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RESEARCH REPORT

RAN Backward: A Test of the Visual Scanning Hypothesis

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Rapid automatized naming (RAN) is strongly correlated with reading fluency. A substantial part of this correlation is ascribed to the serial nature of the task. In this study, we tested the hypothesis that the left-to-right and downward scanning direction of reading and RAN may partially underlie their relationship. 107 Grade 6 Greek children were assessed on RAN digits and objects, a reversed-direction version of RAN digits, and word- and passage-reading fluency. The correlations of regular RAN with reading were not larger than those of RAN backward, ruling out visual scanning as an explanation of the relation between RAN and reading.

Rapid automatized naming (RAN) is strongly correlated with, and predictive of, reading fluency across ages and orthographies (e.g., Kirby, Georgiou, Martinussen, & Parrila, 2010). The reasons for this association remain unclear, as frequently lamented by researchers (e.g., de Jong, 2011; Georgiou, Parrila, & Kirby, 2009). In their seminal article, Wolf and Bowers (1999) identified a number of component processes underlying RAN performance, which largely coincide with processes presumably underlying fluent reading. Along these lines, Norton and Wolf (2012) conceptualized RAN as a "microcosm or mini-circuit of the later-developing reading circuitry" insofar as "RAN tasks and reading are seen to require many of the same processes, from eye saccades to working memory to the connecting of orthographic and phonological representations" (p. 430).

A variety of theoretical proposals have attempted to account for the relationship between RAN and fluent reading, including phonological, orthographic, lexical, general processing speed, and other cognitive factors (see Kirby et al., 2010, for a review). Of importance, RAN correlates with reading more strongly when presented in serial form, that is, all items printed on a single sheet,

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than when presented in discrete form, that is, individual items presented isolated on the screen (e.g., de Jong, 2011; Logan, Schatschneider, & Wagner, 2011). Reading fluency is also typically assessed in serial form, that is, with a list of words (or passage) presented simultaneously for reading rather than isolated. Therefore, the serial nature of processing may be responsible for a substantial part of the shared variance, beyond any phonological or orthographic factors. In other words, task demands related to the presentation format, rather than to the cognitive processes effecting stimulus naming, may underlie much of the unique contribution of RAN to reading ability (Logan et al., 2011).

Oculomotor programming and associated attentional processing is an obvious candidate for the common serial factor between RAN and reading fluency. Rapid engagement and disengagement from one item to the next is necessary for fluent progression through the list. Moving the eyes with temporal and spatial precision from one item to the next one immediately to its right, and occasionally one line down, is a skill that must underlie effortless and successful processing of text; it must likewise underlie timely completion of a RAN array. Thus, Clarke, Hulme, and Snowling (2005) hypothesized that RAN differences between readers may be related to the development of systematic visual scanning of text materials. In a study from the neuroimaging record, performance of covert RAN tasks during fMRI led to activated areas related to voluntary saccades and shifts of spatial attention (Misra, Katzir, Wolf, & Poldrack, 2004). Consistent with this line of thought, Kuperman and Van Dyke (2011) and Logan et al. (2011) suggested that RAN tasks may be predictive of reading largely because they require the same eye-movement patterns.

Skillful control of eye movements depends on and benefits from reading experience insofar as "fast readers make shorter fixations, longer saccades, and fewer regressions than slow readers" (Rayner, 1998, p. 392). In addition, reading experience is causally related to the development of an asymmetric perceptual span, that is, a right-side parafoveal advantage, allowing processing of more letters to the right than to the left of fixation (for English readers; but the other way around for Hebrew readers; Rayner, 1998). Parafoveal processing has been specifically suggested to underpin the relationship between RAN and reading fluency (Jones, Ashby, & Branigan, 2012; Jones, Obregón, Kelly, & Branigan, 2008). It seems plausible, therefore, that the propensity for accurate eye movement control in younger (preliterate) children, or the efficiency of the overlearned, automatized procedures effecting left-to-right-then-down control in older children (skilled readers) makes up for at least some portion of the as yet unaccounted-for common variance between RAN and reading fluency. This idea—cast in similar terms by Clarke et al. (2005, p. 83), Logan et al. (2011, p. 22), and Kuperman and Van Dyke (2011, p. 62)—may be termed "visual scanning hypothesis."

A practical advantage of this proposal is that it is simple to test, because it relies on the fixed directional processing of the RAN arrays. Therefore, if children are asked to perform the same task in an unusual order, that is, to name items in a RAN array starting at the bottom right and working their way toward the top left, then all of their learned spatial attentional and oculomotor procedures for reading are of little use and, moreover, the asymmetry of their perceptual span becomes disadvantageous. If RAN and reading fluency are strongly correlated in part because of the left-to-right-then-down scanning of the page, then working backward through the RAN array should produce measures less correlated with reading fluency than standard RAN measures.

Scarborough and Domgaard (1998) examined this prediction in 56 English-speaking Grade 3 children from a predominantly poor and minority student body. Reading accuracy correlated .49 with digits forward and .38 with digits backward, apparently a nonsignificant difference leading to rejection of the scanning hypothesis. In the present study, we sought to examine the visual scanning hypothesis further, using a larger sample, representative of the general population, and with reading fluency as the outcome measure. We focused on the concurrent relationship between RAN and reading fluency for older children who have achieved reading proficiency and are largely skilled and efficient in processing printed materials, aiming to uncover a specific aspect of the common substrate between RAN and reading. Greek is a relatively transparent orthography (Protopapas & Vlahou, 2009) in which the relationship between RAN and reading remains strong throughout development (e.g., Georgiou, Papadopoulos, Fella, & Parrila, 2012). Therefore, the age and orthographic system examined in this study are particularly suited to the stated purpose.

METHOD

Participants

107 Greek children (58 girls; age $M = 11$ years 10 months, $SD = 4$ months) attending Grade 6 participated in the experiment with parental consent. Children were unselected from the general population in a middle-class Athens province. They were recruited on a voluntary basis, after obtaining research permission from the Ministry of Education.

Materials

Three naming tests were administered, including RAN digits forward (RAN-DF), RAN digits backward (RAN-DB), and RAN objects forward (RAN-OF). Each RAN test included 50 items and was presented in a single-screen array of five rows of 10 items. Digits were presented in black 28-point Arial font on a white background. They included 2, 3, 5, 7, and 9, pronounced /ˈðio/, /ˈtria/, /ˈpɛndɛ/, /ɛˈfta/, /ɛˈɲa/, respectively; these words were bisyllabic, including three with penultimate-syllable stress and two with final-syllable stress. Objects included color drawings of an apple, a chicken, a vase, a gift, and a ball, pronounced /ˈmilo/, /ˈkota/, /ˈvazo/, /ˈðoro/, /ˈbala/, respectively; these words were bisyllabic and had penultimate-syllable stress.

Two reading tests were administered, including a word list and a passage fluency test. The word list included 50 words presented in a single-screen array of five columns of 10 items. The words were selected from a word fluency list used in previous studies (e.g., Protopapas, Sideridis, Simos, & Mouzaki, 2007), including 31 two-syllable and 19 three-syllable frequent words. Finally, passage C from the Test of Reading Performance (Sideridis & Padeliadu, 2000) was used for the timed passage reading test. It included 52 words distributed in seven sentences taking up about five lines.

Previous studies in Greek have shown high test–retest reliability for very similar measures (Grade 6 coefficients: RAN-D, .90; RAN-O, .80; word fluency, .93; text fluency, .83; see Georgiou et al., 2012) and very high alternate-list correlation for word fluency (.94 in Grades 2–4; Protopapas et al., 2007).

Procedure

For each test, the child was presented with the corresponding naming set on the computer screen and asked to name (or read) aloud the items one by one as quickly as possible without making mistakes. In RAN-DB, children were instructed to name the digits starting at the lower right corner and working leftward row by row, to finish at the top-left corner. Production of the intended words was verified prior to the digit and object tasks.

Administration order was fixed for all participants and alternated between word and RAN tasks. Each task was simultaneously recorded on the computer via a headset. 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 & Weeninck, 2012).

RESULTS

Naming times were inverted and multiplied by the number of items to produce measures of items per second. Errors were very rare[1] and were not taken into account in the analyses. No data points were removed. Table 1 presents the descriptive statistics for each measure, indicating no significant deviations from normality. Table 2 shows the correlations among the measures. Parametric and nonparametric indices (not shown) were nearly identical, alleviating concerns regarding bivariate distribution assumptions. Direct comparison of the correlation coefficients (following Meng, Rosenthal, & Rubin, 1992) revealed no significant difference between the correlations of RAN-DF and RAN-DB with word fluency ($z = 1.62$, $p = .105$) or with passage fluency ($z = 1.12$, $p = .261$).

To examine the contribution of RAN measures to word and passage fluency, we performed hierarchical regression analyses. The results, displayed in Table 3, indicated that RAN-DF alone accounted for about 37% of the variance in word fluency and 7% of the variance in passage fluency (Model 1), whereas the corresponding percentages for RAN-DB were 49% and 12%, respectively (Model 2). When entered after RAN-DF, in Model 1, RAN-DB accounted for substantial amounts of variance in both word (16%) and passage fluency (5.5%). In contrast,

TABLE 1
Descriptive Statistics and Tests of Normality

	Descriptives						*Shapiro-Wilks*	
	M	*SD*	*Min*	*Max*	*Skew*	*Kurt.*	*W*	*p*
RAN-OF	1.36	.22	.77	1.90	−.11	−.23	.99	.88
RAN-DF	2.13	.47	1.08	3.38	.09	.01	.99	.74
RAN-DB	2.03	.35	1.08	2.98	.00	.26	.99	.86
Word list	1.60	.33	.92	2.40	.06	−.34	.99	.42
Passage	2.53	.47	1.32	3.80	−.28	.18	.98	.27

Note. All measures in items (symbols or words) per second. $N = 107$. O = Objects; D = Digits; F = forward; B = backward.

[1]The mean number of uncorrected errors, including omissions, ranged between .0 and .5 across tasks. The mean number of self-corrections, including false starts and repetitions, ranged between .4 and 1.7. In particular, for RAN-DF and RAN-DB, uncorrected errors $M = .0$ ($SD = .3$) and $M = .0$ ($SD = .4$) and self-corrections $M = .4$ ($SD = .9$) and $M = .7$ ($SD = 1.2$), respectively.

TABLE 2
Correlations Among the Tasks

	RAN-OF	*RAN-DF*	*RAN-DB*	*Word List*
RAN-DF	.37			
RAN-DB	.58	.65		
Word list	.54	.61	.70	
Passage	.41	.26	.35	.62

Note. Pearson's product-moment correlation coefficients (r) of the inverted measures. $N = 107$. O = Objects; D = Digits; F = forward; B = backward. All $p < .01$.

TABLE 3
Hierarchical Regressions Predicting Word List and Passage Fluency From Rapid Naming

		Word List Fluency		*Passage Fluency*	
Step	*Variable*	ΔR^2	p	ΔR^2	p
Model 1					
1	RAN-DF	.37	<.0005	.07	.007
2	RAN-DB	.16	<.0005	.06	.012
Model 2					
1	RAN-DB	.49	<.0005	.12	<.0005
2	RAN-DF	.04	.003	.00	.618
Model 3					
1	RAN-DB	.49	<.0005	.12	<.0005
2	RAN-OF	.03	.014	.07	.005
3	RAN-DF	.04	.004	.00	.592

Note. $N = 107$. O = objects; D = digits; F = forward; B = backward.

RAN-DF accounted for much less variance after RAN-DB was controlled for, in Model 2, and was only significant in word fluency (4%).

Presumably, RAN-DF and RAN-DB share everything except visual scanning direction. Therefore, if the residual variance in word fluency that was accounted for by RAN-DF after RAN-DB was controlled for were due to visual scanning, it should also be accounted for by RAN-OF, which shares visual scanning with RAN-DF. In that case, RAN-DF would not account for any variance when entered in the regression equation after both RAN-DB and RAN-OF, as in Model 3. However, RAN-OF failed to pick up any of this variance—even though it did account for a further 3%—because the unique contribution of RAN-DF (now entered at Step 3) remained unchanged and significant after controlling for RAN-OF (entered at Step 2; see Table 3, bottom row).

DISCUSSION

The aim of this study was to determine if RAN backward (processing the RAN array right-to-left, then up with a rightward sweep) would correlate less with reading fluency than standard RAN (processed in the reading direction, i.e., left-to-right, then downward). The answer to this question is clearly negative, as the correlation coefficients between RAN-DB and reading fluency were numerically larger than between RAN-DF and reading fluency (albeit not significantly different, similar to Scarborough & Domgaard, 1998). Because the variance shared by (forward-direction) RAN-DF and RAN-OF did not contribute to the prediction of reading fluency, we may confidently reject the hypothesis that the *directionality* of attentional processing and oculomotor programming plays a role in the explanation of the RAN–reading relationship. That is, despite years of reading practice, presumably resulting in asymmetric perceptual span and highly skilled direction-specific visual processing, this common aspect of the RAN and reading tasks does not make up a significant individual-differences component underlying their shared variance. Therefore, the nature of the sequential processing link that presumably causes serial RAN to predict fluency much better than discrete naming must be sought elsewhere.

This conclusion is consistent with the observation that the correlation between RAN and reading does not appear to be affected by the format of fluency assessment. Word fluency tasks are commonly presented in a column rather than row format, and this is why the columnar arrangement was used in the present study as well. One might argue that testing word list fluency in a column format has weakened the conclusions of our study because visual scanning is not fully shared among our naming and reading measures. We offer three reasons to resist this criticism: First, the vertical aspect of fluency lists was top-to-bottom, consistent with the usual reading direction and shared with RAN-DF but not with RAN-DB. The columnar format necessitates a primary vertical rather than horizontal scanning direction, as far as spatial attention and oculomotor requirements are concerned, and may constitute a crucial element in the visual processing of stimulus arrays, moving down successive lines or rows. Second, we already know from a host of previous studies regarding RAN and reading fluency that these particular formats are strongly correlated. If RAN, typically administered in rows, is strongly correlated with word list fluency, typically administered in columns, then the scanning direction cannot play a major role in their relationship, consistent with our findings and against the visual scanning hypothesis.

The third and most important consideration against the column-format criticism is that passage fluency serves as a reference condition. If the correlation of RAN-DF with word list fluency was underestimated due to the directionality difference, then this might have allowed RAN-DB to dominate the relationship for reasons unrelated to the hypothesis under scrutiny. However, if that were the explanation for our results, then it should apply as well to the prediction of passage fluency. Because passage fluency was measured using the standard reading direction, similar to the row-by-row processing of RAN arrays, its correlation with RAN-DF is not susceptible to underestimation due to directionality mismatch. Yet RAN-DB (a) was more highly correlated with passage fluency than RAN-DF; (b) accounted for significant variance in passage fluency when entered second in the regression, after RAN-DF was controlled; and (c) took up the RAN-DF variance when entered first.

In discussing the role of different administration formats we might keep in mind that the major determinant of the correlation between reading fluency and RAN need not derive from concurrent method variance. Superficial task features are an unlikely cause of the strong and persistent RAN–reading relationship because correlations are also observed with less similar measures (such as RAN time and reading accuracy) and because robust longitudinal predictors (nonalphanumeric RAN) can be recorded before children learn to read. Instead, let us assume that efficiency or propensity in a skill domain (such as visual scanning or cognitive executive control) both supports early RAN performance and forms a substrate for future fluent reading. In beginning readers, individual differences in this precursor skill are concurrently expressed in serial naming tasks and longitudinally predict fluency development. Later, when fluent reading is established, RAN may assess a full-fledged outgrowth of the precursor skill and thereby correlate with fluency indirectly, without necessarily matching the current fluent reading task. In this hypothetical situation there is no reciprocal relation but only a unidirectional common cause. Therefore RAN need not be longitudinally predicted by reading, and it may predict subsequent reading development before the emergence of fluency and of the parafoveal advantage. Our results suggest that directionality in general and the asymmetric efficiency of parafoveal processing in particular[2] cannot play a major role in the RAN–reading relationship. This conclusion is consistent with developmental findings showing that reading does not predict RAN longitudinally (Lervåg & Hulme, 2009; Wagner et al., 1997). Specifically, because reading has a causal effect on the right-side parafoveal advantage, but not on RAN, it is unlikely that this advantage can account for the RAN–reading relationship.[3]

In a related study, Jones, Branigan, and Kelly (2009) tested adults with and without dyslexia in rapid naming of letter arrays. They contrasted presentation of isolated letters, at the center of the screen or at their array locations, with standard simultaneous presentation. There was no performance difference between conditions with letters displayed individually, regardless of fixed versus progressing location, leading to the conclusion that oculomotor demands per se do not drive RAN performance differences. This was not a test of the visual scanning hypothesis because readers did not have the opportunity to preview a subsequent item while processing the current one. Therefore, they could not have benefited from parafoveal previewing or from precise temporal reallocation of attention from one stimulus to the next. This could explain why readers without dyslexia failed to benefit from the matrix arrangement when stimuli were presented in isolation, whereas they did benefit with simultaneous presentation (cf. Zoccolotti et al., 2012, with similar findings from Italian children with and without dyslexia).

Our data confirm previous findings of enduring moderately high correlations between RAN and reading fluency in Greek, particularly as far as single-word reading is concerned (see Georgiou et al., 2012; Papadopoulos, Georgiou, & Kendeou, 2009; Protopapas & Skaloumbakas, 2008). Passage fluency is less well predicted by RAN than isolated word fluency (as expected; cf. Antoniou & Patsiodimou, 2008; Georgiou et al., 2012) and seems more strongly related to object naming than to digit naming, consistent with an increased role of semantic processing in passage fluency at this age (Georgiou, 2010). Our findings are also consistent with those of previous studies conducted in relatively transparent orthographies and with children of comparable age (e.g., Escribano & Katzir, 2008; Vaessen & Blomert, 2010; van den Bos, Zijlstra, & van den Broeck, 2003).

The great overlap between RAN-DB and reading fluency, unique or partially shared with other RAN measures, suggests that the sequential nature of RAN and reading warrants further scrutiny. If RAN-DB turns out to be reliably more strongly correlated with reading than RAN forward, this would point not to automatization of visual scanning but, rather, to controlled sequential processing of cognitive cascades. The dominance of a task requiring an unusual spatial progression in

[2]Although we did not document a parafoveal advantage in our sample, it seems reasonable to assume that it exists, based on the robustness and universality of the relevant findings in the literature and the age and reading experience of the children tested.

[3]We are grateful to an anonymous reviewer for this argument.

the prediction of reading fluency is consistent with the established view of visual control during reading as an involved process largely driven by processing demands and text properties (Rayner, 1998). In other words, fluency may be a paragon of cognitive control and executive efficiency rather than a trivial series of "automatic" transitions and mappings. In particular, skilled fluent reading may be much more dependent on the ability to control an active pipeline of overlapping lexical processes going through word sequences rather than on individual word recognition or other superficial aspects of the visual stimuli. Further research, including cognitive modeling of serial naming and fluent reading, will be necessary to disentangle the sequential and item-related components of both RAN and fluent reading performance.

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