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by

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Born on 13 December 1989 in São Pãulo

RAPID AUTOMATIZED NAMING AND PHONOLOGICAL AWARENESS:
THE PREDICTIVE EFFECT FOR LEARNING TO READ AND WRITE AND THEIR RELATIONSHIP WITH DEVELOPMENTAL DYSLEXIA

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Rapid Automatized Naming and Phonological Awareness: The predictive effect for learning to read and write and their relationship with developmental dyslexia

Work submitted to obtain a doctoral degree in Developmental Disorders for the Stricto Sensu Postgraduate Program at Mackenzie Presbyterian University - São Paulo/SP and Cotutella University of Luxembourg

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PATRÍCIA BOTELHO DA SILVA

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Thesis presented to the Graduate Program in Developmental Disorders of Mackenzie Presbyterian University, as a partial requirement to obtain a Doctor of Developmental Disorders degree.

Approved March 4th, 2020.

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Summary

Among the predictors of reading, rapid automatized naming (RAN) and phonological awareness (PA) are the best predictors. The predictive effect of these abilities is different, and they predict different aspects of reading, being dependent on the orthographic regularity of the language as well as the student's level or grade in school. The double deficit theory describes these two components as impaired in people with dyslexia and reading disabilities. Longitudinal studies that analyze cognitive processes supporting the development of reading and literacy are important for understanding processes in good readers as well as will help mitigate the effects of dyslexia and reading disability.

The present thesis pursues two major aims. The first aim is to analyze the structure and predictive effect of RAN and PA skills on reading and writing tasks in Brazilian Portuguese in two studies. Study 1 sought to investigate the structure of RAN tests for Brazilian Portuguese throughout its development according to age. The results were important in determining the bidimensional model (alphanumeric and non-alphanumeric) throughout development of age and development of literacy. In addition, the results showed that the period between kindergarten and elementary school may show greater development of RAN skills in conjunction with literacy learning. In Study 2, we sought to investigate the predictive effect of PA and RAN on the development of reading and writing ability in Brazilian Portuguese. The results showed that RAN ability was a better predictor than PA of reading and writing skills for Brazilian Portuguese in relation to reading and writing speed. In addition, the type of stimulus of RAN influenced the predictive effect. Alphanumeric RAN better predicts reading, while non-alphanumeric stimuli predict writing.

The second aim of this study is to compare the performance of children and adolescents with and without developmental dyslexia in RAN, PA, and reading tests and to verify the predictive effect of RAN and PA in participants with dyslexia. Study 3 showed that the cognitive profile of dyslexic children was compatible with a single deficit in RAN according to double deficit theory. Impairment has only been found in RAN ability as well as in processes such as visual attention, which is an underlying process of RAN skills. Therefore, despite the importance of PA for the development of reading and writing, both in good readers and in those with reading impairments, RAN ability proved to be a better predictor for both groups in Brazilian Portuguese.

Keywords: rapid automatic naming; phonological awareness; literacy; reading development; Brazilian Portuguese

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CHAPTER 1: GENERAL INTRODUCTION

Besides being a desirable skill in itself, reading is also the way we access almost all academic information. Learning to read is a complex process that requires a variety of skills, including the explicit presentation of the alphabetic principle. However, some skills can be assessed even before the literacy process begins and have been predictive of learning. Predictive skills include rapid automatized naming (RAN) and phonological awareness (PA) (Handler & Fierson, 2011) .

RAN is the ability to name a series of symbols as quickly as possible, such as letters, numbers, colors, or objects. One can analyze the subject's ability to perceive and assess the names of different types of symbols quickly and accurately. This ability relates to the time it takes information to be processed in order to integrate the recognition of visual stimuli with the expressive aspects of language. Such ability demands the integration of different cognitive functions such as perception, motor skills, attention, language, and executive functions (Wolf & Denckla, 2005). PA, on the other hand, is the ability to decode phonologically, converting visual symbols into their sounds. Thus, PA is a measure that correlates with the subsequent ability to read accurately (Cardoso-Martins & Pennington, 2001).

Reading is a process that develops with the automation of cognitive processes and depends on the development of underlying cognitive processes and predictive skills such as PA and RAN. In addition, both PA and RAN are important in the early identification of reading impairment. Longitudinal studies can help us better understand cognitive reading processes and reading development. From this, the present study seeks to identify through longitudinal study and cross-sectional study how RAN and PA skills are related to reading and writing.

CHAPTER 2: RAPID AUTOMATIZED NAMING AND PHONOLOGIC AWARENESS IN THE DEVELOPMENT OF READING AND IN READING IMPAIRMENT

Rapid Automatized Naming

The first studies describing RAN tasks related to the investigation of alexia deficits, in which difficulty in integrating visual and verbal processes occurs. Norman Geschwind first described this in 1965 in patients who had difficulty naming colors. Subsequently, neurologist Martha Denckla, inspired by Geschwind's studies, sought to further investigate the relationship between RAN and dyslexia (Norton & Wolf, 2012). Denckla and Rudel (1976) developed a consistent paradigm that involves assessing reading fluency through Rapid Automated Naming (RAN). Visual stimuli used for assessment are letters, numbers, objects, or colors. The stimuli are presented in linear sequences, just as in text reading (Wolf & Denckla, 2005). Reading is linear, so the symbols of the RAN tests are presented in linear sequence and can also be called rapid serial naming (Wolf & Denckla, 2005). However, in this study we will use the term rapid automatic naming.

During RAN tasks, attentional, linguistic, perceptual, and motor processes are integrated (Wakamiya et al., 2011; Torppa et al., 2011). The information processing procedure first involves visual processing for feature detection and visual discrimination of the stimuli being viewed. After that, visual characteristics need to be integrated with the previously stored orthographic, numeric, or image representations, depending on the type of stimulus. Subsequently, the brain accesses the stored phonological representations necessary for correct identification of the symbol name. Finally, the phonological record is accessed and retrieved to activate and integrate semantic and conceptual information with all other information. This final step helps in comprehension of the information so that during the naming task, meaning can be accessed, making it possible to understand what is being seen (Aguilar-Vafaie, Safarpour, Khosrojavid, & Afruz, 2012; Wolf & Denckla, 2005).

RAN is, therefore, a cascading skill requiring visual processes, phonological and orthographic mapping, and articulatory planning. Different items can be processed simultaneously in different steps. With RAN comes a parallel processing of the observed items in the automation of early reading skills. Thus, items can be processed automatically, and executive control monitors the process through specific phases. Automatic naming helps in reading distinct words, beginning with serial processing and moving on to reading the word as a whole. Naming task processing also develops and changes during learning, resulting in the ability to process multiple items at the same time as cascading and processing intrabound (letter and syllable) and inter-word aspects (Protopapas, Altani, & Georgiou, 2013).

RAN depends on attentional processes and components, feature detection, visual discrimination and identification patterns, feature integration with spelling and phonological representations, access to the phonological label, activation and integration of semantic information, and articulation (Siddaiah & Padakannaya, 2015). RAN measures are predictive of reading; RAN can be assessed before children learn to read, and testing can be used as early measure of risk for reading difficulties (Norton & Wolf, 2012).

The paradigm stimuli created by Denckla and Rudel (1976) can be divided into two factors: alphanumeric (letters and numbers) and non-alphanumeric (colors and objects). The factors are divided because of the nature of the stimuli as well as the underlying cognitive processes measured and their developmental pattern (Åvall et al., 2019; Närhi et al., 2005; Protopapas et al., 2013; Rodriguez et al., 2015; Van Den Bos, Zijlstra & Spelberg, 2002).

Learners are exposed to RAN stimuli in different categories and process those stimuli at different developmental phases. Names for objects and colors come first within the development process. Letters and numbers are recognized and named later in development, at a time associated with the beginning of formal education. The cognitive processing underlying each stimulus is different; colors and objects can activate several possible names (they are polysemous), while letters or numbers are generally linked to a single possible naming response. This processing difference means that the time needed to name colors and objects is longer than that for letters and numbers (Hornung et al., 2017). But this order of development depends on the automatization of visual-verbal reaction time. Executive operating processes begin to process stimuli in parallel (Protopapas et al., 2013). This automatization is affected by word frequency, operativity or figurative stimulus, and visual reversibility of letters (Denckla & Rudel, 1974). RAN latencies are not related to how early the stimuli were learned but to how automatized the naming process was. In children gaining literacy, naming objects and colors comes quickly because they are familiar stimuli. With more practice and exposure to letters and numbers, children can become faster at naming them, because the capacity for automaticity is larger (Norton & Wolf, 2012).

Various studies point to the relationship between fast automatic naming and good reading performance (Aguilar-Vafaie et al., 2012; Albuquerque & Simões, 2010; Norton & Wolf, 2012; Protopapas et al., 2013; Wolf & Denckla, 2005). For example, Albuquerque & Simões (2010) verified the differences between the ages in RAN tasks in 904 children and adolescents from 7 to 15 years. The results showed that naming time in the numbers task decreases with age. Thus, there is greater development of skill at early schooling ages, where the time needed to name is even longer. However, as schooling and reading develop, the time of automatic naming decreases.

Studies shows that RAN is correlated with reading accuracy and fluency (Araújo, Reis, Petersson, & Faísca, 2015). Therefore, RAN represents an early approximation to reading speed for words and is an important predictor for reading fluency. Fluency is important for reading comprehension (Babayiğit & Stainthorp, 2010; Lervåg & Hulme, 2009; van de Ven, Voeten, Steenbeek-Planting, & Verhoeven, 2017; Wolf & Denckla, 2005). The relationship between RAN and reading does not change in terms of fluency and is relevant throughout the school years. The RAN-reading relationship is important in terms of accuracy for early readers (kindergarten to first/second grade) and then decreases. The RAN-reading relationship is dependent on the orthographic regularity of the language; in opaque orthographies like English, the effect of a higher reading-ratio correlation between kindergarten and first/second year decreases in later years, whereas for transparent orthographies like Italian there was no effect of the series on the relation (Araújo et al., 2015).

Longitudinal studies have shown the predictive effect of RAN in relation to reading fluency of words, pseudowords, and text (Babayiğit & Stainthorp, 2010; Lervåg & Hulme, 2009; van de Ven et al., 2017). RAN is related to the development of text reading fluency as a whole, and not only to its initial development (van de Ven et al., 2017). Thus, RAN measurements have a high correlation with reading fluency, which is important for reading acquisition (Ibrahim, 2015).

The types of RAN stimuli in the test also have different effects on the development of reading. Studies with alphanumeric stimuli show higher effect sizes between RAN and reading. Alphanumeric stimuli, especially letters, are tasks closer to reading fluency processes and may present an effect of letter-sound knowledge (Araújo et al., 2015).

Alphanumeric RAN is more predictive of reading abilities than color/object RAN in the kindergarten to first grade transition and from the first year until the second year of school (Hornung et al, 2017). Some studies show that the predictive value of RAN and reading become more relevant from the third year of elementary school (Bowers, 1995; Torsegen et al., 1997; Georgiou et al., 2013); other studies show that the predictive effect is higher in early reading development (Wagner, Torgesen, Rashotte, Hecht, & et al, 1997). The relationship between RAN and reading may present a two-way pattern, since with the development of reading, RAN skills may improve as well (Compton, 2003). On the other hand, this relationship may be unidirectional, with only RAN predicting later reading skills (Wei, Georgiou, & Deng, 2015).

Studies show that RAN correlates better with measures of word and text reading, which are related to orthographic processing. However, RAN is also correlated somewhat with the reading of pseudowords and text comprehension. Thus, RAN is also related to phonological processing, although usually pseudowords measures in studies are derived from real words, which involves access to orthographic representations (Araújo et al., 2015). In a study that aimed to analyze the predictive value of RAN in relation to reading words, text, and writing with third- and fourth-grade children, RAN was more related to reading fluency and reading text. After controlling for PA and handwriting variables, RAN better predicts writing fluency; however, this relationship is less influential (Albuquerque, 2017).

Another important factor regarding the predictive effect of RAN on reading is orthographic consistency. In relation to orthographic consistency, the RAN-reading relationship depends on the type of test used and the school year. Alphanumeric RAN and the fluency and accuracy of reading seems to have a greater effect in opaque orthographies, and the effect of this relationship is better for beginning readers. However, this relationship in transparent orthographies is more regular throughout the years. Intermediate orthographies present smaller effects in relation to orthographic consistency and the RAN-reading relationship (Araújo et al., 2015). RAN has a strong effect on reading fluency in different orthographies due to serial and articulation processes that assist in the development of fluency. Therefore, different orthographic systems may have different predictive values. The predictive value of RAN and spelling may be mediated by phonological processes in transparent spelling systems such as Chinese and Finnish and by spelling processing in opaque spellings such as English (Georgiou et al., 2016).

Phonological Awareness

Like RAN, phonological processing skills are important for reading development. There are three phonological processing abilities: phonological memory, phonological access to lexical storage, and phonological awareness (PA). Phonological memory refers to the temporary storage and encoding of sound information; phonological access to lexical storage refers to the ability to retrieve phonological codes from memory; and PA is related to sensitivity to the structure of oral language. Anthony & Francis (2005) sought to analyze the development of PA and its importance for reading. Among phonological processing skills, PA is the ability most related to literacy (Anthony & Francis, 2005).

PA is the ability to convert words into a phonological representation, i.e., to recognize, discriminate, and manipulate the sounds of speech to create words. For this, oral language is important because it builds the representation and knowledge of phonological structure of spoken words (Anthony & Francis, 2005; Shapiro, Carroll, & Solity, 2013; Swanson, Trainin, Necoechea, & Hammill, 2003). PA ability involves blending sounds, separating (segmenting) words in sounds, recombining sounds of words, and identifying common sounds between different words (rhymes). In addition, tasks can include dividing a unit of word structure into syllables or phonemes. Within the development of PA, oral language and the linguistic structure are of great importance. The development of PA is affected by the linguistic and syllable structure and the formation of words. The development of phoneme awareness is of great importance for written language and literacy. When literacy begins, PA becomes faster, especially in alphabetic languages with transparent orthographies (Anthony & Francis, 2005).

There are two main patterns of development of PA. First, children begin to manipulate and recognize syllables; later, they are able to recognize rhymes and eventually phonemes. As their age progresses, their skills become more effective. Second, children can discriminate words with similar sounds before manipulating sounds within words (rhymes and alliterations) and mixing information before segmenting words (transposition and manipulation) (Anthony & Francis, 2005).

In the literacy process, children in the first year of primary school do not have enough experience in PA and have a better understanding of syllables and rhymes in relation to phonemes (Erdoğan & Erdoğan, 2010). These PA skills are of direct importance at the beginning of literacy, especially in first grade, unlike the second grade where phonological skills may have little relation to reading prediction (Rothou, Padeliadu, & Sideridis, 2013). Thus, as school progresses, the predictive value of PA decreases (Wagner et al., 1997), which may be related to the measures and forms of assessment used with older children. The influence of fluent reading on the development of PA is little investigated, however, since reading and decoding instruction facilitates performance on PA tests (Hogan, Catts, & Little, 2005).

Cunningham et al. (2015) carried out a study to investigate the importance of different components of phonological tasks for the prediction of early decoding abilities. The article points out the importance of both input and phonological output. There are two stimulus-specific components of phonological tasks: 1) the linguistic nature of the stimulus and the phonological complexity of the stimulus as predictors of decoding, and 2) the production of a verbal response as another predictor of decoding. Hogan et al. (2005) found significant results regarding the prediction of PA for reading in kindergarten to second grade, but not in predicting second grade to fourth grade measures of reading. When the measure was phonetic awareness in second grade, a small but significant amount of variance in fourth grade reading was predicted. In addition, the results showed an inverse pattern with respect to the predictive value for the second to fourth grade where word reading results predicted performance in PA in fourth grade.

Longitudinal Studies and Predictive Value of RAN and PA for Reading

RAN and PA are predictors of reading skills in typically developing children (Bowers, 1995; Cardoso-Martins & Pennington, 2001; Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997) and for children at risk for learning difficulties and disorders such as dyslexia (Hornung et al, 2017a; Justi & Cunha, 2016; Peterson et al 2017). This relationship between skills can be independent and is related to reading maturity (Swanson et al., 2003).

Studies have sought to analyze the predictive effect of RAN and PA on reading development. RAN is correlated with reading comprehension and fluency. PA, on the other hand, is a measure that correlates with the later ability to read accurately and with phonological decoding, helping the conversion of visual symbols in their sounds (Bowers, 1995; Cardoso-Martins & Pennington, 2001; Torgesen et al., 1997).

The contribution of predictors also depends on the developmental stage of reading. The reading of words occurs through phases. The first phase, the decoding phase, depends on a phonological guide in which one to one conversion of graphemes and phonemes is performed. After this first phase, children read longer and more complex words with more complex orthographic structures. With this, the orthographic lexicon develops, including new words learned. Therefore, the connections between graphemes, phonemes, semantics, and word structures are strengthened with the reading experience, according to the phonological coherence model. The development of writing seems to be trajectory dependent on individual differences. PA contributions appear to be more relevant to spelling than contributions from RAN.

Writing is not just a one-to-one reversal of word reading, but both depend on access to orthographic, phonemic, and semantic structures. These individual differences may be due to the greater difficulty of writing, since the conversion of phonemes to graphemes depends on many variations and access to specific orthographic structures, and there are more graphemes to choose from when writing down a phoneme. Thus, both grapheme-phoneme (reading) and phoneme-grapheme (writing) conversion skills have predictors, and word reading presents RAN as the best predictor, and writing the skills of PA (Schaars, Segers, & Verhoeven, 2017). In addition, reading can be an important precursor to the development of second-grade writing (Schaars et al., 2017). Thus, writing skills are the best predictor of PA skills (Babayiğit & Stainthorp, 2010).

RAN, PA, and the reading relationship depend on multiple factors such as the type of stimulus used, the type of measure used to assess reading and writing, and the consistency of orthographies in different languages. A meta-analysis study (Swanson et al., 2003) with the objective of analyzing the relationship between PA, RAN, and word reading showed that the contribution of PA and RAN to reading occurs independently. Some factors influence this relationship; the correlation coefficient was higher for the youngest age group, although this factor was not related to the magnitude of the correlations between the abilities, only in relation to reading comprehension/PA. All correlations were moderated by the grade level, specifically for real-word reading/RAN coefficients and reading comprehension/PA coefficients (Swanson et al., 2003).

In addition, according to school progression and consequently learners' experience and reading instruction, the contributions of PA and RAN to word recognition are stronger. The coefficient of regression for real word reading and pseudoword reading was greater to PA but RAN have a moderate effect, and the difference between the coefficients is small. For reading comprehension, the coefficient was higher for RAN and reading with higher difference between values. PA and RAN predict different components of reading. PA presents better effects for pseudoword reading factor, whereas RAN measures presents better effects for reading comprehension factor. Thus, although RAN and PA present correlations with each other, according to reading development, the development curve for each ability changes uniformly (Swanson et al., 2003).

Analyses of different types of writing have shown that different orthographic systems have distinct linguistic predictors. Thus, there are differences in the predictive value for different language systems between PA and RAN (Georgiou et al., 2008; Pae, Sevcik & Morris, 2010; Furnes & Samuelsson, 2011; Georgiou et al., 2012). In some studies, the predictive effect of reading shows that this effect depends on orthography regularity (Georgiou et al., 2008; Pae et al., 2010; Georgiou et al., 2012; Peterson et al 2017). Studies across different orthographies, opaque and transparent, with early development in reading and spelling, compare patterns of predictors. The results showed that there are mixed effects between PA and RAN on reading and spelling. The predictive effect between PA and reading is higher in opaque orthographies, because the time needed to establish reliable grapheme-phoneme recording depends on the writing system. In transparent orthographies this is more consistent, and the correspondence letter-sound is more regular (Furnes & Samuelsson, 2011). However, the effect of RAN seems to be less impacted by spelling consistency than PA is (Landerl et al., 2019).

Regarding nonalphabetic language, such as Chinese, the association between PA, RAN, and reading presents a similar pattern. The correlation between RAN and accuracy and fluency of word reading is higher in relation to PA and these measures. However, the relationship between RAN and reading depends on the type of RAN and reading outcome measure, with a higher RAN-reading ratio for fluency ability. Both age and grade had no influence on the analyses. Therefore, the predictive effect of RAN and PA on reading can be analyzed in different orthographic systems and language regularities (Song, Georgiou, Su, & Hua, 2016).

Studies show that in typically developing children, reading accuracy is more strongly correlated with phonemic awareness, whereas reading speed or fluency showed stronger correlations with rapid naming (González-Valenzuela et al, 2016; Albuquerque, 2011; Park & Uno, 2015). PA continues to be associated with dictation accuracy in writing, while RAN presented correlations with dictation accuracy and fluency (Albuquerque, 2011).

A Brazilian study also found a higher relationship between RAN and reading fluency in relation to phonological abilities; both contribute to writing in Brazilian Portuguese. Thus, RAN and PA contribute to reading accuracy and fluency, as well as to writing independently, for Brazilian Portuguese (Justi & Roazzi, 2012).

González-Valenzuela, Díaz-Giráldez, and López-Montiel (2016) sought to analyze the contribution of different cognitive skills to the reading of words and pseudowords in Spanish first-grade children. The results showed that PA, phonological memory, and RAN of alphanumeric stimuli are the best predictors of word and pseudoword reading skills, depending on the measure and type of linguistic unit considered. Fast automatic naming was the best predictor of accuracy and reading speed measurements.

As schooling progresses and reading skill develops, the predictive value between the two skills (RAN and PA) changes. RAN is a better predictor of tasks involving orthographic information in the first two years of literacy, whereas PA is a better predictor of reading pseudowords. Thus, the abilities present distinct variations in relation to their predictive values, RAN being related to arbitrary associations between visual material and sound, whereas PA is more related to the systematic learning of letter-sound correspondence (Manis, Seidenberg, & Doi, 1999).

For primary and secondary school readers, a longitudinal study has shown that RAN is a predictor of reading speed ability independent of previous reading ability. Phonological abilities predict spelling aspects only when previous reading skills were controlled. With this, fast automatic naming is a predictive ability independent of previous reading knowledge (Babayiğit & Stainthorp, 2010). Longitudinal studies show that the relationship between PA-reading decreases as school progresses, while RAN-reading increases as schooling progresses (Albuquerque, 2012; Georgiou et al., 2013; Vaessen e Blomert, 2010).

Albuquerque (2012) analyzed the relationship and specific influence of RAN on different components of reading and writing in first- and second-year Portuguese children. Decoding accuracy and reading fluency were evaluated, and accuracy in dictation and writing fluency was considered. PA correlated with reading accuracy, whereas automatic naming was related to fluency. However, comparing first-year results with second-year results, all correlations of PA decreased with schooling, while automatic naming correlations increased. PA remained associated with accuracy in dictation in writing, while automatic naming correlated with dictation accuracy and also fluency in writing.

Ibrahim (2015) analyzed the influence of RAN for reading in third- and fifth-grade Arabic-speaking children. The subtests of letters and numbers were applied, with tests of reading of isolated words and pseudowords. The results showed that letter naming and number naming correlated with measures of reading fluency of words and pseudowords. There was a moderate correlation with accuracy measures in third-grade children for reading words and pseudowords, while in fifth grade there was correlation only with pseudoword reading. It was concluded that RAN measurements are strongly correlated with reading fluency measurements.

Bowers (1995) conducted a longitudinal study with children from the first year of elementary school. Results suggest that RAN ability was important mainly in the third to fifth year of elementary school. According to the author, during this period orthographic codifications develop. Similarly, Torgesen et al. (1997) conducted a longitudinal study to verify variations in the correlations between PA, RAN, and reading in two schooling periods: second to fourth and third to fifth grades. The results showed that third-grade RAN scores correlated with the spelling coding variations found when children were in fifth grade. These results were not observed in PA. In addition, children with reading difficulties in third grade had greater variations in RAN than they did in fifth grade.

Other studies indicate that the relationship between RAN and reading is more important than PA in the early years (Furnes & Samuelsson, 2011; Park & Uno, 2015). Thus, the results of studies in readers of different languages do not converge on the predictive value of RAN and PA tasks. However, these measures may assist in the diagnosis of learning disabilities in reading and writing (Wolf & Bowers, 1999; Germano et al., 2012; Wimmer & Schurz, 2010; Wakamiya et al., 2011; Torppa et al., 2011).

RAN and PA in Developmental Dyslexia

Rapid naming tests and PA tests are the two best predictors of reading problems and difficulties. Naming speed tests, particularly for letters and numbers, provide one of the best measures for differentiating good and bad readers. This is because both rapid naming and reading involve visual recognition of stimuli and access to their phonological representation. This predictive ability—and the fact that the tests are simple, fun, and quick to administer—make naming tests a relevant part of any battery or diagnostic assessment of oral or written language. Naming tests make a major contribution to a full understanding of individuals' reading skills (Wolf & Denckla, 2005). In fact, tests that evaluate rapid automatic naming are used in many countries as diagnostic tools for reading problems (Kirby et al., 2010). Since the RAN test was formed, this instrument has been used to assess learning difficulties. Denckla and Rudel (1976) have already shown differences in naming speed between groups of children with learning disabilities and control groups of children.

Learning disorders may interfere with educational, social, and economic development. These disorders can manifest as an imperfect ability to listen, speak, read, spell, write, understand, concentrate, solve mathematical problems, and organize information. Approximately 80% of children with learning disorders are dyslexic. Developmental dyslexia is a learning disorder that involves reading impairment. Impairments can occur in skills such as PA and rapid automatic naming that are important for reading development (Handler & Fierson, 2011).

Developmental dyslexia is a neurodevelopmental learning disability characterized by a specific and persistent deficit in the acquisition of reading and spelling skills that cannot be explained by deficits in other cognitive abilities, insufficient educational opportunities, or inappropriate literacy instruction (intelligence and sensory abilities are intact). Reading ability must be below the expected average for the child's age, or the subject should present acceptable performance only with immense effort. Within the diagnostic criteria, symptoms include reading words inaccurately or slowly and with effort and difficulty understanding the meaning of what is read (American Psychiatric Association, 2014; Shaywitz & Shaywitz, 2005; Pennington, 2009). Impairments in decoding, word recognition, and reading comprehension are also present in dyslexia. These difficulties are reflected in phonological components, resulting in difficulties in using the alphabetic code. Secondary consequences may also occur; little reading experience prevents the increase of vocabulary, written expression, and development of precursor skills. People with dyslexia may read accurately but have persistent problems with fluency, meaning that even over time they continue to read slowly and not automatically (Handler et al., 2011 Norton & Wolf, 2012; Peterson & Pennington, 2012).

Among the hypotheses that seek to explain the deficits found in developmental dyslexia, the phonological and double deficit hypotheses stand out. The phonological hypothesis posits deficits in the processing of sound structures related to the underactivation of left-brain hemisphere areas responsible for language (Spironelli et al., 2008). Despite its prominence, the phonological deficit model has been subject to cumulative scrutiny (Snowling, 2008). Some authors have proposed that it is not enough to verify phonological processing deficits alone (Pennington, 2006; Snowling, 2008). In any case, there is evidence that the phonological deficit alone is not enough to explain performance on the RAN (Wolf, Bowers, & Biddle, 2000).

Because reading involves linguistic, visual, and attentional processes, some variable patterns of cognitive difficulties may contribute to reading difficulty across children (Norton, Beach, & Gabrieli, 2014). Thus, the theory of single deficits in phonological processing does not currently hold, since other cognitive impairments independent of the phonological process, such as visual attention and RAN deficits, temporal sampling or processing, visual-spatial attention or perceptual impairments, and learning deficits are all found in dyslexia (Peterson & Pennington, 2012; Norton, Beach & Gabrieli, 2014).

Wolf and Bowers (2000) developed the double deficit theory to explain children with dyslexia. This theory proposes the existence of two central and mutually causal components: PA and RAN. When there are no difficulties in either skill, there are no difficulties in reading. When there are difficulties, they can present in both or in only one of the components; a deficit may impact only phonological processing or only naming speed. However, when both skills are impaired there is a double deficit, and the difficulties encountered in learning to read become more prominent and stronger. The reading impairment manifests itself differently depending on the number and type of components involved. There is also evidence that deficits in both RAN and PA are often associated with more severe and persistent literacy difficulties than isolated deficits in RAN or PA (Kirby et al., 2010). Children with difficulties in both PA and RAN show more severe and persistent reading difficulties than children with deficits only in PA, even when the two groups of children are matched for PA (Kirby, Parila, & Pfeiffer, 2003; Papadoulos et al, 2009).

Phonological processing skills such as phonological memory and PA are impairments found in dyslexia, and impairments in PA are of major importance for reading development. In dyslexia, difficulties in PA are reflected in written language and persist from preliteracy to adulthood (Anthony & Francis, 2005; Norton & Wolf, 2012). The impairment in relation to phonological processing causes a failure in the development of phonological representations with segmented impairment in PA abilities, and inaccurate processing steps, being these related losses not only related to phonemes but also in other PA skills (Peterson & Pennington, 2012).

In his follow-up study of 130 children from elementary school to elementary school, Cronin (2011) showed that PA and RAN influence the increase and development of word and pseudoword reading skills. Children with double deficits presented a lower growth curve than good readers and children with only one impairment (RAN or PA). The study concluded that both PA and RAN are essential predictors of reading and have a different developmental pattern for reading ability according to cognitive impairment.

Brazilian studies have shown that poor RAN ability is related to reading impairment in Brazilian Portuguese. Bicalho and Alves (2010) compared the performance in the automatic serial naming test of children with and without learning complaints. Results indicated that second and fifth grade children with learning complaints were slower at automatic serial naming than children without complaints. Similarly, Capellini and Lanza (2010) compared the performance of students with and without learning disabilities in PA, rapid naming, reading, and writing tests. Results showed that children with reading difficulties performed poorly in all tasks.

Capellini et al. (2007) evaluated naming speed in three groups of boys: those with dyslexia, those with Attention Deficit Disorder (with or without hyperactivity), and good readers. Results showed a significant difference between the groups, and good readers were faster than the other two groups. Boys with dyslexia underperformed subjects with ADHD. Worse performance by children with dyslexia is explained by the presence of a phonological processing deficit in these participants.

Similarly, in a recent study aiming to investigate the role played by PA and RAN in predicting persistent as opposed to transient reading difficulties in Brazilian Portuguese orthography, the authors found that the children with both transient and persistent reading difficulties performed significantly worse than the controls on the PA measures, but by the end of kindergarten only the persistent difficulties group performed worse than the controls on the RAN measures. Therefore, difficulties in both PA and RAN were associated with persistent reading difficulties in their sample (Michalick-Triginelli & Cardoso-Martins, 2015).

CHAPTER 3: AIMS OF THE PRESENT THESIS

The major objectives of the present thesis are twofold. First, I mean to establish the predictive effect of RAN and PA skills in reading and writing tasks in Brazilian Portuguese through longitudinal studies. Study 1 sought to investigate the structure of RAN tests for Brazilian Portuguese, throughout its development. The aim of the study was in order to analyze how the duration of RAN decreases throughout development and whether the intercorrelations of the four naming stimulus types (digits, letters, objects, and colors) at various age levels are developmentally invariant. After examining how RAN ability can be understood through development, the predictive effect of PA and RAN on the development of reading and writing ability in Brazilian Portuguese was analyzed in Study 2.

The second major aim of this research was to analyze the predictive effect of PA and RAN on developmental dyslexia. Thus, Study 3 aimed to determine the cognitive profile of participants with dyslexia as well as to examine the predictive efficacy of RAN and PA in identifying dyslexic individuals.

CHAPTER 4: STUDY 1

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The structure of rapid automatized naming in children aged 4–9 years

Abstract

Rapid automatized naming (RAN)—an important ability for reading development—is used widely; however, the underlying factor structure of RAN tests is unclear, and there are issues concerning dimensional universality across cultures and orthographies. Therefore, we analyzed how RAN decreases across development and whether the intercorrelations of four naming stimuli—colors, objects, numbers, and letters—are developmentally invariant at various age levels. Participants were 858 children aged 4–9 years who were learning to read in Brazilian Portuguese. All children completed a standardized Brazilian RAN test. Results showed that the best data fit was provided by a two-factor model, which was consistent across all age groups. We conclude that, in Brazilian children, RAN assessed with diverse stimuli measures unitary and bidimensional skills in 4–9-year-old children. The findings have key implications for the use of RAN in research and for the interpretation of RAN performance in clinical and education settings.

Keywords: rapid automatized naming; alphanumeric rapid automatized naming; non-alphanumeric rapid automatized naming; factor structure; bidimensional model.

Introduction

Rapid automatized naming (RAN) tests measure how quickly and accurately a person can name visual symbols, such as letters and objects, that are serially presented on a page. The stimuli used in RAN tests are familiar, restricted, and repeated several times in the test. RAN is a complex process with multiple processing tasks such as attention, access to the phonological code, and activation and integration of semantic and conceptual information (Wolf & Denckla, 2005). A RAN test can be administered before children are formally introduced to literacy, and they are frequently used to identify children at risk for reading difficulties (Justi & Cunha, 2016).

According to phonological processing theory, RAN tests relate to reading because they tap into the ability to rapidly retrieve phonological information. Consequently, RAN is seen as a predominantly implicit phonological processing task (Logan et al., 2009). According to others, RAN involves more than phonological processing (Wolf, Bowers, & Biddle, 2000).

An abundance of research has shown that performance on RAN tests is linked to reading development across cultures and orthographies (Altani et al., 2017; Georgiou et al., 2008, 2012; Pae et al., 2010; Peterson et al., 2017). Thus, the development pattern of RAN tasks also depends on the orthographic regularity of the language since, for opaque language, the effect on the relationship between RAN-reading is kindergarten and first/second year and then a decrease. So, after second grade, the relationship between RAN-reading decrease. Unlike for transparent languages, there is no serial effect in the reading-RAN relationship (Araujo et al., 2015).

Denckla and Rudel (1974) developed an extensive battery of automatized naming tests, including alphanumeric items (letters and numbers) and non-alphanumeric items (colors and objects), because these different tasks present a dissociation of naming ability in accordance with individuals' development (Norton & Wolf, 2012). According to the period of development, object naming begins from the age of 2 years. Second, naming colors develops as a figurative element. Letters and numbers are recognized and named later in development, which is associated with the beginning of formal education. However, this order of development depends on the automatization of visual-verbal reaction time. This automatized is affected by word-frequency, operativity or figurative stimuli, and visual reversibility (letters) (Åvall et al., 2019; Cohen et al., 2018; Denckla & Rudel, 1974).

In addition to uncertainties concerning what exactly RAN tests measure, there has been no consensus regarding the underlying factor structure of different RAN tests. A key question that remains is whether RAN tests with different stimuli tap into a unitary process (unidimensional) or if they measure separate skills. This study addresses this question by exploring the underlying factor structure of RAN, assessed with diverse stimuli in children from Brazil who were learning to read in Brazilian Portuguese. RAN tests can present two different patterns of development among elementary school children according to their age: alphanumeric and non-alphanumeric (Åvall et al., 2019; Närhi et al., 2005; Protopapas et al., 2013; Van Den Bos, Zijlstra & Spelberg, 2002). The non-alphanumeric stimuli can be used with preschool children, and alphanumeric stimuli can be used when children are older since they are correlated with reading (Araujo et al., 2015).

It has also been argued that RAN tests using different stimuli, while sharing common components, also represent unique variance that depends on the nature of the stimuli used. The most consistent finding is that alphanumeric stimuli (letters and numbers) generally relate to one factor whereas non-alphanumeric stimuli (objects and colors) relate to another underlying factor (Åvall et al., 2019; Närhi et al., 2005). Studies have consistently found that school-aged children name digits and letters faster than objects and colors (Åvall et al., 2019; Bowey et al., 2005; Rodriguez et al., 2015). This difference in naming times might be related to the nature of the stimuli: while pictures of colors or objects can activate several possible names, digit and letter symbols are generally linked to a single possible response (Hornung et al., 2017). Non-alphanumeric stimuli involve semantic lexical coding access and alphanumeric stimuli involve asemantic coding (Hornung et al., 2017). This could also lead to different processes being involved in RAN letter/digit and RAN object/colors (Carte, Nigg, & Hinshaw, 1996, Tannock, Martinussen & Frijters, 2000; Wolf, 1991).

Studies with older children have, however, shown that the predictive relationship between RAN and reading depends on the type of RAN measure used. This might suggest that the underlying structure of RAN tests depends on the age of the assessed children and their literacy development (Cohen et al., 2018). Whereas a unifactorial solution might emerge in pre-literate children, a two-factor solution might best account for RAN performance in literate children (Van Den Bos et al., 2002).

Therefore, we analyzed how RAN decreases across development and whether the intercorrelations of the four naming stimulus types— digits, letters, objects and colors— at the various age levels are developmentally invariant. Specifically, we examined Brazilian children across different ages and reading levels: pre-literate (4- and 5-years-old) and literate (6–9-years-old). RAN has been scantly used in clinical settings in Brazil; although, it is a widely used in research settings. Recently, a Brazilian RAN test (Teste de nomeação automática [automatic naming test] - TENA test) was created and standardized for use in both settings (Silva, Mecca, & Macedo, 2018). However, to date, no study has analyzed the underlying factor structure of the RAN tests in a population of Brazilian children.

Method

Participants

Participants were 858 (50.7% boys) children aged 4–9 years (M = 6.51, SD = 1.72). Children were recruited from three Brazilian States (São Paulo, Amazonas, and Maranhão). In Amazonas, children were recruited from a rural area only; in the other cities, children were recruited from urban areas. Regarding the Human Development Index, São Paulo has the higher index (0.833), and the others showed medium to low indices (Maranhão, 0.683; Amazonas, 0.780). These data show differences concerning demographic information and socioeconomic and education differences. Children who failed to perform at least one of the tests owing to lack of knowledge of stimuli or other criteria for interruption of application were excluded from analyses.

Procedure

Data were collected through protocols previously collected in different studies conducted by the [blinded for review]. The work was submitted to the [blinded for review] Research Ethics Committee and was conducted in compliance with the requested requirements (no. 80902017.8.0000.0084).

All children were evaluated after consent of parents/educators providing oral consent. All participants were monolingual speakers of Brazilian Portuguese. All participants were either tested by the first author or by trained students (undergraduate or masters) in educational sciences or psychology. Children without visual impairments or neuropsychiatric disorders were included in the study. Also, do not include children with complaints of learning difficulties. The protocols were selected based on the inclusion and exclusion criteria of the study. The test session lasted 15 minutes and took place in a school in each state.

Instrument

RAN tasks (TENA) were administered individually and evaluated individuals' ability to see a picture and name it. The TENA task consisted of four stimulus cards: colors (pink, brown, black, blue, and green), Numbers (2, 4, 8, 5, and 9), objects (cat, sun, bed, hand and pencil) and letters (O, A, S, P, and D). Each stimulus card consisted of five different items, each replicated 10 times. The children were instructed to name the items as quickly as possible, and the time taken to name all items on a card was used as the score error and self-corrections. The time took for the examinee to complete the task was used for analyses (Silva et al., 2018).

Statistical analyses

Initially, descriptive statistics were performed on the sample and time scoring variables of the RAN test. Then, two concurrent models were adjusted and compared, owing to uncertainty about the factorial structure of the RAN. Model 1 assumed that RAN subtest performance was owing to the same latent factor; i.e., a unidimensional model. Model 2 assumed that alphanumeric and non-alphanumeric ability impacts the number and letter subtests and colour and objects subtests, respectively; i.e., a bidimensional model.

Owing to the multivariate nonnormality and the continuous nature of the data, a maximum likelihood estimator with Satorra-Bentler scaled χ^2 and robust standard errors was applied to accommodate non-normal continuous data (Finney, DiStefano & Kopp, 2016). Model fit was evaluated as follows: root mean square error of approximation (RMSEA) < 0.05, comparative fit index (CFI) > 0.90, Tucker-Lewis Index (TLI) > 0.90, and the standardized root mean square residual (SRMR) < 0.10 (Kline, 2005).

Next, a multiple-group confirmatory factor analysis (MG-CFA) was conducted to evaluate the stability of measurements over time. These analyses were conducted to check for the existence of measurement bias owing to be part of a different group for a specific measurement model (Hirschfeld & Brachel, 2014; Timmons, 2010). Consequently, before proceeding to the MG-CFA analysis, it is necessary to have a measurement model specified. The MG-CFA was divided into four steps. First, we investigated *configural* *invariance*—when a model with the same configuration is specified in all groups and no constraints are imposed. Second, we tested the *metric of weak factorial invariance*—where all factor loadings are constrained to be equal between groups and is used to analyze if corresponding factor loadings are equivalent. Third, we tested the *scalar or strong factorial invariance*, which is used to analyze if the measurement intercepts are also equivalent between groups, in addition to the factor loadings. Last, we examined *strict factorial invariance* to analyze if the corresponding latent factor covariances, means, and variances of the measure were equivalent between groups by imposing constraints on the measurement error variances (Thompson, 2016).

To examine model fit, the same parameters used to check the confirmatory models were used. The evaluation of measurement invariance was performed by comparing the four models described above: CFI differences ≤ 0.01, SRMR differences ≤ 0.03 (or 0.01 for models with intercepts and residual variances constraints), RMSEA differences ≤ 0.015, and Satorra-Bentler scaled chi-square difference test significance (Bryant & Satorra, 2012), following the revision made by Thompson (2016). All analyses were conducted using R software (R Core Team, 2019) and lavaan (Rosseel, 2012), psych (Revelle, 2018).

Results

Descriptive statistics

Descriptive statistics concerning participants' completion of the RAN subtests are presented in Table 1. Mean completion decreased with age for all tasks, including a strong decrease between 5- and 6-years-old. Pearson's correlation matrix with Bonferroni correction is also presented. All subtests were strongly correlated.

Table 1

Descriptive statistics for examinees' task completion time by age and zero-order correlations of RAN subtests

	Age	Total	4;0 – 4;11	5;0 – 5;11	6;0 – 6;11	7;0 – 7;11	8;0 – 8;11	9;0 – 9;11	Correlation		
	N	808	137	151	154	119	147	150	1	2	3
1. Color		73.16 (37.73)	117.70 (60.56)	90.72 (33.14)	66.66 (28.06)	62.98 (20.37)	57.54 (18.52)	55.29 (16.82)			
2. Object	Mean	68.21 (27.67)	99.83 (35.02)	85.24 (26.42)	62.14 (15.85)	57.52 (13.31)	53.39 (13.55)	51.61 (13.33)	0.73***		
3. Letter	(SD)	51.90 (36.07)	104.21 (55.24)	90.44 (43.59)	49.71 (24.96)	41.00 (17.04)	35.90 (16.84)	34.48 (12.83)	0.68***	0.71***	
4. Number		54.89 (31.28)	106.65 (45.19)	87.64 (32.14)	53.92 (21.78)	48.52 (17.77)	38.35 (13.01)	37.89 (12.68)	0.69***	0.73***	0.76***

Note: ***p < .0001

The distribution of examinees' task completion time showed a similar pattern, indicating positive asymmetry (Figure 1). Mardia's skewness and kurtosis and Shapiro-Wilk tests were used to check the multivariate and univariate normality of the variables. Both indicated that the distributions were not normal (Table 2); therefore, a robust estimator was choose for the CFA.

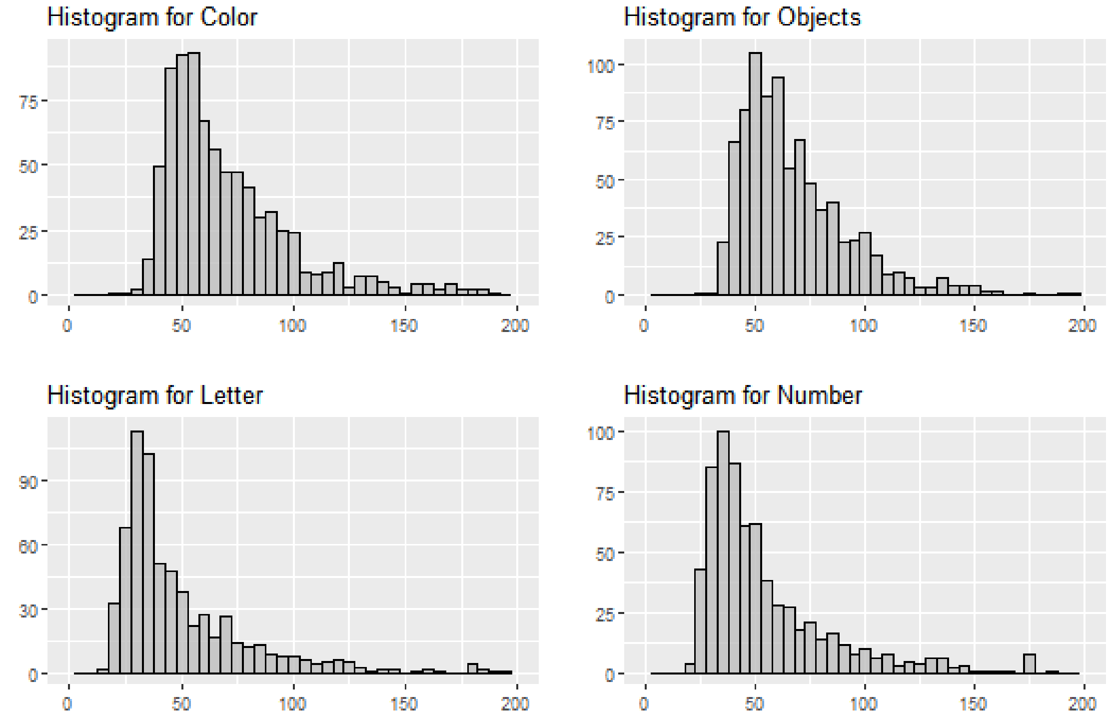

Figure 1. Histogram for the time of completion for each RAN subtest

Table 2

Mardia’s skewness and kurtosis and Shapiro-Wilk test results

Multivariate normality	**Chi-square statistic**	**p**
Mardia's skewness	3964.917	< .0001
Mardia's kurtosis	139.121	< .0001
Univariate normality	**Shapiro-Wilk**	**p**
Color	0.8442	< .0001
Object	0.8663	< .0001
Letter	0.7000	< .0001
Number	0.7652	< .0001

Confirmatory factor analyses

Initially, the unidimensional and bidimensional models were adjusted for all age ranges. The fit statistics are shown in Table 3. The bidimensional model showed a better fit than did the unidimensional model. A Satorra-Bentler scaled chi-square difference test-square comparison between both models indicated that the bidimensional model was significantly improved compared to the unidimensional model ($\Delta \chi^2_{SB} = 9.237$, $p = .0023$). Therefore, the two-factor structure model that better represented the data was used in the following studies.

Table 3

Comparative fit indices between the one- and two-factor models

Model	χ^2	df	p	CFI	TLI	RMSEA
Unidimensional	15.019	2	< .001	0.965	0.894	0.212 [0.121-0.318]
Bidimensional	0.292	1	.589	1.000	1.004	0.000 [0.000-0.111]

The next step was the MG-CFA, considering each age as a separated group. The aim of this analysis was to verify whether these different regression parameters were equal across groups (Hirschfeld & Brachel, 2014). The results are presented in Table 4.

Table 4

Four nested models testing the factor structure of the RAN tasks across the groups simultaneously with Maximum likelihood estimation with robust standard errors (MLM) estimation

Model	Fit indices					
	χ^2	Df		CFI	RMSEA	SRMR
Configural invariance	3.919	6		1.000	0.000	0.008
Weak factorial invariance	15.878	16		1.000	0.000	0.047
Strong factorial invariance	35.004	26		.989	0.071	0.062
Strict factorial invariance	144.575	46		.644	0.300	0.209
	$\Delta\ \chi^2_{SB}$	**Δ df**	**p**	**Δ CFI**	**Δ RMSEA**	**Δ SRMR**
Configural vs. weak	11.408	10	.32666	0.00	0.000	0.039
Weak vs. strong	22.851	10	.01131*	-0.01	0.071	0.015
Strong vs. strict	76.046	20	< .001***	-0.35	0.229	0.146

Note: *p < .05; **p < .01; ***p < .001.

First, configural model invariance was examined to determine whether the number of latent variables and their loading patterns were similar across groups (Hirschfeld & Brachel, 2014). If the combined model had good fit, the model had configural invariance. Our results revealed that the CFI (1.000) and RMSEA (0.000) showed a good fit for all age groups. Thus, the factorial structure (bidimensional model) was replicated for all subgroups. Next, we analyzed weak invariance—verifying whether the magnitude of the loadings was similar across groups (Hirschfeld & Brachel, 2014). The weak model also showed good adjustment indices. Comparing the CFI value with the CFI value of the configural invariance model (Δ CFI = 0.00) and the RMSEA difference (Δ RMSEA = 0.000) revealed that both were under the expected interval. This means that the models were invariant in terms of loadings (slopes) between the groups. In practical terms, the units of measure in each group progress equivalently (an increase of one point means the same for the two groups). Then, we analyzed strong invariance—whether the item intercepts were similar across groups (Hirschfeld & Brachel, 2014). Comparing the CFI value with the CFI value of the weak factorial invariance model revealed that the CFI (Δ CFI = -0.01) and RMSEA (Δ RMSEA = 0.071) changes were beyond the expected difference. The difference in the adjustment indices and the significance of the chi-square difference provided evidence that the models were not equivalents; that is, the intercepts between the groups varied. In practical terms, it is not possible to compare the means between groups since it is not possible to say that they are due to the latent variable and not to the observable measure (the time, in our case). In other words, each age group cuts the y-axis at a different point. Strict invariance implies that the loadings, intercepts, and the residual are similar across groups. The CFI (Δ CFI = -0.35) and RMSEA (Δ RMSEA = 0.229) changes were not adequate; therefore, a baseline model was fit across groups with a similar loading pattern; however, the magnitude of the parameters varied.

Discussion

The aim of the present study was to determine how RAN decreased across development and whether the intercorrelations of the four naming stimulus types at various age levels are developmentally invariant. In our study, it was not possible to compare between ages since the measures were independent in the multigroup analysis. Despite the same factor for all ages, a different pattern was observed. Therefore, development changes in the interrelations of the RAN test were not found; however, we observed evidence of developmental changes across ages and differences per kindergarten and elementary school years. 4 and 5 year olds are part of preschool and have social relations education and pre-literacy skills teaching. Children aged 6 to 9 are in elementary school, which is the beginning of the period of literacy and development of reading and writing skills. This is an expected result because RAN test results increase as a function of age, and this is related to access routes in an integrated lexical network (Åvall et al., 2019; Georgiou et al., 2014; Van Den Bos et al., 2002; Wile & Borowsky, 2004). According to the reading models, access to the lexical network is related to a faster reading in which word characteristics are accessed directly and without the need for the use of grapheme-phoneme conversion strategies. Thus, as reading develops, new word characteristics are being stored and direct lexical access may occur (Silva et al., 2015). In initial literacy acquisition, RAN object and color are the best predictors of later reading development; whereas, post-literacy development, letters and numbers may be a better predictor (Araujo et al., 2015; Cummine et al., 2014; Hornung et al., 2017).

We observed a significant decrease in naming time between the ages of 5 and 6 years. Prior studies showed that mean time was decreased in older children in other languages (Åvall et al., 2019; Denckla & Rudel, 1974; Hornung et al., 2017) including Brazilian Portuguese (Ferreira-Mattar et al., 2019; Silva et al. 2018). The RAN latencies are not related to how early the stimuli were learned, but the automatization of the naming process. Young children name objects and color faster than letters and numbers because they are more familiar with them. With more practice and exposure to letters and numbers, children will get faster and develop automaticity (Cohen et al., 2018). We revealed this process may be happening between the ages of 5 and 6 years.

Cohen et al. (2018) showed that the performance on the letter RAN differed across age groups; i.e., older children were faster than younger children. Therefore, expertise with the stimulus facilitates automation and naming speed. In Brazil, children begin to learn letters and numbers systematically, and this learning is focused on literacy at age 6 years and stop learning stimuli with color and objects at school. Four- and five-year-old children typically learn through audio, colors and shapes—without the systematic teaching of written language. Writing happens only spontaneously (Brasil, 2012, 2018). From the age of 6 years, there is systematic teaching of reading and writing, starting the process of literacy (Brasil, 2012, 2018). Thus, the development of automation in RAN tasks is related to the reading development period. This relationship is associated with similar patterns of brain activation during both tasks (Cummine et al., 2014).

As previously shown, the relationship with alphanumeric stimulus are increase in development with schooling and between color/pictures the access can be less improve. Increased development of naming ability happens between 4 and 6 years, while alphanumeric abilities occur later (Åvall et al., 2019). Letters and numbers are recognized and named later in development, and they are associated with the beginning of formal education (Denckla & Rudel, 1974). From this, the bidimensional model enables greater understanding throughout development, since according to the grade the process of automation of RAN skills occurs differently.

We revealed that the bidimensional factor model had a better fit, as in other studies (Närhi et al., 2005; Protopapas et al., 2013; Van Den Bos et al., 2002); however, Van Den Bos et al. (2002), using an exploratory design, showed a good fit for these two-factor models, unidimensional and bidimensional. The bidimensional model is only stable for older children owing to the development of RAN skills and its interaction with the literacy process; therefore, the bidimensional model would not apply to all ages. However, Van Den Bos et al. (2002) analyzed age groups together, and we analyzed by age. In contrast, van den Boer, Jimenez, and de Jong (2015) found a stable pattern for the alphanumeric and non-alphanumeric RAN factors from the age of 8 years, mirroring our results.

RAN latencies depend on how automatized the naming process is and is affected by word-frequency, operativity or figurative stimuli, and visual reversibility (letters) (Denckla & Rudel, 1974). The bidimensional model shows different skills for each factor. Letters and numbers are related to semantic skills, letter-sound mapping, and motor planning/timing. Compared to non-alphanumeric, alphanumeric stimuli (i.e., letters) are related to a greater impact on semantic representations because they involve lexical access to all linguistic possibilities that a letter can present. These differences are critical considering alphanumeric RAN (letters and numbers) separately from non-alphanumeric RAN stimuli (objects and colors) (Cummine et al., 2014). Thus, the bidimensional model is divided into alphanumeric and non-alphanumeric; however, the order of development depends on the automatization of visual-verbal reaction time (Denckla & Rudel, 1974; Hornung et al., 2017). Further, letters and numbers are more sensitive with age and, RAN picture have a higher variance in factor components (Cohen et al., 2018). Colors and objects are related with reading too; however, this relationship differs (Albuquerque, 2012). Thus, the development of naming ability for diverse stimuli develops differently throughout development. Therefore, the bidimensional model may be better at explaining how RAN skill develops.

Alphanumeric RAN is more predictive of reading abilities than RAN color from kindergarten to first year and first year to second year. Although children are familiar with colors in this period, younger children are slower in processing these stimuli; however, they are important because they are often used before literacy. Concerning different letters stimuli, vowel RAN provided a stronger and better predictor among elementary school students (Hornung et al., 2017). Letter and number tasks present an independent developmental pattern that is related to the development of reading and the use of lexical routes for alphanumeric stimuli and connection networks (van den Boer et al., 2016). Therefore, the relationship with alphanumeric stimulus are increase in development and between color/pictures the access can be less improve (Cummine et al., 2014; Hornung et al., 2017; Van Den Bos et al., 2002). Therefore, the alphanumeric task reflects early learning to read rather than colors and pictures (Meyer et al., 1998). Consequently, the bidimensional model is important for understanding the RAN construct throughout school development and learning to read. Since the present study analyzed the best factor model for different age groups and with different developments in reading ability, the bidimensional model is more appropriate than the unidimensional model.

In addition, the effect of age on developing RAN and RAN-reading relationship skills was small and may have a more uniform pattern over time (Araujo et al., 2015; Åvall et al., 2019). The current results are in agreement with this affirmation since the model used can be applied for all ages, and since age may only have a minor effect on reading development.

Conclusion

In 4–9-year-old Brazilian children, RAN assessed with different types of stimuli (including alphanumeric and non-alphanumeric) was best explained with a bidimensional structure owing to the development and literacy processes in Brazilian Portuguese. In addition, only participants' age was used as a measure, and this factor appears in the literature as having greater stability throughout the development of RAN ability than others measure such as grade. In addition, it was not possible to perform age comparisons to ascertain the specific periods in which developmental changes occur owing to multigroup analyses showing differences between groups. From this, new studies comparing other factors, such as school grade, are necessary. This was the first study with the objective of analyzing the intercorrelations between RAN tests for Brazilian Portuguese; thus, it is necessary to perform new studies to verify its effects. The findings have key research implications for the use of RAN tests and concerning the interpretation of RAN performance in clinical and education settings.

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CHAPTER 5: STUDY 2

Unpublished manuscript

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Phonological Awareness and Rapid Automatized Naming:

Predictors of Literacy in Early Primary School

Abstract

Phonological awareness (PA) and rapid automated naming (RAN) are important predictors of reading. The predictive effect of these abilities depends on grade, type of stimulation, and orthographic and linguistic regularities. This study analyzed the relationship of PA and RAN in learning how to read and write in early primary school. Children were tested during the first three years of elementary school, in measures of PA, RAN, writing test and isolated word reading and sentence reading measures were applied. Results showed that RAN was a better predictor of reading and writing speed skills than PA. Additionally, alphanumeric RAN was a better predictor of single word reading skills, while non-alphanumeric RAN was the only predictor of writing skills. The predictive effect of PA depends much more on previous language regularities and reading level, whereas RAN is independent and more predictive of the development of reading and writing speed skills.

Keywords: phonological awareness; rapid automatized naming; reading development; writing development.

Introduction

Reading is a key to academic success. Many fundamental skills are required in reading acquisition and reading difficulties may emerge if those skills are not developed. Thus, a greater understanding of the cognitive process involved in early reading development may help to identify risks for reading difficulties and also to develop early diagnostic tools regarding these difficulties (González-Valenzuela, Díaz-Giráldez, & López-Montiel, 2016; Hornung, Martin, & Fayol, 2017b).

The process of learning how to read involves the explicit presentation of the alphabetic principle. However, some skills may be assessed even before the beginning of the literacy process, and these skills have been shown to be predictors of learning (Handler & Fierson, 2011). Protopapas, Altani, and Georgiou (2013) suggest that phonological awareness (PA), rapid automatized naming (RAN), alphabetics, and vocabulary are all significant predictors of successful literacy acquisition in several languages.

RAN is an ability that self-develops even prior to the learning of reading. Additionally, RAN continues to progress over time. This ability measures the capacity to perceive a visual symbol such as letters and colors and then to recover the name of the symbol accurately and quickly. Both RAN and reading involve visual recognition of stimuli and access to their phonological representations (Wolf & Denckla, 2005). RAN tasks involve a complex process involving multiple processing skills such as attention, access to phonological code, activation and integration of semantic and conceptual information (Albuquerque & Simões, 2010).

Very few studies have sought to examine the combined effect of different cognitive correlates between RAN and reading performance in children. The predictive effect of RAN on reading depends on many factors such as age, types of stimulis or type of reading measurement used. The types of stimuli used in RAN testing also have different effects on the development of reading. Studies with alphanumeric stimuli show higher effect sizes between RAN and reading. Alphanumeric stimuli, especially letters, are tasks closer to reading fluency processes and may present an effect of letter-sound knowledge (Araújo, Reis, Petersson, & Faísca, 2015). Alphanumeric RAN has been found to be the best predictor of reading skills as well as math skills (Hornung et al., 2017b).

In addition to these factors, others to be considered for their potential impact on research results are the measures used to evaluate reading (reading words, pseudowords or text). Studies show that RAN correlates better with measures of word reading and text reading, i.e., related to orthographic processing. However, RAN also presents a moderate relation with the reading of pseudowords and text comprehension. In addition, this relationship with reading is dependent on whether the instrument employed to measure reading is designed to measure fluency or accuracy. Studies with fluency analysis show a larger effect size, while there are also studies that show a correlation with accuracy (Araújo et al., 2015). The relationship with fluency is expected because both fluency and RAN tasks depend on the rapid execution of cognitive processes. Thus, regardless of the process involved in reading, RAN correlates differently with different reading measures (Araújo et al., 2015; Norton & Wolf, 2012).

Longitudinal studies have shown the predictive effect of RAN regarding reading, fluency of words, pseudowords and text (Babayiğit & Stainthorp, 2010; Clayton, West, Sears, Hulme, & Lervåg, 2019; van de Ven, Voeten, Steenbeek-Planting, & Verhoeven, 2017). In relation to text reading fluency, RAN is related to the development of this ability and not only with initial performance (van de Ven et al., 2017). Thus, RAN measurements have a high correlation with reading fluency, which is important for reading acquisition (Ibrahim, 2015; Landerl et al., 2019).

In relation to fluency, the relationship between RAN and reading does not change and is relevant throughout all school years. For accuracy, the RAN-reading relationship becomes important for early readers (kindergarten to first/second grade), but then its importance declines. In addition, this relationship depends on the orthographic regularity of the language, and the effect is higher RAN-reading correlation between kindergarten and first/second years, decreasing in later years for opaque languages, whereas for transparent orthographies there was no effect on the relationship over time (Landerl et al., 2019). This suggests that the relationship between literacy and RAN may change with literacy development (Peterson et al., 2018). Children’s age and school grade are also important, given that they reflect different stages in the learning processes for reading and writing.

In relation to orthographic consistency, the RAN-reading relationship depends on the type of test used and the school year of the student. Alphanumeric RAN and the fluency and accuracy of reading seem to have a greater effect for opaque orthographies and the effect of this relationship is greater for beginning readers. However, in transparent orthographies this relationship is stable across time. Intermediate orthographies present with smaller effects based on orthographic consistency and the RAN-reading relationship (Araújo et al., 2015; Landerl et al., 2019).

In a study that aimed to analyze the predictive value of RAN in relation to word reading, text reading, and writing for children of third and fourth grade classes in European Portuguese, the results showed that RAN would be more related to reading fluency than reading accuracy and would also be more correlated with text reading than other forms of reading. In relation to writing, RAN is a better predictor of writing fluency, but after controlling for PA and handwriting variables, this relationship is less pronounced (Albuquerque, 2017).

Therefore, different orthographic systems may have different predictive values of the relation between RAN and reading. RAN has a strong effect on reading fluency in different orthographies due to serial and articulation processes that assist in the development of fluency. In relation to writing, however, the predictive value of RAN and spelling can be mediated by phonological processes in transparent spelling systems (Chinese and Finnish) and by orthographic processing in opaque spellings (English) (Wei, Georgiou, & Deng, 2015).

Thus, like RAN, phonological processing skills are important for reading development. PA is the ability to convert words into a phonologically representation, i.e., the ability to recognize, discriminate, and manipulate the sounds of speech to create words. Among phonological processing skills, PA is the ability most related to literacy (Anthony & Francis, 2005). Oral language is important because it builds the representation and knowledge of the phonological structure of spoken words (Anthony & Francis, 2005; Shapiro, Carroll, & Solity, 2013; Swanson, Trainin, Necoechea, & Hammill, 2003).

Regarding the development of PA, there are two main patterns of development. First, children begin to manipulate and recognize syllables; later, they are able to recognize rhymes, followed by an ability to recognize phonemes. As their age progresses these skills develop and become more effective. Second, children can discriminate between words with similar sounds before being able to manipulate sounds within words (rhymes and alliterations) and are able to mix information before segmenting words (transposition and manipulation) (Anthony & Francis, 2005).

In the literacy process, children do not have sufficient experience in PA in the preschool period and therefore presented with better performances in syllables and rhymes than in phonemes (Erdoğan & Erdoğan, 2010). These PA skills have a direct importance at the beginning of literacy, especially in the first grade. However, this is not necessarily the case in second grade where phonological skills may have little relation to reading prediction (Rothou, Padeliadu, & Sideridis, 2013). Thus, as the child progresses in school, the predictive value of PA decreases (Wagner, Torgesen, Rashotte, Hecht, & et al, 1997). These data may also be related to the measurement tools and forms of assessment that are used in testing with older children. As a result, the inverse relationship between the development of fluent reading and PA has barely been investigated. However, since reading and decoding instruction evolve and develop over time, the increased knowledge of the language sound structure also facilitates their performance in PA tests over time (Hogan, Catts, & Little, 2005).

Hogan et al. (2005) found significant results regarding the prediction of PA for reading in the kindergarten group to second grade, but not in predicting second grade to fourth grade measures of reading. However, when the measurement is phonetic awareness in second grade, it predicted a small but significant amount of the variance in fourth grade reading. In addition, the results showed an inverse pattern with respect to the predictive value for the second to fourth grade age group in which the word reading results predicted the performance in PA in fourth grade.

RAN and PA are predictors of reading skills in typically developing children (Bowers, 1995; Cardoso-Martins & Pennington, 2001; Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997) and in children at risk for learning difficulties and disorders such as dyslexia (Hornung et al., 2017b; Peterson et al., 2018). This relationship between skills can be independent and is related to reading maturity (Swanson et al., 2003).

A meta-analysis study with the objective of analyzing the relationship between PA, RAN and word reading showed that the contributions of PA and RAN to reading occur in an independent manner. Some factors influence this relationship. Age was not related to the magnitude of the correlations between the abilities, but it was in relation to reading comprehension and PA. However, the correlation coefficient was higher for the youngest age group. Regarding the grid factor, all correlations were moderated by the grid level, specifically for real-word reading / RAN coefficients and reading comprehension / PA coefficients (Swanson et al., 2003).

In addition, according to school progression and consequently the experience and reading instruction, the contributions of PA and RAN to word recognition are stronger. Regarding reading measures, the coefficient of regression for real word reading and pseudoword reading was greater to PA, but RAN has a moderate coefficient of regression and the difference between the coefficients is small. For reading comprehension, the coefficient was higher for RAN and reading with a higher difference between the values. PA and RAN predict different components of reading. PA loaded meaningfully on the pseudoword reading factor, whereas RAN measures loaded meaningfully on the reading comprehension factor. Thus, although RAN and PA present correlations with each other, according to the development of reading, the development curve for each ability is changing uniformly (Landerl et al., 2019).

Regarding nonalphabetic language, such as Chinese, the association between PA, RAN and reading presents a similar pattern. The correlation between RAN and accuracy and fluency of word reading is higher than the relationship between PA and these measures. However, the relationship between RAN and reading depends on what type of measurements were made for RAN and reading outcome, with a higher RAN-reading ratio for fluency ability. Both age and grade had no influence on the analyses. Therefore, the predictive effect of RAN and PA in relation to reading can be analyzed in different orthographic systems and linguistic regularities (Song, Georgiou, Su, & Hua, 2016).

In some studies, the predictive effect of reading shows that this effect depends on orthography regularity (Georgiou, Papadopoulos, Fella, & Parrila, 2012; Georgiou, Parrila, & Papadopoulos, 2008; Pae, Sevcik, & Morris, 2010; Peterson et al., 2018). Studies across different orthographies, opaque and transparent, compared patterns of predictors with early development in reading and spelling. The results showed that there are mixed predictive effects for PA and RAN on reading and spelling. The predictive effect between PA and reading is higher in opaque orthographies because the time to establish reliable grapheme-phoneme recording depends on the writing system. In transparent orthographies this is more consistent and the correspondence letter-sound is more regular (Furnes & Samuelsson, 2011).

In typically developing children, reading accuracy was more strongly correlated with phonemic awareness, whereas reading speed or fluency showed stronger correlations with RAN (González-Valenzuela et al., 2016; Park & Uno, 2015). In addition, studies show that the relationship between PA and reading decreases as the student progresses in school and as the relationship between RAN and reading increases (Albuquerque, 2012; Vaessen & Blomert, 2010). For writing, PA continues to be associated with dictation accuracy, while RAN presented correlations with dictation accuracy and fluency (Albuquerque, 2012).

Therefore, PA contributions appear to be more relevant to spelling than RAN contributions. Thus, word reading skills are best predicted by RAN, whereas writing skills are best predicted by PA. In addition, reading can be an important precursor to the development of second grade writing (Schaars, Segers, & Verhoeven, 2017). Thus, writing skills are best predicted by PA skills (Babayiğit & Stainthorp, 2010).

A Brazilian study also found a higher relationship between RAN and reading fluency in relation to phonological abilities. For writing, both (PA and RAN) contribute to writing in Brazilian Portuguese. Thus, for Brazilian Portuguese, RAN and PA contribute to reading accuracy and fluency, as well as to writing independently (Justi & Roazzi, 2012).

Therefore, both PA and RAN are predictors of accuracy for word and pseudoword reading, while RAN is a better predictor of fluency and efficiency in relation to these skills. Predictive effects then depend on the age, grade, and orthographic system of students in each study (González-Valenzuela et al., 2016).

For Brazilian Portuguese, no longitudinal studies were found in the literature that seeks investigate the predictive effects of RAN and PA relating reading and spelling. The present study contributes to the knowledge about the general underlying principles in literacy development. So, the aim of this study was to analyze the relationship of PA and RAN to learning how to read and write in early primary school.

METHOD

Participants

Participants in this study were 83 children (39 girls and 44 boys) who were assessed in the first, second and third grades. In the first grade cohort, the mean age was 6.23 (0.43) years, in the second grade was 7.20 (0.40) years, and in the third grade was 8.13 (0.56) years. All were native Portuguese speakers and attended school regularly. The participants were selected from São Paulo private schools. Participants in the study were children who presented with parental consent and oral consent. Participants with visual, motor or hearing impairments were excluded from the study.

Instruments

Rapid Automatized Naming (RAN) Test: A Brazilian RAN test is administered individually and evaluates the individual's ability to see a visual picture and name it. The RAN tests consists of four stimulus cards, respectively containing colors (pink, brown, black, blue and green), numbers (2, 4, 8, 5 and 9), objects (cat, sun, bed and pencil) and letters (o, a, s, p and d). Each stimulus card consisted of five different items, each replicated 10 times. The children were instructed to name the items as quickly as possible, and the time taken to name all items of a card was used to score errors and self-corrections. We used the measure of time to analyze the results (Silva, Mecca, & Macedo, 2018).

Phonological awareness of oral production: It consists of 10 sub-tests that measure different levels of phonological awareness: syllabic synthesis, phonemic synthesis, judgment of alliteration, syllabic segmentation, phonemic segmentation, syllabic manipulation, phonemic manipulation, syllabic transposition, and phonemic transposition. For each subtest, specific oral language manipulation instructions are required for each step. Each subtest is made up of two sample items and four test items with one point for each. Each subtest has a total score of four points. For the total score, the totals of each subtest are summed (Seabra & Capovilla, 2012).

Written Sentences Comprehension Test (WSCT) (computerized version): This test evaluates the ability to comprehend sentence reading. The test is made up of 46 items, using the first six examples. The screens contain a written sentence followed by five alternative figures to choose from, of which only one corresponds well to the sentence. In each item the child should read the sentence and click on the picture that best represents the meaning of the sentence read. We computed mean time taken to answer each item (milliseconds) and accuracy (Toledo Piza, de Macedo, Miranda, & Bueno, 2014)

Reading Competence Test (RCT) (computerized version): this test evaluates word recognition skills and strategies by judging correspondence between picture and written word pairs. The child must press a "correct" or "incorrect" button according to pairs displayed. Seventy-eight items are divided into seven word-picture categories as follows: regular correct words (RC), where a regular word corresponds to paired image; irregular correct words (IC), where an irregular word corresponds to paired image; semantic confusion (SC), when the word is not semantically related to the picture; pseudoword with visual confusion (VC); pseudoword with phonological confusion (PhC); pseudoword with orthographic errors but correct phoneme-grapheme conversion (PNw) and pseudoword not derived from a real word (WNw). We computed mean time taken to answer each item (milliseconds) and accuracy (Toledo Piza et al., 2014).

The Picture-Print Writing Test (PPWT) (computerized version): this test evaluates isolated words writing. In this test, 36 figures are presented, and children were instructed to write the name of each figure. Pictures are centered on the screen with a blank line below for the subject to write in the words corresponding to each picture. We computed mean time taken to answer each item (milliseconds) and accuracy (Toledo Piza et al., 2014).

Procedures

This project was submitted and approved by the Research Ethics Committee of [blinded for review] (CAAE: 80902017.8.0000.0084). After this stage, contact with schools was made to request the permission of the institution's management and informed consent forms were sent to parents and children to request their participation in the research. Consent for testing was obtained for all children. The sample was selected for convenience according to the location. Data collection was conducted in two schools and all participants were either tested by the first author or by trained bachelor's or master's students in educational sciences or psychology. The assessment was held in schools during the class period, as previously agreed with the institution in order to not affect the activities and routine of the students. Cognitive, linguistic and reading/spelling measures were assessed in all years (first, second and third grade). The assessment sessions were divided into three one-hour meetings.

Data Analysis

Missing treatment

Some missing cases were observed on the second and third time points. The amount of missing cases in time 2 was eight cases for colors and numbers and seven cases for objects and letters, and in time 3 was 17 for all subtests. This missing data was due to children having left the school when the data was collected, which allows to classify this missing data as random (MAR – Missing at random). Little (2013) shows that for this type of missing data the missing information is mostly recoverable with little or no bias, and that recovery improves the model's interpretability. For this reason, following the recommendations of Little (2013), a multivariate imputation was implemented to estimate the blank cases' values. For all subtests in all time points a weighted predictive mean matching method was used and the correlation matrix between each subtest was used to check whether the imputation made any change on the correlations. This treatment was implement using mice (van Buuren & Groothuis-Oudshoorn, 2011) package for R software (R Core Team, 2019)

Confirmatory factor analysis

The adequacy of alphanumeric and non-alphanumeric model for RAN assessment was check by a confirmatory factor analysis approach. For each time point, a model considering the bifactorial structure was tested and the correlation between both latent variables was allowed. The degree of the fit of models were evaluated by the robust Root Mean Square Error of Approximation (RMSEA) < 0.05, the robust Comparative Fit Index (CFI) > 0.90, the robust Tucker-Lewis Index (TLI) > 0.90, and the Standardized Root Mean Square Residual (SRMR) < 0.10 (Klime, 2005) and a maximum likelihood estimation with robust standard errors and a Satorra-Bentler scaled test statistic was implemented. Considering the number of predictors on the path model, we had opted to calculate the estimated values for the latent variables (alphanumeric and non-alphanumeric) like a factor score, for each time point. The reliability of each variable, for each time point, was also generated. These analyses were implemented on lavaan (Rosseel, 2012) and semTools (Jorgensen, Pornprasertmanit, Schoemann, & Rosseel, 2019) packages also for R software (R Core Team, 2019).

Path analysis

To investigate the role of PA and RAN on learning to read and write in early primary school we modelled a path using those measures as predictors of performance in three assessments, WCST, RCT and PPWT, which assess writing, reading, comprehension, recognition and judging strategies skills related to literacy. The path analysis is a methodological approach which extends the multivariate regression and allows one to specified direct and indirect associations between variables estimating this unique effect when controlling for all other specified associations, being generally applied in longitudinal design studies (Little, 2013).

In our study, the predictor variables (PA and RAN – alphanumeric and non-alphanumeric) were correlated with each other but not with the predicted variables (WCST, RCT and PPWT), while the predicted variables were correlated with each other but not with the predictor variables. The autoregressive paths for each variable in the model were inserted to control the effects of estimates leading to the same constructs. Cross-lagged effects from the predictor to the predicted variables were modelled to indicate the association effect of the predictor from one time point on the predicted variable at time point +1.

The final model was selected in regard of fitting index, using as reference the same statistics used in confirmatory factor analysis. Two unexpected associations were included in the final model: a residual correlation between PA at time point 3 and WSCT at time 2, and a cross-lagged path of RAN-alphanumeric at time point 1 on WSCT at time point 3.

Results

The correlation matrix of original and imputed data for each subtest at successive time points is show in Table 1. The magnitude of correlations does not change significantly from original to imputed data, which means that the multivariate imputation preserved the relations between these variables across time lapse.

Table 1

Correlations between

	Original			Imputed		
	C_T1	**C_T2**	**C_T3**	**C_T1**	**C_T2**	**C_T3**
C_T1	1			1		
C_T2	0.626	1		0.631 [0.470-0.751]	1	
C_T3	0.579	0.634		0.543 [0.345-0.695]	0.636 [0.461-0.763]	1
	O_T1	**O_T2**	**O_T3**	**O_T1**	**O_T2**	**O_T3**
O_T1	1			1		
O_T2	0.718	1		0.712 [0.579-0.808]	1	

Note. C_T1: color subtest at time point 1; C_T2: color subtest at time point 2; C_T3: color subtest at time point 3; C_T4: color subtest at time point 4; O_T1: object subtest at time point 1; O_T2: object subtest at time point 2; O_T3: object subtest at time point 3; O_T4: object subtest at time point 4; L_T1: letter subtest at time point 1; L_T2: letter subtest at time point 2; L_T3: letter subtest at time point 3; L_T4: letter subtest at time point 4; N_T1: number subtest at time point 1; N_T2: number subtest at time point 2; N_T3: number subtest at time point 3; N_T4: number subtest at time point 4.

Next, the factorial structure for each time point was also tested. The model fit for all years were adequate and alphanumeric and non-alphanumeric factorial model was replicated for all years. The correlations between both latent variables are .888, .723 and .797 for years one, two and three, respectively.

Table 2

Model fit indexes for years 01, 02 and 03 for alphanumeric and non-alphanumeric model

Year	χ^2	**df**	**CFI**	**TLI**	**RMSEA**	**RMSEA 90% CI**
1	0.731	1	1.000	1.003	0.000	[0.000-0.000]
2	0.486	1	1.000	1.024	0.000	[0.000-0.000]
3	0.039	1	1.000	1.052	0.000	[0.000-0.177]

The reliability coefficient for alphanumeric factor increases from each year to another, varying from acceptable (year 01) to good (years 02 and 03). For non-alphanumeric factors an increase is noted from year 01 to year 02 and a decrease from year 02 to year 03, varying from poor and acceptable.

Table 3

Reliability for alphanumeric and non-alphanumeric scores for years 01-03

	Year 01			Year 02			Year 03		
	Alphanumeric	Non-alphanumeric	Total	Alphanumeric	Non-alphanumeric	Total	Alphanumeric	Non-alphanumeric	Total
Cronbach's α	0.714	0.544	0.745	0.808	0.734	0.806	0.843	0.649	0.790
McDonald's ω	0.714	0.544	0.776	0.808	0.735	0.851	0.875	0.668	0.834

In terms of path analysis, model fit was adequate ($\chi^2_{(76)}$ = 113.88, p = 0.003; CFI = 0.924; TLI = 0.895; RMSEA = 0.092 [0.054-0.125]). The relationships were unidirectional, and the influence of RAN factor occur in different ways for each factor. The alphanumeric factor is statistically significant on time point 1 and predicts the performance on WSCT in time point 2 and time point 3, and the effect on early comprehension of sentence reading is small in comparison with the latter time point (Alpha 1 to WSCT 2: B = 0.41, SE = 0.16, p = 0.012; Alpha 1 to WSCT 3: B = 0.68, SE = 0.30, p = 0.022). The non-alphanumeric factor was statistically significant and predicts both PPWT and RCT performance, with the ability on RAN non-alphanumeric on the previous year being a predictor of word recognition and word writing on the current year (N-alpha 1 to PPWT 2: B = 0.63, SE = 0.12, p < 0.001; N-alpha 2 to PPWT 3: B = 0.17, SE = 0.06, p = 0.008; N-alpha 1 to RCT 2: B = 0.33, SE = 0.15, p = 0.024; N-alpha 2 to RCT 3: B = 0.18, SE = 0.09, p = 0.037) measured by the assessments. The Phonological

Awareness was only significant to predict the WSCT on year 2 (CF 1 to WSCT 2: B = 0.24, SE = 0.10, p = 0.015) and its influence decreased for the later measures. The Figure 1 contains all the associations and their respective magnitudes for the final path model.

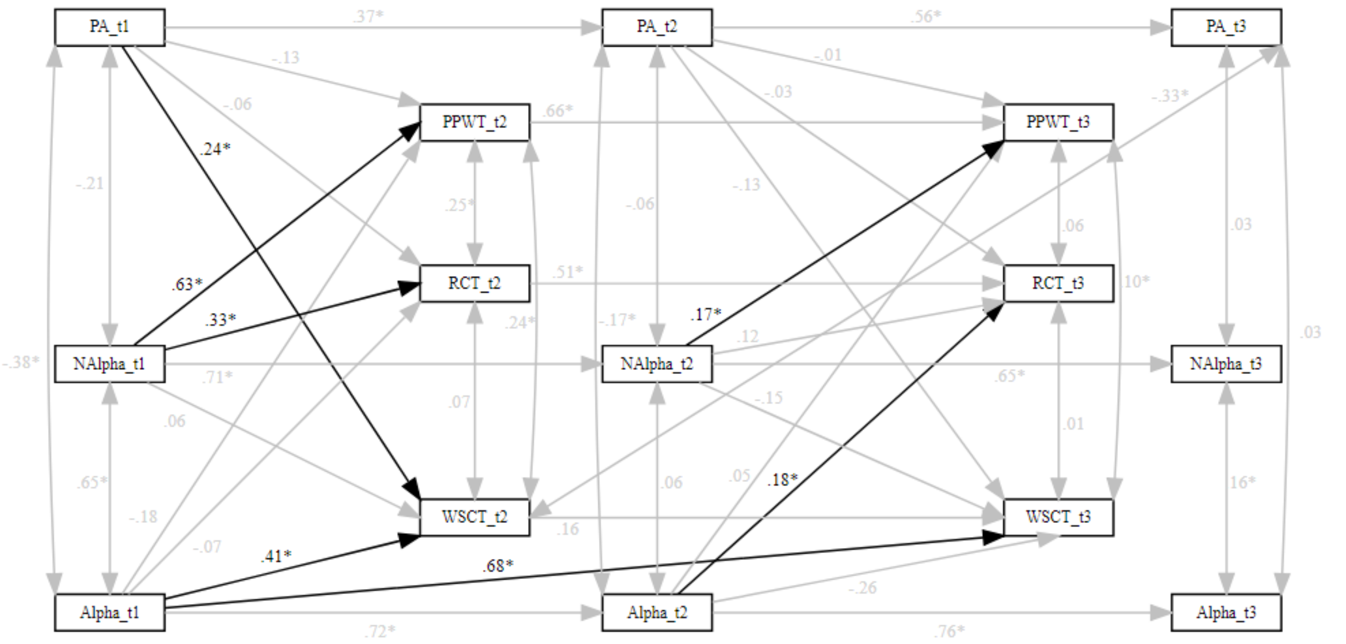

Figure 1. Longitudinal path model for years 01 to 03 and their associations

Discussion

The aim of this study was to analyze the relationship of PA and RAN on students' ability to learn how to read and write in early primary school. For this, a longitudinal study of cognitive accompaniment of the first to third grade was conducted.

Results showed that in relation to reading and writing speed measurements, RAN was a better predictor of reading and writing for Brazilian Portuguese. These results are in agreement with the literature that shows a higher predictive effect of RAN in relation to reading fluency (Albuquerque, 2017; Araújo et al., 2015; Ibrahim, 2015; Justi & Roazzi, 2012; Landerl et al., 2019; Song et al., 2016; Wei et al., 2015), while PA would be more related to accuracy (González-Valenzuela et al., 2016; Park & Uno, 2015). Justi

& Roazzi (2012) also found greater effect between RAN and reading fluency when compared to the relationship between PA and reading of Brazilian Portuguese.

Efficient reading depends on visual, language, orthographic processes, working memory, motor movements, and comprehension, attention and cognitive skills to develop reading speed and accuracy skills. By developing these skills, the reader can acquire automaticity of reading requiring less awareness for the process. During literacy, the first step for children is to turn printed codes into oral language codes. The second step is the comprehension of the reading material so that is possible to make connections with previous knowledge and analysis of the text contents. Fluency is therefore the stage in which sublexical units, words, text contents, linguistic and perceptual processes interact to acquire accuracy and automaticity, providing cognitive resources for the comprehension of the material read. Fluency is defined as the idea that successful reading depends not only on accuracy but also on automaticity of multiple cognitive and linguistic processes, requiring minimal conscious effort (Norton & Wolf, 2012). Therefore, with the development of reading skills, the reader ensures greater fluency and automation.

RAN is a cascading skill. It involves visual processes, phonological and orthographic mapping, and articulatory planning. Different items can be processed simultaneously in different steps. Thus, when the automation of early reading skills occurs a parallel processing of the observed items happens. Thus, items can be processed automatically, and executive control monitors the process through specific phases. RAN and word reading reflect the efficiency of simultaneously processing multiple items (Protopapas et al., 2013). From these findings, both fluency and RAN tasks depend on the rapid execution of cognitive processes that are due to serial and articulation processes that assist in the development of fluency (Araújo et al., 2015; Georgiou, Aro, Liao, & Parrila, 2016). As a result, the relationship between RAN and reading lies in the fact that both involve similar cognitive and neural mechanisms of processing and phonological, semantic and mainly articulatory access (Cummine, Szepesvari, Chouinard, Hanif, & Georgiou, 2014).

PA was a predictor of reading and word and pseudoword performance only for the second grade. This result was also found only for the French language in the study by Landerl et al. (2019). The association between PA and reading was complex and mostly interactive. For the other more transparent languages, such as Dutch and Greek, PA did not predict reading. The authors discuss the fact that the predictive effect of phonological awareness is more sensitive and dependent on task characteristics, developmental status, and orthographic complexity. Thus, the predictive effect of PA is greater for opaque orthographies (Furnes & Samuelsson, 2011; González-Valenzuela et al., 2016), which is not the case in Brazilian Portuguese.

In addition, PA seems to depend much more on early reading skills than RAN, since studies show significant relationships in the opposite direction (reading-PA) (Hogan et al., 2005; Landerl et al., 2019). Peterson et al. (2018) also found a modest effect of the relationship between PA and reading in children from kindergarten and first grade. Therefore, the relationship between PA and reading appears to be less causal than is generally attributed to this relationship (see Landerl et al., 2019 and Peterson et al., 2018). Therefore, PA is most affected by language regularity and literacy period (Anthony & Francis, 2005). PA has direct importance in the beginning of literacy, especially in the first grade, but it has little predictive effect for children in the second grade (Hogan et al., 2005; Rothou et al., 2013).

The results showed that alphanumeric and non-alphanumeric RAN predict different reading and writing modalities. Alphanumeric and non-alphanumeric RANs present distinctions regarding the assessed skills, as well as the pattern of development throughout schooling (Cummine et al., 2014; Denckla & Rudel, 1974; Hornung, Martin, & Fayol, 2017a). The difference in processing between RAN colors / object and alphanumeric is in the semantic aspect that the first group of RAN involves semantic lexical coding access while alphanumeric involves asemantic coding. These stimuli are promising because before literacy they are used very frequently (Hornung et al., 2017b). Therefore, the predictive effect of RAN depends on the type of evidence used (Araújo et al., 2015).

Regarding measures of reading isolated words, alphanumeric RAN was a better predictor. Alphanumeric RAN performance in the first year predicted reading performance in the second and third years. Studies have shown that alphanumeric RAN is a better predictor of reading skills (Araújo et al., 2015; Hornung et al., 2017b). Naming speed, particularly for letters, represents an early and initial approximation with reading speed for words and it is an important predictor for reading fluency. Fluency, in turn, is essential for understanding (Norton & Wolf, 2012; Wolf & Denckla, 2005). Moreover, reading speed and efficiency showed stronger correlations with alphanumeric rapid naming (González-Valenzuela et al., 2016). Our findings replicate Furnes & Samuelsson (2011) research, where RAN predicted word and pseudoword reading from grade one to grade 2 in the US and Australia. Also, PA was not considered a reliable predictor of reading skills beyond kindergarten in transparent orthographies, given that in the combined U.S. and Australian sample PA diminishes as a significant predictor beyond grade 1. In a study by van de Ven et al. (2017), RAN contributed both to the level of reading fluency of words and pseudowords and texts. The authors argue that the effects of RAN on secondary grades are found in languages with moderately transparent spelling, which is the case of Portuguese and the results of the present study corroborate these findings.

For sentence reading and comprehension, non-alphanumeric RAN in the first year predicted reading and comprehension in the second year, while alphanumeric RAN in the second year predicted reading performance in the third. Regarding PA, RAN is the best predictor of reading comprehension skills (Swanson et al., 2003). RAN skills present greater complexity and distinct cognitive processes compared to phonological processing alone. RAN involves visual, perceptual, attentional, memory and articulatory processes. In addition, lexical processes of phonological, orthographic and semantic access are activated during RAN (Wolf, Bowers, & Biddle, 2000). Therefore, there is a greater proximity to reading and comprehension of sentences by presenting similar cognitive processes.

Comprehension processes are required while reading sentences. Reading isolated words involves identification processes, while reading sentences involves understanding. Both involve cascading or parallel processes during which an item is phonologically processed, the previous item is articulated, and the next item is visually recognized (Albuquerque, 2017). Unlike reading single words, the predictive effect of RAN was different both RAN and non-alphanumeric were predictive. Non-alphanumeric RAN was predictive for reading in the second year. These results were also found by Hornung (Hornung et al., 2017a) in which the first year alphanumeric RAN measurements did not predict the second year comprehension measures, but as in the present study the third year results were not analyzed. Kibby, Lee, & Dyer (2014) also found RAN had a later predictive effect for reading and comprehension of sentences and texts in children from 8 to 12 years, i.e., older children. Thus, it appears that alphanumeric stimuli have a later predictive effect on reading and sentence comprehension.

For non-alphanumeric stimuli, naming colors and objects presents two extra steps compared to the reading of single words. Prior to the linguistic output step, abstract conceptual processes are activated for establishing the meaning of the image, and then codes with the possible names within the mental lexicon are activated. In the case of colors and objects, the last step occurs quickly because the stimuli are well defined and with few semantic possibilities, which is the first important step in establishing the difference between reading and naming speed (van den bos, Zijlstra, & lutje Spelberg, 2002). Automatic naming processes involve final steps of conceptual and semantic access (Aguilar-Vafaie, Safarpour, Khosrojavid, & Afruz, 2012; Wolf & Denckla, 2005) that may be related to reading sentences. These also involve syntactic accesses with search for sense and meaning. Reading sentences would also be related to distinct processing steps in relation to reading single words. Therefore, the processing speed of these more conceptual and semantic steps in earlier series is more important for sentence reading and comprehension, since non-alphanumeric stimuli were important for the early development of the skill reading and comprehension of phrases.

Therefore, RAN was a better predictor of single word reading speed and sentence comprehension skills. Studies have sought to analyze the predictive effect of RAN and PA in the development of reading. Results show that RAN has been correlated with reading comprehension and fluency. PA is a measure that has been correlated with the later ability to accurately read and with phonological decoding (words and pseudowords), helping to convert the visual symbols into their sounds (Albuquerque, 2012; Bowers, 1995; Cardoso-Martins & Pennington, 2001; Torgesen et al., 1997). With this, it is evident that as in the study by Song et al. (2016) RAN measurements were better predictors of reading skills, and the predictive effect of RAN-reading depends on the type of measurement used. The present study found that alphanumeric stimuli were better predictors for single word reading velocity measures, whereas for non-alphanumeric stimuli reading and compression measures are important at the beginning of skill development, while alphanumeric stimuli are relevant later.

Regarding writing, non-alphanumeric RAN was the only predictor of writing speed. Non-alphanumeric RAN in the first year predicted writing performance in the second year, just as RAN in the second year predicted writing performance in the third year. This result disagrees with the findings of Schaars et al. (2017) and Babayiğit & Stainthorp (2010) who describe that writing skills present the best predictor of PA skills.

Non-alphanumeric stimuli involve a single conceptual and semantic possibility during information processing, unlike alphanumeric stimuli (van den bos et al., 2002). Apparently, more specific conceptual steps and restricted semantic possibilities seem to be more relevant and similar to the writing of the alphanumeric stimuli.

Writing is not just a one-to-one reversal of word reading, but both depend on access to orthographic, phonemic, and semantic structures. Individual differences are more noticeable for writing because of the greater difficulty with writing ability. This is because the conversion of phonemes to graphemes depends on many variations and access to specific orthographic structures, and there are more graphemes to choose from the phoneme (Schaars et al., 2017).

As previously stated, RAN involves final stages of conceptual and semantic access (Aguilar-Vafaie et al., 2012; Wolf & Denckla, 2005). This is not the case for PA. Regarding writing, the predictive value of RAN and spelling may be mediated by phonological or orthographic processes (Georgiou et al., 2016). Thus, RAN involves many more processes similar to writing processes than PA, and RAN and writing can share a similar spelling processing component (Cho & Chiu, 2015).

From this, it was concluded that RAN was a better predictor of reading and writing skills, with a discrete contribution of PA only to the early stages of the literacy process. In addition, the predictive effect of RAN depends on the type of test used for reading as well as the types of RAN stimuli. Isolated alphanumeric RAN words were a better predictor for reading, while for non-alphanumeric RAN writing was the only predictor. In the present study, only reading speed measurements were used and the accuracy measurements were not analyzed. Moreover, in the reading test of isolated words, the stimuli of words and pseudowords were not analyzed separately. Further studies should be conducted to verify whether the predictive effect of RAN and PA changes when using these new measures.

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CHAPTER 6: STUDY 3

Unpublished manuscript

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Developmental Dyslexia: The Role of Cognitive Profile and its Relationship with Phonological Awareness and Rapid Automatized Naming

Running title: Cognitive profile of developmental dyslexia

Abstract

Developmental dyslexia is characterized by different cognitive profiles. From these profiles, different subtypes of dyslexia can be identified. In addition, the double deficit theory postulates that there are two core skills present in the cognitive profile of dyslexics that may be mutually (double deficit) or separately (single deficit) impaired. The aim of this study was to examine the cognitive profile of participants with dyslexia as well as to assess the predictive validity of rapid automized naming (RAN) and phonological awareness (PA) in identifying dyslexic individuals. To accomplish this, 30 children and adolescents with developmental dyslexia age-matched with good readers participated in the study. Participants were compared on the Wechsler Intelligence Scale for Children – 4th Edition and a measure of reading as well as in PA and RAN. Regression tree analysis was conducted to verify the predictive effect of RAN and PA in relation to the differentiation of the groups. The results indicated that dyslexics in the present study have preserved working memory skills, as well as basic oral language skills and processing speed for visual stimuli, but present with impairments in visual attention skills. Regarding PA and RAN, no differences were found between groups in PA, but there was a difference in all RAN measures. In addition, the results of the regression tree analysis showed that RAN is a better predictor for differentiating the groups. However, the cognitive profile of the dyslexics in the study demonstrates impairments related to surface dyslexia, as well as simple deficits with impairments only in abilities related to RAN. For Brazilian

Portuguese-speaking children and adolescents, RAN was the best predictor in differentiating dyslexics from good readers.

Keywords: developmental dyslexia; cognitive profile; rapid automatized naming; phonologic awareness; double deficit theory; surface dyslexia.

Introduction

Developmental dyslexia is the most common learning disability, affecting approximately 5-10% of the general population (Zeffiro and Eden 2000) and 9% of school-aged children (Pennington 2009). Dyslexia is characterized by a specific and persistent deficit in the acquisition of reading and spelling skills that cannot be explained by deficits in other cognitive abilities or insufficient educational opportunities (Caravolas et al. 2012). Within the diagnostic criteria, symptoms include reading words inaccurately or slowly and with effort, and difficulty understanding the meaning of what is read (American Psychiatric Association [APA] 2014; Pennington 2009; Shaywitz and Shaywitz 2005). The reading ability must be below the expected average for the age or the individual should present acceptable performance but require a considerable amount of effort. Furthermore, difficulties are identified in decoding, word recognition, and reading comprehension tasks. These difficulties are reflected in the phonological components resulting in difficulties in using the alphabetic code (APA 2014; Handler et al. 2011). In addition, these difficulties may lead to secondary consequences, such as little exposure to reading, which in turn weakens vocabulary development, writing expression, and reading precursors. Therefore, dyslexics may be able to read accurately, but might present persistent fluency difficulties, which means that they can continue to present slow, non-automatized reading over the years (Handler et al. 2011; Norton and Wolf 2012; Peterson and Pennington 2012).

Cognitive performance measures reveal different dyslexia profiles (Zoubrinetzky et al. 2014), with impairments in phonological, visuospatial, attentional, and executive abilities. Besides alterations in these abilities, losses in spelling, phonology, short-term memory, rhyme, and whole-word processing can also be observed (Menghini et al. 2010; Tamboer et al. 2016). The two main dyslexia subtypes associated with cognitive losses are phonological dyslexia and visual surface dyslexia (Giofrè et al. 2019). On one hand, the phonological subtype presents significative losses to nonwords reading, proper use of grapheme-phoneme conversion strategies, but significant impairments in phonological awareness (PA). On the other hand, surface dyslexia presents specific difficulties in reading irregular words and in the use of reading strategies via direct lexical access to representations of words with impairments in rapid naming (Peterson et al. 2013; Zoubrinetzky et al. 2014).

One tool that has been shown to provide useful information for the diagnosis of dyslexia is the Wechsler Intelligence Scale for Children – 4th Edition (WISC-IV). This scale can provide information not only about the occurrence of specific cognitive deficits in developmental dyslexia but also about the strengths and weaknesses of dyslexics' cognitive profiles. In this scale, tendentially, dyslexics present weaknesses in subtests that assess working memory and phonologic coding, such as Digit Span and Arithmetic. Other subtests in which dyslexics can obtain lower scores in comparison to other groups without reading difficulties are Vocabulary, Information, and Letter–Number Sequencing. Comparing the performance within the cognitive profiles, the main subtests with scores below the expected levels are Digits, Letter–Number Sequencing, and Coding (De Clercq-Quaegebeu et al. 2010). In relation to the index score on WISC-IV, the cognitive profile of dyslexics can reveal impairments in working memory and processing speed

(Cornoldi et al. 2014; De Clercq-Quaegebeu et al. 2010; Toffalini et al. 2017) and on subtests that rely on verbal abilities.

Another characteristic of the cognitive profile of dyslexic children is that they present deficits in phonological awareness (PA) and rapid automatized naming (RAN). These two specific abilities are important in the development of reading skills and have been found to be particularly associated with dyslexia (Caravolas et al. 2012; Handler et al. 2011).

Phonological processing abilities like phonological memory and PA are abilities that often are found to be impaired in dyslexia, and impairments in PA are of major importance in reading development. PA is the ability to recognize, discriminate, and manipulate speech sounds to create words. Thus, PA supports the explicit knowledge of speech sounds by facilitating the process of "combining" the speech phonemes in printed graphemes. Therefore, PA is related to a good development of oral language and depends on linguistic structures and characteristics. In dyslexia, these difficulties are reflected in written language and persist from the preliteracy period to adulthood (Anthony and Francis 2005; Norton and Wolf 2012). The ability of PA is important for the initial learning of reading and with the automation of phonological and decoding skills as well as the ability to identify the sound structure of language (Anthony and Francis 2005; Hogan et al. 2005; Rothou et al. 2013). Impairments in PA are found in dyslexics, and is a well-described symptom reported in the literature in Brazil (Capellini et al. 2007; Capellini et al. 2008; Deuschle and Cechella 2009; Dourado et al. 2005; Germano et al. 2009; Lima et al. 2008). However, these impairments may not be present in the cognitive profile of dyslexic individuals (de Jong and van der Leij 2003; Landerl and Wimmer 2000).

Similar to PA, research has shown that RAN is another predictor of reading and that RAN deficits are typically found to be associated in children with, or at risk of, reading difficulties (see Araújo and Faísca, 2019; Araújo et al. 2015 for a review). RAN is the ability to name as fast as possible symbols that are visually presented. This ability requires visual and motor eye movements, as well as access to phonological representations. RAN tasks depend on automaticity, and are the best predictor of reading fluency, requiring connecting and automatizing whole sequences of letters or stimuli with their linguistic information (Norton and Wolf 2012). In relation to the type of RAN task, stimuli can be separated into alphanumeric and nonalphanumeric. The nonalphanumeric stimuli have been found to be better predictors for children who have not entered school yet or have not had enough contact with stimuli involving letters and numbers. The alphanumeric stimuli are better predictors for groups of children who are in the alphabetization process and also for proficient readers and have been found to be more strongly correlated with reading (Araújo et al. 2015).

The predictive role of RAN depends on some factors such as grade, the reading domain measured, and the alphabetic and orthographic systems (Araújo et al. 2011; Clarke et al. 2005; Pennington et al. 2001). Dyslexic readers performed slower and more poorly on RAN tasks when compared to good readers. These results persist throughout development and during adulthood, even in groups of compensated and high functioning dyslexics, hence suggesting that the RAN impairments persist and are stable during development (Araújo and Faísca 2019). RAN impairments can be seen not only in dyslexia but also in other disabilities such as attention deficit hyperactivity disorder. RAN skills are not only related to phonological processing but also to verbal processing speed and visual and integration skills (Alves et al. 2016).

After decades of extensive research, the proposition of a phonological processing deficit as the cognitive basis of developmental dyslexia is now generally accepted (Ramus et al. 2003; Snowling 2001; Vellutino et al. 2004; Ziegler and Goswami 2005). The phonological deficit model posits that developmental dyslexia is the result of deficits in phonological processing, particularly in PA (Pennington 2009) and a phonological processing deficit (Ramus et al. 2003).

Despite its important position in the reading literature, the phonological deficit model has been the subject of scrutiny (Snowling 2008; Wolf and Bowers 1999). For instance, some authors have proposed that phonological processing deficits alone are not enough (Pennington 2006; Snowling 2008; Wolf and Bowers 1999) or even needed (Pennington 2006; Wolf and Bowers 1999) for the presence of reading difficulties. In addition to this, considering that reading involves linguistic, visual, and attentional processes, some variable patterns of cognitive difficulties may contribute to reading difficulties among children (Norton et al. 2014). Therefore, the single phonological deficit model is not currently once other cognitive impairments, independent of the phonological process that are found in dyslexia cases, like visual attention and RAN deficits, temporal sampling or processing deficits, and visual–spatial attention or perceptual learning deficits (Norton et al. 2014; Peterson and Pennington, 2012).

For instance, in a study conducted by Wolf and Bowers (1999), the results indicated that phonological abilities alone could not explain children’s RAN performance; hence, the authors postulated a double deficit hypothesis of dyslexia, which proposes two independent deficits as the underlying cause of reading difficulties/dyslexia, PA and RAN. According to this hypothesis, three major types of impaired readers can be identified (Norton and Wolf 2012; Wolf and Bowers 1999). Two subtypes are characterized by the existence of a single deficit at the level of phonological processing:

1) the phonological-deficit subtype, defined by the presence of a PA deficit but with adequate RAN abilities; and 2) the RAN-deficit subtype, defined by the presence of a RAN deficit but with adequate PA abilities. A third subtype is defined by the co-occurrence of both deficits (Wolf and Bowers 1999; Wolf et al. 2002). However, even with some exceptions, several studies conclude that RAN impairments seem to be more related to slower reading speed while, on the other hand, PA impairments appear to be more related to spelling difficulties (Torppa et al. 2013; Wimmer et al. 2000).

Several studies have examined the double deficit hypothesis and the cognitive impairments associated with specific deficits in RAN, PA, or both, finding distinct and independent impairments between the dyslexic profiles proposed (Asadi and Shany 2018; Cronin 2011). In addition, several studies have shown that children with difficulties in both PA and RAN present more severe and persistent reading difficulties than children with deficits only in PA (e.g., Wolf and Bowers et al. 1999; Kirby et al. 2003; Kirby et al., 2010; Lovett et al. 2000; Manis et al. 2000), even when the two groups of children are matched for PA (Kirby et al. 2003; Papadoulos et al. 2009). In accordance with the double deficit hypothesis, a recent study on Portuguese Brazilian orthography aimed to investigate the role played by PA and RAN in predicting persistent as opposed to transient reading difficulties in Brazilian Portuguese-speakers. The authors found that both the children with transient and persistent reading difficulties performed significantly worse than the controls on the PA measures, but only the persistent difficulties group performed more poorly than the controls on the RAN measures by the end of kindergarten. Therefore, results from this study suggest that the presence of difficulties in both PA and RAN was also associated with persistent reading difficulties in their sample of children acquiring literacy in Brazilian Portuguese (Michalick-Triginelli and Cardoso-Martins 2015). On the other hand, in another study, the authors (Pennington et al. 2001) did not find their results to reflect the double deficit hypothesis, with the double deficit groups not performing consistently better than the single deficit groups. Similar results were found in other studies, in which the phonological model hypothesis appeared to better explain the results (e.g., Ackerman et al. 2001; Schatschneider et al. 2002; Vaessen et al. 2009).

Brazilian studies have not aimed to analyze the effect of PA and RAN on dyslexia, as well as their relationship with the cognitive profile of dyslexics. The studies have only compared the groups on the PA and RAN skills without describing the importance of these skills for identification of the disorder. Furthermore, double deficit theory can be investigated for the detection of diagnostic and identification characteristics. Based on this, the present study aims to determine the cognitive profile of participants with dyslexia as well as to examine the predictive efficacy of RAN and PA in identifying dyslexic individuals.

METHOD

Participants

A total of 60 participants were enrolled for this study: 30 children and adolescents (5 girls) with a diagnosis of developmental dyslexia aged from 7 to 12 years (M = 9.70, *SD* = 1.51) and 30 children as clinical referral controls matched for age (M = 9.77, *SD* = 1.54) and gender. All were native Portuguese speakers and attended school regularly. The participants in the dyslexia group were evaluated between 2015 and 2019 by an interdisciplinary group of the *Associação Brasileira de Dislexia* (ABD; Brazilian Dyslexia Association). For the dyslexic group, we included only children with a cognitive profile compatible with developmental dyslexia and without comorbidities with other disabilities. The criteria used for diagnosis were from a standard test and they included:

(a) a reading age at least 18 months lower than expected according to their chronological age, (b) a score more than two standard deviations below the average on tests of word, pseudoword, and text reading, and (c) the absence of global intellectual difficulties.

The participants in the control group were selected from São Paulo private schools. We selected only children without school, reading, or writing complaints. To determine this, we analyzed the scholastic records of each child and their teachers' opinions.

All participants agreed to participate in the survey through parental consent and oral consent. Thus, the work was carried out in accordance with the requirements of the Mackenzie Presbyterian University Research Ethics Committee (CAAE: 80902017.8.0000.0084). Consent for testing was obtained for all children.

Instruments

Wechsler Intelligence Scale for Children - 4th edition (WISC-IV)

General cognitive abilities were assessed using the Brazilian version of the WISC-IV (Weschler 2013). The WISC-IV gives five main scores for index abilities and a full-scale IQ, which correspond to the factors derived from factor analytic studies. This measure comprises verbal and execution subtests. The WISC-IV has 15 subtests, 10 of which are core subtests that are usually used to measure the four index scores and the full-scale IQ. The four index scores are: Verbal Comprehension Index, Perceptual Reasoning Index, Working Memory Index, and Processing Speed Index. Both the full-scale IQ and the five main scores derived from the index abilities are analyzed (Weschler 2013).

Rapid Automatic Naming (RAN) Test

The RAN test seeks to evaluate the total time required for the participant to name alphanumeric and nonalphanumeric symbols. The RAN task consisted of four stimulus cards, respectively containing colors (red, yellow, black, blue, and green), numbers (2, 6, 4, 7, and 9), objects (book, chair, dog, hand, and star), and letters (a, o, s, d, and p). Each stimulus card contained five different items, each replicated 10 times. The children were instructed to name the items as quickly as possible, and the time taken to name all items on a card was used as the score error and self-corrections. We used four RAN scores in our analysis: a) time, error, and self-correction for each stimulus card; b) RAN total as the sum of the reaction time (RT) for all four subtests; c) RAN alphanumeric as the sum of the RT for the number and letter cards; and d) RAN nonalphanumeric as the sum of the color and object cards (Wolf and Denckla 2005).

Phonological Skills Profile Test

It seeks to analyze the phonological abilities of synthesis, addition, segmentation, subtraction, substitution, rhyme, sequential rhyme, syllable reversal and articulatory image. The application is individual and the instructions are given orally and may present visual support as in the articulatory image subtask. The test features two input items for task comprehension verification, and four items that are scored differently according to the task ranging from 1 to 2 points for each hit. At the end is added the total hits for each subtask and the total sum of all subtasks. Only the total of the test was used, since the subtasks have a varied and different total score for each one (Carvalho et al. 1998).

Reading Pseudowords

This test has 96 items that are created based on familiar structures of Brazilian Portuguese real words (pseudowords) and unfamiliar structures (strange pseudowords). Regarding length, the items are formed by one syllable (18 items), two syllables (54 items), three syllables (22 items), and four syllables (2 items). The participant is asked to read one item at a time as quickly as possible and without making mistakes. The total reading time as well as the total number of correct answers is recorded. Efficiency was calculated using the equation [accuracy/speed for item]. (Brazilian Dyslexia Association, not published).

Reading Words

This test is based on 94 real words from Brazilian Portuguese. The test consists of words of two syllables (72 items), three syllables (20 items), and four syllables (2 items). The participant is asked to read the items as quickly as possible without errors. The total reading time is recorded as well as the total number of correct answers. Efficiency was calculated using the equation [accuracy/speed for item] (Brazilian Dyslexia Association, not published).

Text Reading

This test is formed by 18 expositive texts directed to each school grade. The texts have a number of words according to the complexity of the text. Reading is performed aloud, and the total reading time is recorded. The text was previously selected as appropriate to the student's educational level. For analysis we used the total reading time and efficiency was calculated using the following equation [accuracy/total time] (Saraiva et al. 2005).

Procedure

For the dyslexia group, medical records of children and adolescents who had already completed the neuropsychological and multidisciplinary assessment were analyzed. The evaluation consisted of neuropsychological, speech therapy, psychopedagogical, and medical tests. The selection of medical records took place systematically in order to identify those who met the inclusion criteria of the study. After selecting the medical records, the data were tabulated. The control group was selected based upon the descriptive data of age and gender of the dyslexia group and after analysis and discussion with teachers and examining the school curriculum. Children and adolescents were evaluated during school time (i.e., out of class in 3 one-hour meetings). After the evaluations were completed, all participants received a report on their performance.

Data Analysis

Descriptive and inferential statistics were performed using IBM SPSS software, version 22.0. The level of significance for the interpretation of analyses was 5% ($p \leq .05$). Student's *t*-tests were conducted to compare the dyslexic and control group on the WISC-IV indexes and subtests, and in the RAN, PA, and reading tests. Furthermore, a regression tree analysis (Breiman et al. 1984) was conducted. The aim was to identify variables that could predict if participants were in the dyslexia or control group. To do this, all RAN and PA measures were introduced to the model. We also calculated the accuracy, sensitivity and specificity of the model. The analysis was carried using the rpart package (Therneau & Atkinson 2019) in R.

Results

Comparing the dyslexia group and control group

To compare both groups, we used Student's *t*-test. In relation to the neuropsychological measures, statistically significant differences were found in two WISC-IV categories of Verbal Comprehension (Similarities and Information), with the dyslexia group having lower scores. The effect had a medium magnitude for both. Additionally, significant differences were found in Complete Figures category of the Perceptual Reasoning Index, and in the Arithmetic category of the Working Memory Index. In the first instance, the dyslexia group demonstrated higher means, and in the second it was the opposite. Both effects were of a medium magnitude. Table 1 presents the means and standard deviations of the groups for each measure, *p*-values, and effect sizes.

With regard to the reading measures, several significant differences were found. In RAN color, numbers, and objects, differences between the two groups on all measures were statistically significant with the exception of the number of errors. The magnitude of the effects ranged from medium to large. All measures of RAN letters were significantly different, with effect sizes between medium and large. When there were significant differences, the dyslexia group was slower, had more errors, and self-corrected fewer times.

In addition, the differences between groups on the RAN total, alphanumeric, and nonalphanumeric scores were also statistically significant, with the dyslexia group having a higher score. RAN total and alphanumeric scores demonstrated an effect size of large magnitude, while RAN nonalphanumeric score presented an effect size of medium magnitude. No significant difference was found in PA. In the reading of words and pseudowords, significant differences were found between the groups in accuracy, speed, and efficiency. The magnitude of the effect was large for all measures. The dyslexia group was less accurate, slower, and less efficient. Lastly, significant differences were found in the text reading: the dyslexia group was slower and less efficient. The means and standard deviations for each group, as well as *p*-values and effect sizes of the RAN, PA, and reading measures are presented in Table 2.

Regression tree model to predict dyslexia with the RAN and the PA

Lastly, a regression tree model was created to identify predictor variables that could assign the participants to the dyslexia or control groups. Initially, all RAN and PA measures were introduced to the model. The model selected three variables to predict which group (dyslexia or control) the participant would be assigned to. The variables were: Time on RAN letters; Self-Corrections on RAN colors; and Errors on RAN colors.

The model indicated that if Time on RAN letters was equal to or higher than 34 seconds, participants would be placed in the dyslexic group. Participants with performance under 34 seconds would be evaluated with the Self-corrections on RAN colors. If the participants had 1 or more self-corrections, they would be placed in the control group, if they had 0 self-corrections, they would go to the next node. In the next node, participants were evaluated by the Errors on RAN colors. If the participants had 1 or more errors, they would be categorized as dyslexic, and if not, they would be assigned to the control group. The decision tree of the model is presented in Figure 1 (Appendix 4).

The accuracy of the model was 88.33%, indicating that seven participants were not assigned to the correct group. Specifically, two dyslexic participants were predicted to be in the control group, revealing a sensitivity of 93.33% in the model, and five control participants were predicted as dyslexic, resulting in a specificity of 83.33% for the model.

Discussion

The aim of this study was to analyze the cognitive profile of children and adolescents with dyslexia compared to good readers, as well as to examine the predictive effect of PA and RAN. To accomplish these aims, comparative analyses were performed between the groups in relation to performance on the WISC-IV test, as well as on reading measures, PA, and RAN.

Results of the WISC-IV test did not reveal significant differences between the two groups of participants on the test factor indexes. Previous studies that investigated the cognitive profile of dyslexics on WISC-IV found impairments in verbal skills, processing speed, and working memory. Of these, memory plays a fundamental role in establishing the cognitive profile, although it may vary depending on the dyslexia subtype. Participants with phonological dyslexia have significant impairments in working memory, whereas those with surface dyslexia tend to perform normally in this skill (De Clercq-Quaegebeu et al. 2010). The lower performance of dyslexics on the Arithmetic subtest, which is a component of the Working Memory Index, suggests that they have attention, sequencing, fluidity of reasoning, and logical difficulties that are the skills evaluated by the subtest (Wechsler 2013)

Participants with dyslexia in the present study showed no impairment in the Verbal Comprehension Index. Other studies indicate impairment in language and verbal skills in developmental dyslexia (Arduini et al. 2006; D'Angiulli and Siegel 2003). The subtests that make up the sum of the index are more homogeneous measures regarding expression and verbal conceptualization, which involve a high level of language processes (De Clercq-Quaegebeu et al. 2010), suggesting that participants with dyslexia have a preserved cognitive profile in relation to a high level of language processes. However, participants with dyslexia performed worse in the subtests Similarities and Information that are components of the Verbal Comprehension Index. The Similarities subtest is one of the main tests of the Index and seeks to assess verbal reasoning, concept formation, and oral comprehension. The Information subtest is a supplemental test that seeks to assess the ability to acquire, retain, and retrieve factual knowledge and information acquired in school and daily life (Wechsler 2013).

Differences were also found in the Complete Figures and Arithmetic subtests. The Arithmetic subtest seeks to assess working memory, mental alertness, concentration, attention, short- and long-term memory, numerical reasoning, and attention. The Complete Figures subtest measures visual perception and the organization, concentration, and visual recognition of essential details of different objects (Wechsler 2013). Therefore, the dyslexics' cognitive profile difficulties in the present study are related to more complex language processing stages, such as comprehension, storage of verbal contents, and attentional and visual processes. In short, efficient reading depends on visual, language, and orthographic processes, working memory, motor movements, and comprehension, attention, and cognition abilities for developing accuracy and reading speed skills (Menghini et al. 2010; Tamboer et al. 2016). By developing these skills, the reader can acquire automatic reading.

Giofrè et al. (2019) identified two clusters related to cognitive profiles and dyslexia subtypes. On one hand, the visual subtype presents with higher IQs and better performance on the Perceptual Reasoning Index compared with the Verbal Comprehension Index. This profile is in accordance with the profile found in this study. On the other hand, phonological dyslexics present with lower IQs with an opposite pattern, being characterized by patterns of greater loss in phonological abilities. Still, both groups had impaired visual skills, so visual impairment was a general impairment of dyslexia.

During literacy, the child must transform printed codes into oral language codes and then be able to understand the text and relate it to previous knowledge. These abilities are important for the literacy process, and they are deficient in children with reading failure such as dyslexia (Norton and Wolf 2012). In fact, dyslexics perform worse on tests that involve reading isolated items, as well as texts that require understanding and integration of information at different stages (Peterson and Pennington 2012; Norton et al. 2014).

The pattern of responses and errors made in the reading tests suggests that the dyslexic profile in the present study is similar to that observed in surface dyslexia. Surface dyslexics present impaired visual attention with preserved PA skills. Visual attention is the ability to integrate and process spelling information simultaneously quickly and accurately, outlining the number of letters to be processed in a word. Impairment in visual attention can cause deficits in reading irregular words and reading speed, being related to the profile of surface dyslexia (Giofrè et al. 2019). Furthermore, these losses may affect the reading of pseudowords (Zoubrinetzky et al. 2014**)**. Impaired visual attention may be present in the profile of dyslexics who speak Brazilian Portuguese (Lima et al. 2008).

Regarding measures of word, pseudoword, and text reading, the dyslexic group exhibited inferior performance for all measures with large effect sizes. In this sense, the dyslexics present a mixed profile of difficulties in relation to the reading of both pseudowords and real words. The study by Zoubrinetzky et al. (2014) showed that dyslexic children with mixed reading profiles may have cognitive impairments in phonological processing and independent visual attention. Thus, the cognitive profile of dyslexics in the present study seems to be related to visual dyslexia, since the reading profile is mixed.

No significant differences were found in PA between the two groups. PA is the oral language ability that assists in the early stages of reading development, and is part of the phonological processing deficit found in dyslexia (Pennington 2009; Ramus et al. 2003; Snowling 2001; Vellutino et al. 2004; Ziegler and Goswami 2005). The PA ability develops as reading proficiency develops (Anthony and Francis 2005). These PA abilities are of direct importance at the beginning of literacy, as reading development phonological skills may have little relation to reading performance prediction (Rothou et al. 2013). In addition, decreasing the predictive effect of PA according to school progression and age may be related to the measures and forms of assessment used with older children, as reading and decoding instruction evolves and children develop the ability to sound the structure of language facilitating the performance on PA tests (Hogan et al. 2005). In fact, other studies with dyslexic children also found no impairment in PA (de Jong and van der Leij 2003; Landerl and Wimmer 2000) suggesting that the results demonstrate that the difficulties in PA are present in first graders and tend to disappear by the end of primary school. Landerl and Wimmer (2000) did not find a significative difference in PA between dyslexic and good readers after the second grade. Moreover, the absence of differences may be related to the difficulty level of the PA test for older participants and, as reading develops, phoneme manipulation skills tend to be less important (de Jong and van der Leij 2003). The relation between PA and reading is not a causal relation, despite the importance of this ability for reading development. Therefore, the existence of impairment in this ability does not necessarily result in impairment in reading (Blomert and Willems 2010).

On the other hand, differences were found between groups for automatic naming. Indeed, RAN ability is a predictor of reading ability in both good readers and dyslexics (Araujo et al. 2015), and is an important measure for early identification and risk for reading impairment (Georgiou et al. 2012). Naming speed is the ability that integrates visual information and its phonological representations quickly and accurately. In addition, mechanisms of inspection and lexical retrieval in all items, with saccadic programming, multiple-item sequencing, eye–voice coordination, and executive attentional mechanisms are required (Araujo and Faísca 2019; Norton and Wolf 2012).

The results show that the dyslexic group impairments are related to the fast integration of these abilities and not only to processing the phonological information. In addition, the dyslexic profile of the present study tends to lead to difficulties in visual attention and verbal programming. Giofrè et al. (2019) found significant impairments in processing speed skills for nonverbal stimuli assessed by the Wechsler scales, unlike the results of the present study. Thus, since the processing speed skills for visual stimuli are preserved, as the results showed in relation to the WISC-IV processing speed index, it can be assumed that the impairments are in the verbal plane, since RAN skill processing involves verbal stimuli with verbal integration (De Clercq-Quaegebeu et al. 2010; Lima et al. 2008).

The poorer performance of Portuguese-speaking dyslexics in naming speed corroborates findings in other languages. These impairments are associated with reading difficulties. A recent meta-analytic review aimed to analyze RAN impairments in a group of dyslexic children in comparison to typical readers showed that the dyslexic group performed poorly and slower in RAN tasks (Araújo and Faísca 2019). In addition, dyslexics had a higher number of errors and fewer self-corrections; therefore, they exhibited difficulties in retrieving the vocabulary present in the lexicon and performing integration with motor and visual skills. Considering the type of RAN measure used, time or accuracy, time measures differentiate the groups better, with dyslexic children performing worse on both RAN measures and with a higher number of errors compared to the typical controls. In relation to the type of task (colors, objects, letters, digits), the dyslexic group presented impairments on all types of tasks, although the effect size was larger in the number and letters subtasks, followed by objects and colors. In addition, the largest effects sizes emerged on the letters task. When comparing alphanumeric and nonalphanumeric stimuli, the former showed larger effect sizes. Age appeared to not significantly impact the results, with dyslexia impairments being stable with age. These results were also found by Araújo and Faísca (2019): in relation to the variables in the orthographic system and transparency of the writing system, no significant results were found. Araújo and Faísca (2019) showed that for any orthographic system RAN and dyslexia impairments are significant and show larger effect sizes. These results persist throughout development and during adulthood, even in groups of compensated and high functioning dyslexics, suggesting that the RAN impairments persist and are stable during development (Clarke et al. 2005; Pennington et al. 2001).

The dyslexic group's inferior performance on RAN tasks may be related to interference control, because this type of test demands working memory ability. The correct naming of a given stimulus depends on the inhibition of the responses already emitted in order to avoid possible interference. Naming colors and objects requires a higher degree of inhibitory responses due to the semantic character of the stimuli and response competition of alternative candidate names (Bexkens et al. 2014). Thus, the greater number of errors in the dyslexic group can be explained due to difficulties in inhibiting responses during rapid naming, as well as the difficulty in cognitive flexibility to correct them quickly.

Regression results showed that automatic naming measures discriminated better between groups than PA, although many studies have found a modest predictive effect of RAN on phonological abilities in developmental dyslexia (Aguilar-Vafaie et al. 2012; Cardoso-Martins and Pennington 2001; Pennington et al. 2001). However, the findings of the present study may be related to the fact that the predictive effect of RAN depends on linguistic regularity and the orthographic system (Araujo et al. 2015; Swanson et al. 2003). Thus, for Brazilian Portuguese-speakers, RAN seems to be a more effective measure to differentiate between dyslexic groups and controls. Studies with readers of

Brazilian Portuguese corroborate these findings in that RAN measures were good measures for the early identification of risks for reading difficulties (Justi and Cunha 2016), as well as for children and adolescents with reading impairments (Bicalho and Alves 2010; Capellini and Conrado 2009; Capellini and Lanza 2010; Germano et al. 2012; Lima et al. 2008; Michalick-Triginelli and Cardoso-Martins 2015; Silva et al, 2012;).

Letter naming speed was a better predictor in differentiating the groups in the present study. Thus, 22 of the 30 participants with dyslexia took more than 34 seconds to name the 50 letters. In fact, naming alphanumeric items, such as letters and numbers, is described as a better predictor of reading skills (Hornung et al. 2017). Studies with alphanumeric stimuli show higher effect sizes between RAN and reading because these tasks are closer to reading fluency processes. RAN is correlated with fluency because both fluency and RAN tasks depend on the rapid execution of cognitive processes (Araujo et al. 2015). In addition, the 3 children in the control group who took more than 34 seconds to name the letters were the youngest, aged 7 and 8 years, as naming ability develops as children progress and read. According to the automation of visual-verbal integration skills, children develop greater fluency and faster task accomplishment as they age (Norton and Wolf 2012). As a result, younger children may perform poorly compared to older children.

In addition to letter naming time, performance in the self-corrections and number of errors in colors were additional measures in discriminating the groups. Generally, dyslexics showed fewer self-corrections and more errors in the color board. These results corroborate the findings of a study by Areces et al. (2018), where the dyslexic group performed worse on RAN tasks; however, the color subtest was the best predictor of reading difficulties in their study. The difference of processing between RAN nonalphanumerics (i.e., colors and objects) and alphanumerics (i.e., letters and numbers) is related to semantics; in other words, the first group of RAN involves semantic lexical coding access and alphanumeric is asemantic coding. These stimuli are promising because before literacy they are very often used (Hornung et al 2017). In addition, two dyslexics aged 12 years were identified as controls because they had fewer errors in color naming. Thus, older dyslexic individuals may present less impairment in relation to these abilities.

The results regarding both group comparisons and the regression data show that phonological processing deficits alone are not enough (Pennington 2006; Snowling 2008) or even needed (Pennington 2006; Wolf and Bowers 1999) for a diagnosis of dyslexia. Studies that seek to analyze the differentiated profiles in PA and RAN deficits in individuals with dyslexia find differences in relation to double deficits and single deficits (Pennington et al. 2012; Wolf et al. 2002). Thus, the data of the present study are in agreement with the double deficit theory of Wolf and Bowers (1999), as the dyslexic profile in the present study is single deficit in RAN, without losses in PA. The double deficit theory postulates that there is independence between the losses found in PA or RAN and that these losses may even occur mutually. Therefore, reading impairment manifests itself differently, depending on the number and type of components involved. The losses can be single (PA or RAN) or double (PA and RAN) (Norton and Wolf 2012; Wolf and Bowers 1999;). Losses in RAN present deficits separate from PA (Asadi and Shany 2018; Cronin 2011; Powell et al. 2007; Wolf and Bowers 1999).

Losses in relation to double deficits appear in different spellings and orthographic systems. In addition, the losses related to naming speed deficits may present a differentiated profile of difficulties in relation to the double deficit or phonological deficit profile. In a recent study, in the Arabic language, the participants were separated three groups: deficits only in PA, deficits only in RAN and double deficit. When comparing the cognitive profiles of the three groups in relation to working memory, morphological knowledge, vocabulary, syntactic knowledge, reading, and orthography, the double deficit group underperformed in all the measures when compared to the RAN deficit group, but had a similar performance to the PA only group. Therefore, a similar pattern was found between the double deficit group and the PA group, with the two groups underperforming the RAN group in all the measures, apart from reading and writing speed. The similarity between the impairments found between the PA and the double deficit group might indicate that deficits in phonological processing are more prevalent in individuals with double deficits (Asadi and Shany 2018). Similar results regarding the distinct profile of the three difficulty groups were found in a longitudinal study comparing the development of word and pseudoword reading. The double deficit group had a poorer growth in reading ability. The groups with only PA or RAN deficits had similar developmental trajectories, suggesting that the impairment in only one ability has a compensatory effect on reading development/acquisition (Cronin 2011). In the present study we found preserved performance of the dyslexic group regarding working memory skills and basic language skills indicating that the profile of single deficit of RAN impairment is similar to that found in these studies. In fact, the dyslexic group presented significant impairments in reading skills, but with superior performance in verbal skills assessed by the other tests. Thus, impairments only in the ability of RAN can have a compensatory effect on the skills required for reading development.

Conclusion

The data from the present study demonstrated the ability to differentiate the cognitive profile of dyslexic children and adolescents, as well as indicated that RAN ability was a better predictor for differentiating the groups. In conclusion, RAN is an important measure to assess reading difficulties in Brazilian Portuguese-speakers, as well as being a significant impairment in developmental dyslexia. In addition, the present study found evidence for the double deficit theory for Brazilian Portuguese. Given this, the identification of different cognitive profiles and difficulties beyond phonological processing may help in the intervention and prognostic processes for reading difficulties.

Despite the relevance of the results of the present study, some limitations should be noted and addressed in future studies. The present study used information already collected in other evaluations by other professionals to obtain data regarding the dyslexia group. From this, the measures for the control group were selected by convenience. Thus, the present study could have used another measure to assess the ability of PA to verify if there was a measuring effect to the results found, but it was not possible because the data had been previously collected. The number of study participants was selected based on the number of medical records of the dyslexic group presenting a difficulty profile compatible with the study selection criteria. From this, it was not possible to obtain a larger number of participants who met the selection criteria. Further studies should be conducted with a larger number of participants and other measures to verify the hypotheses raised in the present study.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author Contributions

PB designed the study, collected the data, analyzed the data, and wrote the manuscript. RT wrote the manuscript. PL analyzed the data and wrote the manuscript. AN and LS collected the data. PA wrote and revised the manuscript. EM designed the study, analyzed the data, wrote and revised the manuscript.

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Data Availability Statement

The raw data supporting the conclusions of this manuscript will be made available by the authors, without undue reservation, to any qualified researcher.

Table 1. Means and standard deviation of each group in the measures of WISC-IV, significance levels, and effect sizes.

	Dyslexia Group		**Control Group**				
Index and Subtests	M	*SD*	M	*SD*	*p*-value	*t*	Cohen's *d*
Total IQ score Index	115.233	11.752	116.200	10.400	.737	-0.337	0.09
Verbal Comprehension Index	114.167	14.874	119.067	12.393	.171	-1.386	0.36
Similarities	12.733	2.876	14.333	2.397	**.023***	-2.341	0.60
Vocabulary	12.833	2.520	13.133	2.813	.665	-0.435	0.11
Comprehension	12.467	1.776	12.500	2.224	.949	-0.064	0.02
Information	11.700	3.365	13.533	2.649	**.022***	-2.345	0.61
Reasoning with words	12.828	2.989	12.367	3.135	.566	0.578	0.15
Perceptual Reasoning Index	117.767	12.594	115.933	12.892	.580	0.557	0.14
Block Design	12.733	2.828	12.967	2.710	.745	-0.326	0.08
Picture Concepts	13.000	2.605	11.933	2.572	.119	1.583	0.41
Matrix Reasoning	13.138	2.532	13.100	2.796	.957	0.055	0.01
Complete Figures	12.448	2.384	11.133	2.460	**.042***	2.084	0.54
Working Memory Index	102.700	12.377	104.733	11.459	.512	-0.660	0.17
Digit Span	10.100	2.784	9.967	2.428	.844	0.198	0.05
Letter–Number Sequence	10.828	1.891	11.633	2.312	.149	-1.463	0.38
Arithmetic	10.833	2.119	12.300	2.693	**.022***	-2.345	0.61
Processing Speed Index	105.500	10.572	106.033	14.050	.869	-0.660	0.04
Coding	10.433	1.906	10.897	2.907	.471	-0.726	0.19
Symbol Search	11.467	2.013	10.964	2.202	.368	0.908	0.24
Cancelation	10.448	2.720	9.267	2.876	.111	1.620	0.42

*$p < .05$

Table 2. Means and standard deviation for each group on measures of RAN, PA, reading words/pseudowords, and text reading, significance levels and effect sizes.

	Dyslexia Group		**Control Group**				
	M	*SD*	M	*SD*	*p*-value	*t*	Cohen's *d*
RANcolor_Speed	58.733	22.119	47.167	11.588	**.014***	2.537	0.66
RANcolor_Error	0.467	0.776	0.433	0.728	.864	0.172	0.05
RANcolor_ self-corrections	0.067	0.254	0.700	0.794	**<.001*****	-4.160	1.07
RANobject_Speed	50.567	15.078	42.433	8.110	**.012***	2.602	0.67
RANobject_Error	0.333	0.758	0.233	0.504	.550	0.602	0.16
RANobject_ self-corrections	0.100	0.403	0.633	0.718	**<.001*****	-3.547	0.92
RANletters_Speed	43.067	22.744	27.733	7.100	**<.001*****	3.525	0.91
RANletters_Error	2.200	3.566	0.500	1.253	**.017***	2.463	0.64
RANletters_ self-corrections	0.033	0.183	0.400	0.724	**.009****	-2.690	0.70
RANnumbers_Speed	37.867	16.712	27.633	5.928	**.003****	3.161	0.82
RANnumbers_Error	0.367	0.850	0.200	0.484	.335	0.933	0.24
RANnumbers_ self-corrections	0.067	0.254	0.467	0.629	**.002****	-3.231	0.83
RAN total score	190.233	68.387	144.967	25.055	**<.001*****	3.404	0.88
RAN alphanumeric	80.933	39.090	55.367	11.857	**<.001*****	3.428	0.89
RAN nonalphanumeric	109.300	34.214	89.600	18.556	**.007****	2.772	0.72
PA	61.500	7.143	62.833	6.438	.451	-0.759	0.20
Reading Words_accuracy	72.467	19.057	91.433	2.285	**<.001*****	-5.413	1.40
Reading Words_Speed	3.178	1.786	1.386	0.696	**<.001*****	5.120	1.32
Reading Words_Effiency	29.102	16.435	78.458	34.219	**<.001*****	-7.121	1.84
Reading Pseudowords_accuracy	64.067	19.813	91.267	3.151	**<.001*****	-7.426	1.92
Reading Pseudowords_Speed	3.048	1.017	2.106	0.867	**<.001*****	3.822	1.00
Reading Pseudowords_Efficiency	23.911	11.791	49.378	17.172	**<.001*****	-6.661	1.73
Reading Text_Speed	302.967	181.661	119.133	50.183	**<.001*****	5.343	1.38
Reading Text_ Efficiency	53.219	34.699	123.001	53.409	**<.001*****	-6.001	1.55

*p < .05 **p<.01 ***p < .001

Figure 1. The regression tree model. The selected variables are shown in the white boxes and their cut-off values are shown in bold. The boxes at the bottom represent the number of each category of participants. Numbers on the left are the dyslexic group participants and numbers on the right are the control group participants.

CHAPTER 7: GENERAL DISCUSSION

The two aims of this thesis were to analyze the predictive effect of RAN and PA in reading and writing and to verify the predictive effect of the two skills to diagnose developmental dyslexia. Initially Study 1 sought to analyze the structure of the RAN test for Brazilian Portuguese, since no Brazilian studies on this topic existed. In Brazil there is only one standardized and validated RAN test, which is still underutilized in clinical and school environments (Silva, Mecca, & Macedo, 2018), unlike tests for PA, for which several Brazilian Portuguese instruments for clinical and school application exist (Carvalho et al., 1998; Moojen et al., 2015; Seabra & Capovilla, 2012a; Seabra & Capovilla, 2012b).

The results of Study 1 showed that the two-dimensional model is better representative of RAN ability throughout development in children aged four to nine than one-dimensional. The division in two factor (alphanumeric and non-alphanumeric stimuli) is important as the two factors develop differently throughout reading development and learning (Åvall et al., 2019; Närhi et al., 2005; Protopapas et al., 2013; Van Den Bos, Zijlstra & Spelberg, 2002).

Nonalphanumeric stimuli are used with younger children who have not yet gone through the literacy process. These stimuli are learned and automated early in development. By starting literacy, children come into greater contact with letters and numbers and decrease exposure to stimuli from colors and objects. Thus, alphanumeric stimuli become more effective and automated (Araujo et al., 2015; Hornung et al., 2017b). From this, the separation of the construct into two factors favors the understanding of the ability of RAN throughout development and according to the development of literacy.

In addition, the results showed that naming speed decreased between the ages of five and six years. Prior studies showed that mean time of naming was decreased in older children in other languages (Åvall et al., 2019; Denckla & Rudel, 1974; Hornung et al., 2017a, Albuquerque, 2012), including Brazilian Portuguese (Ferreira-Mattar et al., 2019; Silva et al. 2018). The RAN latencies are not related to how early the stimuli were learned but to the automation of the naming process (Cohen, Mahé, Laganaro, & Zesiger, 2018). We revealed that this process may be happening between the ages of five and six.

From the bidimensional model and the development of naming ability, the relationship with alphanumeric stimulus increases in development with schooling, and between color/pictures the access can be less improved. Increased development of naming ability happens between four and six years, while alphanumeric abilities occur later (Åvall, Wolff, & Gustafsson, 2019).

The results of our first study helped us understand how RAN ability and the instrument used in Study 2 are shown throughout development according to age and what the factorial structure (bidimensional) of this instrument is. Study 2 was conducted to verify the predictive effect of RAN and PA between the first and third year of elementary school on learning to read and write. The results showed that RAN was a better predictor of reading and writing speed skills than PA. These results corroborate the findings in other studies that describe RAN as a better predictor of fluency skills (Albuquerque, 2017; Araújo et al., 2015; Ibrahim, 2015; Justi & Roazzi, 2012; Landerl et al., 2019; Song et al., 2016; Wei et al., 2015).

As in the study by Landerl et al. (2019) on more transparent orthographies such as Greek and Dutch, PA did not predict reading ability. On the other hand, unlike in English (Landerl et al., 2019), PA in fisrt grade predicts word reading in second grade. These differences may be due to linguistic regularity and the causal mechanism of PA and reading abilities, since PA is important initially for the development of reading. From this, the predictive effect of PA seems to be more dependent on the characteristic linguistic regularities of the task, and the predictive effect of PA is greater for opaque orthographies (Furnes & Samuelsson, 2011; González-Valenzuela, Díaz-Giráldez, & López-Montiel, 2016). In addition, the PA effect is more dependent on early reading skills (Hogan et al., 2005; Landerl et al., 2019).

Our results showed that the type of RAN test as well as the type of reading or writing test is an important factor in verifying the predictive effect throughout the grades. Alphanumeric RAN was the only predictor for word reading in the second and third years, while non-alphanumeric RAN was the only predictor for writing. These data reinforce the findings of Study 1, in that the factors measure distinct abilities.

For sentence reading and comprehension, both alphanumeric and non-alphanumeric stimuli were predictive of reading ability. Non-alphanumeric stimuli had a predictive effect on the onset of the ability to read and understand sentences, while alphanumeric stimuli were important for the third year. While reading sentences, comprehension processes are required. Reading isolated words involves identification processes, while reading sentences involves understanding (Albuquerque, 2017). Both alphanumeric and non-alphanumeric stimuli are important for understanding (reading sentences), while for identification processes (reading word) only alphanumeric stimuli are relevant. In the third grade it seems that sentence identification and comprehension processes depend much more on stimuli such as letters and numbers that are more automated at this stage. This is due to the semantic access processes in which alphanumeric stimuli depend. From that, RAN is the best predictor of reading comprehension skills (Swanson et al., 2003). For writing, only non-alphanumeric RAN is relevant because of the nature of the stimuli and steps of more direct and concrete semantic processes and specific orthographic processes (Aguilar-Vafaie et al., 2012; Cho & Chiu, 2015; Wolf & Denckla, 2005).

Deficits in RAN and PA are present in children at risk for learning difficulties and disorders such as dyslexia (Araújo and Faísca, 2019; Asadi and Shany 2018;; Capellini et al. 2008; Cronin 2011; Deuschle and Cechella 2009; Germano et al. 2008; Hornung et al, 2017; Justi & Cunha, 2016; Kirby et al. 2003; Kirby et al., 2010; Lima et al. 2008;; Michalick-Triginelli and Cardoso-Martins 2015; Norton et al. 2014; Peterson et al 2017; Peterson & Pennington, 2012; Torppa et al. 2013; Wolf and Bowers 1999; Wimmer et al. 2000). Study 3 was conducted to verify the cognitive profile of participants in the dyslexia group compared to good readers, as well as to verify the predictive effect of PA and RAN in identifying the difficulties presented. The results of Study 3 showed that the cognitive profile of the children with dyslexia in our study was compatible with the surface subtype. The dyslexic cognitive profile difficulties in Study 3 are related to more complex language processing stages such as comprehension, storage of verbal contents, and attentional and visual processes. In addition, preserved abilities were found in PA but significant losses in RAN. Surface dyslexia presents specific difficulties in reading irregular words and in the use of reading strategies via direct lexical access to representations of words with impairments in RAN (Peterson et al. 2013; Zoubrinetzky et al. 2014). In addition, children with dyslexia in the present study showed no impairment in working memory, which is usually associated with the cognitive profile of dyslexia and related to the surface dyslexia profile (De Clercq-Quaegebeu et al. 2010).

As in other studies (de Jong & van der Leij 2003; Landerl & Wimmer 2000), no difference was found between children with dyslexia and good readers in PA ability. This could be because difficulties in PA may disappear with development (Landerl & Wimmer 2000), as was the case in Study 3 participants.

In contrast, a significant difference was found regarding RAN ability. Other studies also showed differences in RAN ability between groups of good readers and readers with dyslexia (Araújo & Faísca 2019; Bexkens et al. 2014; Clarke et al. 2005; Pennington et al. 2001). In addition, the ability of RAN was a better predictor for differentiating between groups than PA.

The double deficit theory postulates that both PA and RAN may be impaired in dyslexia with difficulty profile in both skills or difficulty profile in a single skill (Norton & Wolf 2012; Wolf & Bowers 1999). Thus, losses in RAN may appear separately in relation to PA (Asadi and Shany 2018; Cronin 2011; Powell et al. 2007; Wolf and Bowers 1999). RAN is the ability that integrates visual information and its phonological representations quickly and accurately. In addition, RAN involves mechanisms of inspection and lexical retrieval in all items, including saccadic programming, multiple-item sequencing, eye-voice coordination, and executive attentional mechanisms. The people with dyslexia in our study present impairments regarding visual-verbal integration, lexical retrieval, and visual attention with verbal programming. Thus, the results of the present study are in accordance with the double deficit theory (Wolf & Bowers 1999) regarding the independence of PA and RAN skills and different difficulty profiles for each skill.

CONCLUSION

RAN skills were better predictors of reading skills in both children who read well and those with reading impairments than PA. RAN tests differ in their development pattern, and the predictive effect of these skills varies as a result of the RAN test used. The present study had limitations in sample size and the length of longitudinal follow-up. However, it was the first longitudinal study that sought to analyze the predictive effect of RAN and PA for Brazilian Portuguese and to verify the profile of these skills in developmental dyslexia. Further studies should be conducted to verify the effect of spelling regularities in relation to the predictive effect of these skills.

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APPENDIX

Appendix 1

Manuscript Details

Manuscript number	JECP_2019_581
Title	The structure of rapid automatized naming in children aged 4–9 years
Article type	Full Length Article

Abstract

Rapid automatized naming (RAN)—an important ability for reading development—is used widely; however, the underlying factor structure of RAN tests is unclear, and there are issues concerning dimensional universality across cultures and orthographies. Therefore, we analyzed how RAN decreases across development and whether the intercorrelations of four naming stimuli—colors, objects, numbers, and letters—are developmentally invariant at various age levels. Participants were 858 children aged 4–9 years who were learning to read in Brazilian Portuguese. All children completed a standardized Brazilian RAN test. Results showed that the best data fit was provided by a two-factor model, which was consistent across all age groups. We conclude that, in Brazilian children, RAN assessed with diverse stimuli measures unitary and bidimensional skills in 4–9-year-old children. The findings have key implications for the use of RAN in research and for the interpretation of RAN performance in clinical and education settings.

Keywords	rapid automatized naming; alphanumeric rapid automatized naming; non-alphanumeric rapid automatized naming; factor structure; bidimensional model
Taxonomy	Cognitive Psychology
Corresponding Author	Patrícia Botelho da Silva
Corresponding Author's Institution	Mackenzie Presbyterian University
Order of Authors	Patrícia Botelho da Silva, Alexandre Luiz de Oliveira Serpa, Pascale Engel de Abreu, Elizeu Coutinho de Macedo
Suggested reviewers	Alessandra Seabra, Natália Dias

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Appendix 2

Elsevier Editorial System(tm) for Learning and Individual Differences
Manuscript Draft

Manuscript Number:

Title: Phonological Awareness and Rapid Automatized Naming: Predictors of Literacy in Early Primary School

Article Type: Full Length Article

Keywords: phonological awareness; rapid automatized naming; reading development; writing development.

Corresponding Author: Mrs. Patrícia Botelho da Silva,

Corresponding Author's Institution:

First Author: Patrícia Botelho da Silva

Order of Authors: Patrícia Botelho da Silva; Amanda D Cardoso; Alexandre Luiz O Serpa; Pascale Engel de Abreu; Elizeu C de Macedo

Abstract: Phonological awareness (PA) and rapid automated naming (RAN) are important predictors of reading. The predictive effect of these abilities depends on grade, type of stimulation, and orthographic and linguistic regularities. This study analyzed the relationship of PA and RAN in learning how to read and write in early primary school. Children were tested during the first three years of elementary school, in measures of PA, RAN, writing test and isolated word reading and sentence reading measures were applied. Results showed that RAN was a better predictor of reading and writing speed skills than PA. Additionally, alphanumeric RAN was a better predictor of single word reading skills, while non-alphanumeric RAN was the only predictor of writing skills. The predictive effect of PA depends much more on previous language regularities and reading level, whereas RAN is independent and more predictive of the development of reading and writing speed skills.

Appendix 3

Developmental Dyslexia: The Role of Cognitive Profile and its Relationship with Phonological Awareness and Rapid Automatized Naming

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Appendix 4

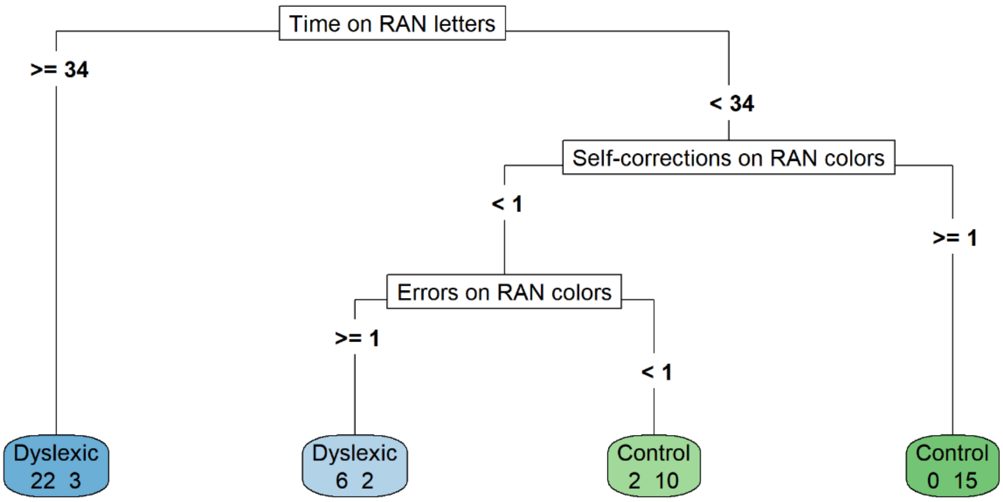

Figure 1 - Regression tree model