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Research Article

Rapid Automatized Naming (RAN) Taps a Mechanism That Places Constraints on the Development of Early Reading Fluency

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ABSTRACT—*Previous studies have shown that rapid automatized naming (RAN) is a correlate of early reading skills; however, the interpretation of this finding remains controversial. We present the results from a 3-year longitudinal study. RAN, measured with nonalphabetic stimuli before reading instruction has begun, is a predictor of later growth in reading fluency. After reading instruction has started, RAN continues to exert an influence on the development of reading fluency over the next 2 years. However, there is no evidence of a reciprocal influence of reading fluency on the growth of RAN skill. We suggest that RAN taps the integrity of left-hemisphere object-recognition and naming circuits that are recruited to function as a critical component of the child's developing visual word-recognition system.*

In the last 20 to 30 years, psychologists have made large strides in understanding the processes involved in learning to read. One of the clearest findings is that children's awareness of the sound structure of spoken words (phonological awareness) is a powerful predictor of variations in learning to read and that deficits in such skills are probably a critical causal factor in many cases of reading difficulty (Bowey, 2005). Another less well understood, and more controversial, predictor of reading development is rapid automatized naming (RAN). RAN is assessed by very simple tasks where children name aloud objects, colors, or symbols (letters or digits) as quickly as they can.

Children's performance on RAN tasks correlates with variations in early reading skills both concurrently and longitudinally, even after variations in phonological awareness, verbal IQ, and earlier reading skills have been accounted for (Compton, 2003; de Jong & van der Leij, 1999; Parrila, Kirby, & McQuarrie, 2004; Schatschneider, Fletcher, Francis, Carlson, & Foorman, 2004; Wagner et al., 1997; Wolf & Bowers, 1999). Several explanations for the relationship between RAN and reading have been proposed. Arguably, the most critical issue concerns causality. We can distinguish three possible causal relationships between RAN and reading: RAN might tap mechanisms that cause differences in learning to read; differences in learning to read might cause differences in RAN; or there may be a bidirectional causal relationship (i.e., RAN might tap mechanisms that cause differences in learning to read and differences in learning to read might cause differences in RAN).

The dominant view has been that RAN taps a basic causal influence on reading development. For example, Wagner and Torgesen (1987) and Wimmer, Mayringer, and Landerl (2000) argued that RAN and reading are associated because they both tap the speed with which phonological representations can be retrieved from long-term memory. This idea fits well with findings that RAN is a better predictor of reading fluency than it is of reading accuracy (Schatschneider et al., 2004). A similar, but broader, hypothesis is that the correlation between RAN and

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reading reflects the fact that both depend on variations in the rate of development of a global speed of processing construct (Kail & Hall, 1994; Kail, Hall, & Caskey, 1999).

An opposing view, which has less support, is that differences in RAN arise, at least in part, as a consequence of differences in reading ability. Bowey (2005) stressed the fact that alphanumeric (i.e., digit and letter) RAN is more strongly related to reading skills than nonalphanumeric RAN (i.e., colors, objects) and suggested that differences in alphanumeric RAN may be a consequence of early differences in reading ability (specifically, differences in letter knowledge). If RAN is best understood as reflecting letter knowledge, then nonalphanumeric RAN measured in prereaders should not predict growth in reading.

Only a handful of longitudinal studies exist that can speak to whether RAN, measured in preliterate children, taps a plausible cause of later differences in reading ability. Although alphanumeric RAN does appear to be a better predictor of later reading than nonalphabetic RAN (Compton, 2003; Wagner et al., 1997), nonalphanumeric RAN measured in prereaders has, nevertheless, been shown to predict later reading (de Jong & van der Leij, 1999; Kirby et al., 2003; Landerl & Wimmer, 2008). We sought to establish whether RAN is likely to tap a cause of differences in the rate of learning to read by showing that nonalphabetic RAN, measured before children can read, is predictive of later variations in reading skill, as well as tracing the interrelationships between RAN and reading longitudinally over the first 2 years of learning to read.

The study we report is part of a large-scale longitudinal study of reading development in a representative sample of Norwegian children. We assessed the growth of text-reading fluency and four different RAN tasks (colors, objects, digits, and letters) in a large unselected sample over a period of 3 years, starting before the onset of reading instruction. In an earlier report of the first two years of this study (Lervåg, Bråten, & Hulme, 2009), we found that nonalphabetic RAN was a predictor of early variations in a composite measure of reading ability. In light of evidence that RAN pauses are a better predictor of the subsequent development of reading fluency (Neuhaus, Foorman, Francis, & Carlson, 2001) than are RAN articulation durations, we divided the RAN measures into interitem pauses and item-articulation durations. Using individual growth curve models and measures over a 3-year period, we assessed the extent to which RAN is a longitudinal predictor of variations in the rate of growth in reading fluency as well as whether variations in the rate of reading growth, in turn, predict variations in later RAN skills. Our measure of reading was text-reading fluency, rather than reading accuracy, because in shallow orthographies such as Norwegian (Seymour, Aro, & Erskine, 2003), measures of reading accuracy typically show little variance after the earliest stages of learning to read. We found clear evidence that nonalphabetic RAN, measured before children can read, is a good predictor of later variations in reading skill and, conversely, that early variations in reading ability are not good predictors of later variations in RAN. We speculate that RAN may depend on object-naming circuits in the left hemisphere that are recruited to form the basis of the child's developing word-recognition system.

METHOD

Participants

Two hundred thirty-three Norwegian children in the first grade (average age = 6 years 4 months; 123 girls, 110 boys) were recruited to the study 1 year before formal reading instruction started.[1] Two hundred twenty-eight children participated in all the tests at Time 1, and 192 children participated on all tests at all time points.

Design and Procedure

The children were tested on five occasions over a period of 37 months: in October and November of their first-grade year (about 10 months before formal reading instruction; Time 1); in November and December of their second-grade year (about 3 months after the start of reading instruction; Time 2); in May and June, at the end of their second-grade year (Time 3); in November and December of their third-grade year (Time 4); and in November and December of their fourth-grade year (Time 5). All testing was done in school, and the tests were given in a fixed order.

Tests and Materials

A total of 13 different tests were used at different time points. Phoneme awareness, letter knowledge, and verbal abilities were tested at Times 1 and 2. RAN was tested at all five time points (with the exception of the digit and letter RAN tests, which were dropped from Time 1 because only a minority of the children knew all the digit and letter names at that time). Reading fluency was tested at each time point except Time 1, when the children could not read. In addition, RAN at Time 1 was separated into two components: interitem pauses and item-articulation durations.

RAN

RAN was measured by four tests, in each of which the children were required to name 40 items arranged in a quasi-random order on four lines of a sheet. Five items were repeated eight times each. The items were colors, objects, numbers, or letters, and the task was to name them sequentially as fast as possible. Performance was measured by the time it took to name all 40 items on the sheets.

Before a test trial started, we ensured that the child knew the items by having him or her name the five items (printed on a

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[1] In Norway between 1997 and 2006, formal reading instruction started in second grade. In first grade, children gained familiarity with numbers and letters through play activities, but were not taught to read.

separate sheet). These pretests showed that the digit and letter tasks could not be used at Time 1.

RAN Pauses and Articulations

To assess which part of the RAN tests are important for reading development, we separated the response times from two RAN tasks at Time 1 (RAN colors and RAN objects) into pause durations and articulation durations by manually timing the digitally recorded responses using sound editing software (CoolEdit 2000, Syntrillium). All articulation errors were removed from these analyses, along with the preceding pause time. The error rates were low for both the color (2.3%) and object (3.9%) tasks. The resulting measures have good reliability (see Table 1).

Phoneme Awareness

Phoneme awareness was measured by three tests, each of which was discontinued after five consecutive incorrect responses among either the first 8 or the last 16 items.

The phoneme-isolation test consisted of 24 items of increasing difficulty. These items required the child to choose words that began or ended with a specified sound or to supply a specified (initial or final) phoneme from a word or a nonword.

The phoneme-segmentation test consisted of 24 items of increasing difficulty in which the child was asked to count the number of phonemes in a word (8 items) or to pronounce each phoneme in a word (8 items) or a nonword (8 items).

The phoneme-deletion test consisted of 24 items of increasing difficulty. In this test, the child was asked which one of three words a target word was changed into when a phoneme was removed from either the beginning or end of the target word (8 items). Alternatively, the child was asked to delete a phoneme from either the beginning or end of a word (8 items) or nonword (8 items).

Verbal Abilities

Verbal ability was assessed by the Similarities and Vocabulary tests from the Norwegian version of the Wechsler Intelligence Scale for Children, Revised Edition (Undheim, 1978).

Letter Knowledge

Letter knowledge was assessed by asking children to give the name and sound for each letter of the alphabet (both consonants and vowels).

Text-Reading Fluency

Two text-reading fluency tests were constructed using passages from books designed for beginning readers. The children were asked to read these passages as quickly and accurately as they could. The number of words read correctly in 2 min was recorded. This measure has high reliability (see Table 1) and correlates strongly with several other measures of reading skill (see Lervåg et al., 2009).

RESULTS

Descriptive statistics for all the variables used at all time points are shown in Table 1. Because deviations from normality were present for some variables, robust estimation techniques (Yuan-Bentler corrections) were used (MLR in Mplus). Eight children were excluded because their scores for reading fluency at Time 2 were extreme outliers (z score > 3). Missing data were estimated by using FIML.

Predicting Time 2 RAN and Reading From the Time 1 Measures

Variations in Time 2 measures were predicted from the measures taken at Time 1. This was done using the structural equation model shown in Figure 1. The model fitted the data very well: Yuan-Bentler $\chi^2(187, N = 220) = 252.81, p < .001$; comparative fit index = .976; Tucker-Lewis index = .970, root mean square error of approximation = .040 (90% confidence interval = .026–.052); standardized root mean square residual = .051. All loadings from the latent variables to the observed variables were strong and significant, indicating good reliability (factor loadings can be obtained from Arne Lervåg). This model confirms that the RAN-pause and RAN-articulation measures can be meaningfully separated.

The model in Figure 1 shows that the Time 2 measures of reading fluency, phoneme awareness, and RAN are strongly predicted from our Time 1 measures. There were four critical findings from this model. First, text-reading fluency was predicted uniquely by phoneme awareness, letter knowledge, and nonalphanumeric RAN pause durations (50% of the variance accounted for). Second, phoneme awareness was predicted by nonalphanumeric RAN pauses and phoneme awareness (53% of variance accounted for). Third, alphanumeric RAN was strongly predicted by nonalphanumeric RAN pauses and much more weakly by letter knowledge (66% of the variance accounted for). Fourth, nonalphanumeric RAN was strongly predicted by nonalphanumeric RAN pauses but only weakly by RAN articulations (92% of the variance accounted for). This model shows that nonalphanumeric RAN pauses are the more important of the two RAN components for predicting both text-reading fluency and later RAN performance. The model also shows that RAN is a highly stable (reliable) measure and an important predictor of later text-reading fluency.

Prediction of Later Growth in RAN and Text-Reading Fluency

To examine the later growth in RAN tasks and in text-reading fluency (from Time 2 onwards) and their possible reciprocal influence on each other, we estimated two parallel growth models: one considering alphanumeric RAN, and the other considering nonalphanumeric RAN. In these models, the later growth of RAN and text-reading fluency were predicted from

TABLE 1
Means and Reliabilities for All Observed Measures

Measure	Time 1		Time 2		Time 3		Time 4		
	M	Reliability	*M*	Reliability	*M*	Reliability	*M*	Reliability	Time 5 *M*
Phoneme awareness									
Phoneme deletion (range = 0–24)	8.05 (4.94)	.90	15.91 (5.88)	.89	—	—	—	—	—
Phoneme segmentation (range = 0–24)	5.32 (5.85)	.93	18.29 (5.99)	.90	—	—	—	—	—
Phoneme isolation (range = 0–24)	9.08 (6.95)	.94	20.38 (4.09)	.74	—	—	—	—	—
Letter knowledge									
Consonants (range = 0–32)	13.28 (10.25)	—	—	—	—	—	—	—	—
Vowels (range = 0–9)	4.82 (2.80)	—	—	—	—	—	—	—	—
Verbal ability									
WISC-R Vocabulary (range = 0–66)	16.41 (4.40)	.57	20.02 (5.11)	—	—	—	—	—	—
WISC-R Similarities (range = 0–33)	8.93 (3.00)	.46	11.58 (2.86)	—	—	—	—	—	—
RAN									
Color RAN articulation duration (ms)	21.81 (4.36)	.94	—	—	—	—	—	—	—
Object RAN articulation duration (ms)	28.21 (4.92)	.95	—	—	—	—	—	—	—
Color RAN pause duration (ms)	29.09 (14.48)	.86	—	—	—	—	—	—	—
Object RAN pause duration (ms)	40.93 (17.42)	.78	—	—	—	—	—	—	—
Total color RAN duration (ms)	52.23 (15.52)	.71	42.11 (11.28)	.69	39.76 (9.96)	.76	36.44 (8.34)	.82	33.69 (7.73)
Total object RAN duration (ms)	70.14 (19.24)	.64	60.39 (17.47)	.64	57.10 (14.23)	.70	51.52 (11.99)	.69	45.89 (9.90)
Total digit RAN duration (ms)	—	—	38.11 (12.19)	.69	31.72 (8.47)	.68	28.88 (7.23)	.72	24.70 (5.47)
Total letter RAN duration (ms)	—	—	37.54 (14.81)	.66	30.15 (9.93)	.71	26.02 (7.40)	.56	21.88 (4.78)
Text-reading fluency									
Text Reading 1	—	—	53.47 (61.76)	.82	111.40 (70.05)	.93	151.87 (74.42)	.88	210.14 (77.70)
Text Reading 2	—	—	54.98 (55.85)	.88	108.12 (80.82)	.94	153.02 (86.68)	.87	221.79 (87.37)

Note. Reliability was measured by Cronbach's alpha for phoneme awareness and letter knowledge, as well as for rapid automatized naming (RAN) articulation and pause durations. For all other measures, reliability was measured by correlations between the variable at that time point and the following time point. Verbal ability was measured with the Similarities and Vocabulary tests from the Norwegian version of the Wechsler Intelligence Scale for Children–Revised (WISC-R; Undheim, 1978). Standard deviations are given in parentheses. Mean age was 6 years 4 months at Time 1, 7 years 5 months at Time 2, 7 years 11 months at Time 3, 8 years 5 months at Time 4, and 9 years 5 months at Time 5.

earlier measures of these constructs as well as measures of phoneme awareness and verbal ability. The growth in both RAN constructs was nonlinear and represented by fully latent growth models. The growth of text-reading fluency was nonlinear and represented by a quadratic growth model. However, because text-reading fluency at Time 2 did not show measurement invariance with the pattern at later time points (a prerequisite of growth of factors models), it was instead treated as a Time 2 predictor along with phoneme awareness and verbal ability.

Figure 2 shows the simplified parallel-growth model of alphanumeric RAN and text-reading fluency (with nonsignificant paths deleted). This model fitted the data well: Yuan-Bentler $\chi^2(176, N = 216) = 248.37, p < .001$; comparative fit index = .981; Tucker-Lewis index = .975; root mean square error of approximation = .044 (90% confidence interval = .03–.056); standardized root mean square residual = .049. Only alphanumeric RAN at Time 2 (RAN intercept) predicted text-reading fluency at Time 3 (reading-fluency intercept) after accounting for text-reading fluency at Time 2. Perhaps more impressively, alphanumeric RAN at Time 2 (RAN intercept) predicted subsequent variations in the rate of growth in text-reading fluency (reading-fluency slope). Conversely, none of the predictors at Time 2

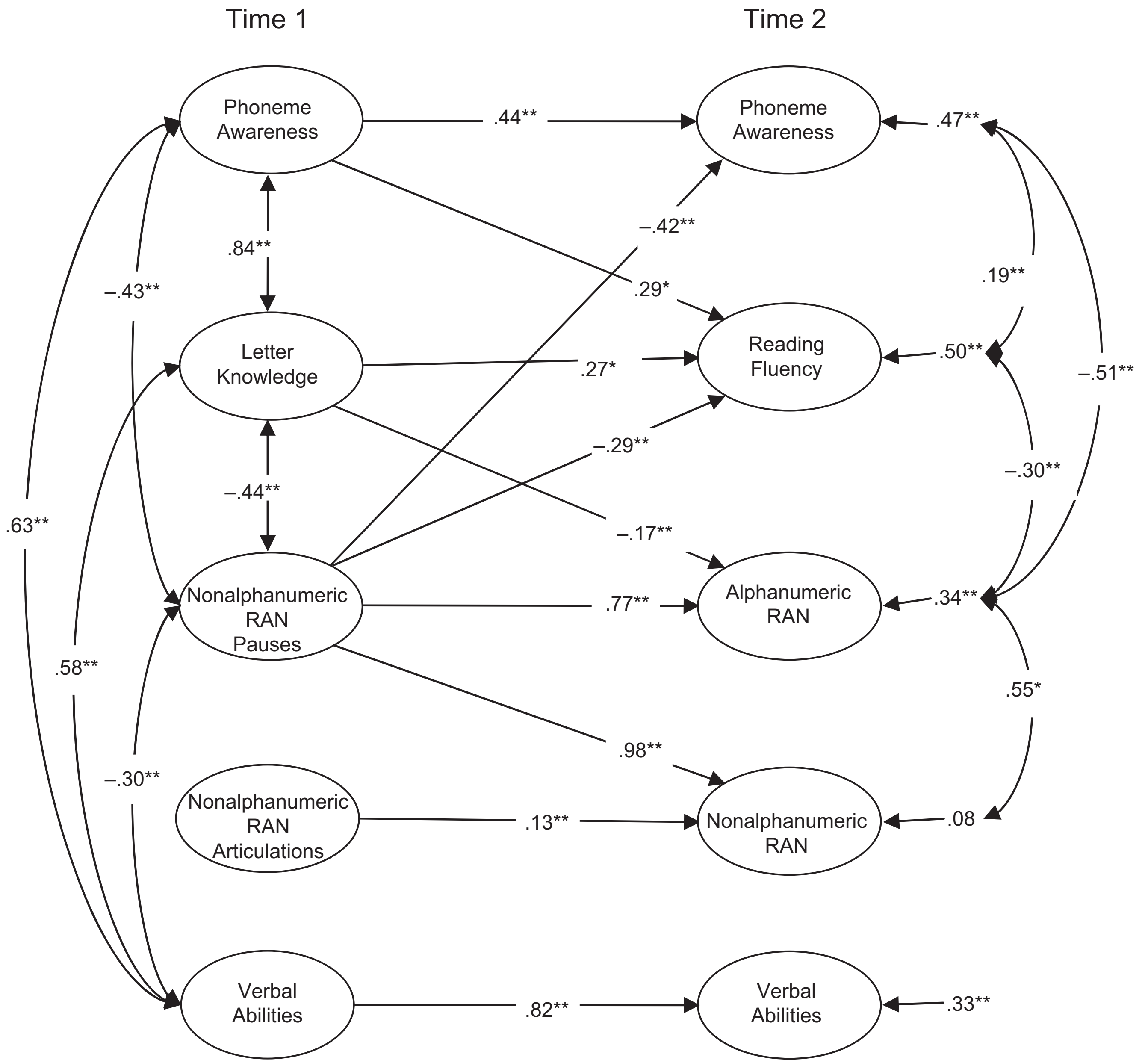

Fig. 1. Structural equation model showing variations in Time 2 (fall of the second-grade year) measures predicted from measures taken at Time 1 (fall of the first-grade year). Predictor variables were phoneme awareness, letter knowledge, verbal abilities, and pause and articulation durations on the nonalphanumeric rapid automatized reading (RAN) task at Time 1. Outcome variables were phoneme awareness, text-reading fluency, alphanumeric RAN, nonalphanumeric RAN, and verbal abilities at Time 2. Single-headed arrows indicate regressions predicting Time 2 measures from Time 1 measures. Double-headed arrows indicate correlations between constructs at Time 1 or between residuals (unexplained variance) of the constructs at Time 2. All coefficients are standardized ($^{*}p < .05$, $^{**}p < .01$).

predicted later growth in alphanumeric RAN (slope) beyond alphanumeric RAN at Time 2 (intercept). The quadratic trend for text-reading fluency in this model reflected the fact that, for children who started out as the fastest readers, the growth in reading fluency tended to level off at later time points. It is noteworthy that, when nonalphanumeric RAN was substituted for alphanumeric RAN, it was not a significant predictor of variations in the rate of growth in text-reading fluency. This finding indicates that there is a close and special relationship between alphanumeric RAN and the later development of text-reading fluency. We speculate that, once reading instruction begins, the efficiency with which alphabetic-sound links can be established is crucial for reading development, and that alphanumeric RAN provides the most direct test of this ability. Finally, it should be noted that variations in reading fluency did not predict variations in the growth of alphanumeric RAN in this model; therefore, we found no support for a reciprocal relationship between the development of reading fluency and RAN.

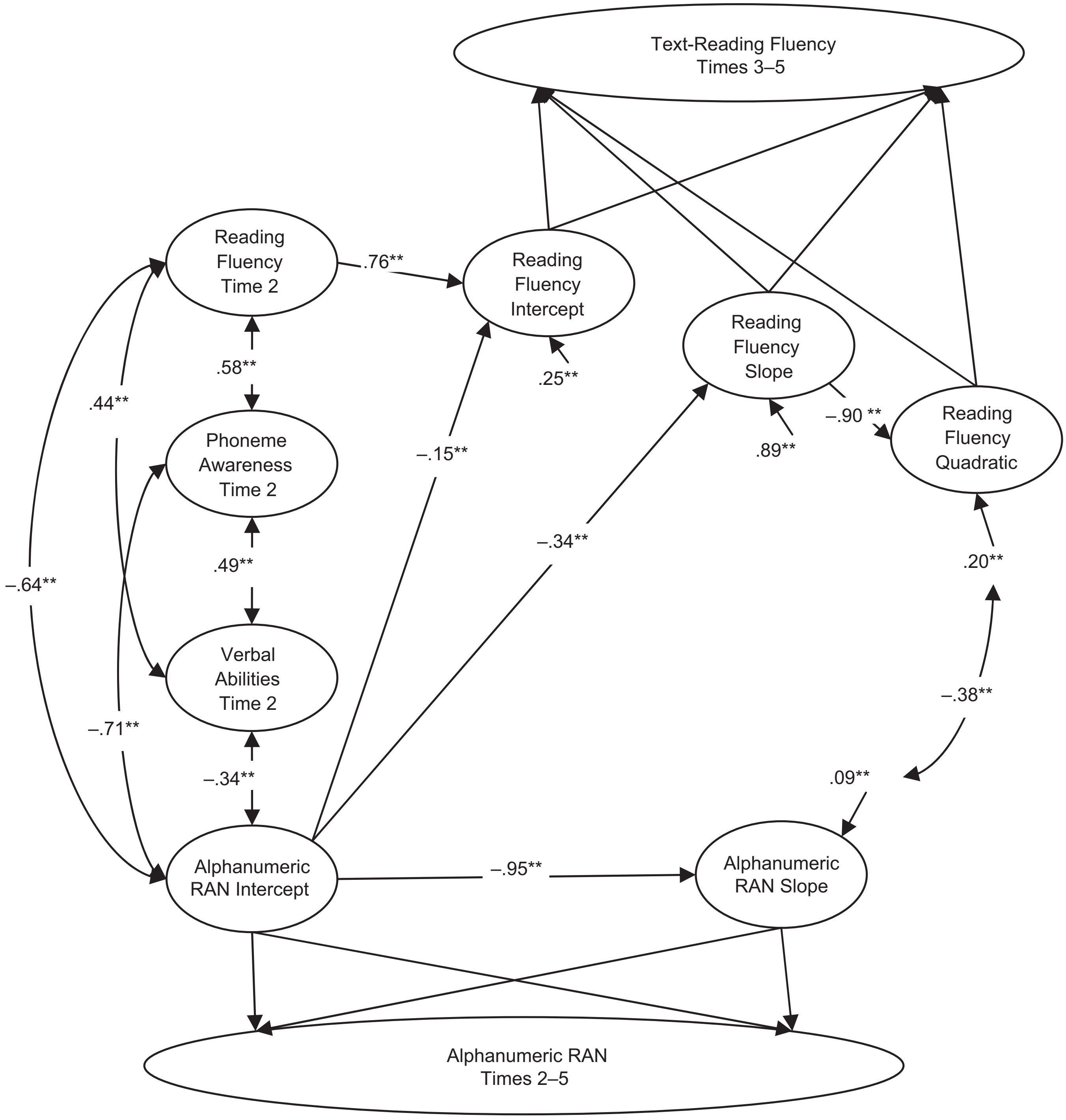

Fig. 2. Parallel (initial status) growth-of-factors model of reading fluency and alphanumeric rapid automatized reading (RAN). Text-reading fluency, phoneme awareness, verbal abilities, and alphanumeric RAN (alphanumeric RAN intercept) measured at Time 2 served as predictor variables. Single-headed arrows indicate regression paths (toward the growth constructs) or factor loadings (from the growth constructs to the time-specific reading and RAN measures). Double-headed arrows indicate correlations between constructs at Time 2 or between the residuals (unexplained variance) for the growth constructs. All coefficients are standardized (**$p < .01$).

DISCUSSION

Our large-scale longitudinal study has revealed a number of critical findings concerning the interrelationships among the development of RAN, phoneme awareness, letter knowledge, and reading. We have shown that variations in nonalphanumeric RAN, phoneme awareness, and letter knowledge, measured before children have started to learn to read, are strong independent predictors of subsequent variations in text-reading fluency. Our findings concerning the critical importance of phoneme awareness and letter knowledge as foundations for the development of early reading skills confirm and extend a number of earlier studies (see Bowey, 2005, for a review). At a more refined level, we have shown that only RAN pause time (and not RAN articulation time) was a predictor of later text-reading fluency. In addition, nonalphanumeric RAN measured at Time 1 was a very strong predictor of later measures of alphanumeric RAN (in this case, both pause time and articulation time were predictors). Later in development, once literacy skills had started to develop, alphanumeric RAN predicted the further growth of text-reading fluency. However, text-reading fluency did not predict growth in RAN. This finding indicates that variations in RAN cannot be explained away as a mere consequence of early variations in reading skill and that RAN and reading do not show reciprocal influences on each other.

RAN Taps a Causal Influence on Early Reading Development

We believe that our results are consistent with the idea that nonalphabetic RAN, measured before reading instruction has begun, taps mechanisms that are causally related to the growth of reading skills. It seems unlikely that the relationship between RAN and reading fluency can be explained in terms of a global speed-of-processing construct (Kail et al., 1999), because this cannot explain the highly specific relationship between RAN pauses and reading (in the absence of an equivalent effect of RAN articulation speed). Instead, this pattern of results seems more compatible with the idea that the speed of phonological retrieval from a visual stimulus (as indexed by the pauses between successive items) is critical for explaining the correlation between RAN and reading skill (cf. Wagner & Torgesen, 1987). Consistent with this, children with reading difficulties suffer phonological problems but perform at age-appropriate levels on nonphonological speed of processing tasks, whereas children of low IQ show deficits in speed of processing but normal phonological skills (Bonifacci & Snowling, 2008).

If RAN taps mechanisms that are causally related to the development of reading skills, how should we conceptualize this relationship? At the most basic level, reading aloud and RAN are both naming tasks. When reading aloud, the child has to retrieve the name for a word; in our nonalphabetic RAN tasks, the child must retrieve the name of an object or color patch. Brain-imaging studies of adult readers suggest that reading and object naming involve very closely related sets of neural circuits: The major difference between reading and object naming is that levels of activation in areas involved in speech production are higher during single-word reading than when naming the objects denoted by the same words (Price et al., 2006). Reading involves activation in a circuit of at least three left-hemisphere brain regions: The mid-fusiform area seems to play a role in word identification, the anterior fusiform seems to play a role in amodal semantic processing, and the superior temporal cortex seems to play a role in articulation (see Price & McCrory, 2005).

The functions of the left mid-fusiform, which is strongly activated both in reading aloud and in naming objects, has been the source of controversy. Some authors have suggested that this region contains a visual word form area (Cohen et al., 2000, 2002). Others have suggested that this region has a more general role in uniquely identifying stimuli (whether objects or words) prior to naming them (e.g., Price et al., 2006). What is not in dispute is that this area is heavily involved in object identification and single-word reading.

These findings from adult brain-imaging studies can be related to a neuro-developmental view of how the reading system develops. From a developmental perspective, it seems reasonable to argue that the left mid-fusiform area may start out as an object-recognition area (an area involved in identifying objects prior to name retrieval), and that this system is then recruited to serve an analogous function in identifying written words. Dehaene (2005) argued that, in evolutionary terms, this area is homologous with areas in the macaque brain involved in object recognition. He argued that these areas are then recruited to serve the related purpose of recognizing printed words in humans and that this area in the human brain has, in turn, developed close connections with language areas subserving name retrieval and semantic processing. In his view, the visual word-form area "should not be considered as a 'module' for visual word recognition, but rather as a population of neurons, distributed and overlapping with other populations involved in object recognition, which becomes progressively attuned to the reading process" (p. 140).

We speculate that RAN taps the integrity of the neural circuits involved in object identification and naming, and that these same neural circuits are recruited to function as a critical component of the child's developing visual word recognition system. The integrity of the left mid-fusiform area and the quality of its connections with areas concerned with name retrieval and production may therefore place constraints on how readily a word-recognition system can be developed.

RAN and Later Reading Development

Our discussion has focused on the prediction of early reading skills from nonalphabetic RAN measured before reading instruction has begun, which seems particularly critical for claims that RAN taps a cause of reading development. Slightly later in development, after children have started to learn to read, it is evident that alphanumeric RAN continues to predict the further growth in text-reading fluency, even after a range of other predictors have been controlled (i.e., earlier reading skills, verbal abilities, and phoneme awareness). It is also the case that alphanumeric RAN at these later time points is powerfully predicted by earlier measures of nonalphabetic RAN. These findings seem entirely consistent with our hypothesis that the integrity of left-hemisphere circuits, involving the left mid-fusiform area and language-processing areas, subserve the development of both alphanumeric RAN and reading skills. In this view, the strong longitudinal relationship between early nonalphabetic RAN skills and later alphabetic RAN skills reflects the fact that both depend on largely common neural mechanisms.

Conversely, variations in text-reading fluency among children did not explain the subsequent growth in either of the two RAN constructs with development. This finding is again consistent with the hypothesis that RAN may be tapping the efficiency of basic neural mechanisms that place constraints on learning to read. However, increases in text-reading fluency, which we have argued depend on the recruitment of these neural systems (cf. Dehaene, 2005), do not bring about a reciprocal increase in RAN. In other words, these findings appear consistent with a unidirectional causal mechanism: Variations in the efficiency of left-hemisphere naming circuits constrain the development of reading skills; however, improvements in reading (brought about by reading practice) do not bring about reciprocal increases in the efficiency of these naming circuits.

Implications

We have shown that RAN, measured before reading instruction begins, predicts the later growth of reading fluency. We have suggested that RAN reflects variations in relatively stable and durable aspects of brain functioning that may be difficult to modify. If this is true, RAN may be particularly useful as an early diagnostic measure that is predictive of later reading difficulties. Conversely, in this view, RAN may hold limited implications for how to intervene to improve reading skills (this possibility is consistent with evidence that training rapid letter naming has little effect on either RAN or reading; de Jong & Vrielink, 2004). However, we should not see individual differences in the mechanisms tapped by RAN as placing some insurmountable limit on a child's reading fluency: There is evidence that remedial programs that include intensive text-reading practice can produce substantial improvements in reading fluency among children with reading difficulties (Torgesen, 2005).

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