Journal of Experimental Child Psychology 116 (2013) 914–929

Contents lists available at ScienceDirect

Journal of Experimental Child Psychology

journal homepage: www.elsevier.com/locate/jecp

Development of serial processing in reading and rapid naming

Athanassios Protopapas [a,*], Angeliki Altani [b], George K. Georgiou [c]

[a] Department of Philosophy and History of Science, University of Athens, GR-15771 Zografos, Greece
[b] Graduate Program in Basic and Applied Cognitive Science, University of Athens, GR-15771 Zografos, Greece
[c] Department of Educational Psychology, University of Alberta, Edmonton, Alberta T6G 2G5, Canada

ARTICLE INFO

Article history:
Received 11 April 2013
Revised 6 August 2013

Keywords:
RAN
Fluency
Reading
Serial processes
Development
Greek

ABSTRACT

Serial rapid automatized naming (RAN) is more strongly related to reading fluency than naming of isolated words, suggesting that the implementation of serial processing may underlie the RAN–reading relationship. In this study, 107 Greek children from Grade 2 and 107 from Grade 6 were tested with discrete and serial naming of digits, objects, and words in 50-item arrays. The correlation between discrete and serial word reading was very high in Grade 2 but only moderate in Grade 6. In confirmatory factor analysis, a reading–naming latent structure fit the Grade 2 data best; in contrast, a serial–discrete structure fit the Grade 6 data. Thus, the superficial longitudinal stability of RAN–reading correlations belies vastly different patterns of interrelations, indicative of changes in the developing cognitive processes underlying both naming and reading. Word fluency tasks in Grade 2 are apparently accomplished largely as a series of isolated individual word naming trials even though multiple individual letters in each word may be processed in parallel. In contrast, specifically serial procedures are applied in Grade 6, presumably via simultaneous processing of multiple individual words at successive levels. It is proposed that this feat requires endogenous control of cognitive cascades.

Introduction

Rapid automatized naming (RAN) correlates strongly with current and future reading fluency across ages and orthographies (Kirby, Georgiou, Martinussen, & Parrila, 2010). This is presumably

* Corresponding author. Fax: +30 210 727 5530.
E-mail address: aprotopapas@phs.uoa.gr (A. Protopapas).

0022-0965/$ - see front matter © 2013 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.jecp.2013.08.004

due to shared component processes underlying both RAN performance and fluent reading. Thus, RAN is conceptualized as a "microcosm or mini-circuit of the later-developing reading circuitry" (Norton & Wolf, 2012, p. 430). The specific processes underlying these concurrent and longitudinal relations remain largely speculative despite decades of research and a variety of theoretical proposals.

Discrete and serial naming

It has long been known that RAN correlates with reading much more strongly when presented in serial form (i.e., all items printed simultaneously on a single sheet) rather than in discrete form (i.e., individual items presented isolated on the screen) (e.g., Bowers & Swanson, 1991; Chiappe, Stringer, Siegel, & Stanovich, 2002; Stanovich, Feeman, & Cunningham, 1983; see also Wolf & Bowers, 1999, for a brief discussion). The serial nature of processing has recently attracted research interest as a potential link between RAN and reading beyond phonological, orthographic, and other general factors (Georgiou, Parrila, Cui, & Papadopoulos, 2013). Studies have examined the RAN–reading relationship both in the general population and in distinguishing between individuals with dyslexia and typically developing readers.

Jones, Branigan, and Kelly (2009) examined discrete and serial letter naming in English-speaking adults with and without dyslexia. They found that the serial format benefited only nondyslexic readers; in contrast, readers with dyslexia named isolated letters faster than letters in a matrix. The impact of serial processing was attributed to the simultaneous activation of multiple visual and phonological representations. Specifically, in the serial task, processing of the current item requires inhibition of a preceding item. Moreover, efficient uptake of information by proficient readers involves parafoveal previewing of the following items (cf. Dare & Shillcock, 2013; Jones, Branigan, Hatzidaki, & Obregón, 2010; Jones, Obregón, Kelly, & Branigan, 2008; Radach, Inhoff, Glover, & Vorstius, 2013; Yan, Pan, Laubrock, Kliegl, & Shu, 2013). In a related study, Zoccolotti and colleagues (in press) compared serial and discrete naming and reading in Italian children with and without dyslexia. They also found that only typically developing readers benefited from the serial format. To interpret this finding, they suggested that cognitive components must be integrated and synchronized with decoding of the visual stimuli while sequentially naming aloud the targets so that each item can be pronounced while the next one is viewed.

In the general English-speaking population, Logan, Schatschneider, and Wagner (2011) examined the concurrent correlations among reading and naming measures in kindergarten, Grade 1, and Grade 2. They focused on the distinction between discrete and serial naming in accounting for variance in reading accuracy. They found that serial naming predicted reading outcomes after controlling for discrete naming and other measures of phonological processing. In contrast, discrete naming did not contribute to reading accuracy variance after controlling for serial naming but instead acted as a suppressor variable, enhancing the contribution of serial naming. Logan and colleagues rejected the "lexical access" hypothesis, according to which the RAN–reading relationship is due to the need for rapid access of phonological codes. Instead, they suggested that aspects of serial processing such as eye movements and parafoveal processing may form the underlying link between RAN and reading.

De Jong (2011) examined developmental differences in the RAN–reading relationship. He identified two classes of Dutch children in Grades 1, 2, and 4 with different patterns of intercorrelations. In the group including most younger children, serial naming tasks predicted both serial and discrete word reading better than discrete naming tasks. In contrast, in the group including most older children, serial naming tasks predicted serial reading and discrete naming tasks predicted discrete reading better than vice versa. De Jong interpreted this pattern as reflecting a change in the way individual words are processed: Whereas during earlier stages of reading development individual words are processed serially (left to right), during later stages they are processed holistically (by sight). Therefore, in the evolving RAN–reading relationship, serial RAN accounts for serial within-word processes during earlier stages and for serial between-word processes during later stages.

In sum, recent comparisons of discrete and serial naming measures have confirmed that the latter are more strongly related to fluent reading and more diagnostic of reading difficulties. This general observation holds in languages varying greatly in orthographic transparency (English, Dutch, Greek, and Italian), so it is not a feature that is dependent on a specific grain size or depth of orthographic processing. One conclusion that emerges from these investigations is that the speed of accessing phonological lexical forms based on visual stimuli cannot be the main cause of the RAN–reading relationship because discrete naming requires as much phonological access as serial naming. Therefore, we need to separate the distinct contributions of lexical access and serial processing and identify candidate cognitive mechanisms for the latter.

Developmental stability and progress

The concurrent relationship between reading fluency and RAN remains strong throughout development. From the earliest stages of learning to read (e.g., Lervåg & Hulme, 2009) through adulthood (e.g., Vukovic, Wilson, & Nash, 2004), greater reading fluency is related to faster RAN performance. Across languages, the correlation is often found to increase through the elementary grades (Georgiou, Papadopoulos, Fella, & Parrila, 2012; Georgiou, Parrila, Kirby, & Stephenson, 2008; Vaessen & Blomert, 2010; Vaessen et al., 2010).

Spanning an unusually large age range, van den Bos, Zijlstra, and lutje Spelberg (2002) studied the developmental relations between RAN and reading in a set of cross-sectional samples of Dutch children attending Grades 2, 4, 6–7, adolescents (15–17 years old), and adults (36–65 years old). They noted that RAN task groupings were unstable in 8- to 10-year-olds, whereas in the older groups two factors distinguished alphanumeric RAN (numbers and letters) from nonalphanumeric RAN (colors and pictures). The increasing concurrent correlation between naming and reading speed was selective to the alphanumeric naming factor. Therefore, general naming speed cannot explain the RAN–reading relationship. Van den Bos (2008) related the difference to the dual coding theory (Paivio, 1990), hypothesizing that reading and alphanumeric tasks are directly processed in the verbal system, whereas color and picture stimuli must pass through the imagery system (cf. Georgiou, 2010).

In sum, the relationship between RAN and reading fluency appears to be strong and stable or increasing. However, neither stability nor increased correlation entails fixed patterns of interrelations among underlying processes. The fact that RAN remains a strong concurrent predictor of reading fluency throughout development does not mean that either RAN or fluent reading is accomplished by a developmentally fixed set of cognitive mechanisms. Conceivably, RAN and reading may involve one common set of cognitive mechanisms in early development and a different common set of cognitive mechanisms after expertise is attained. In both cases, RAN and reading performance would be strongly correlated due to the common processes, but different sets of common processes may be involved at each stage.

Moreover, even if a relatively stable set of cognitive processes were responsible for carrying out each task (i.e., reading and naming), it is conceivable that the correlation between the two tasks might be dominated by a developmentally variable subset of processes. As processes mature, variance may tend to decrease in certain developmentally limited cognitive domains and to increase in other more expansive domains. Therefore, even for the same set of tasks, individual differences might shift from being determined primarily by one set of subcomponents toward gradually being determined by a different set of subcomponents. The magnitude and stability of correlation coefficients across development cannot be taken to indicate a fixed cognitive substrate. A better understanding of the developmental interrelations among RAN and reading tasks is required before more specific pronouncements can be made about their constituent components and underlying cognitive mechanisms across ages.

Rationale and scope of the current study

The relationship between RAN and reading continues to baffle researchers. A common strategy has been to examine the contribution of RAN to reading after controlling for the effects of a presumed mediator. The assumption is that if a processing skill, X, is responsible for the RAN–reading relationship, then controlling for the effects of X should eliminate the RAN–reading correlation. Research has shown, however, that RAN continues to predict reading even after controlling for several constructs such as general cognitive ability (e.g., Badian, 1993), speed of processing (e.g., Bowey, McGuigan, & Ruschena, 2005), letter knowledge (e.g., Kirby, Parrila, & Pfeiffer, 2003), phonological memory (e.g., Bowers, Steffy, & Tate, 1988), articulation rate (e.g., Parrila, Kirby, & McQuarrie, 2004), paired-associate learning (e.g., Lervåg, Bråten, & Hulme, 2009), orthographic knowledge (e.g., Moll, Fussenegger, Willburger, & Landerl, 2009), phonological awareness (e.g., Kirby et al., 2003; Papadopoulos, Georgiou, & Kendeou, 2009), and various combinations of the above (e.g., Bowey et al., 2005; Lervåg et al., 2009; Parrila et al., 2004). Moreover, all of these presumed mediators apply equally to discrete and serial naming. Phonological, orthographic, and articulatory processing are needed as much for naming single items as for naming sequences of symbols. Therefore, to the extent that serial naming is much more strongly related to reading than discrete naming, none of these approaches could ever offer an explanation for the RAN–reading relationship. Hence, we need to study in more detail the differences between serial and discrete naming and to understand what aspects of serial processing are responsible for the relationship with reading and how they develop.

In the current study, we set out to explore the interrelations among a set of naming and reading tasks in two developmentally distinct points, namely Grades 2 and 6. We were primarily interested in the distinction between serial and discrete naming and in the corresponding contributions to reading performance in beginning and intermediate readers. Of particular importance is de Jong's (2011) finding that discrete and serial word reading were more strongly correlated in the beginner group than in the more advanced readers. If this finding could be replicated and related specifically to RAN, it would suggest that we may be able to use discrete and serial naming performance to study the developing mechanisms responsible for the transition from individual word reading toward fluent reading of word lists or sentences.

To examine the changing interrelations between reading and naming, we focused on the role of discrete word reading in accounting for serial word reading variance and thereby potentially mediating the RAN–reading relation. We administered discrete and serial versions of digit and object naming, thereby covering both the alphanumeric and nonalphanumeric domains. We extended de Jong's (2011) study in two important respects. First, instead of analyzing vocal onset latency for the discrete tasks, we analyzed the total production time, including articulation. In this way, serial and discrete measures can be directly compared and contrasted across content types and age groups. Second, instead of using monosyllabic words, which are rare and unrepresentative in Greek (Protopapas & Vlahou, 2009), we used words with two or three syllables. Thus, if the same findings can be replicated, they cannot be attributed to any special features of very short items. Overall, our objective was to identify developmental differences in the patterns of interrelations among naming and reading tasks that might be indicative of differences in underlying cognitive processes.

Methods

Participants

In total, 107 Greek children (54 girls and 53 boys, mean age = 94.0 months, *SD* = 3.3) attending Grade 2 and 107 children (58 girls and 49 boys, mean age = 141.7 months, *SD* = 3.8) attending Grade 6 participated in the experiment with parental consent. Children were recruited on a voluntary basis from the general student population in three public schools at a middle-class Athens province after obtaining research permission from the Greek Ministry of Education. Based on the level and range of participation, we expected this sample to be roughly representative of the general urban population. No standardized tests were administered due to time restrictions.

Materials

Four naming tests were administered: serial and discrete RAN digits (RAN-D) and RAN objects (RAN-O). Digits consisted of 2, 3, 5, 7, and 9, pronounced /'ðio/, /'tria/, /'pɛndɛ/, /ɛ'fta/, and /ɛ'ɲa/, respectively; these words were bisyllabic, including three with penultimate-syllable stress and two with final-syllable stress. They were presented in black 28-point Arial font on white background. Objects consisted of color drawings of an apple, a chicken, a vase, a gift, and a ball, pronounced /'milo/, /'kota/, /'vazo/, /'ðoro/, and /'bala/, respectively; these words were bisyllabic and had penultimate-syllable stress.

There were also two reading tests: serial and discrete isolated word reading. Each test consisted of 50 items, specifically 31 two-syllable and 19 three-syllable frequent words selected from a word fluency list used in reading research (e.g., Protopapas, Sideridis, Simos, & Mouzaki, 2007). All words were among the 1000 most frequent words in the Hellenic National Corpus (Hatzigeorgiu et al., 2000), whereas the easiest items also appeared in the "basic vocabulary" selection of the second-grade reading textbook.

Previous studies in Greek have shown high test–retest reliability for RAN-D and RAN-O (.87 and .83 in Grade 2 and .90 and .80 in Grade 6, respectively; Georgiou et al., 2012) and very high alternate–list correlation for word fluency lists including these words (.94 in Grades 2–4; Protopapas et al., 2007). The internal reliability (Cronbach's α) of raw response times in the three 50-item discrete tasks in the current sample was .96 to .97 for Grade 2 and .98 for Grade 6.

Procedure

Serial RAN tests were presented in a single-screen array of five rows of 10 items. The serial word list was presented in a single-screen array of five columns of 10 items. For each test, the child was presented with the corresponding naming set on the computer screen and was asked to name (or read) aloud the items one by one as quickly as possible without making mistakes. Production of the intended words was verified prior to the digit and object tasks. Each task was simultaneously recorded on the computer via a headset. For all of the serial tasks, the total naming duration from the onset of naming the first item to the offset of the last one was subsequently measured on the waveform using Praat (Boersma & Weenink, 2012).

For the discrete tasks, presentation and response recording was controlled by the DMDX experimental display software (Forster & Forster, 2003). Each item was presented isolated on the screen, black on white background, for a limited time period or until a vocal response was detected using the microphone trigger. Words were displayed in 25-point Arial Narrow font; digits were displayed in 45-point Arial font. The intertrial interval was 750 ms. The maximum presentation time was 2000 ms per item for all naming tasks and 3000 ms for Grade 6 word reading. In Grade 2, words remained on the screen until the experimenter pressed a key to proceed to the next item following a completed production by the child. Individual responses were recorded in audio files, on which accuracy was subsequently marked using CheckVocal (Protopapas, 2007). Response time was measured from the appearance of an item on the screen until the acoustic offset of the spoken word, including both onset latency and articulation time.

Administration alternated between word and RAN tasks in the same fixed order for all participants: (1) serial digits, (2) discrete words, (3) discrete objects, (5) discrete digits, (6) serial words, and (7) serial objects. The reported tasks were interspersed within a larger testing battery of 13 tasks that took approximately 40 min to administer.

Results

Data preparation

Serial naming and reading times were inverted and multiplied by the number of items to produce measures of items per second. Errors, omissions, and self-corrections were very rare and were not taken into account in the analyses. For the discrete measures, mean response times per participant were computed based on correct responses only. Discrete word reading performance for one child in Grade 2 was discarded due to a technical error in stimulus presentation timing. Additional data points were excluded if the error rate exceeded 20% (10 items), which occurred for five children in discrete words and one child in discrete objects (all in Grade 2).

Discrete naming and reading times were inverted and multiplied by 1000 to produce comparable scales with serial naming and to bring the data closer to the normal distribution. A few outliers were noted, including one data point (>1500 ms) in Grade 6 discrete word reading, one data point (>70 s) in Grade 2 serial RAN-D, and three data points (>2000 ms) in Grade 2 discrete word reading. Table 1 pre-

Table 1
Descriptive statistics and tests of normality.

	Descriptives					Shapiro–Wilks	
	N	M	SD	Skew	Kurtosis	W	*p*
Grade 2							
Discrete RAN-O	106	0.88	0.11	.27	−.16	.99	.60
Discrete RAN-D	106	0.99	0.13	.12	−.18	.99	.78
Discrete words	102	0.76	0.12	.24	−.34	.99	.31
Serial RAN-O	107	0.96	0.20	.08	−.68	.99	.48
Serial RAN-D	106	1.58	0.33	.60	−.71	.97	.01
Serial words	107	0.99	0.33	.26	−.27	.99	.55
Grade 6							
Discrete RAN-O	106	1.07	0.13	.21	−.53	.99	.40
Discrete RAN-D	106	1.22	0.15	.29	−.40	.99	.32
Discrete words	105	1.00	0.11	.50	−.45	.97	.01
Serial RAN-O	107	1.36	0.22	−.11	−.32	.99	.88
Serial RAN-D	107	2.13	0.47	.09	−.10	.99	.74
Serial words	107	1.60	0.33	.06	−.43	.99	.42

Note: All measures are in items (symbols or words) per second. O, objects; D, digits.

sents the descriptive statistics for each measure, excluding these outliers. Exclusion left 101 complete datasets in Grade 2 and 105 in Grade 6.[1] Examination of Q–Q plots and the Shapiro–Wilks test of normality indicated no significant deviations from normality except for a mild deviation of Grade 2 serial RAN-D and Grade 6 serial word reading. All analyses were conducted using R (R Core Team., 2012).

Comparisons across grades and tasks

Fig. 1 plots the means for each task as a function of grade. In a 2 (Grade) × 2 (Format) × 3 (Content) mixed-effects analysis of variance (ANOVA) with Huynh–Feldt sphericity correction for *p*, there was a significant triple interaction, $F(2,408) = 4.74$, $\tilde{\varepsilon} = .86$, $p = .013$, $\eta^2_G = .003$.[2] In subsequent 2 × 2 analyses, all two-way interactions were significant as well, necessitating examination of simple effects.

Grade 6 performance was significantly better than Grade 2 in every task (serial objects: $F(1,204) = 184.62$, $\eta^2_G = .475$; serial digits: $F(1,204) = 89.72$, $\eta^2_G = .305$; serial words: $F(1,204) = 167.92$, $\eta^2_G = .451$; discrete objects: $F(1,204) = 118.35$, $\eta^2_G = .367$; discrete digits: $F(1,204) = 133.53$, $\eta^2_G = .396$; discrete words: $F(1,204) = 217.45$, $\eta^2_G = .516$; all $ps < .0005$).

The difference between grades was greater in the serial format than in the discrete format for every type of content (Grade × Format interaction, objects: $F(1,204) = 67.23$, $\eta^2_G = .090$; digits: $F(1,204) = 31.20$, $\eta^2_G = .062$; words: $F(1,204) = 85.83$, $\eta^2_G = .113$; all $ps < .0005$). The difference between grades was greater for digits and words than for objects in both formats (Grade × Content interaction, serial digits–objects: $F(1,204) = 8.11$, $p = .005$, $\eta^2_G = .012$; serial words–objects: $F(1,204) = 23.97$, $p < .0005$, $\eta^2_G = .029$; discrete digits–objects: $F(1,204) = 13.54$, $p < .0005$, $\eta^2_G = .007$; discrete words–objects: $F(1,204) = 14.34$, $p < .0005$, $\eta^2_G = .014$), but there was no difference between digits and words (serial: $F(1,204) = 0.85$, $p = .357$, $\eta^2_G = .001$; discrete: $F(1,204) = 0.54$, $p = .462$, $\eta^2_G = .001$).

In direct comparison among the serial tasks, in both grades digits were faster than words (Grade 2: $F(1,100) = 321.81$, $p < .0005$, $\eta^2_G = .448$; Grade 6: $F(1,104) = 204.05$, $p < .0005$, $\eta^2_G = .295$) and words

[1] Analyses were conducted (a) with the cleaned-up dataset as described, removing incomplete cases only when necessary (i.e., for regression and ANOVA but not for correlation and factor analysis where pairwise correlations suffice); (b) with a complete-case subset, including only the children for whom acceptable data were available in every task; and (c) with the raw dataset—all tasks from all children—including outliers and data from low-accuracy runs. There were no qualitative differences among the results of these alternative analyses. Only results from the cleaned-up dataset are reported. In addition, all analyses were also conducted using onset latency instead of total production time (i.e., excluding articulation time), producing very similar results (not reported).

[2] Effect sizes are reported as generalized eta-square (Bakeman, 2005; Olejnik & Algina, 2003) provided by R package ez (Lawrence, 2012).

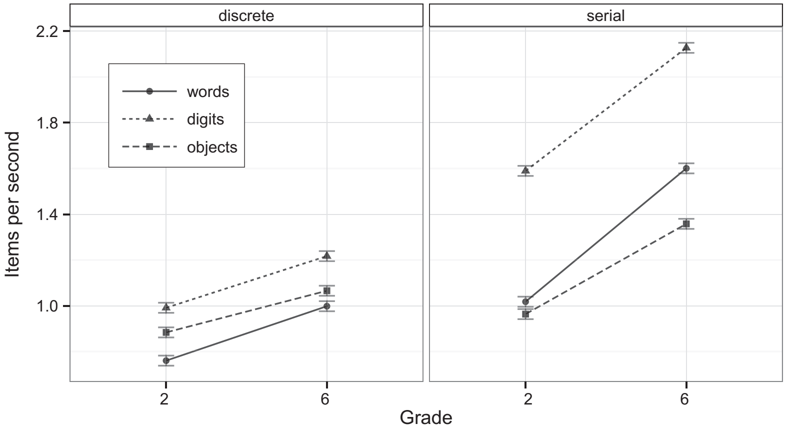

Fig. 1. Mean performance in each task per grade. Error bars show between-participants standard errors.

were faster than objects (Grade 2: $F(1,100) = 4.07$, $p = .046$, $\eta^2_G = .011$; Grade 6: $F(1,104) = 77.74$, $p < .0005$, $\eta^2_G = .157$). In direct comparison among the discrete tasks, in both grades digits were faster than objects (Grade 2: $F(1,100) = 168.26$, $p < .0005$, $\eta^2_G = .164$; Grade 6: $F(1,104) = 315.76$, $p < .0005$, $\eta^2_G = .232$) and objects were faster than words (Grade 2: $F(1,100) = 106.97$, $p < .0005$, $\eta^2_G = .228$; Grade 6: $F(1,104) = 58.41$, $p < .0005$, $\eta^2_G = .072$).

Notably, Grade 2 performance on digits was indistinguishable from Grade 6 performance on words in both formats (serial: $F(1,204) = 0.06$, $p = .809$, $\eta^2_G < .001$; discrete: $F(1,204) = 0.16$, $p = .688$, $\eta^2_G < .001$); their variances also did not differ (by Levene's test, serial: $F(1,204) = 0.36$, $p = .548$; discrete: $F(1,204) = 2.89$, $p = .091$).

Patterns of correlations among tasks

Table 2 shows the correlations among the measures separately for each grade. Focusing on the relationship between word reading and RAN, it is evident that the correlation coefficients are higher among common-format tests in Grade 6 (i.e., serial words with serial RAN and discrete words with discrete RAN) than among mismatching-format tests. In contrast, in Grade 2 the correlation coefficients of discrete and serial words with serial and discrete RAN are very similar. An additional difference is apparent: In Grade 2 serial words correlated very highly with discrete words, whereas in Grade 6 serial words correlated much less strongly with discrete words than with serial RAN.

Table 2
Correlations among tasks for each grade.

	dRAN-O	dRAN-D	dWord	sRAN-O	sRAN-D	sWord
Discrete RAN-O		.80***	.73***	.44***	.11	.32**
Discrete RAN-D	.77***		.68***	.33**	.12	.26*
Discrete words	.47***	.50***		.37***	.19	.42***
Serial RAN-O	.50***	.46***	.51***		.37***	.54***
Serial RAN-D	.29**	.38***	.42***	.65***		.61***
Serial words	.30**	.37***	.83***	.53***	.52***	

Note: Pearson's product–moment correlation coefficients are shown. Grade 2 is below the diagonal; Grade 6 is above the diagonal. d, Discrete; s, serial; O, objects; D, digits.
* $p < .05$.
** $p < .005$.
*** $p < .0005$.

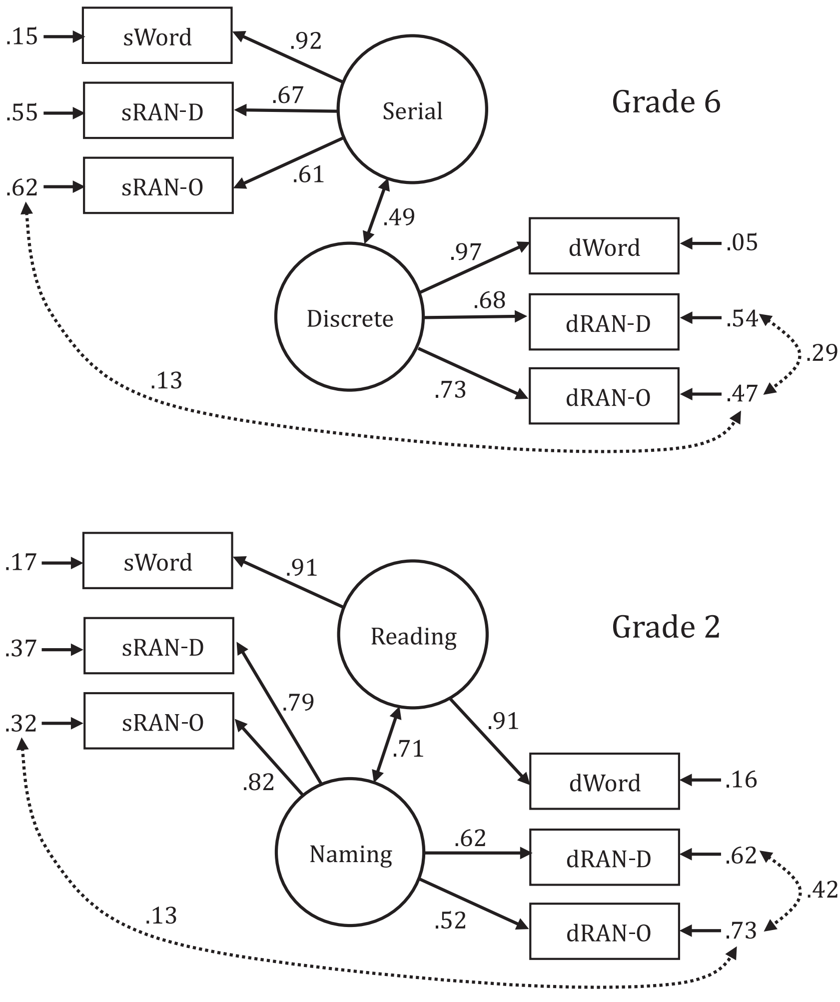

Fig. 2. Best-fitting models resulting from confirmatory factor analysis. Standardized coefficients are shown (latent disturbances set to 1.0). All indicated loadings are statistically significant ($p < .01$). s, serial; d, discrete; O, objects; D, digits.

Correlation coefficients for different groups were compared via a z transformation (Cohen & Cohen, 1983) implemented in the cordif function of the multilevel R package (Bliese, 2012). Conservative correction for 15 comparisons, performed via Bonferroni adjustment to $a = .0033$, allowed only two significant differences to emerge, namely the correlation of discrete words with serial words, which was significantly lower in Grade 6 than in Grade 2, and the correlation between discrete words and discrete RAN-O, which was significantly lower in Grade 2 than in Grade 6. Taking into account the magnitude of the corresponding correlation coefficients, this suggests that discrete words was a lot like serial words in Grade 2 but more like discrete objects in Grade 6. An additional correlation barely missed the correction; serial RAN-D and serial RAN-O were marginally more strongly correlated in Grade 6 than in Grade 2.

To further investigate these patterns of correlations, we performed exploratory factor analyses. Parallel analysis (Horn, 1965) and the "very simple structure" criterion (Revelle & Rocklin, 1979), as provided in R package psych (Revelle, 2012), suggested that two factors should be extracted. Two-factor maximum-likelihood extraction with oblimin rotation was carried out for each grade. Grade 2 solutions resulted in an apparent distinction between a "reading" dimension and a "naming" dimen-

Table 3
Multiple regressions predicting serial words in each grade.

	Grade 2[a]		Grade 6[b]	
	β	*p*	*β*	*p*
Discrete RAN-O	−.29	.001	−.01	.959
Discrete RAN-D	.09	.302	−.09	.468
Discrete words	.79	<.001	.29	.007
Serial RAN-O	.15	.054	.30	<.001
Serial RAN-D	.12	.087	.45	<.001
Total R^2	.75		.54	
Discrete RAN-O	−.24	<.001		
Discrete words	.82	<.001	.23	.002
Serial RAN-O	.23	<.001	.29	<.001
Serial RAN-D			.46	<.001
Total R^2	.73		.53	
Discrete RAN-D&O	−.18	.005	−.07	.479
Discrete words	.80	<.001	.29	.005
Serial RAN-D&O	.24	<.001	.62	<.001
Total R^2	.73		.53	

Note: Standardized regression coefficients and associated probabilities from simultaneous multiple regressions are shown. Top: including all predictors; middle: excluding nonsignificant predictors; bottom: using pooled RAN predictors. O, objects; D, digits; D&O, average of objects and digits.
[a] $N = 101$.
[b] $N = 105$.

sion, whereas Grade 6 solutions led to a distinction between a "serial" dimension and a "discrete" dimension. Confirmatory factor analyses were subsequently carried out on the basis of these groupings using R package sem (Fox, Nie, & Byrnes, 2012). The reading–naming model for Grade 2 (Fig. 2, bottom) produced a nearly acceptable fit ($\chi^2 = 14.13$, $df = 6$, $p = .028$, goodness-of-fit index (GFI) = .956, Tucker–Lewis non-normed fit index ($NNFI$) = .991, Bentler comparative fit index (CFI) = .996, standardized root mean square residual ($SRMR$) = .077, root mean square error of approximation ($RMSEA$) = .113). A corresponding reading–naming model for Grade 6 did not fit the data well ($\chi^2 = 32.25$, $df = 6$, $p < .0005$, $GFI = .899$, Tucker–Lewis $NNFI = .963$, Bentler $CFI = .985$, $SRMR = .178$, $RMSEA = .203$). In contrast, the serial–discrete model for Grade 6 (Fig. 2, top) produced an acceptable fit ($\chi^2 = 7.90$, $df = 6$, $p = .246$, $GFI = .975$, Tucker–Lewis $NNFI = .997$, Bentler $CFI = .999$, $SRMR = .078$, $RMSEA = .055$), whereas the corresponding model for Grade 2 did not ($\chi^2 = 25.87$, $df = 6$, $p < .0005$, $GFI = .919$, Tucker–Lewis $NNFI = .978$, Bentler $CFI = .991$, $SRMR = .103$, $RMSEA = .177$). In each case, error covariance was modeled for the two object naming tasks and the two discrete RAN tasks. Although model fit was not perfect, these analyses confirmed that there are very substantial differences in the pattern of intercorrelations between the two grades.

Prediction of reading fluency

Finally, we conducted regression analyses to determine any specific contribution of naming tasks to word reading fluency (i.e., serial words) beyond the effect of discrete words. These analyses may help us to identify the crucial aspects of serial naming that are predictive of reading fluency. Analyses were carried out in two steps. First, all RAN measures and discrete words were included as predictors, as shown in the top part of Table 3. Subsequently, nonsignificant predictors were removed from the equation, resulting in models with three predictors that did not differ significantly from those with the full predictor set ($p > .05$ via χ^2 test) and accounted for the same proportion of variance (differences in multiple R^2 not exceeding .02), as shown in the middle part of Table 3. Evidently, discrete words was the dominant predictor in Grade 2, whereas serial RAN appeared to be most important in Grade 6.

The high intercorrelations among certain predictor variables may cause concern regarding masking of significant effects due to multicollinearity. Although variance inflation factors fell within a range of

Table 4
Variance proportions in the prediction of serial words.

Variable	Grade 2[a]			Grade 6[b]		
	Unique	Common	Total	Unique	Common	Total
Discrete RAN-O	.03	.06	.09	.00	.10	.10
Discrete RAN-D	.00	.14	.14	.00	.07	.07
Discrete words	.41	.28	.69	.04	.14	.18
Serial RAN-O	.01	.27	.28	.06	.23	.29
Serial RAN-D	.00	.27	.27	.17	.20	.37

[a] $N = 101$.
[b] $N = 105$.

1.18–3.80, condition numbers above 40 were observed in both grades with corresponding variance decomposition proportions of discrete digit and object naming both exceeding .5 (calculated using R package perturb; Hendrickx, 2012). Therefore, an additional set of regression analyses was carried out with the two discrete RAN measures combined into a single discrete RAN variable and the two serial RAN measures combined into a single serial RAN variable. The results, shown in the bottom part of Table 3, confirmed that discrete naming fails to account for significant word fluency variance in Grade 6. In contrast, removing discrete RAN from the Grade 2 fluency prediction resulted in a model with significantly inferior fit and diminished coefficients for both discrete words and serial RAN. Moreover, the regression coefficient for discrete RAN was negative even though its correlation coefficient with word fluency was positive. This is consistent with a suppressive effect (Maassen & Bakker, 2001), indicating that the contribution of serial RAN tasks to Grade 2 fluency is unrelated to responding to individual items within the RAN arrays.

To further dissect the relative contributions in terms of unique and shared variance, we conducted a commonality analysis using R package yhat (Nimon & Roberts, 2012). Table 4 lists the variance proportions for each predictor variable as contributed to word fluency in each grade. Discrete words came out with the largest (by far) unique and total variance proportion accounted for in Grade 2. In contrast, it was a minor contributor in Grade 6, not even sharing much variance with other predictors.

Discussion

We administered reading and naming tasks to Greek children in Grades 2 and 6, aiming to uncover differences in the RAN–reading relationship between different stages of reading development. We replicated in Greek (a) the pattern of results reported by de Jong (2011) in Dutch for two stages in reading development, (b) the suppressive effect of discrete RAN on the RAN–reading relationship in the early grades reported by Logan and colleagues (2011) in English, and (c) the advantage of the serial format for reading and naming times (compared with the discrete format) reported by Jones and colleagues (2009) in English and by Zoccolotti and colleagues (in press) in Italian.

The high correlation between discrete and serial word reading in Grade 2 suggests that serial word processing in Grade 2 is not very different from processing one word at a time. A different picture emerged in Grade 6, with close alignment among serial tasks and (distinctly) among discrete tasks and a much lower correlation between serial and discrete reading. Evidently, advanced readers do not process individual word stimuli separately in serial tasks but employ some kind of overlapping. These findings indicate that the relative stability of moderate to high correlations between reading and naming belie qualitative developmental differences in how reading and naming tasks are carried out. How should we then interpret the concurrent and longitudinal prediction of reading performance by rapid naming measures to take these developmental shifts into account?

Development of processing cascades

Our data are correlational, involving no experimental manipulations, and not aimed at testing particular hypotheses by design. Moreover, they are cross-sectional, including only two age groups, and thus are inadequate to directly support longitudinal inferences. Despite these limitations, we propose a speculative framework for the interpretation of these findings in the context of the recent RAN–reading literature.

Specifically, in the following discussion, we entertain the hypothesis that the serial tasks are increasingly carried out in a cascaded manner. That is, individual items pass through a pipeline of visual recognition, mapping to phonology and then on to articulatory planning. Multiple items are processed simultaneously, so that one item may be processed phonologically while the preceding one is articulated and the next one is recognized visually (cf. Inhoff, Solomon, Radach, & Seymour, 2011; Jones, Ashby, & Branigan, 2013; Morgan & Meyer, 2005). Therefore, the notion of cascade includes (a) *serial* processing of each item through successive stages, (b) *serial* processing of successive items, and (c) *parallel* processing of multiple items in the various stages. Efficient implementation of the cascade would seem to require a high degree of parallelism. When individual items can be processed automatically, executive control schedules and monitors the passage of distinct items through processing stages.

Developmental differences in how word reading is carried out were already emphasized by de Jong (2011). He suggested that the relationship with RAN can help us to identify distinct word reading strategies, shifting from serial to holistic word processing. We extend this idea by suggesting that (a) not only word reading but also processing of naming tasks undergoes major developmental changes, (b) the crucial shift involves the ability to simultaneously process multiple items in a cascaded manner, (c) for word reading this may concern both intraword processes (i.e., sets of letters or syllables within words) and interword processes (i.e., multiple words viewed together in a list or passage), and (d) the relative timing between reading and naming tasks in the shift from an isolated mode of processing to a cascaded one may be attributed to the properties of the stimuli. Thus, the concurrent and longitudinal correlations between RAN and reading may be sought in the emerging parallel processing for items of varying complexity and constitution. In the following sections, we elaborate on this hypothetical framework, discussing in turn the reading tasks, the naming tasks, and the developmental relationship between them.

A microcosm of which reading?

Wolf and Bowers (1999); see also Norton and Wolf (2012) considered RAN to be a microcosm of reading. However, if the cognitive processes underlying successful reading performance are not stable throughout development, then the basis of the concurrent correlation between RAN and reading at some skill level may differ widely from that in another skill level. It may also differ from the basis of the longitudinal correlation that allows prediction of future reading skill from early RAN performance.

Our findings largely replicate those of de Jong (2011) in that serial digit naming was a better predictor of both serial and discrete word reading in beginning readers. In contrast, in more advanced readers discrete naming was a better predictor of discrete word reading and serial naming was a better predictor of serial reading. De Jong interpreted this finding as reflecting serial processing within individual words during the earlier stages insofar as unfamiliar words must be decoded grapheme by grapheme. In contrast, during later stages, many words are identified by sight (i.e., as a whole); therefore, no serial processing need apply word internally. In other words, de Jong interpreted serial RAN as related to both intraword and interword serial processes—the former in beginning readers, the latter in advanced readers. For developing readers, discrete word reading is accomplished serially, and serial RAN reflects this seriality. A high correlation between serial and discrete word reading in beginning readers is consistent with this interpretation insofar as individual words are processed serially in both tasks.

For advanced readers, many words are recognized by sight, but pseudowords are unfamiliar and would presumably require serial processing (even if parts of them can be recognized holistically; cf. Moll et al., 2009). If serial RAN reflected serial intra-item decoding, then it should be more highly correlated with pseudoword reading than with word reading. This prediction has not been borne out in recent work (Dutch: de Jong, 2011; English: Clarke, Hulme, & Snowling, 2005; Greek: Georgiou, Parrila, & Papadopoulos, 2008, but cf. Georgiou et al., 2012; German: Moll et al., 2009). More generally, it has been noted in reviews that RAN is not a good predictor of nonword reading (e.g., Manis, Seidenberg, & Doi, 1999; Wolf & Bowers, 1999). Moreover, under the serial intraword processing hypothesis, serial RAN should also be more highly correlated with multisyllabic word reading than with monosyllabic word reading even for advanced readers. This prediction is at odds with Dutch data (de Jong, 2011; van den Bos, 2008; van den Bos, Zijlstra, & van den Broeck, 2003) and Greek data (Georgiou, Parrila, Papadopoulos, & Scarborough, 2010).

We agree with de Jong (2011) that the core explanatory hypothesis concerns the changing nature of the reading process from beginning to advanced stages. We propose that for beginning readers the task of serial word reading is accomplished largely in a sequence of self-contained steps, each involving the discrete processing of an isolated word. This accounts for the high correlation between serial and discrete word reading in Grade 2. In contrast, by Grade 6 children have become efficient in processing individual words and can sequence successive stimuli in a cascaded manner. At this age, serial word reading is no longer dominated by the recognition of individual words; hence, discrete word reading correlates less strongly with it.

Discrete versus serial naming

Discrete and serial naming exhibited notable differences between grades. The correlation between discrete digit and object naming was essentially identical in the two grades, whereas the correlation between the serial versions was significantly higher in Grade 2 than in Grade 6. The more than 50% shared variance between the two discrete naming tasks seems unrelated to fluent reading because discrete RAN did not contribute unique variance to serial words in Grade 6 and suppressed variance related to single-item processing in Grade 2. In contrast, the variance shared among the serial naming tasks was related to fluent reading in both grades, as revealed in the commonality analysis.

This pattern may be interpreted by taking into account the nature of the stimuli. Digit naming involves direct arbitrary mappings of visual symbols to phonological labels (cf. Manis et al., 1999). In contrast, object naming must be mediated by conceptual activation from the recognition of the depicted object, followed by selection of the corresponding lexical lemma (Poulsen & Elbro, 2013; cf. Roelofs, 2003). Thus, digit naming can be inherently faster than object naming (e.g., Georgiou et al., 2012; van den Bos et al., 2002; also mentioned in reviews, e.g., Norton & Wolf, 2012). Individual differences in symbol naming, related to efficient visual processing and phonological retrieval may be largely in place by Grade 2 and underlie the correlation between discrete digit and object naming across ages.

Turning to the serial tasks, automatization of the unmediated mappings in digit naming would permit efficient scheduling of successive items into cascades. Individual differences in serial digit naming gradually become dominated by the more demanding aspect of cognitive sequencing. Thus, the correlation between serial and discrete digit naming is diminished by Grade 6. In contrast, automatization remains limited in object naming due to conceptual mediation (cf. Poulsen & Elbro, 2013) for both formats of the task. Therefore, serial and discrete object naming remain correlated through Grade 6. The bulk of individual differences shifts from individual to cascaded processing in alphanumeric serial naming more than in nonalphanumeric serial naming. This shift causes the correlation between serial digit and serial object naming to diminish as well.

Although the hypothesis of an efficient cascade is speculative, not directly indicated by our data, recent work on RAN is consistent with this interpretation. For example, the eye–voice span extends beyond the fixation time, indicating look-ahead of upcoming items while articulating previous items (cf. Inhoff et al., 2011; Jones et al., 2010, 2013; Logan et al., 2011; Morgan & Meyer, 2005). Moreover, shorter overall naming times are observed when the same stimuli are presented in serial form rather than in discrete form (Jones et al., 2009; Yan et al., 2013; Zoccolotti et al., in press). This facilitation would not be possible without some form of overlapping processing for successive items. Our proposal highlights the differential development of cognitive components underlying serial RAN performance. These include (a) direct and conceptually mediated visual–verbal mapping, (b) simultaneous processing of multiple items, and (c) executive scheduling and monitoring of the individual stimuli to maximize efficiency and minimize interference (cf. Jones et al., 2013).

Development of parallel processing

It is notable that Grade 2 digit naming performance was indistinguishable from Grade 6 word performance both in absolute levels and in intercorrelations between serial and discrete tasks. This is consistent with the idea that cascaded processing in multistimulus arrays depends on the automatization of processing the individual array components and not on general cognitive maturation. If processing of individual digits is simpler than processing individual words, then cascaded processing may be possible for digits well before it is possible for words. Perhaps this is why children with dyslexia, who are greatly hampered by the serial format in word reading, are nevertheless able to benefit somewhat from multiple-item displays in digit and color naming (Yan et al., 2013; Zoccolotti et al., in press).

RAN items may be easier to process than words because of their single-symbol length, small set size (closed set for digits), earlier visual familiarity, or any combination of these. The use of simple stimuli for a reading-like process of visual–verbal association and articulatory output exposes individual differences in cognitive functions that are crucial for reading development. This may help to explain why serial naming tasks are strong longitudinal predictors of word reading even before reading instruction as well as a strong concurrent and longitudinal classifier of reading difficulties (Bishop & League, 2006; Georgiou, Parrila, Manolitsis, & Kirby, 2011; Landerl & Wimmer, 2008).

Individual differences in cascaded processing of list items may index the future ability of children to make progress in both intraword and interword processes, that is, to move on (a) from multiple individual grapheme–phoneme associations toward "sight-word" reading and (b) from isolated word recognition toward fluent reading of sentences. Cascaded processing entails successful parallel processing of multiple stimuli, or aspects of stimuli, in separate streams that must be kept distinct. In serial RAN tasks, parallel streams concern successive symbols, one of which is articulated while the next is processed. Parallel processing of multiple elements might also underlie effective word decoding in beginning to intermediate readers (perhaps after an early stage of serial letter-by-letter processing). If word recognition is not yet sufficiently automated to yield holistic sight-word responses, individual letters must be handled simultaneously, in distinct parallel streams, to achieve an orthographic match.

De Jong (2011) suggested that serial RAN correlates with early reading because individual words are processed in parts. Our proposal differs in proposing a parallel, rather than serial, process of handling the individual word parts. The shift in focus from serial to simultaneous processing may help to accommodate findings of increased and persistent confusion among adjacent RAN items associated with poor reading performance (Jones et al., 2008, 2010, 2013). It is also consistent with findings that readers with dyslexia are increasingly hampered with multiple-item displays of longer words (Zoccolotti et al., in press) or more digits (Hawelka & Wimmer, 2005), are affected less by removal of parafoveal information (Yan et al., 2013), and have a narrower visual attention span (Bosse, Tainturier, & Valdois, 2007). This is not an issue limited to dyslexia because the size of the visual span is developmentally related to reading performance in typically developing samples as well (Kwon, Legge, & Dubbels, 2007).

Limitations and prospects

Findings in Greek have so far aligned well with findings in other languages with relatively transparent orthographies (Georgiou, Parrila, & Liao, 2008; Georgiou et al., 2008). Therefore our choice of language is not expected to limit the prospects for generalization. Nevertheless, more cross-linguistic research will be necessary before general conclusions can be drawn. The picture may be different in less transparent orthographies considering less developed reading skills that require primary considerations of accuracy rather than fluency.

Currently, the cascaded processing hypothesis is but a speculative framework of interpretation. We propose it on the basis of cross-sectional correlational data that cannot support causal inferences. Further substantiation with targeted experimental research must examine whether there is any lasting theoretical value in it.

An additional challenge arises for models of word recognition, which concern processing of a single stimulus at a time. The observed advantage of naming lists over discrete items suggests that we may need to address fluent reading as an internally generated control process. This process simultaneously engages and disengages different items at different stages, in sync with visual input and articulatory output, while retaining individuated representations throughout the pipeline. If reading performance depends on the efficiency of this process, then it may need to be incorporated into future cognitive models of reading and its failures.

Conclusions

We administered a set of discrete and serial naming and reading tasks to Greek children in Grades 2 and 6. We found substantial differences in the pattern of shared and nonshared variance among these tasks. We suggest that the relationship between reading and RAN, and the reason for their concurrent and longitudinal correlations, does not remain constant throughout development. Itemized processing during the early stages of each task turns into efficient cascaded processing through lists as skills develop and processing of individual items can be automatized and effectively isolated. The precise temporal progression underlying this development may vary substantially between tasks, stimulus domains, and orthographies. Further understanding of naming and reading may arise from a focus on the development of cognitive cascades processing individual stimuli with arbitrary mappings between visual–orthographic and phonological–articulatory forms.

Acknowledgments

We are grateful to Peter de Jong, Rauno Parrila, Jessica Logan, and Pierluigi Zoccolotti for stimulating discussions and very useful comments on the manuscript.

References

Badian, N. (1993). Predicting reading progress in children receiving special help. *Annals of Dyslexia, 43*, 90–109.
Bakeman, R. (2005). Recommended effect size statistics for repeated measures designs. *Behavior Research Methods, 37*, 379–384.
Bishop, A. G., & League, M. B. (2006). Identifying a multivariate screening model to predict reading difficulties at the onset of kindergarten: A longitudinal analysis. *Learning Disability Quarterly, 29*, 235–252.
Bliese, P. (2012). *Multilevel: Multilevel functions.* R package, Version 2.4. Retrieved from: http://CRAN.R-project.org/package=multilevel.
Boersma, P., & Weenink, D. (2012). *Praat: Doing phonetics by computer* (Version 5.3.17) [Computer program]. Retrieved from http://www.praat.org.
Bosse, M.-L., Tainturier, M. J., & Valdois, S. (2007). Developmental dyslexia: The visual attention span deficit hypothesis. *Cognition, 104*, 198–230.
Bowers, P. G., Steffy, R., & Tate, E. (1988). Comparison of the effects of IQ control methods on memory and naming speed predictors of reading disability. *Reading Research Quarterly, 23*, 304–319.
Bowers, P. G., & Swanson, L. B. (1991). Naming speed deficits in reading disability: Multiple measures of a singular process. *Journal of Experimental Child Psychology, 51*, 195–219.
Bowey, J. A., McGuigan, M., & Ruschena, A. (2005). On the association between serial naming speed for letters and digits and word reading skill: Towards a developmental account. *Journal of Research in Reading, 28*, 400–422.
Chiappe, P., Stringer, R., Siegel, L. S., & Stanovich, K. E. (2002). Why the timing deficit hypothesis does not explain reading disability in adults. *Reading and Writing, 15*, 73–107.
Clarke, P., Hulme, C., & Snowling, M. (2005). Individual differences in RAN and reading: A response timing analysis. *Journal of Research in Reading, 28*, 73–86.
Cohen, J., & Cohen, P. (1983). *Applied multiple regression/correlation analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum.
Dare, N., & Shillcock, R. (2013). Serial and parallel processing in reading: Investigating the effects of parafoveal orthographic information on nonisolated word recognition. *Quarterly Journal of Experimental Psychology, 66*, 487–504.
de Jong, P. F. (2011). What discrete and serial rapid automatized naming can reveal about reading. *Scientific Studies of Reading, 15*, 314–337.
Forster, K. I., & Forster, J. C. (2003). DMDX: A Windows display program with millisecond accuracy. *Behavior Research Methods, Instruments, & Computers, 35*, 116–124.
Fox, J., Nie, Z., & Byrnes, J. (2012). *sem: Structural equation models.* R package, Version 3.0-0. Retrieved from http://CRAN.R-project.org/package=sem.
Georgiou, G. (2010). PASS cognitive processes: Can they explain the RAN–reading relationship? *Psychological Science (Chinese), 33*, 1291–1298.
Georgiou, G. K., Papadopoulos, T. C., Fella, A., & Parrila, R. (2012). Rapid naming speed components and reading development in a consistent orthography. *Journal of Experimental Child Psychology, 112*, 1–17.
Georgiou, G. K., Parrila, R., Cui, Y., & Papadopoulos, T. C. (2013). Why is rapid naming related to reading? *Journal of Experimental Child Psychology, 115*, 218–225.

Georgiou, G. K., Parrila, R., Kirby, J. R., & Stephenson, K. (2008). Rapid naming components and their relationship with phonological awareness, orthographic knowledge, speed of processing, and different reading outcomes. *Scientific Studies of Reading, 12*, 325–350.

Georgiou, G. K., Parrila, R., & Liao, C.-H. (2008). Rapid naming speed and reading across languages that vary in orthographic consistency. *Reading and Writing, 21*, 885–903.

Georgiou, G., Parrila, R., Manolitsis, G., & Kirby, J. (2011). Examining the importance of assessing rapid automatized naming (RAN) speed for the identification of children with reading difficulties. *Learning Disabilities, 9*, 5–26.

Georgiou, G. K., Parrila, R., & Papadopoulos, T. C. (2008). Predictors of word decoding and reading fluency across languages varying in orthographic consistency. *Journal of Educational Psychology, 100*, 566–580.

Georgiou, G. K., Parrila, R. K., Papadopoulos, T. C., & Scarborough, H. (2010). Why is RAN related to reading? Manipulating the demands and the format of RAN tasks. In: *Paper presented at the 17th annual meeting of the society for the scientific study of reading* (*SSSR*). Berlin, Germany.

Hatzigeorgiu, N., Gavrilidou, M., Piperidis, S., Carayannis, G., Papakostopoulou, A., Spiliotopoulou, A. et al. (2000). Design and implementation of the online ILSP corpus. In: *Proceedings of the second international conference of language resources and evaluation* (*LREC*) (Vol. 3, pp. 1737–1740). Athens, Greece.

Hawelka, S., & Wimmer, H. (2005). Impaired visual processing of multi-element arrays is associated with increased number of eye movements in dyslexic reading. *Vision Research, 45*, 855–863.

Hendrickx, J. (2012). *perturb: Tools for evaluating collinearity*. R package, Version 2.05. Retrieved from http://CRAN.R-project.org/package=perturb.

Horn, J. (1965). A rationale and test for the number of factors in factor analysis. *Psychometrika, 30*, 179–185.

Inhoff, A. W., Solomon, M., Radach, R., & Seymour, B. A. (2011). Temporal dynamics of the eye–voice span and eye movement control during oral reading. *Journal of Cognitive Psychology, 23*, 543–558.

Jones, M. W., Ashby, J., & Branigan, H. P. (2013). Dyslexia and fluency: Parafoveal and foveal influences on rapid automatized naming. *Journal of Experimental Psychology: Human Perception and Performance, 39*, 554–567.

Jones, M. W., Branigan, H. P., Hatzidaki, A., & Obregón, M. (2010). Is the "naming" deficit in dyslexia a misnomer? *Cognition, 116*, 56–70.

Jones, M. W., Branigan, H. P., & Kelly, M. L. (2009). Dyslexic and nondyslexic reading fluency: Rapid automatized naming and the importance of continuous lists. *Psychonomic Bulletin & Review, 16*, 567–572.

Jones, M. W., Obregón, M., Kelly, M. L., & Branigan, H. P. (2008). Elucidating the component processes involved in dyslexic and non-dyslexic reading fluency: An eye-tracking study. *Cognition, 109*, 389–407.

Kirby, J. R., Georgiou, G. K., Martinussen, R., & Parrila, R. (2010). Naming speed and reading: From prediction to instruction. *Reading Research Quarterly, 45*, 341–362.

Kirby, J. R., Parrila, R. K., & Pfeiffer, S. L. (2003). Naming speed and phonological awareness as predictors of reading development. *Journal of Educational Psychology, 95*, 453–464.

Kwon, M.-Y., Legge, G. E., & Dubbels, B. R. (2007). Developmental changes in the visual span for reading. *Vision Research, 47*, 2889–2900.

Landerl, K., & Wimmer, H. (2008). Development of word reading fluency and spelling in a consistent orthography: An 8-year follow-up. *Journal of Educational Psychology, 100*, 150–161.

Lawrence, M. A. (2012). *ez: Easy analysis and visualization of factorial experiments*. R package, Version 4.1-1. Retrieved from http://CRAN.R-project.org/package=ez.

Lervåg, A., Bråten, I., & Hulme, C. (2009). The cognitive and linguistic foundations of early reading development: A Norwegian latent variable longitudinal study. *Developmental Psychology, 45*, 764–781.

Lervåg, A., & Hulme, C. (2009). Rapid automatized naming (RAN) taps a mechanism that places constraints on the development of early reading fluency. *Psychological Science, 20*, 1040–1047.

Logan, J. A. R., Schatschneider, C., & Wagner, R. K. (2011). Rapid serial naming and reading ability: The role of lexical access. *Reading and Writing, 24*, 1–25.

Maassen, G. H., & Bakker, A. B. (2001). Suppressor variables in path models: Definitions and interpretations. *Sociological Methods & Research, 30*, 241–270.

Manis, F. R., Seidenberg, M. S., & Doi, L. M. (1999). See Dick RAN: Rapid naming and the longitudinal prediction of reading subskills in first and second graders. *Scientific Studies of Reading, 3*, 129–157.

Moll, K., Fussenegger, B., Willburger, E., & Landerl, K. (2009). RAN is not a measure of orthographic processing: Evidence from the asymmetric German orthography. *Scientific Studies of Reading, 13*, 1–25.

Morgan, J. L., & Meyer, A. S. (2005). Processing of extrafoveal objects during multiple-object naming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31*, 428–442.

Nimon, K., & Roberts, J. K. (2012). *yhat: Interpreting regression effects*. R package, Version 1.0-4. Retrieved from http://CRAN.R-project.org/package=yhat.

Norton, E. S., & Wolf, M. (2012). Rapid automatized naming (RAN) and reading fluency: Implications for understanding and treatment of reading disabilities. *Annual Reviews of Psychology, 63*, 427–453.

Olejnik, S., & Algina, J. (2003). Generalized eta and omega squared statistics: Measures of effect size for some common research designs. *Psychological Methods, 8*, 434–447.

Paivio, A. (1990). *Mental representations: A dual coding approach*. New York: Oxford University Press.

Papadopoulos, T. C., Georgiou, G. K., & Kendeou, P. (2009). Investigating the double-deficit hypothesis in Greek: Findings from a longitudinal study. *Journal of Learning Disabilities, 42*, 528–547.

Parrila, R., Kirby, J. R., & McQuarrie, L. (2004). Articulation rate, naming speed, verbal short-term memory, and phonological awareness: Longitudinal predictors of early reading development. *Scientific Studies of Reading, 8*, 3–26.

Poulsen, M., & Elbro, C. (2013). What's in a name depends on the type of name: The relationship between semantic and phonological access, reading fluency, and reading comprehension. *Scientific Studies of Reading, 17*, 303–314.

Protopapas, A. (2007). CheckVocal: A program to facilitate checking the accuracy and response time of vocal responses from DMDX. *Behavior Research Methods, 39*, 859–862.

Protopapas, A., Sideridis, G. D., Simos, P. G., & Mouzaki, A. (2007). Development of lexical mediation in the relation between reading comprehension and word reading skills in Greek. *Scientific Studies of Reading, 11*, 165–197.
Protopapas, A., & Vlahou, E. L. (2009). A comparative quantitative analysis of Greek orthographic transparency. *Behavior Research Methods, 41*, 991–1008.
R Core Team. (2012). *R: A language and environment for statistical computing.* Vienna, Austria: R Foundation for Statistical Computing. Retrieved from http://www.R-project.org.
Radach, R., Inhoff, A. W., Glover, L., & Vorstius, C. (2013). Contextual constraint and *N* + 2 preview effects in reading. *Quarterly Journal of Experimental Psychology, 66*, 619–633.
Revelle, W. (2012). *psych: Procedures for personality and psychological research.* R package, Version 1.2.1. Retrieved from http://CRAN.R-project.org/package=psych.
Revelle, W., & Rocklin, T. (1979). Very simple structure: Alternative procedure for estimating the optimal number of interpretable factors. *Multivariate Behavioral Research, 14*, 403–414.
Roelofs, A. (2003). Goal-referenced selection of verbal action: Modeling attentional control in the Stroop task. *Psychological Review, 110*, 88–125.
Stanovich, K. E., Feeman, D. J., & Cunningham, A. E. (1983). The development of the relation between letter-naming speed and reading ability. *Bulletin of the Psychonomic Society, 21*, 199–202.
Vaessen, A., Bertrand, D., Tóth, D., Csépe, V., Faísca, L., & Reis, A. (2010). Cognitive development of fluent word reading does not qualitatively differ between transparent and opaque orthographies. *Journal of Educational Psychology, 102*, 827–842.
Vaessen, A., & Blomert, L. (2010). Long-term cognitive dynamics of fluent reading development. *Journal of Experimental Child Psychology, 105*, 213–231.
van den Bos, K. P. (2008). Word-reading development, the double-deficit hypothesis, and the diagnosis of dyslexia. *Educational & Child Psychology, 25*, 51–69.
van den Bos, K. P., Zijlstra, B. J., & lutje Spelberg, H. C. (2002). Life-span data on continuous-naming speeds of numbers, letters, colors, and pictured objects, and word-reading speed. *Scientific Studies of Reading, 6*, 25–49.
van den Bos, K. P., Zijlstra, B. J., & van den Broeck, W. (2003). Specific relations between alphanumeric-naming speed and reading speeds of monosyllabic and multisyllabic words. *Applied Psycholinguistics, 24*, 407–430.
Vukovic, R. K., Wilson, A. M., & Nash, K. K. (2004). Naming speed deficits in adults with reading disabilities: A test of the double-deficit hypothesis. *Journal of Learning Disabilities, 37*, 440–450.
Wolf, M., & Bowers, P. G. (1999). The double-deficit hypothesis for the developmental dyslexias. *Journal of Educational Psychology, 91*, 415–438.
Yan, M., Pan, J., Laubrock, J., Kliegl, R., & Shu, H. (2013). Parafoveal processing in rapid automatized naming: A comparison between Chinese normal and dyslexic children. *Journal of Experimental Child Psychology, 115*, 579–589.
Zoccolotti, P., de Luca, M., Lami, L., Pizzoli, C., Pontillo, M., & Spinelli, D. (in press). Multiple stimulus presentation yields larger deficits in children with developmental dyslexia: A study with reading and RAN tasks. *Child Neuropsychology*.