

**COMPONENT PROCESSES SUBSERVING RAPID AUTOMATIZED
NAMING IN DYSLEXIC AND NONDYSLEXIC READERS**

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ABSTRACT

The current study investigated which time components of rapid automatized naming (RAN) might predict group differences between dyslexic and nondyslexic readers (matched for age and reading level), and how these components relate to distinct reading measures. Subjects performed two RAN tasks (letters and objects) and data were analyzed through a response time analysis. Our results demonstrated that impaired RAN performance by dyslexic readers mainly stem from enhanced inter-item pause times and not from difficulties at the level of post-access motor production (expressed by articulation rates). Moreover, we also verified that overall RAN performance in dyslexics, and inter-item pause times, account for a significant proportion of variance in reading ability besides the effect of phonological processes. Therefore, it appears that underlying non-phonological factors may lie at the root of the association between rapid naming and reading ability. In normal readers, RAN performance becomes associated with reading ability only at early ages (i.e., in reading-matched controls), and in this case it appears to be the inter-item pause times of the RAN task that explain the association.

Keywords: dyslexia, rapid naming, orthographic processing, response time analysis

INTRODUCTION

One of the most robust concurrent and longitudinal predictors of reading outcome is rapid automatized naming (RAN; for a review see Kirby, Roth, Desrochers, & Lai, 2008), defined as how quickly children can name a visually presented array of high-frequency items (Denckla & Rudel, 1976). Slow performance on RAN tasks has long been known to be associated with poor reading performance. RAN reliably distinguishes between dyslexic and non-dyslexic readers (e.g., Jones, Branigan, & Kelly, 2009; for an overview, see Wolf, Bowers, & Biddle, 2000) and the relative contribution of RAN to reading is also stronger in less able readers (Araújo, Pacheco, Faísca, Petersson, & Reis, 2010; Johnston & Kirby, 2006; McBride-Chang & Manis, 1996).

Despite the acknowledged importance of RAN in predicting (poor) reading skills, the exact nature of this relation remains undetermined. Various researchers have discussed that RAN primarily reflects the access and retrieval of phonological codes from long-term memory (e.g., Chiappe, Stringer, Siegel, & Stanovich, 2002; Pennington, Cardoso-Martins, Green, & Lefly, 2001; Schatschneider, Carlson, Francis, Foorman, & Fletcher, 2002; Torgesen, Wagner, & Rashotte, 1994; Wagner, Torgesen, Laughon, Simmons, & Rashotte, 1993). Others, however, hypothesized that the “phonological deficits and the processes underlying naming speed are separable sources of reading dysfunction” (Wolf & Bowers, 1999, p.416) and thus there is a dissociation between the processes involved in phonological and RAN tasks. In essence, research into the relationship between reading, RAN, and phonological skills has yielded mixed results (e.g., Cardoso-Martins & Pennington, 2004; Patel, Snowling, & de Jong, 2004; Parrila, Kirby, & McQuarrie, 2004; Pennington et al., 2001), though

there is substantial evidence showing that RAN accounts for unique variance in reading beyond the effect of other measures of phonological processing (e.g., Kirby, Parrila, & Pfeiffer, 2003; Landerl & Wimmer, 2008; Manis, Doi, & Bhadha, 2000).

In line with this “second deficit”, Bowers and colleagues proposed an orthographic basis for the relation between RAN and reading, i.e., RAN is a marker of difficulties in orthographic, rather than phonological, processing (Bowers & Newby-Clark, 2002; Bowers & Wolf, 1993; Wolf, Bowers, & Biddle, 2000). Authors’ argument is that slow naming speed prevents the precise integration of visual letter sequence information in words, which is necessary in order to pick up commonly occurring orthographic patterns and, thus, hinders the acquisition of an efficient orthographic lexicon. This hypothesis has since received some empirical support (Georgiou et al., 2008; Roman, Kirby, Parrila, Wade-Woolley, & Deacon, 2009); however, some recent papers also dispute this view (Moll, Fussenegger, Willburger, & Landerl, 2009; Papadopoulos et al., 2009). In addition, some researchers have sought to disentangle the influence of visual versus phonological processes in serial naming. For instance, Jones and colleagues demonstrated in an eye-movements study that when naming sequences of letters, the performance of dyslexics is particularly poor under conditions of increased visual-orthographic confusion. The authors concluded that both visual and phonological processes influence rapid naming (Jones, Obregón, Kelly, Louise, & Branigan, 2008; see also Jones, Branigan, Hatzidaki, & Obregón, 2010).

As pointed out by Neuhaus and colleagues (Neuhaus, Foorman, Francis, & Carlson, 2001), one constraint on the current understanding of what does RAN reflect stems from the fact that two sources of variance might confound interpretation of RAN results: the time taken to articulate each of the items – *articulation time* – and the

duration of pauses between the sequenced articulations – *inter-item pause*. With few exceptions, previous research has approached RAN as a unitary measure by obtaining a single performance time for the entire test (i.e., RAN total time). Nevertheless, evidence suggest that articulation time and inter-item pause components are not reliably related (Cobbold, Passenger, & Terrel, 2003; Georgiou, Parrila, & Kirby, 2006) and are both uniquely predictive of reading efficiency (Georgiou, Parrila, & Kirby, 2009). Accordingly, Georgiou and colleagues' work showed that each component of RAN (digits) accounted for additional unique variance in reading well beyond the contribution shared by articulation and inter-item pause times (Georgiou, Parrila, & Liao, 2008). These findings demonstrate that the cognitive processes that underpin the articulation and pause time components of the RAN behavioral response are separable of each other.

Previous research on intratask RAN components – the majority with children at early grades of reading development – has provided partly conflicting results. While the studies mostly agree that inter-item pauses are the key to understand the mechanisms that drive the RAN-reading relationship (e.g., Georgiou et al., 2006; Lervåg & Hulme, 2009; Neuhaus, Foorman et al., 2001), the role of articulation time is less clear. For example, Georgiou and colleagues (2006; Georgiou, Parrila, Kirby, & Stephenson, 2008) found that inter-item pause time was significantly correlated with reading accuracy and fluency, while articulation time was only weakly correlated with the reading measures. Variability in RAN total time has been proved to be mostly attributable to the subjects' variance in the inter-item pauses rather than in articulation times, which probably represents a cognitive process that reaches an asymptotic level early during development (Cobbold et al., 2003; Neuhaus, Carlson, Jeng, Post, &

Swank, 2001). Neuhaus, Foorman and colleagues (2001) also identified that the relationship between RAN inter-item pauses and reading depends on the nature of the stimulus material, being significant during letter-naming but not object-naming and inconsistent during numbers-naming . However, in a larger sample of Grade 1 children, both components of RAN letters and the inter-item pause for the RAN objects task were all found to be associated with reading skills (Neuhaus & Swank, 2002). The results of early work sampling older children have been also equivocal. While some studies report that neither articulation duration nor inter-item pause time were unique predictors of reading skill when age and phonological skills were controlled (Clarke, Hulme, & Snowling, 2005), others found that both components explain unique variance in reading fluency (Georgiou et al., 2009). Thus, it is not well-understood whether the RAN components' influence on reading (and what underlies this relationship) changes throughout the developmental span.

Likewise, it is not completely clear which components of RAN explain the differential relationship between RAN and reading in groups of normal and dyslexic readers, as most studies to date have tested unselected samples. Comparing these populations is of interest since deficits in RAN tasks have been especially linked to reading level of dyslexic readers (e.g., Araújo et al., 2010). In an exception, Anderson and colleagues found that both articulation and inter-item pause time were significantly longer for dyslexic children than for controls (Anderson et al., 1984). However, this study is limited by the small sample used ($n = 6$) and the lack of a reading-matched control group. No group articulation differences were found in Obregon's work (1994, cited by Wolf & Bowers, 1999; see also Snyder & Downey, 1995). In the current study, by using a well-controlled design with dyslexics and normal readers matched in terms

of age and reading level, we sought to clarify which components of RAN accounts for the slow performance characteristic of dyslexics and how these relate to reading as a function of subjects' reading status. Here, the use of two control groups also created the opportunity to investigate further whether the RAN components' influence on reading differs between the early versus later phases of reading development.

In closing, the natural follow-up question concerns the sub-processes behind the timing components of RAN. Some hypotheses to the nature of inter-item pauses have been advanced, including an automatization index of phonological code retrieval (Neuhaus, Foorman et al., 2001). Alternatively, other authors have argued that at the beginning of reading development it is the phonological-processing ability that mediates the relationship between alphanumeric RAN inter-item pauses and reading, whereas later on inter-item pauses reflect the ease of building up orthographic representations (Georgiou et al., 2008). On the other hand, the articulation component represents the actual production of speech and may be more indicative of stimulus familiarity or retrieval of stored representations (De Jong & Van der Leij, 1999; Hulme, Roodenrys, Brown, & Mercer, 1995).

In the present study, we tried to disentangle the different cognitive processes engaged in RAN by analyzing articulation times and inter-item pauses of dyslexics and non-dyslexic readers through both alphanumeric (letter-based) and non-alphanumeric (object-based) tasks. Specifically, the objective of the current study was twofold: first, to clarify which of RAN components engender group differences between normal and dyslexic readers; secondly, to examine the impact of RAN components on reading ability and shed more light on the underlying processes that mediate this relation. For this purpose, in addition to measuring the overall RAN total time, two time measures

will be extracted from the RAN tasks – articulation and inter-item pause times – and groups compared using a response time analysis. A regression-based approach will be also applied to assess the relative importance of each RAN component in predicting different reading measures: high-frequency words reading, a skill most likely to rely on orthographic knowledge, and pseudowords reading, which is a typical measure of phonological decoding. These effects will be estimated after controlling for phonological awareness. Because some recent papers have suggested that speeded naming tasks are mainly phonological processing speed tasks (e.g., Vaessen, Gerretsen, & Blomert, 2009; REF REF), we think that it might be potentially interesting to control effects of both phonological processing speed and phonological processing accuracy. Therefore, accuracy and speed measures for the phonological awareness task were included in the current study.

The first general prediction, in line with Bowers and colleagues (e.g., Bower & Wolf, 1993), is that the unique contribution of RAN total time would be greater for tasks that involve a higher amount of orthographic processing (i.e., for fluency in high-frequency word reading). We would also expect a greater predictive role of RAN letters to reading compared to RAN objects, since the former carry more orthographic information. More importantly, at the time components level, we hypothesized the following: 1) inter-item pauses would be the core differentiator between normal and dyslexic readers; 2) inter-item pauses to a greater degree than articulation times would be associated with reading measures (e.g., Georgiou et al., 2008), especially among children with dyslexia; 3) if inter-item pauses are indeed the key component in RAN-reading relationship, and RAN taps non-phonological processes linked to orthographic

skill, then inter-item pauses (especially for letters) should account for a large proportion of unique variance in high-frequency word reading as opposed to pseudoword reading.

MATERIALS AND METHODS

Participants: Informed consent was obtained from all the parents of participants in compliance with the Helsinki Declaration. Twenty-nine Portuguese children that had been diagnosed with dyslexia (17 males and 12 females, mean age [\pm std] = 9.4 \pm [1.7] years) were recruited through private clinics that specialize in caring for children with learning disabilities. The inclusion criteria for the dyslexic participants were as follows: normal-range intelligence measured by the Raven Colored Matrices (Raven, Court, & Raven, 1998); reading abilities significantly below grade mean level; absence of neurological, emotional or attention problems. The individual reading achievement was assessed through the 3DM reading test (see below), adapted for the Portuguese population from the Differential Diagnosis Dyslexia Battery (Blomert & Vaessen, 2009). Test-retest reliability was high (.91). Scores were converted into z-scores with reference to normative data, which was collected in a large-scale study with 820 Portuguese children in grades 1-4 (Reis et al., in preparation). The z-scores for the 5th grade children were estimated through polynomial regression procedures (Van Breukelen & Vlaeyen, 2005), using the amount of months of formal reading instruction as predictor. Only those subjects who had reading speed scores at least 1.5 SD below the grade mean level of the normative sample were included in the dyslexic group. The dyslexic group was matched with two control groups: twenty-nine *age-matched controls* (18 males and 11 females, mean age [\pm std] = 9.5 \pm [1.8] years) and twenty-nine *reading-matched controls* (14 males and 15 females, mean age [\pm std] = 7.0 \pm [.9]

years), which were classified by their teachers as average pupils. All controls had intelligence scores in the normal range (Raven Colored Matrices) and reading scores (3DM reading test) within or above the average. There were no statistical differences between groups regarding intelligence scores ($p > .05$, both comparisons). Dyslexic readers strongly differed from age-matched ($p < .001$), but not reading-matched controls ($p = .64$), on the 3DM reading scores. Dyslexics and age-matched controls differed significantly from the reading-matched control group in terms of age ($p < .001$ for both).

Stimuli and Procedures: All tasks were selected from the Differential Diagnosis Dyslexia Battery (Blomert & Vaessen, 2009) and adapted for use in the Portuguese population (Reis et al., in preparation). The tasks were displayed on a computer screen, using Presentation software (version 11.0; <http://nbs.neurobs.com/presentation>).

Reading Measure: The 3DM reading test was composed of two lists of high-frequency words and pseudowords. Each list was composed of 75 stimuli distributed on five sheets (15 stimuli per sheet) of increasing difficulty with respect to the number of syllables (2-4), syllabic structure (with and without consonant clusters), and phoneme–grapheme correspondence rules (regular and irregular). For each list, the children had 30s to read aloud as many words as possible. Reading speed was computed as the number of correctly read words per second.

Phonological Awareness: Phonological awareness was tested using a phoneme deletion task. Forty-four pseudowords were created by manipulation of word length

(mono- and disyllabic), syllabic structure (with and without consonant clusters), and position of the phoneme to be deleted (beginning, middle, or end). Subjects listened via headphones to a given stimulus followed by the specific phoneme to be deleted, and they were instructed to repeat the resulting pseudoword without that specified phoneme. The percentage of correct responses was computed and used as the main dependent measure (phonological accuracy). The task has an internal consistency of .94 for accuracy. Phonological processing speed was also calculated by averaging the response latencies between the presentation of the word and the oral response (only correct answers were analyzed). The examiner pressed a button as soon as the subject gave an answer, and response times were automatically computed (time between stimulus offset and the button press). Reliability coefficient of the speed scores was .96.

Rapid Naming Repetition: A rapid naming repetition task with letters and objects was designed based on the classical paradigm by Denckla and Rudel (1976). Five different stimuli were selected for letters (a, d, o, p and t) and objects (shoe, bed, glass, apple and fork) subtests; both were visually presented in two blocks. Each block had three columns of five stimuli, and thus each stimulus was repeated three times per block presentation (15 items per block). Subjects were instructed to name the stimuli as quickly and accurately as possible. The number of correctly named items per second was used as a measure of rapid naming speed. For each subject and task a wave file was created. Before the RAN test started, we ensured that the children knew the items by asking them to name all of the letters and objects in a practice trial. The naming test had a reliability of .82.

Analysis of Sound Files

The digital sound files containing the letter- and object-naming responses for each subject were analyzed. Response times from the two RAN subtests were separated into articulation time (corresponding to the mean from onset to offset of the stimulus vocalization) and inter-item pause duration (corresponding to the mean of the time intervals between the sequenced articulations). The digitally recorded responses were manually timed using sound editing software (CoolEdit 2000, Syntrillium). All articulation errors were removed from the analysis, along with the preceding and succeeding inter-item pause time. The response time measures were not considered when there was a self-correction, a pronoun before the stimulus name (e.g., “an apple” instead of just saying “apple”), or an extraneous verbalization (e.g., coughs). Inter-rater agreement was obtained on a random sample of one third of the data, measured by two independent judges ($r = .98$ for inter-item pause and $r = .97$ for articulation time).

RESULTS

The raw scores from the reading test, the RAN subtests and the phonological awareness task were converted into z-scores with reference to the normative sample (stratified by grade), to improve comparability of performance levels between groups and tasks. Descriptive statistics for all measures are shown in **Table 1**. As expected, dyslexic readers performed significantly worse than both control groups in all tested measures ($p < .001$ for all; Tukey HSD Test).

Overall, low error rates were found in both RAN letter and RAN object subtests (4% and 3%, respectively). Statistical group differences for RAN total time were first tested with repeated measure ANOVAs, including the RAN subtest (objects *vs.* letters)

as within-subject factor and group as between-subject factor. A main effect of group was observed [$F(2,84) = 26.8$; $p < .001$], regardless of the RAN subtest – dyslexics performed significantly slower than age-matched and reading-matched controls ($p < .001$ for both comparisons; Tukey HSD test). Furthermore, both control groups did not differ statistically from each other ($p = .49$). As expected, the main effect of the task was not significant ($p = .28$).

(Table 1 here)

Analysis of the Inter-item Pause and Articulation Time

To test for differences between groups in both RAN components, subjects' raw scores were used. Descriptive statistics are presented on **Table 1**. The results demonstrated that there is a significant interaction between group and RAN component [$F(2,83) = 7.5$; $p = .001$], showing that dyslexics and reading-matched controls differed from age-matched controls on inter-item times ($p < .001$ for both comparisons) but not on articulation times ($p = .60$ and $p = .37$, respectively). Dyslexics and reading-matched controls did not differ on any RAN component ($p > .05$ for both comparisons; Tukey HSD test). A significant three-way interaction was also observed [$F(2,83) = 6.2$; $p = .003$]. While age-matched controls showed less inter-item pause time than articulation time, regardless of the RAN subtest (letters or objects), dyslexics and reading-matched controls showed larger inter-item pause time (over articulation time) during letter-naming (**Figure 1**).

Since the experimental groups differed significantly in their response times, we reanalyzed the data following suggestions by Faust and colleagues (Faust, Balota,

Spieler, & Ferraro, 1999) to ensure that over-additive effects did not contribute to the interactions. When the data were standardized with reference to subjects' individual means, the same pattern resulted, indicating that the outlined interactions are not explained by a spurious scale effect.

(Figure 1 here)

Relationship between RAN and Reading Measures

To investigate the unique contributions of RAN total time, articulation time, and inter-item pauses, to reading ability a set of hierarchical regression analyses with changing order of the predictors were conducted for each group. The relations were estimated after controlling for age and intelligence scores (entered as a block at step 1) and phonological awareness accuracy (step 2). Next, the RAN measures were entered at the third step in the regression equation as the explanatory variables (one at a time). Dependent measures were reading for high-frequency words and pseudowords; the analysis was done separately for each reading measure. Using this procedure, we were able to investigate whether the components of RAN contributed significantly to reading measures when controlling for the other variables.

The results of the regression analyses revealed first that RAN total time (especially for letters) explained unique variance of reading of high-frequency words and pseudowords in dyslexics (range = 14.5% to 24.4%) and in reading-matched controls (range = 10.9% to 24.4%), while its contribution in age-matched controls' reading fell into nonsignificant levels.

At the time components level, data indicated that after age, intelligence level and phoneme deletion accuracy were entered into the equation only inter-item pause time continued to make a significant contribution to high-frequency word reading in dyslexics (range = 12.2% to 15.1%); this relation was higher for RAN letters than for RAN objects. None of the components of RAN explained a significant amount of variance in dyslexics' pseudoword reading ability (albeit RAN total time for letters did). In contrast, for age-matched controls, articulation time and inter-item pauses were always unrelated to measures of reading fluency (high-frequency word and pseudoword reading). For reading-matched controls, the relationship between RAN total time and high-frequency word reading fluency was mainly attributed to the inter-item pause time component, especially during letter-naming (range = 10.3% to 16.2%). Both articulation time and inter-item pauses (RAN letters) made significant contributions to pseudoword reading fluency in this group (range = 11.7% to 27.7%), with inter-item pauses' contribution being more substantial (**Table 2** and **3**).

At a final step, the regression analyses were repeated with age, intelligence scores, and both phonological awareness accuracy and speed entered before each component of RAN. Notably, the results were highly similar to all other analyses. Inter-item pauses continued to significantly predict dyslexics' reading of high-frequency words (Letters, $R^2=16.8\%$; Objects, $R^2=11.9\%$). A unique contribution of inter-item pauses to high-frequency word reading (Letters, $R^2=14.9\%$) and to pseudoword reading (Letters, $R^2=28.5\%$) was also observed for reading-matched controls.

(Table 2 and 3 here)

DISCUSSION

Some authors have argued that RAN total time can be segregated into separate components (the articulation time and the inter-item pause intervals) that better reflect the online cognitive processes utilized in completing the task (Cobbold et al., 2003; Neuhaus, Foorman et al., 2001). The main objective of this investigation was to examine the relation between these constituent components of RAN and reading ability in a sample of normal and dyslexic readers.

Overall, the present study found that dyslexic readers are significantly slower on RAN tasks when compared to age- and reading-matched controls. Both RAN letters and RAN objects were found to be different between reader groups, which suggest that dyslexics' slow performance was not due to a lower reading experience/practice or a limited knowledge of letter names. This main result was therefore compatible with the idea that a failure to automatize the necessary skills for rapid naming is a core difficulty in dyslexia (e.g., Wolf & Bowers, 1999).

A more detailed analysis of the sources of naming variance indicated that slow RAN in dyslexics mainly stem from longer inter-item pauses, and not extra time taken by these subjects to articulate stimulus names. Hence, this finding extends previous research with unselected samples (Georgiou et al., 2006; Lervåg & Hulme, 2009; Neuhaus, Foorman et al., 2001) to suggest that the source of differences between normal and dyslexic readers is the efficiency of the cognitive process(es) that take place during inter-item pauses. In turn, the post-access articulatory-motor factors (reflected in articulation times) do not seem to be an important index to distinguish between reading groups. This outcome contradicts, however, early studies showing that dyslexics differentiated from normal readers both in terms of articulation duration and inter-item

pause time (Anderson et al., 1984; Snyder & Downey, 1995). Methodological differences between the studies may have accounted for this discrepancy. For instance, Anderson and colleagues (1984) used a small sample size of dyslexics, thereby limiting the generalization of the results.

The present investigation also offers some insight on how RAN total time, its components, and reading ability are related to and on the processes that may be responsible for this relationship. Consonant with previous studies (e.g., Araújo et al., 2010; Johnston & Kirby, 2006), we found that the RAN ability to predict reading is dependent on subjects' age and reading level. Reading performance in dyslexics and reading-matched controls was found to be predicted by RAN total time, but no association was identified in age-matched controls. In addition, as hypothesized, regression analyses showed that dyslexics' reading performance is predicted by inter-item pause time, but not articulation time, in RAN (letters and objects). This result was compatible with the group differences in this experiment and other recent reports (e.g., Giorgiou et al., 2008; Lervåg & Hulme, 2009), and clearly highlight the potential role of RAN inter-item pauses in understanding factors related to slower reading. Similarly, when rapid naming becomes associated with reading ability in normal readers at earlier ages (reading-matched controls), it seems that the inter-item pause component of the RAN task (especially for letters) lies at the root of the association with reading. This finding deserves our attention when arguments are made regarding the less important role of RAN in the beginning years of reading acquisition, as this may actually result from the fact that the measurement of total performance time in RAN tasks fails in distinguish two separate sources of variance that contributes to reading. On the other hand, the lack of relatedness between RAN components and reading ability in age-

matched controls, contrarily to Georgiou and colleagues' (2009) findings, was possible due to an asymptotic level already attained by this sample in RAN performance (McBride-Chang & Manis, 1996). The age-matched participants in this study were generally good readers, a fact that may have attenuated the relation.

At the same time, to the extent that dyslexics' reading ability was still explained by RAN inter-item pauses after phonological awareness was controlled, the results are not easily accommodated by a phonological basis for the relation between inter-item pauses and reading (e.g., Nehaus, Foorman et al., 2001; Nehaus & Swank, 2002); for example, that inter-item pauses reflect the speed of phonological access and retrieval processes. The current study also uncovered the greater predictive weight of dyslexics' RAN inter-item pauses for high-frequency word reading fluency than for pseudoword reading fluency. This result, again, suggests that phonological processing is unlikely to be the only explanation of why inter-item pauses are related to reading. If this was the case, we should rather observe a strong relation with pseudoword reading ability, as this ability should more strongly depend on a detailed phonological analysis of the stimuli.

Accordingly, considering that the main difference between our reading measures is the higher involvement of orthographic processing in high-frequency word reading, our findings offers some support to the Bowers and colleagues' view (e.g., Bowers & Newby-Clark, 2002) that RAN is related to variation in orthographic skills. This is further suggested by our observation of greater associations between inter-item pauses and reading fluency for alphanumeric RAN (letters) compared to non-alphanumeric RAN (objects), because letters carry more orthographic information than objects. Other investigations have supported this orthographic hypothesis in the past,

including those showing that RAN is a better predictor of the variance in “pure” orthographic tasks (e.g., orthographic choice tasks) and text fluency than in grapheme–phoneme decoding ability (Wolf et al., 2002). Georgiou and colleagues (2008), with an unselected sample of Grade 1 to 3 students, also verified that inter-stimulus pause time is more strongly related to orthographic knowledge than other measures, including phonological awareness (see also Georgiou et al., 2009). Interestingly, RAN inter-item pause time’s relationship to orthographic knowledge increased across the developmental span, whereas the concurrent correlations between inter-item pauses and phonological awareness declined across time. The present data seem to be (at least in part) in line with this finding. We observed that the RAN inter-item pause only predicted fluency in high-frequency word reading in dyslexics, while its impact on younger control readers of approximately 7-years was more substantial for pseudowords reading ability (range = 15.3% to 23.5%). Thus, it is possible that across time, inter-item pause in RAN is not measuring the same skill, or the processes responsible for its association with reading have different weights.

Finally, although current evidence appears to favor a possible link between inter-item pauses and orthographic processing, especially in dyslexics, alternative explanations are still possible. This study found that despite the fact that inter-item pauses in letter-naming explained a somewhat higher amount of variance in dyslexics’ reading ability than inter-item pauses in object-naming did, the last still made a significant contribution. This finding may suggest that the reason RAN inter-item pauses are related to poor reading may involve another mechanism in addition to orthographic processing. Similar to orthographic whole-word recognition of the letter strings, the RAN objects must be recognized and, like access from orthographic to

phonological word representations in lexical reading, RAN requires activation of phonological entries via instantiated visual recognition units (Hawelka et al., 2010). It is possible that longer inter-item pauses may also reflect the subjects' inability to integrate visual pattern information with stored stimulus representations and, potentially, the slow access to phonological codes from visual recognition units. This clearly needs further investigation before a straightforward conclusion can be drawn. Recently, Stainthorp and colleagues (2010), investigating the relation between visual processing and poor RAN performance, also bring out a fruitful area for future research. The authors found that slow RAN children have difficulty in visual feature discrimination. Potentially, one consequence of such a deficit would be a suboptimal ability to map letter-sound correspondences in the early stages of reading acquisition, which may subsequently affect the ease with which children set up representations of words in the orthographic lexicon.

In sum, in this study we verified that the relationship between RAN components and reading ability is dependent on age and reading level. We also provided evidence that the process(es) reflected in inter-item pause time constitute the main source of naming difficulties in dyslexia, being the articulation times unrelated to measures of reading. Current data were more in line with the view that the connection between RAN inter-item pauses and reading is mediated (but is not restricted to) by factors involved in orthographic skill than with the phonological processing account.

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TABLES

Table 1. Average performance on cognitive tasks for the three reading groups (CA, age-matched controls; CR, reading-matched controls)

	Dyslexics		CA Group		CR Group	
	Mean	SD	Mean	SD	Mean	SD
RWR speed (correct items/sec)^a	-1.76	.66	.52	.90	.04	.64
PWR speed (correct items/sec)^a	-1.75	.68	.81	.83	-.04	.63
Phoneme Deletion (accuracy)^a	-1.39	.55	.39	.72	.01	.75
Phoneme Deletion (speed)^a	-.80	1.18	.18	.78	-.29	.97
RAN Letters (items/sec)^a	-.88	1.11	.54	1.02	.09	.63
Articulation Times (ms)	332.5	52.5	290.1	43.2	342.6	99.3
Inter-item Pauses (ms)	410.3	246.0	221.9	129.3	478.8	252.0
RAN Objects (items/sec)^a	-.99	.84	.47	1.04	-.08	.73
Articulation Times (ms)	609.1	95.7	542.3	86.8	623.8	107.2
Inter-item Pauses (ms)	411.4	210.8	226.1	112.0	377.6	136.0

Note: RWR, Real word reading; PWR, Pseudoword reading; RAN, Rapid automatized naming.

^a: Standardized *z* scores.

Table 2. Hierarchical regression analysis predicting high frequency word reading skills: Unique variance accounted by RAN response timing measurements.

	Dyslexics		CA Group		CR Group	
	ΔR^2	Δp	ΔR^2	Δp	ΔR^2	Δp
1. Age + IQ	.015	.820	.135	.162	.049	.517
2. Phoneme Deletion	.201	.018	.023	.429	.268	.004
RAN Letters						
3. RAN Total Time	.244	.003	.060	.197	.109	.043
3. Inter-item Pause	.151	.025	.046	.260	.162	.012
3. Articulation Time	.025	.379	.098	.094	.033	.277
RAN Objects						
3. RAN Total Time	.145	.028	.030	.367	.007	.625
3. Inter-item Pause	.122	.046	.024	.419	.103	.050
3. Articulation Time	.014	.519	.087	.117	.000	.940

Note: CA, age-matched controls; CR, reading-matched controls.

Table 3. Hierarchical regression analysis predicting pseudoword reading skills: Unique variance accounted by RAN response timing measurements.

	Dyslexics		CA		CR	
	ΔR^2	Δp	ΔR^2	Δp	ΔR^2	Δp
1. Age + IQ	.098	.263	.024	.740	.027	.696
2. Phoneme Deletion	.224	.008	.267	.006	.201	.017
RAN Letters						
3. RAN Total Time	.211	.003	.001	.837	.244	.003
3. Inter-item Pause	.060	.140	.010	.581	.277	.001
3. Articulation Time	.044	.210	.000	.955	.117	.050
RAN Objects						
3. RAN Total Time	.079	.087	.084	.093	.043	.248
3. Inter-item Pause	.041	.226	.070	.126	.103	.067
3. Articulation Time	.000	.957	.075	.114	.010	.573

Note: CA, age-matched controls; CR, reading-matched controls.