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Examining the Importance of Assessing Rapid Automatized Naming (RAN) for the Identification of Children with Reading Difficulties

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The purpose of this study was to assess the diagnostic value of rapid automatized naming (RAN) in the identification of poor readers in two alphabetic orthographies: English and Greek. Ninety-seven English-speaking Canadian (mean age = 66.70 months) and 70 Greek children (mean age = 67.60 months) were followed from Kindergarten until Grade 3. In Kindergarten and Grade 1, they were assessed on measures of RAN, phonological awareness, and letter knowledge. In Grade 3, they were assessed on measures of reading accuracy (for the English sample) and reading fluency (for the Greek sample). The results of logistic regression and receiver operating curve (ROC) analyses indicated that RAN was a significant predictor of an individual's risk for reading difficulties when assessed in Grade 1 in English and in both Kindergarten and Grade 1 in Greek. Although the logistic models (including RAN as one of the predictors) accurately identified the majority of the children who turned out to be poor readers, they also over-identified as poor readers a large number of children who did not manifest reading difficulties later on.

Keywords: Reading Accuracy, Fluency, Phonological Awareness, Letter Knowledge.

The motto "the best intervention is early prevention" is now widely promoted in the area of reading disabilities (National Reading Panel, 2000). However, in spite of the acknowledged importance of early identification of children at-risk for reading disabilities, there is still controversy as to (a) what processing skills could accurately identify these children, and (b) when is the best time to assess these processing skills in order to improve prediction (Bishop & League, 2006; Schatschneider, Fletcher, Francis, Carlson, & Foorman, 2004). Letter knowledge and phonological awareness have dominated the field of research in the last three decades (Scarborough, 1998). It is argued that both skills are critical for the acquisition of the alphabetic principle which, in turn, is necessary for reading (e.g., Goswami & Bryant, 1990; Jorm, Share, Maclean, & Matthews, 1984). The purpose of the present study was to assess the diagnostic value of rapid automatized naming (RAN) in the identification of poor readers in two alphabetic orthographies: English and Greek. Examining the importance of assessing RAN is critical under the light of recent arguments that RAN is uniquely associated with reading disabilities (e.g., Heikkilä, Närhi, Aro, & Ahonen, 2008; Willburger, Fusseneger, Moll, Wood, & Landerl, 2008).

Briefly, rapid automatized naming (RAN) refers to how quickly an individual can pronounce the names of a set of visually presented highly familiar symbols. For example, a child may be shown a page of 50 color patches (red, green, yellow, blue, black) presented in semi-random order and asked to name them as quickly as possible. The four types of stimuli that have been used most often are colors, objects, digits, and letters. Research on RAN began in the 1970s (Denckla, 1972; Denckla & Rudel, 1976; see also Denckla & Cutting, 1999, on the history of RAN and Bowers and Ishaik (2003) and Kirby, Georgiou, Martinussen, and Parrila (2010), for the most recent review of the literature on RAN) and was stimulated by Wolf and Bowers' (1999) seminal paper on the double-deficit hypothesis, according to which children with deficits in both phonological awareness and RAN are poorer readers than children with single deficits in either phonological awareness or RAN.

There is now a wealth of evidence suggesting that RAN is a strong predictor of reading in several languages (e.g., de Jong & van der Leij, 1999; Georgiou, Parrila, & Liao, 2008; Kirby, Parrila, & Pfeiffer, 2003; Landerl & Wimmer, 2008; Lepola, Poskiparta, Laakkonen, & Niemi, 2005; Liao, Georgiou, & Parrila, 2008; Papadopoulos, Georgiou, & Kendeou, 2009; Schatschneider et al., 2004). RAN performance, particularly when alphanumeric stimuli are used, distinguishes average from poor readers during childhood (e.g., Badian, Duffy, Als, & McAnulty, 1991; Cornwall, 1992; Savage et al., 2005) and in adulthood (e.g., Chiappe, Stringer, Siegel, & Stanovich, 2002; Felton, Naylor, & Wood, 1990; Parrila, Georgiou, & Corkett, 2007). Importantly, RAN has survived as a predictor of reading even after controlling statistically for IQ (e.g., Cornwall, 1992), articulation rate (e.g., Parrila, Kirby, & McQuarrie, 2004), speed of processing (e.g., Bowey, McGuigan, & Ruschena, 2005), discrete naming (e.g., Bowers & Swanson, 1991), short-term memory (e.g., Parrila et al., 2004; Powell, Stainthorp, Stuart, Garwood, & Quinlan, 2007), letter knowledge (e.g., Kirby et al., 2003), and phonological awareness (e.g., Kirby et al., 2003; Manis, Doi, & Bhadha, 2000; Papadopoulos et al., 2009).

Several theoretical accounts have been proposed to explain the relationship between RAN and reading (see Kirby et al., 2010, for a review). For example, Torgesen, Wagner, and their colleagues (Torgesen, Wagner, & Rashotte, 1994; Wagner & Torgesen, 1987) have argued that RAN assesses the rate of access to and retrieval of stored phonological information in long-term memory. Initially, RAN was called "phonological recoding in lexical access" and was considered as part of the phonological processing family along with phonological awareness and phonological memory. More recently, Bowey et al. (2005) proposed that at the beginning of reading development, both over-learned letter knowledge and phonological processing ability mediate the relationship between RAN and reading while at later levels of reading development, it is primarily phonological processing ability that mediates the relationship.

The majority of studies that examined the contribution of RAN and other cognitive skills to reading have focused on the group-level differences in the predictors of reading using reading-disabled and control groups. Although significant group differences on a measure may be detected, it does not necessarily mean that the same measure can discriminate and predict skills reliably at an individual level. More recently, researchers have demonstrated that it is possible to derive a probability score for developing reading difficulties for each individual using a logistic regression equation (e.g., Catts, Fey, Zhang, & Tomblin, 2001; Puolakanaho et al., 2007). This probability score is important for clinicians who are frequently asked to make a decision as to whether a child should be referred for further assessment and intervention. However, what cutoff probability level could be considered good enough to discriminate between children who have a risk and children who do not have a risk for reading difficulties? Catts et al. (2001) have suggested that a probability score greater than .30 indicates risk for developing reading difficulties in later years.

Only a handful of studies have examined the contribution of RAN in the prediction of an individual's risk to develop reading difficulties (e.g., Badian, 1998; Catts et al., 2001; O'Connor & Jenkins, 1999; Puolakanaho et al., 2007; Savage et al., 2005). Comparing the results across these studies is difficult for four reasons: First, they assessed RAN with different tasks. It is generally accepted that alphanumeric (letters and digits) RAN tasks are more strongly related to reading than non-alphanumeric (colors and objects) RAN tasks (Georgiou, Parrila, Kirby, & Stephenson, 2008; Wolf, Bally, & Morris, 1986). By administering non-alphanumeric RAN tasks some researchers may have underestimated the effects of RAN (e.g., Catts et al., 2001; Puolakanaho et al., 2007). However, we also need to acknowledge the fact that alphanumeric RAN is difficult to administer in preschool or in kindergarten because the majority of the children are not familiar with the digits or the letters.

Second, different studies have used different cutoff scores to identify the poor readers (see Johnson, Jenkins, Petscher, & Catts, 2009, for a review on the use of different cutoff scores). For example, Wilson and Lonigan (2010) used the 25th percentile, Protopapas, Skaloumbakas, and Bali (2008) the 20th percentile, and Puolakanaho et al. (2007) the 10th percentile as a cutoff score. The 25th percentile may be too lenient, thus resulting in an over-identification of children as poor readers.

Third, the sampling procedure varies across these studies. Pennington and Lefly (2001), for example, recruited children with low and high familial risk of dyslexia. In contrast, Catts et al. (2001) oversampled children with language and nonverbal cognitive impairments.

Finally, different studies have employed different statistical approaches that vary on the assumptions they make and the questions they address (Press & Wilson, 1978; Tabachnick & Fidell, 2001). Some studies have used discriminant function analysis (Gijsel, Bosman, & Verhoeven, 2006; Pennington & Lefly, 2001; Savage et al., 2005). Some others have used logistic regression analysis (Badian, 1998; Catts et al., 2001). Still others, more recently, have used receiver operating characteristic (ROC) analysis (Wilson & Lonigan, 2010) or a combination of logistic regression and ROC analysis (Puolakanaho et al., 2007).

The studies that have used comparable approaches have also provided partly conflicting evidence (Catts et al., 2001; Puolakanaho et al., 2007). For example, Catts et al. (2001) examined the contribution of several cognitive processing skills in Kindergarten and found that RAN—measured with an animal-naming task—was not a significant predictor of the reading outcome in Grade 2 when Block Design was included in the logistic regression analysis. Only when Block Design was removed from the equation did RAN marginally predict the probability of developing reading difficulties in Grade 2. In contrast, working with Finnish children, Puolakanaho et al. (2007) found that RAN—measured with an object naming task—at the age of 3.5 and 5.5 years—was a significant predictor of individuals' risk to develop reading difficulties in Grade 2, even after controlling for the effects of phonological awareness and familial risk of dyslexia.

The present study makes three contributions: First, we examined the contribution of RAN at two different time points; in Kindergarten and in Grade 1. It is possible that RAN is important only after the commencement of reading instruction (see Wagner et al., 1997). Second, we have followed the same children from Kindergarten until Grade 3. Previous studies identified the poor readers in Grade 2 (e.g., Catts et al., 2001; Puolakanaho et al., 2007). We argue that particularly in English by Grade 3, the reading difficulties are more stable and, as a result, we have better chances to identify the "true" poor readers. Finally, we examined the contribution of RAN in two different alphabetic orthographies. If RAN is a stronger predictor of reading in transparent orthographies than in opaque orthographies (e.g., de Jong & van der Leij, 1999; Georgiou, Parrila, & Papadopoulos, 2008), then it should play a stronger role in the prediction of an individual's risk for reading difficulties in Greek than in English. Within the family of alphabetic scripts, Greek provides an interesting contrast to English because of its high degree of regularity for reading (see Porpodas, 2004, for a description of Greek orthography). In what follows we present first the results with English-speaking children (Study I) and then the results with Greek children (Study II).

STUDY I

Method

Participants

The participants were 161 English-speaking Canadian children who began the study in senior kindergarten when they were about 5 years of age (mean age = 66.7 months, *SD* = 3.6 months). This is the first year of compulsory schooling, in which children attend either half or alternative days. Formal reading instruction began in Grade 1 and was eclectic; some phonics instruction was provided in the course of programs that were primarily whole language. The participants were part of a longitudinal project extending from kindergarten until Grade 5 (see Kirby et al., 2003, for a detailed description of the project). By Grade 3, the sample consisted of 99 children. To assess whether attrition posed a threat to the study, we compared the participants who had left the study by Grade 3 with those who remained on each of the kindergarten variables used in the study. *T* tests indicated that there were no significant differences between the two groups on any of the kindergarten and Grade 1 measures (all *p*s > .10). Beyond the attrition, two children with missing data on some variables in Kindergarten were further eliminated from the analyses. Thus, the final sample consisted of 97 children.

The participants were drawn from a broad range of schools in Kingston, Ontario, Canada, representing a range of socioeconomic backgrounds. Consistent with the population in the region, all but a few of the children were Caucasian. Each year approximately half of the children were female. The only requirements for participation in the study were informed parental consent and ability to understand the task instructions.

The curriculum in which the children were exposed to in Ontario is set centrally, but in broad terms. Lists of acceptable textbooks are provided, but the teachers have considerable leeway in applying the broad curriculum goals to their classrooms. The kindergarten curriculum has little formal academic content, and Grade 1 is when formal reading instruction begins. Reading instruction consists of code- and meaning-oriented activities.

Measures

Three measures of phonological awareness were administered (all taken from Wagner, Torgesen, Laughton, Simmons, & Rashotte, 1993). *Sound Isolation* required the participant to identify the first, the last, or the middle sound in a word. There were six practice items and 15 test items consisting of three- and four-phoneme one- or two-syllable words. *Phoneme Elision* required the participant to repeat a word after deleting an identified phoneme. The specific instructions were as follows: "Say the word /cat/. Now say the word /cat/ without the /k/." All phonemes to be deleted were consonants, the position of which varied. After the target phoneme was deleted, the remaining phonemes formed a word (e.g., /seed/ without the /d/ leaves /see/). There were six practice items and 15 test items consisting of three- to five-phoneme one- or two-syllable words. In *Phoneme Blending* the participant was presented orally with a sequence of phonemes and was asked to pronounce the word that resulted when the phonemes were blended together (e.g., "What word does /m/ – /oo/ – /n/ say?"). Length increased from two to six phonemes. Each of the three phonological awareness tests was discontinued after four mistakes in the last seven items, and in each the score was the number of items correct. Wagner at al. (1993) reported the alpha reliability coefficients of these three measures in kindergarten to be, respectively, .89, .71, and .88. A composite phonological awareness score (average z scores on Sound Isolation, Phoneme Elision, and Phoneme Blending) was calculated and used in further analyses.

Two measures of RAN were used in the study: Color Naming and Picture Naming. In each task the child had to name a series of 32 randomly ordered colors or pictures, each taken from a set of four (colors: blue, green, red, and yellow; pictures: bird, horse, pig, and cat). Practice was provided to ensure that the children were familiar with the standard names of the colors and pictures. The stimuli were presented in eight rows of four items. The child's score in each task was the number of seconds taken to name the stimuli correctly. Although no reliability coefficients are available for these measures, their correlation in the present sample was .74 in Kindergarten and .71 in Grade 1. A composite RAN score (average z scores on RAN Colors and Pictures) was calculated and used in further analyses.

Letter-Name Knowledge was assessed by administering the Letter Identification test (Clay, 1993). Participants were asked to identify each of the upper- and lowercase letters. Two lowercase letters, *a* and *g*, were presented in two different fonts, so the total possible score was 54.

Two subtests from the Woodcock Reading Mastery Tests-Revised (Woodcock, 1987) were used to assess reading ability in Grade 3. Form H of Word Attack and Word Identification subtests were used. Word Attack measures participants' ability to apply phonic and structural analysis skills in pronouncing pseudowords or low frequency words that are not recognizable by sight (e.g., *dee*, *apt*, *ift*). Word Identification requires the participant to read isolated words aloud (e.g., *is*, *you*, *and*). Woodcock (1987) reported split-half reliability coefficients for Word Attack and Word Identification for Grade 3 children to be .91 and .97, respectively.

Procedure

Participants were examined three times: April/May of the kindergarten year, October/November of Grade 1 (Fall), and October/November of Grade 3 (Fall). The phonological awareness, the RAN, and the letter recognition tasks were administered in Kindergarten and Grade 1 and the reading measures were administered in Grade 3. All participants were tested individually in their respective schools during school hours by trained experimenters. Testing lasted roughly 40 minutes.

Classification of Children as Poor and Normal Readers

Given the purpose of this study which was to provide a mechanism for the identification of Kindergarten or Grade 1 children who are at risk for reading difficulties in Grade 3, it was necessary to divide the participants into those who did and those who did not demonstrate reading difficulties in Grade 3. Reading difficulties were defined as scores greater than 1 SD below the mean on the composite measure of reading accuracy (average *z* scores on Word Identification and Word Attack). Using this criterion, 80 children were classified as normal readers and 17 children were classified as poor readers.

Statistical Analysis

To examine the relationship between the Kindergarten or Grade 1 measures and the Grade 3 reading status, we used logistic regression analysis followed by ROC analysis. In many ways, logistic regression analysis is similar to multiple regression analysis, but differs in that the dependent variable is categorical (Peng, Lee, & Ingersoll, 2002). In multiple regression analysis, one would predict an individual's actual score in Grade 3. In logistic regression analysis, one would predict an individual's likelihood of having a reading difficulty in Grade 3. The central mathematical concept that underlies logistic regression is the logit—the natural logarithm of an odds ratio (the probabilities of Y happening (i.e., a student has reading difficulties in Grade 3) to probabilities of Y not happening (i.e., a student does not have reading difficulties in Grade 3)).

The logistic regression analysis was performed in SPSS v.18. In order to determine whether assessing RAN was important for the prediction of a child's risk for reading difficulties, we first estimated the fit of a model in which letter knowledge and phonological awareness were the only predictors. Second, we estimated the fit of a model after adding RAN to the set of predictors. The second model resulted in a χ^2 value with 3df which was compared against the χ^2 value of the first model with 2df. A significant change in the χ^2 value (greater than the χ^2 critical value for 1df and $p <$ .05) would imply that the inclusion of RAN improved the prediction. The analysis was performed twice: once with the Kindergarten measures and once with the Grade 1 measures.

In order to assess the results of the logistic regression models that included RAN as one of the predictors, several indexes were used. First, the statistical significance of each predictor was tested using the Wald χ^2 statistic. Second, the Hosmer-Lemeshow's goodness-of-fit statistic was used to assess the fit of the logistic model against actual outcomes. An additional descriptive measure of goodness-of-fit used was Nagelkerke's R^2. Finally, the classification accuracy of the prediction was calculated. Classification accuracy is generally described in terms of sensitivity and specificity, or false positive and false negative rates. Whereas sensitivity and specificity are indices that are calculated from the perspective of the outcome classification, false positive and false negative rates are calculated from the perspective of the screening prediction. Specifically, sensitivity refers to the percentage of children who turned out to have reading difficulties and who also had a Kindergarten or Grade 1 probability score at or above the cutoff value of risk for reading difficulties. In contrast, specificity refers to the percentage of children who turned out to be normal readers and also had a Kindergarten or Grade 1 probability score under the cutoff value of risk for reading difficulties. The false positive rate is the percentage of children who were predicted to have reading difficulties, but who turned out to be normal readers, and false negative rate is the percentage of children who were predicted to be normal readers, but who turned out to have reading difficulties. The classification accuracy was calculated on the basis of three probability cutoff scores. The first two probability cutoff scores (.50 and .25) were selected because they are the values most typically presented in the literature (Peng et al., 2002). The third probability level (.20) was selected because it represents an optimal probability level in which sensitivity is close to 90%, a rate which is considered acceptable for clinical decision making without sacrificing specificity (e.g., Catts et al., 2001; Wilson & Lonigan, 2010).

Following the results of the logistic regression analysis, ROC curves were generated for each one of the predictor variables at each grade. The method is often used in medical research to explore a measure's ability to detect individuals who have a disorder from those who do not have it (e.g., Greiner, Pfeiffer, & Smith, 2000; Hanley & McNeil, 1982). A ROC curve is a plot of the sensitivity against 1-specificity for different cutoff points of a predictor. The effectiveness of each one of the predictors is determined by evaluating the area under the curve (AUC). AUC is the proportion of the area falling below the ROC curve: values range from .50 to 1.00 with .50 denoting chance performance of the predictor variable and 1.00 denoting perfect performance (Swets, 1988). To assess whether the difference between two AUCs was significant, we first calculated a z score (see Hanley & McNeil, 1983, for the formula) and then we referred to the tables for the normal distribution. Values of z above the critical value of 1.96 were taken as evidence that the two AUCs differed significantly at the .05 level of significance.

Results and Discussion

First, we examined the descriptive statistics and the distributional properties of the measures used in the study. Phoneme Blending (Kindergarten: *mean* = 5.68, *SD* = 5.22; Grade 1: *mean* = 9.82, *SD* = 4.19) and Phoneme Isolation (Kindergarten:

mean = 4.07, *SD* = 4.28; Grade 1: *mean* = 7.79, *SD* = 4.65) were normally distributed across grades. Letter knowledge (Kindergarten: *mean* = 35.84, *SD* = 17.66; Grade 1: *mean* = 48.14, *SD* = 8.59) was negatively skewed in Grade 1 and Phoneme Elision (Kindergarten: *mean* = 3.13, *SD* = 4.14; Grade 1: *mean* = 6.64, *SD* = 4.69) was positively skewed in Kindergarten. RAN Colors (Kindergarten: *mean* = 37.47, *SD* = 11.50; Grade 1: *mean* = 30.70, *SD* = 10.67) and RAN Pictures (Kindergarten: *mean* = 41.34, *SD* = 12.25; Grade 1: *mean* = 32.89, *SD* = 12.08) were positively skewed in both grades. To normalize the distributions, the extreme scores in each task were moved to the tails of the distributions (Tabachnick & Fidell, 2001). Second, we calculated the correlations between the constructs. In Kindergarten, RAN correlated -.47 and -.37 with letter knowledge and phonological awareness, respectively. In Grade 1, the corresponding correlations were -.23 and -.41. In addition, letter knowledge correlated .58 with phonological awareness in Kindergarten and .44 in Grade 1.

Next, we performed logistic regression which was followed by ROC analyses. The results of the logistic regression analyses are presented in Table 1. In Kindergarten, only letter knowledge had a significant partial effect on the reading outcome. Although the inclusion of RAN in the model increased both Nagelkerke's R^2 from .28 to .32 and the overall classification accuracy from 82.5% to 84.5%, the model that included RAN did not significantly differ from the first model that did not include RAN ($\Delta\chi^2(1)$ = 2.65, *ns*). In Grade 1, both phonological awareness (Wald χ^2 = 11.34, $p < .001$) and RAN (Wald χ^2 = 3.83, $p < .05$) were unique predictors of the reading outcome. The inclusion of RAN in the model increased Nagelkerke's R^2 from .50 to .55 and the overall classification accuracy from 89.7% to 91.8%. In addition, the χ^2 change was significant ($\Delta\chi^2(1)$ = 4.55, $p < .05$) and the model fitted the data very well (Hosmer-Lemeshow test yielded a $\chi^2(8)$ of 14.55, which is not significant at the .05 level).

Table 1. ***Logistic Regression Predicting Decision From Letter Knowledge, Phonological Awareness, and RAN in English***

Grade Level	Predictor	B	Wald χ^2	p	$\Delta\chi^2$ (df=1)	Odds Ratio
Kindergarten						
Model 1	LK	-.051	6.67	.010		.95
	PA	-.656	1.05	.305		.52
Model 2	LK	-.042	4.20	.040		.96
	PA	-.692	1.06	.303		.50
	RAN	.515	2.62	.106	2.65	1.67
Grade 1 Fall						
Model 1	LK	-.042	1.99	.158		.09
	PA	-2.382	14.04	.000		.96
Model 2	LK	-.042	1.84	.175		.96
	PA	-2.367	11.34	.000		.09
	RAN	.621	3.83	.050	4.55*	1.86

Note. LK = Letter Knowledge; PA = Phonological Awareness; RAN = Rapid Automatized Naming. * $p < .05$.

The classification outcomes based on the two grade-specific models, with three cutoff values of prediction probability scores are presented in Table 2. In Kindergarten, when the probability cutoff level was .50, sensitivity was very low (29.4%) and specificity was very high (96.3%). Adjusting the probability cutoff value to .20 resulted in a significant increase in sensitivity (76.5%) without sacrificing specificity too much (73.8%). Compared to Kindergarten, the sensitivity level in Grade 1 was higher for every probability level. Particularly, when the probability level was set at .20, 88.2% of the poor readers were correctly identified. With respect to the false positive and false negative rates, it is obvious that reducing the probability value increases the number of children who were predicted to have reading difficulties but who turned out to be normal readers. In Kindergarten, when the probability level was set at .20, the false positive rate was quite high (61.7%), but dropped in Grade 1 to 46.4%. The latter is very close to the one reported in Catts et al.'s (2001) study (48.4%). These results suggest that approximately half of the sample predicted to have reading difficulties turn out to have reading difficulties. The good news is that the false negative rate was relatively low (6.3% in Kindergarten and 2.9% in Grade 1), which means that the chances of a child who was predicted to have good reading skills but who actually turned out to be a poor reader are very small.

Table 2. ***Classification Accuracy at the Different Probability Cutoff Levels Using the Grade-Specific Logistic Models***

Grade	Probability Level	Classification accuracy, %	Sensitivity %	Specificity %	False Positive %	False Negative %
Kindergarten						
	.50	84.5	29.4	96.3	37.5	13.4
	.25	80.4	70.6	82.5	53.8	7.0
	.20	74.2	76.5	73.8	61.7	6.3
Grade 1						
	.50	91.8	76.5	95.0	23.5	5.0
	.25	85.6	88.2	85.0	44.4	2.8
	.20	84.5	88.2	83.8	46.4	2.9

The question then becomes what the implications of this classification are. On one hand, all classification indices suggest that when the probability cutoff level is set at .20, we are able to detect almost all of the children who will eventually turn out to be poor readers. Thus, remediation will be given to the ones in need. On the other hand, selecting a probability cutoff value as low as .20 increases the number of children predicted to have reading difficulties but who turn out to be normal readers. In essence, remediation will also be given to students who do not necessarily need it.

The ROC Analysis

The results of the ROC analysis are presented in Figure 1. Because higher performance (slower times) in RAN is associated with higher probability scores, the ROC curve for RAN is shown above the reference line. In contrast, because lower performance in phonological awareness and letter knowledge is associated with higher probability scores, the ROC curves for phonological awareness and letter knowledge are shown below the reference line. In Kindergarten, the AUC for letter knowledge, phonological awareness, and RAN was .80, .73, and .73, respectively. In Grade 1, the AUC for letter knowledge, phonological awareness, and RAN was .83, .89, and .75, respectively. In all cases, the screening measures predicted the reading outcome significantly better than chance level. No significant differences between the AUCs were found in either one of the grades (all *z*s < 1.96).

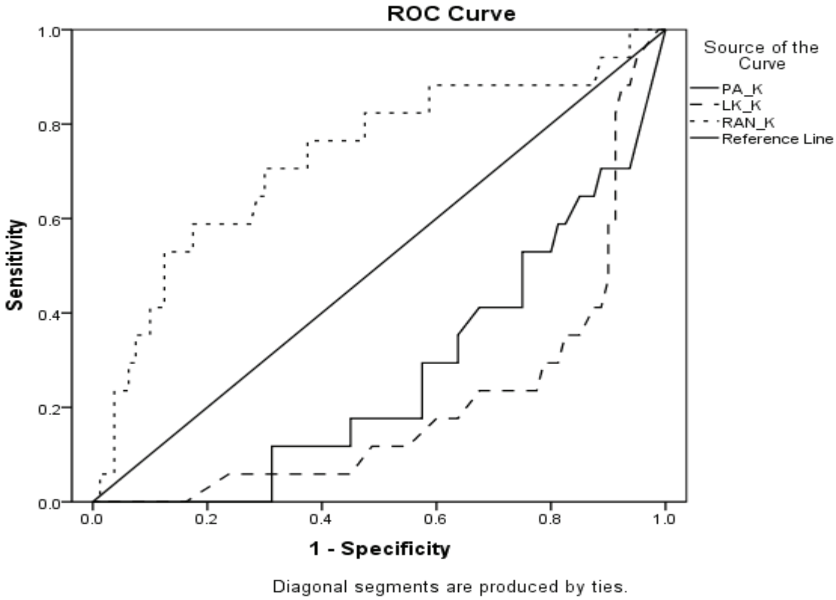
STUDY II
Method

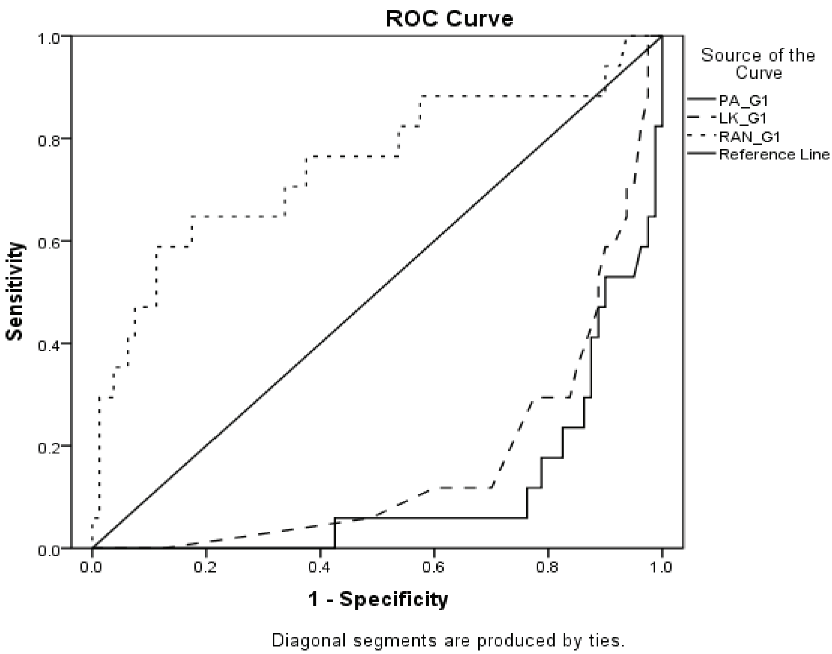
Participants

Letters of information describing the study were sent to parents of 232 kindergarten students in four schools in Rethymno, Crete, Greece. One hundred seventy-seven Greek students were given parental permission to participate in the study. Of these, 95 (50 males and 45 females; 67.01 months, *SD* = 2.93) students were randomly selected to be part of the present study. There were no students excluded based on linguistic or other grounds. All the participating children were native speakers of Greek, Caucasian, and had an average non-verbal intelligence (Raven's Progressive Matrices: *Mean* = 15.55, *SD* = 3.13). By Grade 3 the sample consisted of 70 children (33 girls and 37 boys, mean age = 101.60 months, *SD* = 3.05). In order to determine whether the performance of the children who withdrew from the study differed significantly from the rest of the children, we performed *t* tests on their kindergarten performance scores. None of the *t* tests reached significance (all *p*s > .11). Thus, all the data analyses were performed with the 70 children for whom a full data set was available across time.

The children were attending public kindergarten schools that were following the same curriculum delivered by the Greek Ministry of Education. There is no formal reading instruction in Kindergarten; however, children receive phonological awareness training through activities in the classroom and are familiarized with written text through fairy tales and theatrical play. Formal reading instruction, which places a heavy emphasis on mastering the grapheme-phoneme correspondence rules, begins in Grade 1. All the schools use the same textbooks and reading materials.

***Figure 1*. ROC Analysis for the English Data: Kindergarten, Grade 1.**





Measures

Three measures of phonological awareness were administered. In *Initial Sound Matching* the children were shown a target picture of an object and then asked to select among three pictures which one shared the same initial sound as the target one. For example, the children would be provided with a stimulus word (e.g., /kota/ → chicken) and then asked to choose one of three words that alliterated with it (e.g., /γata/, /molivi/, /kalaθi/ → cat, pencil, basket). Ten items were given to the children, following two practice items. Cronbach's alpha reliability coefficient in our sample was .68. *Phoneme Elision* required the participant to repeat a word after deleting an identified phoneme. This task was adapted in Greek from the CTOPP (Wagner, Torgesen, & Rashotte, 1999) and consisted of three practice items and 29 test items: four test items were two syllable words and required the participant to say the word without saying one of the syllables (i.e., say /topi/ (ball) without saying /pi/), and the remaining 25 items required the participant to say a word without saying a designated sound in the word (i.e., say /poli/ (city) without saying /p/). The position of the phoneme to be removed varied across those 25 items. Testing was discontinued after three consecutive errors. A participant's score was the number of correct items. Cronbach's alpha reliability coefficient in our sample was .94. In *Phoneme Blending* the participant was asked to listen to a series of separate sounds and then put the separate sounds together to make a whole word. There were five practice items and 20 test items: three test items required the participant to put together two syllables to make a word (i.e., /me/, /no/), five test items required the participant to put an onset and a rime together to make a word (i.e., /m/ and /as/), and the remaining 12 items required the participant to put individual sounds together to make a word (i.e., /k/, /a/, /l/, /o/). The number of phonemes to be blended varied from 2 to 10. Testing was discontinued after three consecutive errors and a participant's score was the number of correct items. Cronbach's alpha reliability coefficient in our sample was .91. A composite phonological awareness score (average z scores on Sound Isolation, Phoneme Elision, and Phoneme Blending) was calculated and used in further analyses.

Two measures of RAN were used: Color Naming and Picture Naming. Both RAN tasks were presented on a laptop computer screen. Prior to beginning the timed naming, each participant was asked to name the colors/objects in a practice trial to ensure familiarity. Color Naming was adopted in Greek from the RAN/RAS test battery (Wolf & Denckla, 2005) and required participants to state as quickly as possible the names of five colors (blue, black, green, red, or yellow). The colors were arranged semi-randomly in five rows of ten. The names of the colors in Greek are "μπλε" (/*ble/*) for blue, "μαύρο" (/*mavro/*) for black, "πράσινο" (/*prasino/*) for green, "κόκκινο" (/*kokino/*) for red, and "κίτρινο" (/*kitrino/*) for yellow. In turn, Picture Naming was adopted in Greek from CTOPP (Wagner et al., 1999). Participants were required to state as quickly as possible the names of six pictures (ball, cat, tree, chicken, key, and apple) that were arranged semi-randomly in four rows of nine. The total time to completion was recorded was the participant's score. The names of the pictures in Greek are "μπάλα" (/bala/) for ball, "γάτα" (/γata/) for cat, "δέντρο" (/ðedro/) for tree, "κότα" (/kota/) for chicken, "κλειδί" (/kliði/) for key, and "μήλο (/milo/) for apple. Although no reliability coefficients are available for these measures in Greek, Color and Picture Naming correlated .61 with each other in Kindergarten and .70 in

Grade 1. A composite RAN score (average z scores of RAN Colors and Pictures) was calculated and used in further analyses.

Letter-Sound Knowledge was measured only in Kindergarten. The participants were asked to provide the sound of each uppercase Greek letter presented in random order on a laptop screen. The maximum score was 24. Cronbach's alpha reliability coefficient in our sample was .95.

Word Attack was measured in Grade 1. The task consisted of 45 pronounceable non-words that were derived from real words after changing two or three letters (either by substituting them or using them backwards). A participant's score was the number of items correct. We administered Word Attack instead of letter-sound knowledge in Grade 1 because the latter reaches ceiling at the beginning of Grade 1 (Tafa & Manolitsis, 2008) and is no longer useful for diagnostic purposes. Cronbach's alpha reliability coefficient for Word Attack in our sample was .86.

Reading ability in Grade 3 was assessed with two measures: a word-reading fluency task and a non-word reading fluency task. In the word-reading fluency task, the children were asked to read as fast as possible a list of 104 words, divided into four columns of 26 words each. In the non-word reading fluency task, the children were asked to read as fast as possible a list of 63 pseudowords. A short, 8-word/non-word practice list was presented before each subtest. In each task, children's score was the number of correct words/non-words read within a 45-second time limit. The two measures correlated .87 with each other in Grade 3.

Procedure

Participants were examined three times: April/May of the kindergarten year, April/May of Grade 1 (spring), and April/May of Grade 3 (spring). All participants were tested individually in their respective schools during school hours by trained experimenters. Testing lasted roughly 40 minutes.

Classification of Children as Poor and Normal Readers

In order to identify the children with reading difficulties in Grade 3 we used the same procedure that has been described in Study I. However, instead of using reading accuracy measures to define the poor readers, we used reading fluency measures. This was done because in transparent orthographies such as Finnish, German, or Greek, reading accuracy reaches ceiling by the end of Grade 1 and provides little diagnostic information (e.g., Georgiou, Parrila, & Papadopoulos, 2008; Tafa & Manolitsis, 2008). Thus, reading difficulties were defined as scores greater than 1 SD below the mean on the composite measure of reading fluency (average z scores on word-reading fluency and nonword-reading fluency tasks). Using this criterion, 61 children were classified as good readers and 9 children were classified as poor readers.

Statistical Analysis

We performed the same analyses as described in Study I.

Results and Discussion

First, we examined the descriptive statistics and the distributional properties of the measures. Letter-sound knowledge (Kindergarten: *mean* = 12.33, *SD* = 7.87) and Initial Phoneme Matching (Kindergarten: *mean* = 7.09, *SD* = 2.52) were normally distributed. Phoneme Blending (Kindergarten: *mean* = 3.74, *SD* = 3.08; Grade 1: *mean* = 11.33, *SD* = 4.47) and Phoneme Elision (Kindergarten: *mean* = 3.60, *SD* = 5.47; Grade 1: *mean* = 14.83, *SD* = 8.99) were positively skewed in Kindergarten. In turn, RAN Colors (Kindergarten: *mean* = 93.01, *SD* = 32.69; Grade 1: *mean* = 60.89, *SD* = 21.09) and RAN Pictures (Kindergarten: *mean* = 60.72, *SD* = 16.93; Grade 1: *mean* = 42.86, *SD* = 11.85) were positively skewed in both grades. Finally, Word Attack (Grade 1: *mean* = 32.59, *SD* = 8.85) was negatively skewed. To normalize the distributions, the extreme scores in each task were moved to the tails of the distributions (Tabachnick & Fidell, 2001). Second, we calculated the correlations between the constructs. In Kindergarten, RAN correlated -.37 with letter knowledge and -.36 with phonological awareness. The correlation between letter knowledge and phonological awareness was .58. In Grade 1, RAN correlated -.36 with Word Attack and -.22 with phonological awareness. The correlation between Word Attack and phonological awareness was .62.

Next, we performed logistic regression analyses (see Table 3). In Kindergarten, all three predictor variables were significant. The inclusion of RAN in the model increased both Nagelkerke's R^2 from .25 to .52 and the classification accuracy from 87.1% to 92.9%. A test of the model that included RAN against the one that excluded RAN yielded a significant χ^2 change ($\Delta\chi^2(1) = 13.27$, $p < .001$). The model including RAN fitted the data very well (Hosmer-Lemeshow test yielded a $\chi^2(8)$ of 7.83, *ns*) and was able to correctly classify 55.6% of the children who were predicted to be poor readers and 98.4% of those who were predicted to be normal readers (for an overall classification accuracy of 92.9%). In Grade 1, only RAN was a significant predictor of the reading outcome (Wald $\chi^2 = 5.91$, $p < .05$). The inclusion of RAN in the model increased Nagelkerke's R^2 from .29 to .49, but did not alter the overall classification accuracy (88.6%). A test of the model that included RAN against the one that excluded RAN yielded a significant χ^2 change ($\Delta\chi^2(1) = 6.49$, $p < .05$). The model including RAN fitted the data very well (Hosmer-Lemeshow test yielded a $\chi^2(8)$ of 5.22, *ns*).

The classification outcomes based on the two grade-specific models, with three cutoff values of prediction probability scores are presented in Table 4. The third probability level was set to .20 in Kindergarten and .13 in Grade 1, because that was the level in which sensitivity was closer to 90% accuracy, a rate which is considered acceptable for clinical decision making. As expected, reducing the probability level from .50 to .20 in Kindergarten or to .13 in Grade 1 resulted in an improvement in sensitivity: 77.8% and 88.9% of the poor readers were correctly identified in Kindergarten and Grade 1, respectively. The specificity remained high in both grades (86.9%).

With respect to the false positive and false negative rates, reducing the probability value from .50 to .20 (in Kindergarten) or .13 (in Grade 1) resulted in an increase in the number of children misclassified as poor readers and in a decrease in the number of children misclassified as good readers. In Kindergarten, the false positive and false negative rates were 53.3% and 3.6%, respectively. In other words, only

46.7% (100% - false positive) of the children predicted to have reading difficulties, based on a cutoff value of .20, turned out to have reading difficulties, and most who are predicted to be good readers did not have reading difficulties (96.4%; 100 - false negative). In Grade 1, both false positive and false negative rates dropped to 50.0% and 1.8%, respectively.

Table 3. ***Logistic Regression Predicting Decision From Letter Knowledge, Phonological Awareness, and RAN in Greek***

Grade Level	Predictor	B	Wald χ^2	p	$\Delta\chi^2$ (df=1)	Odds Ratio
Kindergarten						
Model 1	LK	-.214	6.60	.010		.81
	PA	.493	1.41	.235		1.63
Model 2	LK	-.175	4.52	.034		.84
	PA	1.012	4.69	.030		2.75
	RAN	2.525	8.71	.003	13.27***	12.49
Grade 1 Fall						
Model 1	WAT	-.108	6.72	.010		.90
	PA	-.216	.23	.632		.81
Model 2	WAT	-.040	.61	.435		.96
	PA	-.209	.18	.675		.81
	RAN	1.478	5.91	.015	6.49*	4.39

Note. LK = Letter Knowledge; PA = Phonological Awareness; RAN = Rapid Automatized Naming; WAT = Word Attack.
* $p < .05$. *** $p < .001$.

Table 4. ***Classification Accuracy at the Different Probability Cutoff Levels Using the Grade-Specific Logistic Models***

Grade	Probability Level	Classification accuracy, %	Sensitivity %	Specificity %	False Positive %	False Negative %
Kindergarten						
	.50	92.9	55.6	98.4	16.6	6.2
	.25	90.0	66.7	93.4	40.0	5.0
	.20	85.7	77.8	86.9	53.3	3.6
Grade 1						
	.50	88.6	33.3	96.7	40.0	9.2
	.25	90.0	66.7	93.4	40.0	5.0
	.13	87.1	88.9	86.9	50.0	1.8

These findings are similar to what we have observed in Study I for the English-speaking children and in line with the findings of previous studies (e.g., Catts et al., 2001; Pennington & Lefly, 2001). Although the sensitivity and specificity indices and the overall classification accuracy would suggest that the logistic models have clinically useful discriminatory power, the predictions identify not only the true positives but also a large proportion of children who do not manifest reading difficulties later on.

The ROC Analysis

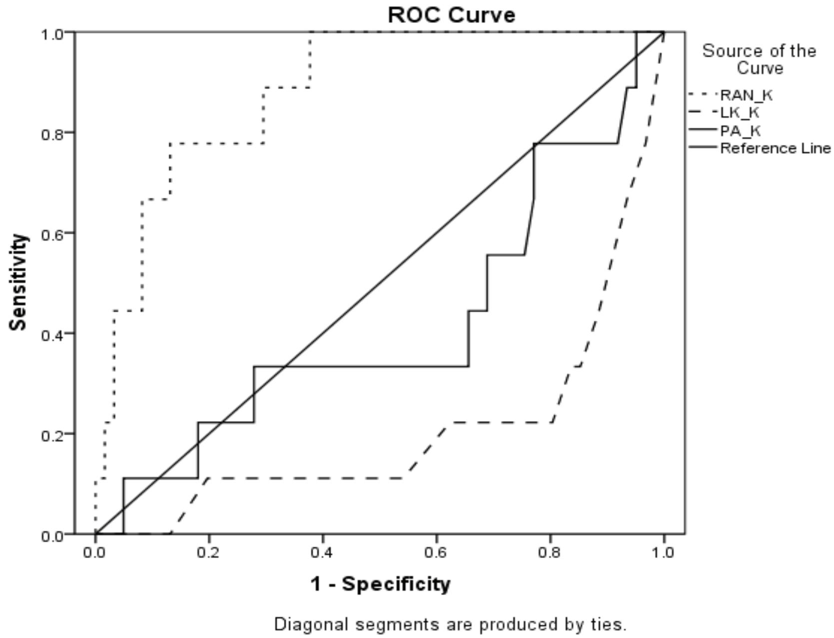
The results of the ROC analysis are presented in Figure 2. In Kindergarten, the AUC for letter knowledge, phonological awareness, and RAN was .80, .59, and .88, respectively. In Grade 1, the AUC for word attack, phonological awareness, and RAN was .76, .70, and .87, respectively. The AUC for phonological awareness in Kindergarten did not significantly differ from chance level. When we compared the AUCs for the different predictor variables, only the differences between RAN and phonological awareness ($z = 2.90$, $p < .01$) and letter knowledge and phonological awareness ($z = 2.13$, $p < .05$) in Kindergarten reached significance.

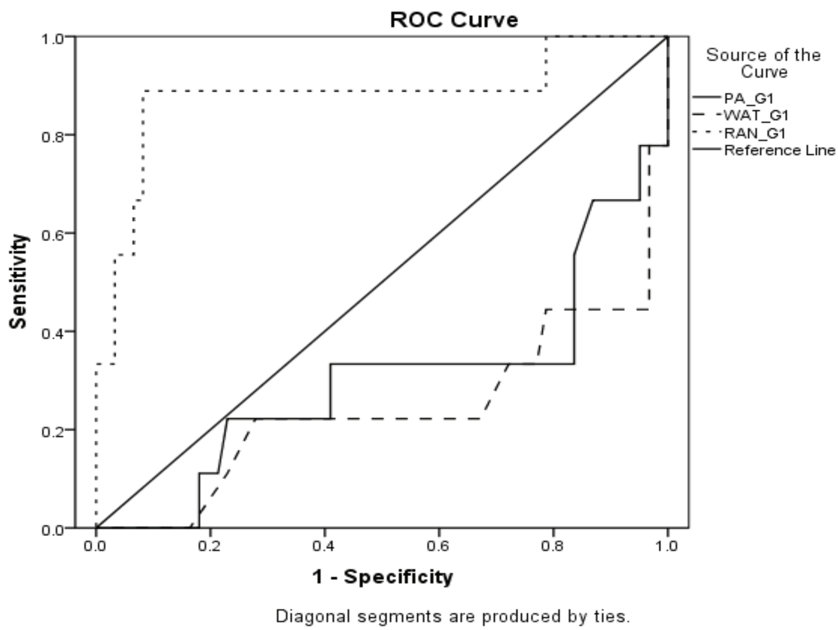
General Discussion

The purpose of the present study was to evaluate the usefulness of assessing RAN for the early identification of children with reading difficulties in two languages varying in orthographic consistency: English and Greek. RAN, along with measures of phonological awareness and letter knowledge, was assessed in Kindergarten and Grade 1. In the past, RAN was subsumed under the phonological processing umbrella (Wagner & Torgesen, 1987). Consequently, hypothesized naming-speed deficit readers would either be misclassified as having phonological deficits and given inappropriate intervention, or missed altogether because of adequate phonological decoding skills.

The results of our study are in line with the findings of previous studies (e.g., Badian, 1998; Gijsel et al., 2006; Puolakanaho et al., 2007; Savage et al., 2005) suggesting that RAN is an independent, significant predictor of an individual's risk for reading difficulties when assessed in Grade 1 in English and when assessed in both Kindergarten and Grade 1 in Greek. The prediction probability of performance for RAN was quite strong in Greek (AUC was .88 in both grades) and moderate in English (AUC was .73 and .75 in Kindergarten and Grade 1, respectively) without any significant differences between grades. This, in turn, would suggest that assessing RAN in either Kindergarten or in Grade 1 would provide the same diagnostic information. Puolakanaho et al. (2007) demonstrated that a combination of predictor variables (including RAN) could identify poor readers as young as 3.5 years old with 81% accuracy and as young as 5.5 years old with 84% accuracy. These numbers are similar to the ones we have found in this study and suggest that early identification of poor readers is possible from Kindergarten with a high degree of precision.

***Figure* 2. ROC Analysis for the Greek Data: Kindergarten, Grade 1.**





However, it is also worth noting that RAN was a stronger predictor of an individual's risk for reading difficulties in Greek than in English (AUC in both Kindergarten and Grade 1 was higher in Greek). This was expected on the basis of previous cross-linguistic studies with unselected samples (e.g., Georgiou, Parrila, & Papadopoulos, 2008; Mann & Wimmer, 2002) and suggests that the use of RAN tasks is absolutely critical for the identification of children at-risk for reading difficulties in consistent orthographies. This is likely due to the proximity in the nature of the RAN tasks and the reading fluency outcomes (Lervåg & Hulme, 2009).

A question that arises from the findings of this study is what probability level could be considered high enough to warrant our attention and perhaps further referral of that child for a comprehensive assessment and intervention. Catts et al. (2001) have suggested a cutoff value of .30. If the probability of reading difficulties is less than .30, the risk for reading difficulties could be deemed low and further testing could be carried out only at the discretion of the teacher. If the probability of reading difficulties is greater than .30, the risk for reading difficulties could be considered high enough for further testing and possibly immediate intervention. Our findings suggest a similar cutoff value. For example, when the probability level was set at .25 in Study I, we were able to accurately identify 70.6% in Kindergarten and 88.2% in Grade 1 of the poor readers in Grade 3. The corresponding sensitivity level in Study II was 66.7%.

The flip side of choosing a probability level as low as .20 or .13 (in the case of Grade 1 in Study II) is the increase in the false positive rates. Approximately half of the children predicted to have reading difficulties were not poor readers in Grade 3. Although we can argue that the primary concern should be not to miss any of the children who actually turn out to be poor readers, providing assessment and intervention to a large number of children who may not need it requires significant resources that schools may not have. On the other hand, providing intervention to children who do not need it will not hurt them either. Future studies should examine ways to maximize the discriminatory power of the logistic models without amplifying the false positive rates.

Some limitations of the present study are worth mentioning. First, the results of this study are restricted to the developmental span and the populations examined, and therefore the findings may not apply to later grades, specific reading populations, or children learning to read in other orthographies. Second, the sample sizes were relatively small. Although there is no gold standard for sample size in logistic regression or ROC analysis, a replication of the findings with a larger sample size would be warranted. Third, the measures of the predictor variables were not standardized. As a result, in order to calculate an individual's probability score to develop reading difficulties, someone would need to use exactly the same measures that we have used in this study. Finally, other significant predictors of reading ability such as vocabulary, print awareness, mother's education, or familiar risk of dyslexia were not included in the current study. Certainly, their inclusion could have improved our predictive accuracy.

To conclude, our study has provided compelling evidence that assessing RAN improves our chances to identify early on the children at-risk for reading disabilities. The RAN tasks can be easily administered by teachers and take only a short time to complete. For such a small investment of time, the return appears to be very promising. Wolf and Bowers (1999) characterized RAN as "a microcosm of reading" to highlight the many similarities shared between these two tasks. Although the exact nature of the relationship between RAN and reading remains a mystery, it is beyond doubt that RAN's assessment is beneficial across languages varying in orthographic consistency.

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