s. Recent research has confirmed that literacy skill is not only associated
53 with enhancement in phonological activation but also in visual responses (Dehaene, et al,
54 2010). A meta-analysis by Jobard and Tzourio-Mazoyer (2003) concluded that early
55 visual analysis and the visual word form system are necessary for grapho-phonological

56 and lexico-semantic processing during graphemic parsing (Jobard & Tzourio-Mazoyer,
57 2003; McCandliss, Cohen & Dehaene, 2003; Warrinton & Shallice, 1980). In addition, it
58 has been demonstrated that a deficit in serial letter scanning, controlled by the dorsal
59 visual attention stream (from the posterior parietal cortex), leads to the impairments in
60 visual processing of graphemes and their translation into phonemes (Vidyasagar &
61 Pammer, 2010; Facoetti et al, 2010). Increasing debates have been spurred between
62 vision and phonology scientists over how much variation in dyslexia can be attributed to
63 visual impairments. On one hand, visual research has shown evidence that: (1) people
64 with dyslexia are potentially impacted by sluggish attention shifting (Lallier et al, 2010),
65 a condition in which a reader fails to quickly shift from one visual stimulus to the other
66 (Hari & Renvall, 2001; Roach & Hogben, 2007); (2) readers with dyslexia are more
67 affected by the crowding effect (Callens et al., 2013; Spinelli et al, 2002) - the crowding
68 effect is a common visual effect in which reader cannot read a letter in their peripheral
69 vision if the letter is embedded between other letters. Equally, increasing the letter
70 spacing (reducing the crowding effect) can effectively improve reading in dyslexia (Zorzi
71 et al, 2012; McCandliss, 2012; Gori & Facoetti, 2015; Martelli et al., 2009); (3) Recent
72 studies have shown that pre-reading visual attention function as measured by serial
73 searching and spatial cueing tasks can predict reading skills in grade 1 and 2
74 (Franceschini et al, 2012; Plaza & Cohen, 2007); (4) Moreover, treatments specifically
75 training visual attention skills are reported to improve not only word reading in children
76 with dyslexia but also their pseudo-word decoding skills (Franceschini et al, 2013). On
77 the other hand, however, visual attention deficits are often reported to be comorbid with
78 deficits in phonological skills (Borsting et al., 1996; Cestnick, 2001; Cestnick &

79 Coltheart, 1999; Vellutino et al., 2004; Eden & Zeffiro, 1998; Shaywitz & Shaywitz,
80 2008), and visual deficits alone do not consistently explain the variance in tests of word
81 identification (Vellutino et al., 1994). As a result, visual explanations of dyslexia are
82 often considered to be confounded by phonological deficits (Vellutino et al., 2004; Eden
83 & Zeffiro, 1998; Facchetti, et al., 2005; Facchetti, et al. 2003).

84 More recently, Bosse, Tainturier and Valdois (2007) have proposed the visual
85 attention (VA) span deficit hypothesis that sets out to reconcile the confounding
86 relationship between visual and phonological processes. VA span is defined as the
87 number of distinct visual elements that can be processed in parallel, in a multi-element
88 array within the first 200 ms (Bosse, et al., 2007). Operationally (as introduced in detail
89 in method section), 5 evenly spaced (about 0.6cm) unique letters (20 point) would appear
90 for 200ms, and the participants were asked to report as many as they can. In our previous
91 pilot study with college freshmen, typical readers scored 3.7 whereas dyslexic readers
92 scored 3.0 (sd=0.25). Various studies have found VA span to explain unique variance in
93 single word reading performance controlling for phonological awareness, phonological
94 decoding skills and working memory (Bosse, Tainturier & Valdois, 2007; Bosse &
95 Valdois, 2009; Lallier, Donnadieu & Valdois, 2012; Lallier, Donadieu, Berger &
96 Valdois, 2010; Lallier, Thierry & Tainturier, 2013). This hypothesis can also explain the
97 observation that emerging and dyslexic readers have difficulty in reading long words or
98 pseudo-words that require a wider visual attention span, known as the length effect (van
99 den Boer et al., 2013; Zoccolotti et al., 2005; Rastle & Coltheart, 1998). A recent study
100 has shown that short lines improve reading for a particular group of readers with dyslexia
101 who have short VA span (Schneeps et al, 2013a). To explain the VA span deficit

102 hypothesis for dyslexia, Ans, Carbonnel and Valdois (1998) proposed a multi-trace
103 memory (MTM) model that enables successful word reading: an analytic procedure that
104 focuses on sub-lexical units, which is important for phonological decoding, and a global
105 procedure that requires distributed attention, which relies on VA span, extending over a
106 long string of letters or segments. A large VA span facilitates capturing and connecting
107 between units and “moderate reduction of the VA window size prevents reading in global
108 mode” (Bosse et al, 2007, p201), and force the reader to use the analytic, more phoneme-
109 by-phoneme mode instead. The MTM model further predicts that the analytic mode of
110 reading also depends on VA span because parallel processing of multiple-letter sub-
111 lexical units is necessary for analytic processing (Ans, Carbonnel & Valdois, 1998; Bosse
112 & Valdois, 2009). A VA span reduction impairs multi-letter processing so that the whole
113 letters of long graphemes cannot be simultaneously captured. This will further impede the
114 process of graphemes from being assembled into units that can be parsed as phonemes,
115 and from there words (Vidyasagar & Pammer, 2010; Schneps et al., 2013a,b). As a
116 result, what is rooted in the deficit of visual attention span can manifest as the inability to
117 process or decode an array of graphemes. In brief, VA span can contribute to reading via
118 a network which sometimes process the word sequence as a whole (global procedure) and
119 sometimes focus on sublexical units through seral processing (analytic procedure).

120 Visual Span, Perceptual Span, and Visual Attention Span

121 It has been understood for some time (Huey, 1908) that there is a limit to the
122 number of characters that can be perceived in a glance, and that, therefore, there is a
123 critical interplay between visual perception and eye movements during reading. These
124 concepts have undergone many generations of redefinition and refinement (Bouma, 1970;

125 Motter & Belky, 1998; Vlaskamp, Over, & Hooge, 2005). [Excellent reviews of the
126 history of this research are found in Pelli et al., (2007) and Legge et al. (2007).]

127 This research makes a distinction between “visual span” as defined by Legge
128 (1997) and “perceptual span” as defined by (McConkie & Rayner, 1975; Rayner &
129 McConkie, 1976). While the former considers the number of characters that can be
130 perceived at a glance in the absence of eye movements, the latter considers factors
131 affecting the perception of text during eye movements, accounting for the influence of
132 text perceived in parafoveal locations. The visual attention (VA) span measure as
133 proposed by Bosse, Tainturier and Valdois (2007) relates to these formulations, but the
134 relationship between VA and “visual span” or “perceptual span” differs in important
135 ways that have yet to be established.

136 Theories of visual span are motivated by the observation that text can only be
137 accurately discerned in a window surrounding the locus of fixation, and that text
138 perceived in the parafovea and periphery is dramatically less informative when it comes
139 to reading (Rayner & Bertera, 1979). Legge et al. (2001) defined visual span as the
140 number of characters in a line of text that can be read in a single fixation. In other words,
141 visual span is conceptualized as the window about the fixation point through which text
142 can read. Given that only a limited number of characters are perceived in this window at
143 a glance, the locus of fixation needs to be updated to read words arrayed in a sentence.
144 Provided that gaze advances at a constant rate (Huey, 1908), the larger the visual span,
145 the faster will be the reading speed (Legge, 2007; Legge et al., 2001).

146 It was recently explained that one reason there is a limit to the number of

147 characters able to be perceived at a glance is because of a long-range interaction
148 phenomena in vision known as crowding (Bouma, 1970; 1973; Pelli et al., 2007). When
149 similar visual objects, such as letter forms, are perceived in the periphery, the identity of
150 the cluttered objects are more difficult to discern, when compared with their perception in
151 isolation. This crowding, effect increases with increasing peripheral angle, a functional
152 characteristic known as Bouma’s law. When applied to letters, crowding is observed to
153 be independent of letter size, and it is ordinarily influenced only by the letter spacing and
154 the peripheral angle at which the letters are perceived relative to fixation. This
155 phenomenon gives rise to what Pelli, et al. (2007) referred to as an “uncrowded span” of
156 text surrounding fixation. Outside the uncrowded span, text cannot be accurately
157 perceived due to limitations imposed by crowding. Pelli et al. (2007) demonstrated that
158 the “visual span” as defined by Legge et al., is equivalent to the “uncrowded span”
159 determined by crowding.

160 Operationally, Legge’s visual span task (Legge et al., 2001) measures the
161 eccentricity at which a trigram (three random letters) can be accurately reported. Here,
162 RSVP is used to briefly flash trigrams at various eccentricities to observe response
163 accuracy as a function of angle. Perceptual span, as defined by McConkie & Rayner
164 (1975), differs in that this method typically uses a gaze contingent display to alter the text
165 at various angular distances from fixation as the gaze advances in normal reading. This
166 method allows the observation of the effects of the manipulation on reading speed and
167 eye movements (e.g., regressions). Using this technique, it was found that information in
168 the parafovea is used during reading to guide attention and otherwise improve reading
169 (Inhoff and Rayner, 1986).

170 Of the two methods, VA span is conceptually closer to Legge’s original definition
171 for visual span in that VA span has been assumed to measure the number of letters one
172 can perceive at a glance. A number of variants of the VA span task have been used in the
173 literature, and in this study we use an implementation as originally described by Bosse et
174 al., (2007) calling for a simple global report in response to a briefly presented non-
175 informative letter string 6 characters long. In this version of the task, the characters are
176 widely spaced., VA span differs from the visual span of Legge et al., in a number of
177 important respects. (1) Given that the letters are widely space, the influence of crowding
178 is diminished in the VA span task. (2) While the visual span explicitly measures response
179 to trigrams at well-defined eccentricity, the VA Span task is a global report, and the
180 eccentricity of the target letters is not considered in the total score. (3) VA span is
181 typically assessed through tasks of global and partial report. The partial report only asks
182 participants to report the one letter probed by a cursor after the presentation of stimulus in
183 order to exclude problem with single letter processing. (4) Finally, and perhaps most
184 importantly for applications relevant to dyslexia, the procedures of Legge et al., only
185 present three letters at time, while the global report task here requires respondents to
186 distribute attention to a span of consonant arrays containing twice as many letters. Thus,
187 the VA span task, unlike the visual span, is sensitive to variations in distributed attention
188 among the participants, and this may be important in dyslexia.

189 Rationale for this study

190 The relationship between the VA span task and the visual span is an open
191 question that needs to be explored in depth through future study. However, given that a
192 number of studies have shown that the VA span task is useful in contexts related to

193 dyslexia, the task is potentially powerful because it can be easily administered in situ, by
194 teachers in an educational context. In this study, we used a novel method for presenting
195 the VA span stimulus that was designed for use in schools. It uses custom software
196 running on an inexpensive handheld device (Apple iPod Touch) to permit data collection
197 in school settings with little specialized training. Previous studies in our laboratory
198 (Schneps, et al., 2013a,b) showed that this measure is useful in separating those
199 participants with dyslexia who benefit from augmented text formatting from those who
200 do not. Thus, this implementation of the VA span task may constitute a promising tool to
201 guide the evaluation and treatment of students with dyslexia.

202 It is noteworthy that in all of the previous VA span studies, “reading skill” is
203 equivalent to, and only measured by, word/pseudo-word identification tasks. The
204 relationship between VA span and text reading has been explored (Prado, Dubois &
205 Valdois, 2007; Lobier, 2013), but not with reading comprehension, the ultimate goal of
206 reading. No study, to our knowledge, has examined how well VA span can predict text
207 comprehension, the ultimate goal of reading. Little is known about whether VA span can
208 directly explain reading comprehension controlling for phonological and word-
209 identification skills, or indirectly explain reading comprehension via whole word-
210 identification skills. In addition, if the proposed hypothesis that VA span facilitates
211 reading by capturing a wider range of written segments is correct, it should not only help
212 binding graphemes within word level, but also help binding between words at the
213 sentence level.

214 Current Study and Research Questions

215 Since the MTM model predicts that VA span contributes to reading via two
216 procedures of the same network, one that directly explains reading (global mode) and
217 another one indirectly via phonological decoding skills (analytic mode), it is necessary to
218 adopt an analytical approach that distinguish the two procedures. Therefore, in this study,
219 we used path analysis (Stage, Carter & Nora, 2004; Edward & Lambert, 2007) to
220 examine how well the VA span directly and indirectly explains different levels of reading
221 comprehension in addition to (controlling for) the phonological awareness explanation.

222 Our two primary research questions are:

223 In a group of high school students with dyslexia, in comparison to phonological
224 awareness, 1) does VA span have a total effect (the sum of direct and indirect effect) on
225 reading comprehension? How much of the total effect is mediated by word identification
226 and phonological decoding? Alternatively, is there a direct effect not mediated by word
227 identification and phonological decoding? 2) Does VA span have a total effect on
228 phonological decoding and word identification? How much of the total effect on word
229 identification is mediated by phonological decoding? Is there a direct effect not mediated
230 by phonological decoding?

231 This study is a within-dyslexia-group examination. It does not compare dyslexic and
232 typically-developing readers. We ask the specific question as to whether shorter VA
233 spans are associated with greater reading comprehension difficulty among dyslexic
234 readers who have already shown delayed development in phonological awareness and
235 phonological decoding skills. If a poor VA span adds an additional obstacle to reading
236 comprehension among readers with dyslexia, our study would suggest that there is a
237 potential sub-group within the dyslexic population whose difficulties in reading

238 comprehension are made more severe by a combination of phonological and VA span
239 deficits. Recent research demonstrates that visual accommodations specifically benefit
240 dyslexic readers who have short VA spans (Schneps et al, 2013a, b). Prompt diagnosis
241 and accommodation of VA span deficits will thus benefit those who struggle the most
242 with reading comprehension but also potentially have the most to gain from personalized
243 intervention regimes that address both visual and phonological needs. For this reason, the
244 goal of this paper is to investigate the previously unresearched link between VA span and
245 reading comprehension within the dyslexic population. By demonstrating the importance
246 of VA span for reading comprehension in readers with dyslexia, we pave the way for
247 future studies to compare dyslexic and normal reading populations and investigate
248 whether the role of VA span in reading comprehension is a dyslexia-specific mechanism.

249 **Methods**

250 **Participants**

251 105 high school students with a lifelong history of reading difficulties (39 female,
252 66 male, with a mean of age at 17, $sd = 1.2$) were recruited from Landmark High School,
253 in Beverly (MA), USA. It is a private high school exclusively for students with reading
254 disabilities. Students had a diagnosis from a neuropsychologist, who documented (a) a
255 specific reading disability (b) average or above average non-verbal IQ, and (c) the
256 absence of a neurological impairment, as required by the enrollment criteria for the
257 school. Students who had a diagnosis of ADHD from a neuropsychologist (reported in
258 their school documents) were excluded from this study.

259 Participants in the sample were recruited for an intervention to support reading.

260 We examined performance on VA span, reading comprehension and additional academic
261 and cognitive tests administered to this sample. The data used in this sample is collected
262 before they receive the intervention. As shown in Table 2, the reading measures of the
263 sample ranked at the bottom of the age norm, while nonverbal IQ (block design) ranked
264 around the average. Although every participant had a diagnosis of developmental
265 dyslexia from a neuropsychologist, and we have re-confirmed that they had poor reading
266 measures and normal IQ indeed, we want to remind the readers that we did not
267 systematically evaluate perinatal disorders, ADHD symptoms (those who had an ADHD
268 record were excluded), auditory and visual acuity. It was decided to concentrate on
269 students with a diagnosed reading disability in the first instance, as this is a population
270 where a) the contribution of visual factors to reading ability is most contested and b)
271 demonstration of a link between visual attention and reading comprehension would have
272 the most practical value in terms of potentially adapting text to enhance reading ability in
273 struggling readers. Due to a stipulation of the funder, control data from typical readers
274 was to be collected in a subsequent study, and thus is not available for this paper.

275 High school students were sampled because it is an age that students are exposed
276 to a lot of new, specialized and increasingly multi-syllabic vocabulary items and
277 therefore potentially a period in which VA span is particularly important.

278 Measurements

279 Reading Comprehension

280 Reading comprehension was measured by Gates-MacGinitie Reading Test
281 (MacGinitie et al, 2000). Here we followed procedures recommended in the testing

282 manual. Accordingly, the reading time for this task was constrained to 35 minutes. The
283 test consists of numerous passages. Following each passage, multiple-choice questions
284 are used to gauge reading comprehension. The reasons for choosing this test were (1) it
285 has the difficulty levels sensitive to the age group in the sample; (2) the multiple choice
286 questions result in an objective scoring method; (3) the format of the tasks between
287 different difficulty levels are the same; and (4) the total raw score are the same between
288 different difficulty levels and both scores can be converted to national norms. Students
289 were tested using items designed for both levels 7 and 10 so as distribute sensitivity over
290 a large span of potential reading ability. Each level has 12 passages for reading
291 comprehension. As measured by Lexile (MetaMetrics, 2013), level-7 has less load of
292 reading demand in terms of semantic difficulty and syntactic complexity than level-10. In
293 addition, level-7 has shorter sentences and slightly fewer letters per word compared to
294 level-10 (Table 1). The score for each level was the number of comprehension questions
295 answered correctly. Such difference between level-7 and level-10 allows us to examine if
296 VA span affect levels of reading demand differently.

297 -----
298 Table 1
299 -----

300 Word Reading

301 The word reading task was excerpted from the second edition of the Test of Word
302 Reading Efficiency (TOWRE-2), also known as word reading. It assesses the number of
303 single words an individual can accurately identify and read aloud within 45 seconds. The
304 raw scores were converted to standard scores based on national norms provided by the
305 TOWRE-2 manual (Torgesen, Wagner & Rashotte, 2012).

306 Pseudo-word Reading

307 Similar to the word reading task, the pseudo-word reading task was also excerpted
308 from the TOWRE-2. It measures the number of pronounceable non-words that an
309 individual can accurately read aloud in 45 seconds. It is an indicator of phonological
310 decoding skill. The raw scores were converted to standard scores based on national norms
311 provided by the TOWRE-2 manual (Torgesen, Wagner & Rashotte, 2012). Timed
312 measures were used to capture both accuracy and automaticity. Once individuals are
313 beyond the basic stages of word reading, timed approaches are typically more sensitive to
314 measure word identification skills.

315 Elision

316 In this study, we used the Elision subtest, a 20-item measurement of phonological
317 awareness, taken from the Comprehensive Test of Phonological Processing (CTOPP). It
318 measures a participant's ability to repeat words while deleting designated phonemes. For
319 example, to say "tiger" without saying /g/ is "tire". The number of correct responses was
320 then converted to a standard score based on the national norms provided by the CTOPP
321 (Wagner, Torgesen, Rashotte, 1999).

322 Visual Attention Span

323 The VA span task was administered using custom presentation software (iCue) on
324 a third generation Apple iPod touch device (10.92cm high, 6.10cm wide, 8.89cm
325 diagonally wide). The device has a screen resolution of 640 x 960 pixels at 128 pixels
326 per cm. The luminance was set to a black level of approximately 1.27 cd/m² and a white

327 level of 127.3 cd/m². The image displayed by iCue were generated by computer using
328 custom software written in Matlab. Ambient room luminosity was between 314.0 lux and
329 423.0 lux. Students freely held the device in their hand at a comfortable distance
330 (approximately 35 cm from the eye). To start each trial, the participants tap on the iPod's
331 touchscreen. A centrally-placed fixation marker would appear for 1000 ms, followed by a
332 blank screen of 500 ms. We measured device latencies using an oscilloscope and
333 photodiode prior to the experiment, and the software was adjusted to compensate. The
334 device was taken offline, and other applications turned off to help ensure a stable
335 platform during presentation.

336 Following procedures as described in Bosse (2007), 6 unique letters (Courier font,
337 fixed width 18 pixels and height 24 pixels) each separated by 99 pixels would appear
338 immediately for 200ms. The total length of the string spanned 521 pixels, and the string
339 was centrally placed on the screen. In each trial, the 6 letters were chosen randomly with
340 no order constraint from a letter set (letter set: D, M, R, F, B, P, T, H, L, S. Consonants
341 were chosen to prevent the possibility of pronounceable words resulting from the string).
342 After the 200ms duration, a blank screen would appear. In the VA span task, the
343 participants were asked to report all the letters they could recall, regardless of order. The
344 participants were told to do the best they can, but they were not pressured to always
345 report 6 letters. In partial report task, the participants were asked to report the one letter
346 indicated by a probing cursor after the presentation of the string. After reporting, the
347 participant tapped on the touchscreen to proceed to the next trial. A total number of 24
348 trials were presented for the VA span task and 72 trials for the partial report tasks. Each
349 task was scored separately. For the VA span task, the participant scored 1 for each letter

350 correctly recalled in each trial. The participants were not scored on whether letters were
351 reported in the correct order. The final score is the average score. For the partial report
352 task, the participant only needed to report one letter and score 1 if reported correctly. The
353 final score is averaged, so that an average of 0.6 means 3.6 letters can be accurately
354 identified on a array of 6 targets.

355 At the beginning of the task, the administrator made sure that the participants
356 were holding the iPod 35 cm from their eyes and asked them to maintain this distance
357 while and avoiding moving their bodies. Here, a chin rest was not used to restrict the
358 distance because this would have hindered the students' ability to verbally report their
359 response at the end of each trial. Given that this procedure may introduce variations in the
360 device-eye distance, we conducted a follow up study to investigate the effect of distance
361 on VA span score. Here, using a chin rest to restrict movement, we tested 20 college-aged
362 participants, and compared VA span at a device-eye distance of 35cm and 25cm. No
363 statistically significant difference was observed between the two distances, suggesting
364 that a 10cm movement in position would have negligible impact on the measured scores.
365 In the original experiment, a 10cm movement was noticed and corrected by the
366 experimenter.

367 Memory for Digit

368 Memory for Digit was excerpted from CTOPP as well. It served as a
369 measurement of short term memory. In each of the 21 trials in this task, the experimenter
370 plays an audio track that reads a string of numbers (span range from 2 to 8) to a
371 participant. Afterwards, the participants repeat the numbers in the same order. The

372 participant scores 1 point each time he/she completes a trial without error. The raw score
373 was later converted to a standard score based on the national norms provided by the
374 CTOPP (Wagner, Torgesen, Rashotte, 1999).

375 Block Design

376 Block design is a test of non-verbal intelligence excerpted from Wechsler
377 Abbreviated Scale of Intelligence (WASI, Psychological Corporation, 1999). In this test
378 the participants use two-color printed cubes to replicate geometric patterns printed on a
379 paper within the time limit. The participant is scored based on the time they used to
380 complete each replication task. If the participant replicate incorrectly or exceed the time
381 limit in a trial, the trial is scored 0. The raw score was converted to a standard score based
382 on the norms provided by WASI manual (Psychological Corporation, 1999).

383 Hypothesized Model and Data analytic approach

384 In step 1, we used Mahalanobis distance to detect multivariate outliers. We did
385 not find any outlier when 15 percentile (a rather strict criteria) of the chi-squared
386 distribution was used as the threshold.

387 In step 2, we used path analysis to model the relationship among the variables
388 measured above. Path analysis is particularly useful in the modeling of mediation and in
389 comparing the effects of different factors, via different paths, to the outcomes. We
390 examined the fitness and loadings in the hypothesized path model. The hypothesized
391 model specifies two pathways (shown in Figure 1 with solid arrows only) to reading
392 comprehension: a phonological path and a VA span path. In the phonological path, we

393 specified that Elision, a measure of phoneme-segmentation skill is a precursor of pseudo-
394 wording reading, and pseudo-word reading, a measure of phonological decoding skill, is
395 a precursor of word reading. Finally, word reading skill will be the direct predictor for the
396 scores in levels 10 and 7 of the Gates-MacGinitie Reading Comprehension Test. We
397 separated the comprehension scores in level-7 and level-10 instead of using the
398 composite score of the two because we intended to examine if the cognitive skills
399 (especially VA span) may affect passages with different word and sentence loadings
400 differently. We also allowed Elision to directly explain word reading and both levels of
401 reading comprehension. The loadings of each of the paths in the phonological route will
402 serve to validate the phonological awareness explanation of dyslexia with the sample of
403 105 participants. Building on the phonological route, we added a path from VA span to
404 (a) levels 10 and 7 reading comprehension, and (b) pseudo-word and word reading. This
405 route serves to examine the VA span explanation for word identification and text
406 comprehension controlling for phonological awareness.

407 In step 3, in case the effect of VA span is confounded by IQ, short-term memory,
408 or letter identification within strings in the global report task, we added measures of
409 block design, memory for digit and partial report to the model for validation (as shown in
410 Figure 1 including dashed arrows). In brief, we tested the model with solid arrows to
411 answer our key research question while including the dash arrow to rule out potential
412 confounding variables. Typically, a single letter processing task is taken to control for
413 letter processing. If single letter processing is preserved, the performance in global and
414 partial report mainly reflects the way attention distributes over the letter array. However,
415 we did not administrate the single letter processing task (as will be discussed in the

416 limitation section), instead we used the partial report task as a proxy for letter
417 identification modulated by visual attention when letters are displayed within strings. In
418 other words, partial report is considered as letter identification with visual attention span
419 activated.

420 In step 4, we considered two alternative models (explained by the end of the result
421 section): one that did not specify a directional path from pseudo-word to word reading
422 but allowed the two covary, another one that placed IQ and age as the exogenous
423 predictors for all other variables (including the cognitive and reading skills), while
424 keeping the paths from cognitive to reading skills the same.

425 -----
426 Figure 1
427 -----

428 Results

429 Table 2 presents the descriptive statistics of all variables.

430 -----
431 Table 2
432 -----

433 Table 3 presents the correlation and covariance matrices of the eight variables.
434 The matrix was used to determine whether the hypothesized model (Figure 1) fit the data.
435 model-fit indices reached a consensus of a good overall model fit: the Chi-Square model
436 fit was $\chi^2_{(11, 105)} = 14.90$ ($p = 0.19$); the root mean square error of approximation
437 (RMSEA) was 0.06 within a confidence interval range from 0 to 0.15; the standardized
438 root mean square residual (SRMR) is 0.04; and the CFI is 0.97. We retained the non-
439 significant paths because they were important to test our hypothesis and keep potential

440 confounders controlled for (even though most of the control variables were not
441 significant). Therefore, we did not modify our proposed model (see Figure 2 for the
442 model with coefficients that are statistically significant and their standardized loadings).

443 -----
444 Table 3
445 -----

446 -----
447 Figure 2
448 -----

449 Table 4 shows the parameter estimates of each path in the model. VA span had a
450 direct effect on pseudo-word reading (PD) (est. = 4.207, S.E. = 1.604, $\rho = 0.001$) and
451 level-10 reading comprehension (est. = 10.240, S.E. = 4.693, $\rho = 0.020$). To more directly
452 test the hypothesis that VA span directly contributes to reading comprehension, we
453 compared the current models with a reduced model that does not allow direct link from
454 VA span to level-10 reading comprehension (every other path is specified the same). The
455 current model had a significant better fit than the reduced model ($\chi^2_{(1)} = 4.62$, $\rho = 0.03$).
456 The direct effects from VA span to word reading (WR) (est. = 0.152, S.E.=1.736, $\rho =$
457 0.29) and level-7 reading comprehension (est. = 3.116, S.E.= 5.350, $\rho=0.56$) were not
458 statistically significant.

459 In addition, word reading had a direct effect on both level-10 (est. = 0.811, S.E. =
460 0.279, $\rho < 0.01$) and level-7 reading comprehension (est. = 1.262, S.E. = 0.319, $\rho <$
461 0.001). Pseudo-word reading had a direct effect on word reading (est.= 0.603, S.E. =
462 0.122, $\rho < 0.001$).

463 In contrast to VA span, Elision (ELI) did not have significant direct effect on
464 either level-10 (est. = 0.154, S.E. = 1.231, $\rho = 0.90$) or level-7 (est. = 1.871, S.E. = 1.420,

465 $\rho = 0.18$) reading comprehension. Elision did not have a direct effect on word reading
466 (est. = -0.122, S.E. = 0.440, $\rho = 0.78$), and only marginally on pseudo-word reading (est.
467 = 0.733, S.E. = 0.408, $\rho = 0.06$).

468 -----
469 Table 4
470 -----

471 Table 5 shows each of the indirect effects in the model, from VA span and Elision
472 (a measure of phonological awareness) via pseudo-word reading (a measure of
473 phonological decoding skill) and word reading to reading comprehension in levels 7 and
474 10 via word reading. The indirect effects from Elision on both levels of reading
475 comprehension were not significant. Elision only had a marginally significant indirect
476 effect on word reading. The indirect effects from VA span to two levels of reading
477 comprehension via only word reading were not statistically significant, but the indirect
478 effects from VA span on both level-7 (unstandardized effect = 3.200, S.E. = 1.600, $\rho =$
479 0.04) and level-10 (unstandardized effect = 2.055, S.E. = 1.135, $\rho = 0.07$) reading
480 comprehension via pseudo-word reading and word reading were marginally significant
481 around the level of 0.05. As can be seen in the comparison of the standardized effects of
482 VA span and Elision in Table 5, VA span had consistently larger direct and indirect
483 effects on word identification and reading comprehension than Elision.

484 -----
485 Table 5
486 -----

487 To validate that the relationship between VA span and reading performance was
488 not confounded by letter identification under distributed attention, rapid naming skills,
489 short-term memory, age or IQ, we added the participants' age and scores in partial report

490 task, memory for digits (retrieved from CTOPP), rapid letter naming and block design as
491 covariate to the model, with their paths pointing to both levels of reading comprehension.
492 Block design had a significant effect on reading comprehension (for level-10,
493 unstandardized effect = 0.498, S.E. = 0.273 $\rho = 0.06$; for level-7, unstandardized effect =
494 0.854, S.E. = 0.312, $\rho < 0.01$). Rapid letter naming has significant effect on word reading
495 (unstandardized effect = 0.946, S.E. = 0.446 $\rho = 0.03$) and pseudo-word reading
496 (unstandardized effect = 1.438, S.E. = 0.2322 $\rho < 0.01$). Other control variables did not
497 have significant paths. Adding such covariates did not change the effect of VA span
498 concluded in the above model.

499 We also considered two alternative models. First, Peterson, Pennington & Olson
500 (2013) has shown that pseudo-word reading and word reading might dissociate in
501 developmental dyslexia and that the dissociation rate increases with age. So it was
502 theoretically reasonable to consider that pseudo-word and word reading may be
503 dissociated, especially in the sample of high school students. Therefore, we tested an
504 alternative model that allowed pseudo-word reading and word reading skills to mediate
505 the effect of VA span in parallel (rather than in a chain). The alternative model, however,
506 had a poor models fit ($\chi^2_{(9, 105)} = 34.345$, $\rho < 0.01$; RMSEA = 0.19; CFI = 0.783; SRMR =
507 0.091), the primary reason was that pseudo-word reading had a low correlation with
508 reading comprehension in the sample. Second, rather than placing fundamental predictors
509 such as age and IQ at the same level of specific cognitive skills, we considered a model in
510 which age and IQ may predict other cognitive and reading skills. Such an alternative
511 model led to a poor model fit ($\chi^2_{(18, 105)} = 41.727$, $\rho < 0.01$; RMSEA = 0.13; CFI = 0.853;
512 SRMR = 0.090). Nevertheless, the effect regarding to VA span remained roughly the

513 same (significant on level-10 reading comprehension and pseudo-word reading, but not
514 on level-7 reading comprehension and word reading).

515 In summary, VA span had a statistically significant direct effect on level-10
516 reading comprehension, but not on level-7 reading comprehension; VA span also had a
517 direct effect on pseudo-word reading but only an indirect effect on word reading. VA
518 span was mediated by phonological decoding skill to have an indirect effect on word
519 identification and reading comprehension. Elision did not have a direct effect on either
520 level of reading comprehension. It only had a marginally direct effect on pseudo word
521 reading, and was mediated by pseudo word reading to have an marginally indirect effect
522 on word reading and reading comprehension. In addition, the effects of VA span on word
523 and text reading could not be explained by age, non-verbal IQ, letter identification and
524 short term memory.

525 **Discussion**

526 The resulting model confirmed literature findings (Mellard, Fall & Woods, 2010;
527 Vellutino et al, 2007; Swank & Catts, 1994) that suggest that phonological awareness
528 (measured by Elision) significantly contributes to phonological decoding of pseudo-
529 words, phonological decoding significantly contributes to the ability to read words, and
530 the word identification is an immediate contributor to reading comprehension.

531 These findings also confirmed published evidence (Bosse, Tainturier & Valdois,
532 2007) that VA span explains unique variance in phonological decoding controlling for
533 phonological awareness. Bosse, Tainturier and Valdois (2007) concluded that VA span
534 contributes to both word reading and pseudo-word reading which was agreed with

535 through the pairwise correlation in our study, as shown in Table 2. Our finding also
536 converged with previous evidence that visual spatial attention is more essential for
537 pseudo-word reading than for word reading (Sieroff et al., 1988; Ladavas et al., 1997;
538 Auclair & Sieroff, 2002; Facoetti., 2006). Our study results further showed that VA span
539 explains word reading exclusively through the indirect path via phonological decoding.
540 Results from our analysis showed that the effect of VA span on word reading via
541 phonological decoding was similar (slightly larger) to the effect from phonological
542 awareness (Elision) to words reading via phonological decoding, suggesting that both VA
543 span and phonological awareness aid the analytical approach of word identification. In
544 contrast to VA span, phonological awareness, as measured by Elision, did not have a
545 statistically significant direct effect on reading comprehension. It only had a direct effect
546 on phonological decoding, via which it had an indirect effect on word identification.
547 Elision didn't have a significant direct effect on reading comprehension, and its indirect
548 effect was marginal. In other words, the effect of Elision was fully mediated by
549 phonological decoding and word identification.

550 Beyond confirming published research evidence, this study provided two new and
551 important findings. Firstly, VA span had a statistically significant direct effect on reading
552 comprehension at the more difficult level. Since we controlled for word identification in
553 the analysis, these findings suggested that VA span explains reading comprehension
554 beyond the single-word level, perhaps at the level of phrase or sentence. Secondly, VA
555 span did not have a statistically significant direct effect on reading comprehension at the
556 easier test level. In other words, VA span only had a direct effect on the difficult level of

557 reading comprehension but not for the easy level (neither level-7 nor level-10 reading
558 comprehension test had a ceiling or floor effect).

559 Our current data did not provide direct evidence to explain the reason that VA
560 span contributes to pseudo-word reading (but not word reading) and the difficult level
561 reading comprehension (but not the easy level). However, this finding is consistent with
562 multiple existing hypothesis. We will try to apply these theories to explain our finding,
563 although it is noteworthy that the explanations remain speculative. More studies are
564 needed to examine the hypothetical claims. Our finding supported the visual attention
565 deficit theory hypothesis (Bosse et al., 2007) and the length-effect theory (van den Boer
566 et al., 2013) that one needs a wide visual attention span to quickly connect multiple
567 phonemic units in one fixation in order to decode the whole word. If one fails to grasp
568 multiple graphemes quickly, it will be difficult for the reader to combine the graphemes
569 into units that can be parsed as phonemes, and then into a whole word. For such a reason,
570 this difficulty could manifest as a phonological decoding deficit. A short VA span may
571 also prevent one from capturing the upcoming visual element into the graphemic
572 (visuospatial sketchpad), and eventually the phonological, buffer (Baddeley & Hitch,
573 1975; Baddeley, 2000). It may disrupt pseudo-word reading more than word reading
574 because pseudo-word reading requires accurate tracing each phoneme and has higher
575 demands on the graphemic buffer than real words (Tainturier & Rapp, 2003, Torgesen,
576 Wagner & Rashotte, 2012). Furthermore, the visual cues in the visuospatial sketchpad are
577 important to direct eye fixation. If one has a poor VA span due to a narrow visual span,
578 the visual cues may fall out of the reading window, which leads to the failure to control
579 eye saccades during reading (Bouma & deVoogd, 1974). It has been reported that short

580 VA span corresponds to more rightward fixation for dyslexic readers (Prado, Dubois &
581 Valdois, 2007), which may suggest failure to locate rightward visual cues. Moreover,
582 reformatting a wide line of text into short and multiple rows dramatically reduces the
583 regression saccades (Schneps et al, 2013b) and improves reading comprehension for a
584 subgroup of dyslexia readers with short VA span (Schneps et al, 2013a). This suggests
585 that eliminating the need to look for visual cues in the rightward peripheral vision reduces
586 the confusion one encounters when trying to distinguish between words, a particular
587 difficulty made severe for those with short VA span.

588 We hypothesize that just as VA span helps one to connect letters and phonemes to
589 decode a word, it may also help dyslexic readers make connections between words for
590 successful reading. To comprehend a sentence, words and phrases must be combined
591 fluently so that their meanings are not lost before the next words are processed (Curtis &
592 Kruidenier, 2005).

593 Our data do not provide a direct explanation of this differences in effect. Based on
594 the fact that the most difficult (level-10) reading comprehension tests contained longer
595 sentences and a higher load of semantic difficulty and syntactic complexity than the level
596 7 reading tests (Table 1), it is reasonable to speculate that VA span is particularly useful
597 for readers in grasping sentence segments with unfamiliar semantics or in connecting
598 more words in complicated and long phrases. In comparison, simpler text has more sight
599 words and simpler phrases and/or sentence structure so that readers do not need to
600 correctly collect every piece of graphemic, phonemic and lexical information. Therefore,
601 it reduces the readers' reliance on distributed attention to identify and bind such
602 information. This pattern is analogous to the role that VA span plays in word

603 identification (i.e., VA span explains pseudo-word reading better than word reading) as
604 discussed above.

605 **Limitations**

606 It is noteworthy that the sample in this study is uncommon. All of the subjects
607 were high school students enrolled in a special school for language impairment that
608 provides long-term and intensive training focusing on phonological awareness. Given
609 that those in this sample attended these programs for a minimum of 1 to 11 years (mean =
610 3.84, SD = 2.3), these participants represent a highly compensated sample. The role of
611 VA span for younger or beginning readers, for whom phonological awareness is essential
612 for the ability to read (Pennington & Lefly, 2001), is yet to be explored. We will also be
613 cautious with generalizing the results of this study to the broader high school population
614 with dyslexia. The phonological interventions received by the sampled students in the
615 school specialized for students with dyslexia may reduce variability in phonological
616 awareness, which may reduce its power as a predictor. For high school students with
617 dyslexia who have not received intensive remediation in phonological awareness and
618 phonological decoding skills, phonological awareness may contribute more variance to
619 reading comprehension, and the strength and pattern of the VA span effect on reading
620 comprehension may be different from this study's findings. In addition, we did not
621 administrate the single letter identification task, and only used the partial report task as a
622 proxy. As mentioned in data analysis section, typically, single letter identification task is
623 tested to make sure single letter processing is preserved. While the partial report task
624 controlled for letter identification modulated by distributed attention over letter string, we
625 do not know if performance in this task is rooted in skills for identification of a letter

626 when it is presented as a single unit. Finally, note that the direction of the arrow in the
627 path diagram (Figure 1 and Figure 2) does not imply causality. They are postulations
628 based on theory. Empirically, our data cannot answer the question as to whether students
629 can improve reading comprehension by increasing their visual attention span. Future
630 randomized controlled experiments and longitudinal data can better examine this
631 question.

632 **Conclusion**

633 This study suggests that 1) word and pseudo-word identification have a
634 significant VA span component. What has been considered a phonological decoding skill
635 measured by pseudo-word reading task could be complicated by a compromised ability to
636 quickly identify and connect graphemic units using visual attention; 2) VA span can
637 operate within and beyond the single word level and can be activated when vocabulary,
638 phrases or sentence structure is unfamiliar and/or very long. When words and sentences
639 are short and simple, this process is not as critical because less binding is needed. The
640 relationship between the response to visuospatial attention and the eponymous Visual
641 Attention span task is as yet not well understood. Nevertheless, this study, linking
642 previously unresearched relationship between VA span and reading comprehension, lends
643 support to a growing body of evidence indicating that visuospatial attention plays a more
644 important role in dyslexia than is often assumed. There is at least a sub-group of dyslexic
645 reader whose reading comprehension are troubled by a combination of phonological and
646 VA span deficits. Thus, comprehensive diagnosis and specific accommodation are
647 necessary for those who struggle the most.

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Table 1.

Mean and standard deviation of Lexile, sentence length, word count and word length of level-7 and level-10 reading comprehension tests.

	lexile measure	Sentence Length	Word count per passage	Word length
Level-7	1096.36 (165.30)	18.71 (5.04)	116.54 (28.72)	4.45 (2.24)
Level-10	1191.82 (204.88)	20.78 (5.56)	123.45 (38.31)	4.75 (2.66)

Lexile measure indicates semantic difficulty and syntactic complexity, it was measured using Lexile analyzing from lexile.com.

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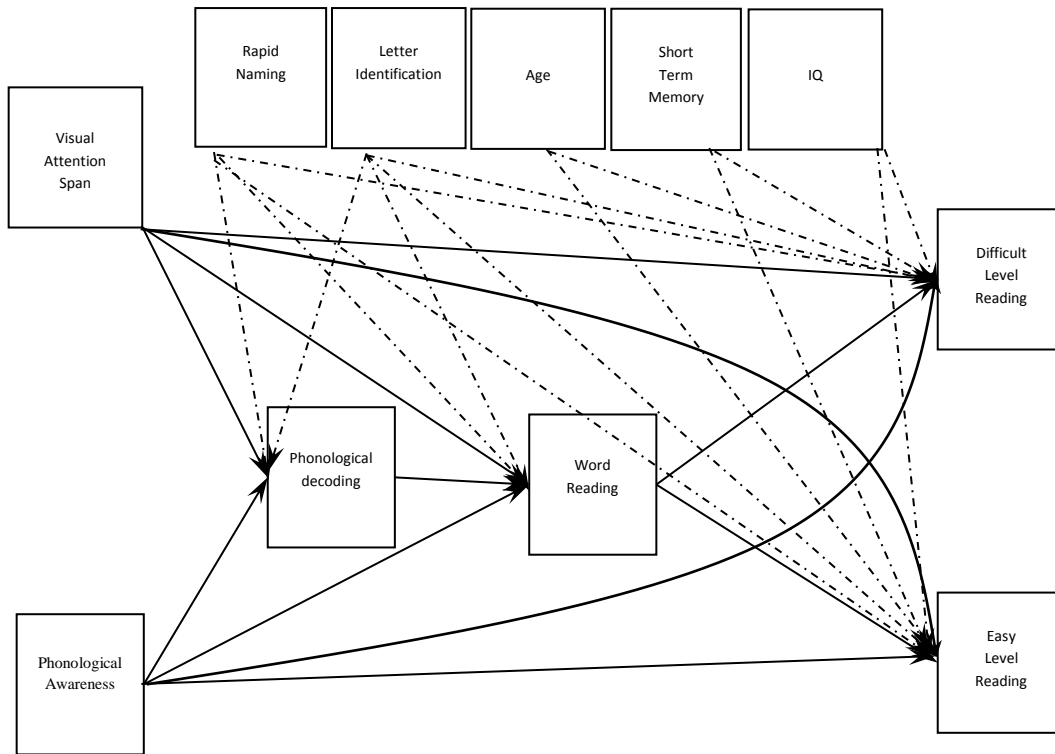


Figure 1. Path diagram for the conceptual model, in solid arrows, of reading comprehension explained by word identification (measured by word reading), phonological decoding (measured by pseudo word reading), phonological awareness (measured by elision task), and Visual Attention (VA) span. Age, IQ, short-term memory, rapid naming and letter identification are included, as shown with dashed arrows, to control for potential confounding relationship.

Table 2.

Descriptive statistics of variables

Variable	Mean	SD	Percentile: mean/(± 1 SD)
Elision (normed)	8.91	2.18	37 / (9-63)
Word Reading Efficiency (normed)	78.52	9.86	8 / (2-23)
Pseudo Word Efficiency (normed)	79.71	8.26	9 / (3-21)
Rapid Letter Naming (normed)	6.93	2.34	16 / (2-37)
Memory for Digit (normed)	9.15	2.99	37 / (1-16)
Block Design (normed)	47.38	10.28	53 / (27-82)
VA Span (global)	3.29	0.66	-
Partial Report Task	0.60	0.13	-
Reading comprehension, Level-7 (normed/raw)	537/30.55	32.9/9.41	Grade 8.5
Reading comprehension, level-10 (normed/raw)	544/23.11	26.7/9.12	Grade 9.1

In the last column, the first number is the percentile in the norm for the mean, the numbers in the parenthesis are the percentile in the norm for the score one standard deviation below and above the mean. The VA span and partial report tasks do not have norms, therefore their percentile score are omitted.

In the partial report task, an average of 0.60 means 3.6 letters can be accurately identified on a array of 6 targets.

Table 3

	1	2	3	4	5	6	7	8	9
1.Read10	-								
2.Read7	0.74***	-							
3.Word Reading	0.39***	0.41***	-						
4.Pseudo-word	0.13	0.20*	0.53***	-					
5. VA Span	0.28*	0.20*	0.27**	0.37***	-				
6. Elision	0.16	0.20*	0.12	0.29**	0.30**	-			
7. Memory digit	0.11	0.13	0.16	0.27**	0.15	0.05	-		
8.Block Design	0.23*	0.36***	0.06	-0.11	0.08	0.19	0.23*	-	
9. Partial Report	0.05	0.04	0.16	0.06	0.47***	0.14	0.04	-0.01	-
10. Age	0.13	0.12	0.03	0.16	0.10	0.06	0.07	0.18	0.02

The correlations are presented within parenthesis. Read10 is level-10 reading comprehension. Read7 is level-7 reading comprehension.

*.<0.05; **.<0.01; ***<0.001; the α level after Bonferroni correction for multiple test is 0.001.

Table 4

Path analysis parameter estimates, their unstandardized/standardized coefficients, standard errors and p-values for unstandardized coefficients.

<u>Parameters</u>	<u>Unstandardized estimate</u>	<u>S.E.</u>	<u>P-Value</u>	<u>Standardized estimate</u>
Read10-VA	10.240	4.693	0.02	0.255
Read10-WR	0.811	0.279	<0.01	0.298
Read10-BD	0.498	0.273	0.06	0.189
Read7-VA	3.116	5.350	0.56	0.066
Read7-WR	1.262	0.319	<0.001	0.396
Read7-BD	0.854	0.312	<0.01	0.277
WR-PD	0.603	0.122	<0.001	0.512
WR-VA	0.152	1.736	0.29	0.088
WR-ELI	-0.195	0.475	0.68	-0.043

PD-ELI	0.733	0.408	0.06	0.195
PD-VA	4.207	1.604	<0.01	0.336

Read10 is level-10 reading comprehension. Read7 is level-7 reading comprehension. VA is visual attention span. WR is word reading. PD is pseudo-word decoding. ELI is Elision, BD is block design.

Table 5

Direct effects and specific indirect effects, their unstandardized/standardized coefficients, standard errors and p-values for unstandardized coefficients.

<u>Effects</u>	<u>est.</u>	<u>S.E.</u>	<u>p-value</u>	<u>Std. est.</u>	<u>Effects</u>	<u>est.</u>	<u>S.E.</u>	<u>p-value</u>	<u>Std. est.</u>
DIR VA-Read10	10.240	4.693	0.02	0.255	DIR Read10-ELI	0.154	1.231	0.90	0.013
IND VA-WR-Read10	0.123	1.408	0.93	0.003	IND ELI-WR-Read10	-0.109	0.393	0.78	-0.009
IND VA-PD-WR-Read10	2.055	1.135	0.07	0.051	IND ELI-PD-WR-Read10	0.396	0.264	0.13	0.033
DIR VA-Read7	3.116	5.350	0.56	0.066	DIR ELI-Read7	1.871	1.420	0.18	0.130
IND VA-WR-Read7	0.192	2.191	0.93	0.292	IND ELI-WR-Read7	-0.159	0.573	0.78	-0.011
IND VA-PD-WR-Read7	3.200	1.600	0.04	0.068	IND ELI-PD-WR-Read7	0.578	0.371	0.12	0.040
DIR VA-WR	0.152	1.736	0.28	0.088	DIR ELI-WR	-0.122	0.440	0.78	-0.028
IND VA-PD-WR	2.535	1.094	0.02	0.172	IND ELI-PD-WR-PD	0.445	0.262	0.08	0.102

Bold rows are (marginal) statistically significant.

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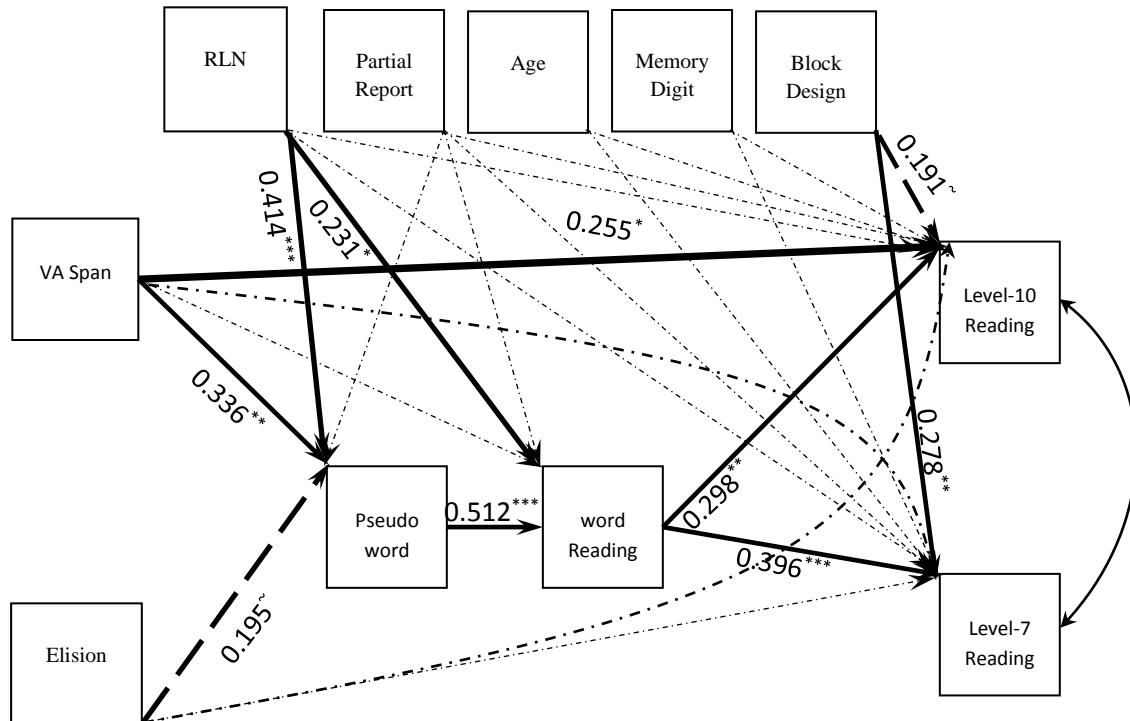


Figure 2. Path diagram for the fitted Model with only significant paths (standardized coefficients) displayed as bold solid lines. Insignificant paths are shown in dashed lines. This figure shows Global VA span has a direct effect on Level-10 reading comprehension, and also has an indirect effect to both levels of reading comprehension via phonemic decoding and word reading skills. Most of the variables controlled for do not have a significant effect on reading comprehension except for block design and rapid letter naming. The labels in Figure 2 are the measurements that correspond to the skills labelled in Figure 1.

- * $\rho \leq 0.05$
- ** $\rho \leq 0.01$
- *** $\rho \leq 0.001$
- ~ $\rho \leq 0.06$