

What does rapid naming tell us about dyslexia?

¿Qué nos cuenta el nombramiento rápido sobre la dislexia?

O que a nomeação rápida nos diz sobre a dislexia?

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Abstract

This article summarizes some of the important findings from research evaluating the relationship between poor rapid naming and impaired reading performance. Substantial evidence shows that dyslexic readers have problems with rapid naming of visual items. Early research assumed that this was a consequence of phonological processing deficits, but recent findings suggest that non-phonological processes may lie at the root of the association between slow naming speed and poor reading. The hypothesis that rapid naming reflects an independent core deficit in dyslexia is supported by the main findings: (1) some dyslexics are characterized by rapid naming difficulties but intact phonological skills; (2) evidence for an independent association between rapid naming and reading competence in the dyslexic readers, when the effect of phonological skills was controlled; (3) rapid naming and phonological processing measures are not reliably correlated. Recent research also reveals greater predictive power of rapid naming, in

particular the inter-item pause time, for high-frequency word reading compared to pseudoword reading in developmental dyslexia. Altogether, the results are more consistent with the view that a phonological component alone cannot account for the rapid naming performance in dyslexia. Rather, rapid naming problems may emerge from the inefficiencies in visual-orthographic processing as well as in phonological processing.

Keywords: Dyslexia, rapid naming, phonological processing, double-deficit.

Resumen

En este artículo se sintetizan algunos de los resultados más relevantes de la investigación destinada a evaluar la relación entre problemas en el nombramiento rápido y las diferencias individuales en el rendimiento de lectura. Una evidencia considerable muestra que los lectores disléxicos tienen problemas en el nombramiento visual rápido. Las investigaciones iniciales atribuían esta dificultad a déficits en el procesamiento fonológico,

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pero los hallazgos recientes sugieren que los procesos no-fonológicos pueden estar en la raíz de la asociación entre pobres habilidades de nombramiento rápido y el rendimiento al leer. La hipótesis de que problemas de nombramiento rápido en la dislexia representan un déficit central independiente parece estar apoyada por: 1) algunos lectores disléxicos presentan problemas para el nombramiento rápido pero intactas habilidades fonológicas, 2) evidencia de una asociación independiente entre el nombramiento rápido y la competencia de lectura en lectores disléxicos, cuando se controló el efecto de las habilidades fonológicas, 3) la ejecución en tareas de nombramiento rápido y las medidas de procesamiento fonológico no se encuentran relacionadas de forma fiable. Los datos revelaron, así mismo, que la velocidad al nombrar, y en particular, el tiempo de pausa entre estímulos en el nombrado rápido, parece ser un predictor más robusto de la lectura de palabras de alta frecuencia que de la lectura de pseudopalabras en la dislexia. En conjunto estos resultados son congruentes con el postulado de que el componente fonológico por sí solo no explica los problemas de nombramiento rápido en la dislexia, sino que las dificultades en esta tarea pueden surgir de la ineficiencia de ambos tipos de procesamiento: fonológico y visual-ortográfico.

Palabras clave: Dislexia, nombramiento rápido, procesamiento fonológico, déficit doble.

Resumo

Neste artigo se sintetizam alguns dos resultados mais relevantes da pesquisa destinada a avaliar a relação entre problemas na nomeação rápida e as diferenças individuais no rendimento da leitura. Uma evidência considerável mostra que os leitores disléxicos têm problemas na nomeação visual rápida. As pesquisas iniciais atribuíam esta dificuldade a déficits no processamento fonológico, mas o achado recentemente sugere que os processos não-fonológicos podem estar na raiz da associação entre pobres habilidades de nomeação rápida e o rendimento ao ler. A hipótese de que os problemas de nomeação rápida na dislexia representam um déficit central independente, parece estar apoiada por: 1) alguns leitores disléxicos apresentam problemas para a nomeação rápida, mas habilidades fonológicas intactas, 2) evidência de uma associação independente entre a nomeação rápida e a competência de leitura em leitores disléxicos, quando

se controlou o efeito das habilidades fonológicas, 3) a execução em tarefas de nomeação rápida e nas medidas de processamento fonológico não estão relacionadas de forma confiável. Os dados revelaram, igualmente, que a velocidade ao nomear, e em particular, o tempo de pausa entre estímulos na nomeação rápida, parece ser um preditor mais robusto da leitura de palavras de alta frequência que da leitura de pseudopalabras na dislexia. Em conjunto estes resultados são congruentes com o postulado de que o componente fonológico por si só não explica os problemas de nomeação rápida na dislexia, senão que as dificuldades nesta tarefa podem surgir da ineficiência de ambos os tipos de processamento: fonológico e visual-ortográfico.

Palavras chave: dislexia, nomeação rápida, processamento fonológico, duplo déficit.

Introduction

Over the years, the most accepted explanatory framework for dyslexia, the *phonological deficit hypothesis*, theorizes that this disorder is caused by a specific deficit within the phonological processing system (Vellutino & Scanlon, 1987; Ramus *et al.*, 2003). The theory posits that phonological encoding and retrieval deficits are the underlying sources of reading difficulties in subjects with dyslexia. This explanation appeals to the fact that if speech sounds are poorly represented, stored or retrieved, then learning grapheme-phoneme correspondences will be affected (Vellutino & Fletcher, 2007). In support of the phonological deficit hypothesis, robust behavioral evidence have demonstrated that dyslexic readers perform poorly on a variety of phonological tasks, such as tasks requiring verbal short-term memory (e.g., digit span), phonological awareness (e.g., phoneme deletion and rhyme judgments) and phonological decoding (e.g., pseudoword reading) (Wagner, Torgesen, & Rashotte, 1994; Ramus *et al.*, 2003; Tijms, 2004). In terms of brain organization, several studies have localized abnormalities in the perisylvian language network of dyslexics compared to normal readers (for a recent review, see Richlan, Kronbichler, & Wimmer, 2009).

However, heterogeneity of cognitive functioning is often observed in dyslexic readers. For example, some dyslexics perform at a normal level on phonological tasks (Di Filippo, De Luca, Judica, Spinelli, & Zoccolotti, 2006; De Luca, Burani, Pai-zi, Spinelli, & Zoccolotti, 2010). Thus, researchers have questioned if the underlying cause of dyslexia might be more varied than an isolated phonological processing problem.

Recently, an interest in exploring the role of other cognitive factors, both at a behavioral and a neurobiological level, has seen a revival. Some authors have argued that dyslexics might suffer from problems in the orthographic processing system, a visually-based system for reading (e.g., De Luca, Borrelli, Judica, Spinelli, & Zoccolotti, 2002; Di Filippo *et al.*, 2006; Bergmann & Wimmer, 2008). For instance, neuroimaging and electrophysiological data have also shown an abnormal activation specifically related to visual orthographic processing in dyslexia, such that orthographic modulations observed in controls, especially in left occipito-temporal cortex, are absent in dyslexic subjects (Helenius, Tarkiainen, Cornelissen, Hansse, & Salmelin, 1999; Maurer *et al.*, 2007; Mark *et al.*, 2009; Araújo, Bramão, Faisca, Petersson, & Reis, 2010; Savill & Thierry, 2011). Notably, these regions correspond closely to the visual word form area (VWFA) of Cohen and colleagues (Cohen *et al.*, 2002; McCandliss, Cohen, & Dehaene, 2003), whose primary function during reading is to “support a form of perceptual expertise for visual word recognition that enables rapid perception of visual words in one’s own language” (Schlaggar & McCandliss, 2007, p. 480).

Moreover, poor reading and phonological skills do not seem to be the only problems in dyslexia because most dyslexic readers also show persistent difficulties with visual naming (Ackerman & Dykman, 1993; Fawcett & Nicolson, 1994; Korhonen, 1995). Stemming from original work by Denckla and Rudel (1976), these naming deficits have mostly been demonstrated using the serial rapid automatized naming (RAN) tasks, though there is additional evidence that subjects with dyslexia perform poorly on confrontation visual naming in which one item is displayed at a time (Denckla &

Cutting, 1999). Serial rapid automatized naming, RAN, consists of a visually presented array of high frequency items, such as letters, digits, colors or objects, repeated multiple times in a randomized order. The participant’s task is to name each of these target stimuli as quickly as possible. Slow performance on RAN tasks has long been known to be associated with poor reading performance (Denckla & Rudel, 1976); RAN reliably distinguishes dyslexics from normally developing readers, “garden-variety” poor readers, and readers with other learning disabilities (for an overview, see Wolf, Bowers, & Biddle, 2000). RAN performance in dyslexia is even poorer compared to that of younger reading-matched average readers, especially in terms of response speed. Thus, we concluded that the difficulties found in dyslexic children are not simply a consequence of lower reading experience/practice nor a trivial developmental delay. The RAN difficulties observed in developmental dyslexia are not restricted to orthographic stimuli but are also found with non-linguistic material involving pictured objects, further supporting this view (Figure 1; Araújo *et al.*, 2011). The relative contribution of RAN to reading variance is also stronger for children with dyslexia than for normal readers (Johnston & Kirby, 2006; McBride-Chang & Manis, 1996).

Because reading and visual rapid naming involve closely related cognitive processes, it is likely that there is a common underlying cause for both deficits observed in dyslexia. Therefore, a detailed characterization of the processes behind impaired rapid naming offers a promising way to deepen our knowledge of reading difficulty itself and dyslexia, as well as direct future research. However, the exact nature of the rapid naming deficits that characterize developmental dyslexia is still not well-understood.

The Impact of Orthography

The orthography that children are acquiring when learning to read is an important factor that needs to be taken into account in reading research. Alphabetic orthographies differ with respect to how consistently letters map onto their corresponding speech sounds. For instance, in writing systems referred as

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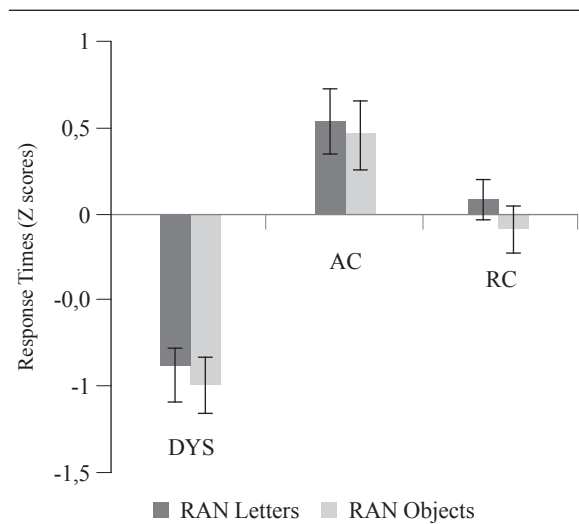


Figure 1. Main effect of group

(DYS: dyslexics; AC: age-controls; RC: reading-controls), regardless of the rapid automatized naming task (RAN). Mean response times for the three groups were converted into z-scores with reference to the normative sample. The error bars represent standard error of the mean. Data from Araújo *et al.* (2011).

consistent, shallow or transparent, such as Italian or Finnish, letter-sound and sound-letter correspondences are consistent, so the same letter is almost always pronounced the same in different words. In contrast, in writing systems referred as inconsistent, deep or opaque, such as English, the same letter is often pronounced differently in different words because the relationship between letters and sounds is not as direct (Ziegler, Perry, Jacobs, & Braun, 2001; Ziegler & Goswami, 2005). It has become clear over the past decade that orthographic consistency is the key factor determining the rate at which reading is acquired in a specific language. The studies converge on the conclusion that the progress of children learning to read in orthographically consistent languages is generally faster than that of children learning to read in orthographically inconsistent languages (e.g., Seymour, Aro, & Erskine, 2003; for a review, see Ziegler & Goswami, 2005).

If the consistency of the orthography is an important factor in the rate of reading acquisition, the next question is to what extent reading depends on the same underlying cognitive skills across these languages. Some evidence suggest that the impor-

tance of underlying cognitive skills in reading is modulated by the orthographic depth. Although English-based studies reliably find a strong and longer-lasting influence of phonological awareness (e.g., Cardoso-Martins & Pennington, 2004; Schatschneider, Fletcher, Francis, Carlson, & Foorman, 2004), a number of studies on consistent orthographies found that phonological awareness measures no longer affect reading after the first grade (Landerl & Wimmer, 2000, 2008). Similarly, studies in Dutch (an orthography characterized by intermediate consistency) confirmed a weaker reading-phonological awareness relation in this orthography than in English (de Jong & van der Leij, 1999, 2002). At the same time, the predictive role of rapid naming in consistent orthographies versus inconsistent orthographies is still under discussion. Several researchers have argued that RAN is a stronger predictor of reading in orthographically consistent languages than in orthographically inconsistent languages, and also for a greater role of rapid naming over phonological awareness in reading development in consistent orthographies (e.g., Wimmer, 1993; Landerl & Wimmer, 2000, 2008). Others, however, have advocated that rapid naming is consistently less important than phonological awareness regardless of the transparency of the script (Patel, Snowling, & de Jong, 2004; Caravolas, Volin, & Hulme, 2005; see also, Ziegler *et al.*, 2010). It is important to keep in mind that in some of the latter studies only early-grade children were assessed. This makes it difficult to generalize the results to the developmental trajectory as a whole. In her thesis, Vaessen (2010, p. 191) concluded that “Orthographic consistency does not so much affect the architecture of the reading network (...) but rather the rate at which the reading system develops”, which means that the contributions of phonological awareness and rapid naming are likely to be equally important in consistent and inconsistent orthographies, although not necessarily within the same time frame.

Interestingly, in a recent cross-linguistic study, Georgiou, Parrila and Liao (2008) examined the relationship between RAN and reading across languages (Chinese, Greek, and English) that vary in orthographic consistency. The authors concluded

that RAN measures some speed of processing, and this factor partially drives the RAN-reading relationship. Beyond this basic level, RAN may be related to reading for different reasons across languages. However, how and to what extent the orthographic consistency “modulates” what underlies RAN-reading relationship is not yet understood. Clearly, future research is warranted.

What Does Rapid Naming Reflect?

The process of rapid naming involves (a) attention to the stimuli, (b) visual processes that are responsible for initial feature detection, visual discrimination, and letter and letter-pattern identification, (c) integration of visual feature and pattern information with stored orthographic and phonological representations in long-term memory, (d) lexical processes including access and retrieval of phonological labels, and (e) organization of articulatory output (Wolf & Bowers, 1999). Here it should be noted that the demands imposed by continuous list format (multiple, matrix presentation of items), as in the classical RAN tasks, and discrete/confrontation naming tasks (individual stimulus presentation) are not exactly the same: continuous versions implicate not only access to the graphemic/visual and phonological properties of stimuli, but also the involvement of other processes, such as saccadic eye movements and sequencing of multiple items, of which in itself requires inhibition of previous (already named) stimuli and efficient processing of upcoming items (Jones, Branigan, & Kelly, 2009). Thus, rapid naming failure could in principle be attributed to a range of possible causes, any one which could lead to dyslexia. Given that the cognitive processes listed above are likely to be engaged by reading, it is not surprising that rapid naming, as typically assessed with RAN tasks, has become a useful correlate and predictor of reading competence and reading failure (Kirby, Parrila, & Pfeiffer, 2003; Kirby, Roth, Desrochers, & Lai, 2008; Landerl & Wimmer, 2008).

A major debate in the research literature is whether impaired rapid naming and the observed phonological processing problems in dyslexics are independent deficits or whether rapid naming

is only a different manifestation of a single underlying phonological deficit. Several authors have argued that rapid naming tasks primarily reflect how quickly phonological codes are accessed from long-term memory. By this reasoning, rapid naming relates to poor reading performance because both skills depend on subjects’ ability to access and retrieve phonological information (Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997; Pennington, Cardoso-Martins, Green, & Lefly, 2001; Chiappe, Stringer, Siegel, & Stanovich, 2002; Schatschneider, Carlson, Francis, Foorman, & Fletcher, 2002). Therefore, rapid naming should be part of the phonological processing construct along with phonological awareness and phonological memory.

Consistent with this theoretical position, some studies provide evidence suggesting that the two constructs, rapid naming and phonological processing, load together in factor analyses (Savage *et al.*, 2005; Savage, Pillay, & Melidona, 2007). However, in their meta-analysis of studies on correlations, Swanson and colleagues described a modest correlation of .38 between rapid naming and phonological awareness (Swanson, Trainin, Necochea, & Hammil, 2003). Vaessen and colleagues (Vaessen, Gerretsen, & Blomert, 2009) argued that although a modest correlation might suggest that naming tasks incorporate only a modest phonological component, it seems to be the phonological component that best predicts reading performance. One of the outcomes from Savage and colleagues’ principal component analysis was that only those aspects of the RAN task related to non-word decoding ability are strongly connected to variation in literacy (Savage *et al.*, 2007).

Moreover, studies with discrete naming paradigms also lend support to a phonological-based account of naming deficits (e.g., Swan & Goswami, 1997a, 1997b; Nation, Marshall, & Snowling, 2001; Faust & Sharfstein-Friedman, 2003; Truman & Hennessey, 2006; Hanly & Vandenberg, 2010). For example, picture naming studies using a cross-modal priming paradigm have reported a greater phonological interference in dyslexic readers compared to normal readers. This finding is consistent with the hypothesis that naming difficulties in dyslexia arise from problems at the level

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of phonological output (Truman & Hennessey, 2006). Likewise, other studies report fewer correct responses and more phonological substitution errors in dyslexic than in normal readers during confrontation naming tasks with pictures (Faust & Sharfstein-Friedman, 2003).

The Double-deficit Hypothesis as an Alternative Approach

A competing theoretical framework known as the *double-deficit hypothesis* (Bowers & Wolf, 1993; Wolf & Bowers, 1999) was developed as an extension of the dominant phonological deficit account; it acknowledges the phonological impairment as a core deficit in dyslexia but proposes that there is a second independent core deficit in processes indexed by rapid naming. The double-deficit hypothesis posits that children with dyslexia can be assigned to one of three subgroups: (1) a subgroup with a single rapid naming deficit; (2) a subgroup with a single phonological processing deficit; and (3) a subgroup with deficits in both domains. The third subgroup is the most impaired. Wolf and Bowers argue that the existence of impaired readers with normal (average) phonological skills and simultaneous naming difficulties makes it unlikely that rapid naming performance can be reduced to a purely phonological deficit. Instead, they propose that there exist an additional non-phonological deficit that accounts for the rapid naming and reading impairments in dyslexia (Wolf & Bowers, 1999; Wolf *et al.*, 2000; Wolf *et al.*, 2002). However, as highlighted in Vukovic and Siegel's review (2006), research testing the validity of the outlined subtypes has not been consistent. While some studies have identified the predicted subtypes (Manis, Doi, & Bhadha, 2000; Powell, Stainthorp, Stuart, Garwood, & Quinlan, 2007; Papadopoulos, Georgiou, & Kendeou, 2009), others have failed to find dyslexics who exhibit impaired rapid naming performance without affected phonological skills (Badian, 1997; Vaessen *et al.*, 2009).

To test the existence of dyslexics with a "pure" rapid naming deficit, as predicted by the double-deficit hypothesis, we examined the performance of Portuguese dyslexic children on reading, serial

rapid naming (letters) and two phonological processing measures. A phoneme deletion task was used as a measure of phonological awareness (both accuracy and speed were considered), and a digit span task was used as a measure of phonological short-term memory capacity. Subtypes of dyslexic children were categorized based on their cognitive profiles. Subjects were defined as having a single rapid naming deficit or a single phonological deficit if they present, respectively, rapid naming performance and phonological processing of at least one standard deviation below the normative grade mean but normal performance in the other domain; normal performance was defined as scores not less than one standard deviation below the mean. Dyslexic readers who presented a z-score of -1 for both phonological and rapid naming measures were classified as showing a double-deficit (Figure 2). This grouping procedure showed that dyslexic readers with dissociated phonological processing and rapid naming deficits can be identified, as we found a subgroup with a single phonological processing deficit (18% of the sample) and, crucially, a subgroup with intact phonological processing capacity but poor rapid naming skills (i.e., a single rapid naming-deficit subtype, 18% of the sample). The finding that dyslexia can occur in the absence of a clear phonological processing impairment but in the presence of a rapid naming deficit is not easily accommodated by an exclusive phonological account for the cognitive processes underlying slow rapid naming. Thus, it appears that something else, beyond phonological ability, lies also at the root of the association between slow rapid naming and impaired reading. This does not mean that phonological factors are irrelevant for the (slow) naming performance, as reflected in cognitive models of visual naming (e.g., Gordon, 1997). Notwithstanding the fact that access and retrieval phonological codes are important aspects of rapid naming, our data suggest that it is unlikely that this phonological component alone best accounts for delayed rapid naming performance in dyslexia. Two additional results from our study support the assumption of independent and combined effects of rapid naming and phonological deficits. First, the dyslexic children with a double-deficit (50% of the sample)

exhibited more severe reading problems than those with only rapid naming or phonological difficulties. Second, we found no indication of a reliable correlation between phonological awareness and rapid naming measures in our dyslexic sample, which again suggests that the two measures are not measuring exactly the same underlying skills (Araújo, Pacheco, Faisca, Petersson, & Reis, 2010).

The claim of a dissociation between rapid naming and phonological processing emphasizes another major prediction of the double-deficit hypothesis: rapid naming should contribute independently to reading outcomes beyond the proportion of variance attributable to phonological processes (Wolf & Bowers, 1999). The research literature on the issue has yielded mixed results. In contrast to the robust findings related to the predictive power of phonological awareness in predicting reading skills (e.g., Ziegler *et al.*, 2010), evidence for a unique contribution of rapid naming has been less convincing. Some studies found that a significant proportion of reading variance was explained by rapid naming measures such as RAN (Manis *et al.*, 2000; Parrila, Kirby, & McQuarrie, 2004; Powell *et al.*, 2007), while others only reported a modest role of RAN in predicting reading performance (Car-

doso-Martins & Pennington, 2004) or failed to find a significant contribution of RAN when the effect of phonology was taken into account (Patel *et al.*, 2004). These apparent inconsistencies may be explained by differences in the orthographic depth of the writing systems in which the studies have been conducted; while the former were conducted in relatively transparent orthographies, the latter mainly stem from opaque orthographies, such as English.

In our research group, we assessed the extent to which there is a unique predictive power for rapid naming beyond the effect attributable to individual phonological processing differences for the Portuguese orthography, which is at mid-point in terms of orthographic consistency. We conducted a series of regression analyses to test if dyslexics' performance in rapid naming (measured through a RAN letters task) predicted reading fluency when controlling for phonology (measured through a phoneme deletion task). The rationale was that if the unique contribution of RAN is evident after phonological skills are controlled, evidence of a unique causal association may be established. In fact, we observed that the variance in rapid naming performance among dyslexics contributed substantially to the variance in fluent reading and this relationship was

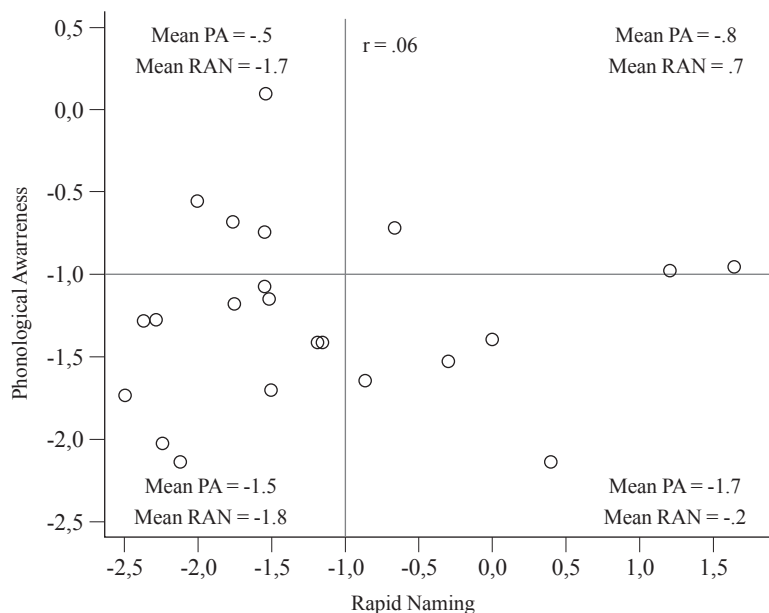


Figure 2. Scatterplot of identified subtypes, with mean z-scores on phonological awareness (PA) and rapid naming (RAN) for each subtype. Data from Araújo, Pacheco *et al.* (2010).

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present when the effect of phonological processing skills was removed ($R^2 = 19\%$; Araújo, Pacheco *et al.*, 2010). These results suggest that the poor rapid naming performance that characterizes subjects with dyslexia reflects an underlying deficit that is relatively independent of a phonological deficit.

Finally, a last point to be added to the discussion on the independent role of RAN refers to data from cross-language comparisons. Conceivably, if the phonological account suffice to explain the RAN-reading relationship, and assuming that phonological processing is more important for reading in inconsistent (e.g., English) than in consistent orthographies (e.g., German; Mann & Wimmer, 2002; McBride-Chang & Ho, 2005), then RAN should exert a much stronger effect on reading in inconsistent than in consistent orthographies. However, this prediction does not seem to be consistent with results from the single-language studies reviewed above.

Early Visual Orthographic Processing Factors: Do They Play a Role?

If rapid naming problems represent a second independent deficit in dyslexia, the question about the nature of these rapid naming problems arises: besides phonology, what cognitive mechanisms underlie rapid naming and mediate the relationship with poor reading? In recent years, various accounts of this relationship have been advanced: rapid naming deficits might reflect some aspect of orthographic processing (Bowers & Newby-Clark, 2002; Georgiou, Parrila, Kirby, & Stephenson, 2008), a general processing speed deficit (Kail & Hall, 1994), a reduced efficiency in integrating orthographic and phonological information (Bowers & Ishaik, 2003), a general problem in retrieving information – either phonological or semantic – from the visual stimuli (Jones, Branigan, Hatzidaki, & Obregón, 2010) and the integrity of the neural circuits involved in stimulus identification and naming (Lervåg & Hulme, 2009), among others.

At present there is no clear “winner” among these competing positions, although it appears that there is a convergence developing towards the view that rapid naming reflects a process that is involved in orthographic processing skill. However, the exact

nature of this underlying process is still unclear. Bowers and colleagues (Bowers & Wolf, 1993; Bowers & Newby-Clark, 2002) proposed that slow processing 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 received some empirical support (e.g., Georgiou, Parrila *et al.*, 2008; Roman, Kirby, Parrila, Wade-Woolley, & Deacon, 2009). However, other recent papers dispute this view, showing, for instance, that rapid naming contributes to nonword fluency over and above orthographic spelling (Moll, Fussenegger, Willburger, & Landerl, 2009; Papadopoulos *et al.*, 2009).

To clarify whether rapid naming does index orthographic skills, we employed a rapid naming task with both letters and non-orthographic stimuli (objects) in a sample of dyslexic children, and examined the relative importance of each type of rapid naming performance in predicting two different reading measures: high-frequency word reading, which calls on orthographic knowledge, and pseudoword reading, which arguably depends on phonological decoding. We observed that the rapid naming ability of dyslexics strongly predicts the fluency in high-frequency word reading as opposed to pseudoword reading. This effect was still present when the individual differences in phonological awareness were removed. Thus, given that the main difference between our reading measures is a greater involvement of orthographic processing in high-frequency word reading, our results support the proposal that the association between slow rapid naming and impaired reading is (at least partly) mediated by a cognitive mechanism relevant to visual orthographic processing. In addition, an orthographic-based explanation seems strengthened by our observation of a greater association between reading ability and alphanumeric RAN (letters) compared to non-alphanumeric RAN (objects), because letters carry more orthographic information than objects (Araújo *et al.*, 2011). In line with this, Georgiou, Parrila and Kirby (2009) suggested that “to the extent that RAN is related to orthographic processing, it is likely an indicator of the ease of access to established orthographic re-

presentations of words in long term memory than to sublexical orthographic information” (p. 529).

At the same time, we have suggested that the reason why rapid naming is related to poor reading may involve another mechanism in addition to orthographic processes, because we found that rapid object naming also accounted for significant and unique variance of the dyslexics’ reading performance (Araújo *et al.*, 2011). Similar to orthographic whole-word recognition of letter strings, rapid naming of objects requires that the pictured objects be recognized, and like access from orthographic to phonological word representations in lexical reading, rapid naming requires access from instantiated visual representations to whole-word phonology (Hawelka, Gagl, & Wimmer, 2010). So, it is possible that poor rapid naming reflects an inability to integrate visual pattern information with stored stimulus representations and, potentially, a slow access from visual recognition units to phonological lexicon entries. Recently, Stainthorp and colleagues (Stainthorp, Stuart, Powell, Quinlan, & Garwood, 2010) emphasized that despite the fact that one of the first stages in rapid naming involves visual processing, the role of visual perceptual processes remain ill understood and under-investigated. The tendency to disregard the early stages of visual processing is possibly related to the impact of the critique of the early studies investigating visual perceptual processing deficits in dyslexia (for an overview, see Vellutino & Fletcher, 2007).

The role of low-level visual factors in dyslexics’ naming performance has so far only been investigated in relatively few studies (for an exception, see Jones, Obregón, Kelly, & Branigan, 2008; Jones *et al.*, 2010; see also Araújo, Faisca *et al.*, 2011). In this context, Stainthorp and colleagues (2010) analyzed the extent to which children with slow RAN performance exhibit prelexical visual processing deficits and found that slow RAN children have difficulty in discriminating simple visual features. Although they concede that the results cannot fully answer questions about causality, the authors argued that a possible deficit in the speed of letter identification, potentially related to an early visual discrimination deficit, may hamper the ability to map the letter-sound correspondences in the early stages of reading

acquisition. Such a deficit might subsequently affect the ease with which children generate representations of words in the orthographic lexicon.

Another potential way to approach the nature of the RAN deficits in dyslexia is to analyze components of these tasks, such as the time taken to articulate each of the items – *articulation time* – and the pause duration in sequenced articulations – *inter-item pauses*. To date, however, the majority of studies have examined RAN in terms of total time (i.e., by obtaining a single performance time for the entire test). Even so, there is evidence that articulation time and inter-item pause components are not reliably related and, therefore, RAN total time is the amalgamation of two qualitatively different processes (Neuhaus & Swank, 2002; Cobbold, Passenger, & Terrel, 2003; Georgiou, Parrila, & Kirby, 2006; Li *et al.*, 2009). Recent investigations of the RAN components have mostly agreed that inter-item pauses are key to understanding the mechanisms that drive the relationship between RAN and reading skills (e.g., Neuhaus, Foorman, Francis, & Carlson, 2001; Georgiou *et al.*, 2006). Within this context, Georgiou and colleagues proposed that alphanumeric RAN inter-item pauses reflect (1) the speed of access to phonological information in long-term memory, particularly during the early stages of reading acquisition, and (2) the ease of generating high-quality orthographic representations, at later stages of reading acquisition or when reading has become automatized (Georgiou, Parrila *et al.*, 2008).

In a recent study, we examined which of the time components of rapid automatized naming are responsible for the poor RAN performance observed in developmental dyslexia and for the differential relationship between RAN and reading in groups of dyslexics and non-impaired readers. The rapid naming performance was analyzed in a response time analysis, which revealed that the slow RAN in dyslexia mainly stems from an enhanced inter-item pause time and not from slower articulation rates. This shows that the cognitive processes behind the inter-item pauses are important sources of the naming difficulty observed in dyslexic children and represent an important index

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for distinguishing between normal and impaired readers (Araújo, Inácio *et al.*, 2011).

Conclusions

Though rapid naming problems in dyslexia may emerge from inefficiencies in the phonological system, there is now evidence that these processes are unlikely to be the sole explanation for why slow rapid naming is related to poor reading. At least one component of the rapid naming performance, characteristic of dyslexia, appears to reflect an underlying deficit that is independent of a phonological deficit. Thus, it seems likely that slow rapid naming is, at least partly, related to visual processes that occur before phonological access and retrieval during rapid naming. The efficiency in accessing

stored stimulus representations from visual feature and pattern encoding and the integration of visual information with its corresponding phonological codes are relevant possible explanations and a fruitful area for future research.

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