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Arabic number writing in children with developmental dyslexia

A escrita de numerais arábicos em crianças com dislexia do desenvolvimento

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Abstract

Number transcoding is a basic numerical processing task that demands verbal skills during its execution. The goal of this study was to investigate number transcoding ability in children with developmental dyslexia. Twenty-three children with typical development and twenty-six children with developmental dyslexia participated in this study. Results showed that children with dyslexia show a deficit in phonological processing as well as in number transcoding. Repeated-measures analysis of covariance indicated that the dyslexia group presented performance below the average in the number transcoding. Regression analyses indicated that short-term verbal memory, phoneme deletion, rhyme judgment task and automatized naming was a strong predictor of number transcoding difficulties. Children with dyslexia present number transcoding deficits regardless of age and educational level.

Keywords: Basic numerical abilities; Dyslexia; Mathematics.

Resumo

A transcodificação numérica é uma tarefa do processamento numérico básico que demanda habilidades verbais durante a sua execução. O objetivo deste estudo foi investigar a habilidade de transcodificação numérica em crianças com dislexia do desenvolvimento. Participaram deste estudo 23 crianças com desenvolvimento escolar típico e 26 crianças com dislexia do desenvolvimento. Os resultados indicaram que crianças com dislexia apresentam um déficit no processamento fonológico e na transcodificação numérica ao longo de todas as séries escolares investigadas aqui. Uma análise de variância de medidas repetidas indicou que o grupo com dislexia apresentou desempenho abaixo da média na transcodificação

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numérica. Análises de regressão indicaram que a memória de curto prazo verbal, a supressão de fonemas, o julgamento de rimas e a tarefa de nomeação seriada rápida foram fortes preditores das dificuldades encontradas na transcodificação numérica. Crianças com dislexia apresentam déficits de transcodificação numérica independentemente da idade e nível de escolaridade.

Palavras-chave: *Habilidades numéricas básicas; Dislexia; Matemática.*

Developmental Dyslexia (DD) is a learning disorder characterized by important difficulties in reading and writing words (American Psychiatric Association, 2014; World Health Organization, 2018). The estimated prevalence for dyslexia ranges from 7% to 17% in school-age children (S. E. Shaywitz & Shaywitz, 2005). From a cognitive point of view, the difficulties observed in children with DD are related to deficits in basic cognitive abilities, especially in phonological processing (Castles & Friedmann, 2014; Kohnen et al., 2018).

There are different hypotheses on the cognitive profile of children with DD, and the most significant ones establish a prominent role of phonological processing skills. Phonological processing is composed of processes of phonological awareness, phonological working memory and lexical access (Wagner & Torgesen, 1987), which are important skills in the decoding of graphic symbols into sounds in speech. A number of studies have shown that phonological skills, particularly phonological awareness, are important predictors of performance in reading and writing tests (Castles & Coltheart, 2004; Elhassan, Crewther, & Bavin, 2017; Kibby, Lee, & Dyer, 2014), and these are impaired in children with DD (Goswami, 2015; Ozernov-Palchik, Yu, Wang, & Gaab, 2016). Thus, children with DD have difficulties in distinguishing, segmenting and recognizing spoken words, in addition to presenting deficits in storage, retrieval and representation of speech sounds (Ramus et al., 2003; Maehler & Schuchardt, 2016). In addition to phonological skills, some studies claim that rapid automatized naming is an important predictor, irrespective of phonological awareness, of children's reading and writing performance (Kibby et al., 2014; Moll et al., 2014) and mathematics performance (Göbel, 2015; Hecht, Torgesen, Wagner, & Rashotte, 2001; Träff & Passolunghi, 2015).

In addition to difficulties in reading and writing words, research has shown that children with DD may present difficulties in mathematics, particularly in tasks that require verbal skills, such as counting, memorizing the multiplication table, performing mental arithmetic, and reading and writing (De Clercq-Quaegebeur, Séverine, Bruno, Lemaitre, & Vallée, 2018; Moll, Göbel, & Snowling, 2015; Simmons, & Singleton, 2008). In fact, among developmental disorders, comorbidity between DD and developmental dyscalculia is one of the most significant because of the scientific production on the subject and relatively high prevalence, which is estimated at around 32% (Desoete, 2008). Therefore, phonological processing has been pointed out as a common factor between reading disorders and mathematical difficulties (Hecht et al., 2001; Simmons & Singleton, 2008).

One of the most basic numerical skills, learned early in school life, is number transcoding, which consists of converting the different number notation systems (Moura et al., 2015). Number transcoding imposes difficulties mainly for children in early school life, and who still do not dominate the place-value syntax of Arabic numbers (Moura et al., 2013; Moura et al., 2015). An important aspect is that transcoding is a point of intersection between numerical skills and verbal phonological skills due to the relationship between verbal and numerical cognitive processes (Lopes-Silva, Moura, Júlio-Costa, Haase, & Wood, 2014).

The study of number transcoding should take into account the lexical and syntactic components of number words. The numerical lexicon consists of units (0 to 9), tens (30 to 90), teens (16 to 19 in Portuguese), hundreds (100 to 900) and thousands. There are also particular cases, that is, numbers that have their own verbal names, which are unrelated to others within the same lexical category, such as numbers *onze* (eleven), *doze* (twelve) and *quinze* (fifteen), which differ from the other teens, and *vinte* (twenty). An important difference is how the syntax of verbal number and Arabic numerals are structured. The syntax of verbal numbers is organized by additive and multiplicative rules. The additive rule indicates a sum relation between numerals (e.g., in Portuguese, in number *vinte e cinco*, the 'e' (and) denotes the addition between twenty and five) and the multiplicative component indicates a multiplication relation (e.g., in number *quatrocentos* (four hundred), there is a multiplication between four and one hundred). Despite these regularities, the structure of verbal numbers ranges among different languages, and this variation influences number transcoding performance (Van Rinsveld & Schiltz, 2016). The Arabic system, on the other hand, is constant among the different languages and its main characteristic is the place-value syntax based on powers of 10. The differences between the syntax of verbal and Arabic numbers represent the main difficulties that children face at the beginning of school life (Moura et al., 2013, Moura et al., 2015; Zuber, Pixner, Moeller, & Nuerk, 2009).

Barrouillet, Camos, Perruchet, and Seron (2004) developed the Developmental, Asemantic, and Procedural model of number Transcoding (ADAPT) model as a proposal to explain transcoding numbers from oral verbal to Arabic form. According to the model, transcoding is an asemantic process, that is, its production system is based on computational algorithms that does not require access to the semantic meaning of numbers. According to the model, syntactically more complex numbers (e.g., 2065) would require more transcoding steps or production rules than simpler numbers (e.g., 25). An advancement achieved by the ADAPT model is taking into account the role of phonological skills and the working memory in number transcoding. According to the model, the verbal forms, after brief storage in the phonological buffer, are decomposed into smaller units, which are manipulated and converted by the production system into the Arabic form. Simpler or more frequent numbers can, after buffering, have their Arabic form retrieved directly from long-term memory.

According to Moeller, Pixner, Zuber, Kaufmann, and Nuerk (2011) and Lambert and Moeller (2019), learning the place-value syntax early in elementary school is a good predictor of more complex calculations in years to come. In children with mathematical difficulties, studies have shown that difficulties in comprehending place-value syntax persist even after the third grade of elementary school (Moura et al., 2013; Moura et al., 2015). Some studies have also found that one of the underlying causes for the difficulty in number transcoding is related to phonological cognitive processes, particularly the verbal working memory (Camos, 2008; Lopes-Silva et al., 2014; Moura et al., 2013).

Few studies have investigated the performance of number transcoding in children with dyslexia. Recently, a study by De Clercq-Quaegebeur et al. (2018) observed that children with dyslexia have mathematical-related deficits, including number transcoding. Other authors have reported case studies of transcoding deficits in patients with brain injury or degenerative diseases (Benavides-Varela et al., 2016; Cipolotti, Warrington, & Butterworth, 1995; Dotan & Friedmann, 2018).

The aim of the present study was to investigate Arabic number writing through dictation in children with developmental dyslexic profile, and how the performance of these children is related to the phonological processing. In addition, we have also investigated the nature of the difficulty in number transcoding, that is, if they arise due to difficulties related to the lexical or syntactic contents of number.

Method

The study was approved by the Research Ethics Committee (CEP-UNB), report No 2.263.519, of the *Instituto de Ciências Humanas da Universidade de Brasília* (Institute of Human Sciences of the University of Brasília) in partnership with the *Secretaria de Saúde do Distrito Federal* (Health Department of the Federal District).

Participants were not diagnosed with psychiatric or neurological disorders nor had been deprived of education. The children in the Dyslexia Group (DG) were recruited from the language clinic of a public hospital in the city of *Brasília*, Federal District, where they received care for language and learning difficulties, and the Control Group (CG) was recruited from a public school in the same city.

The inclusion criterion for the general sample was children and adolescents, Portuguese language speakers, in the age group 7-16 years. The inclusion criteria for the DG were absence of intellectual deficits, characterized by performance above z score of -1.5 on the Raven Test, and significant difficulties in reading isolated words, characterized by performance below the 5th percentile in the word reading task. The inclusion criteria for the CG were children with no difficulties in reading words and absence of intellectual deficits. All tests were applied in a single session that lasted 60 minutes. Psychology students from the University of *Brasília* helped apply the tests. Each test will be explained in detail.

Number transcoding. Writing task of Arabic numbers through dictation, based on the tasks published by Moura et al. (2013) and Moura et al. (2015). In all, 81 numbers from 1 to 4 digits were dictated at different levels of complexity. The complexity of each number was based on the number of transcoding rules (procedures) determined by the ADAPT model. The task was applied collectively in the CG and individually in the DG.

Intelligence. The RAVEN colored matrices test – adapted version to Brazilian Portuguese (De Paula, Schlottfeldt, Malloy-Diniz & Mizuta, 2018) was used to assess fluid intelligence. Gross scores were transformed into Z-scores using the mean and standard deviation reported in the test manual.

Corsi cubes task (Corsi, 1973). Short-term spatial memory was measured by forward retrieval and the working memory was measured by backward retrieval. The total score was calculated, and the total of correct answers for each task was multiplied by the span.

Word reading. Word and Pseudoword Reading Test (WPR, Salles, Piccolo, Zamo, & Toazza, 2013) was applied individually on a computer screen. The 2.5 percentile was adopted as the cut-off point, which is e*quivalent to 1.6 standard deviations bellow mean.*

Rhyme-judgment task. An experimental paradigm (Freitas, 2009) composed of pairs of picture stimuli. Participants should say whether or not the names of the pictures rhymed. The stimuli consisted of 3 training items and 30 test items. The stimuli were presented on a computer screen.

Phoneme suppression task. A series of words were spoken to the participants individually. The instructions were for the participants to repeat the word they had heard, excluding the requested phoneme of the word. The task consisted of 28 items. Participants underwent a training phase containing 4 items.

Digit Span. This task assesses short-term verbal memory and verbal working memory (Figueiredo & Nascimento, 2007). Short-term memory was measured in the forward retrieval and the working memory was measured by backward retrieval.

Rapid Automatized Naming (RAN) tasks. The rapid automatized letter, color, picture and number naming tasks (Wagner, Torgesen, & Rashotte, 1999) were applied individually. Each task was composed of 6 repeated pictures, letters, colors or digits, totaling 72 items divided into two boards with 36 items each. A timer was used to measure response time. The stimuli contained 9 items per line. Errors were not computed.

Data were analyzed using IBM®SPSS® Statistics (version 23.0). All effects were investigated using the t-test for independent samples or factorial ANOVA. When necessary, age (in months) and intelligence were included as covariates in the ANOVA models. A minimum significance level of 0.05 was adopted to identify differences between the groups. Regression analyses were performed to test the predictor variables of performance of the transcoding task and the types of errors committed by children during the task.

Results

The initial sample consisted of 80 participants, 24 in the CG and 56 in the DG. All the participants were Brazilian and Portuguese speakers with ages ranging from 7 to 12 years (*M* = 9.33; *SD* = 1.20). A score of one 1.5 standard deviation below the group mean was adopted as cutoff point for the exclusion of participants with impaired performance in neuropsychological tasks. In the CG, children were excluded if the results in the reading task were below the cut-off point. In the DG, a total of 30 children were excluded, of which 13 children were excluded due to their performance below z-score -1.5 in the Raven test, 13 children because they presented performance above the 5th percentile in the WPR, and 4 children because they did not complete the number transcoding and phonological processing tasks.

The final sample consisted of 49 children of both sexes. The CG was composed of 23 children aged 7-10 years ($M = 8.69$; $SD = 0.92$) and the DG was composed of 26 children aged 8-12 years ($M = 9.88$; $SD = 1.14$). A *t*-test revealed that the children in the DG presented a significantly higher mean age than those in the CG ($t = -3.96$, $p < 0.001$, $SD = 1.14$).

The children were also classified into three levels of schooling to adjust the reduced size of the DG sample; level I was composed of the children enrolled in the 3rd grade (CG: $n = 10$; DG: $n = 10$), level II with children in the 4th grade (GC: $n = 7$; GD: $n = 8$), and level III with children in the 5th and 6th grade (CG: $n = 6$; DG: $n = 8$).

In addition to the difference in age, the two groups also presented significant and strong intelligence differences, with higher scores in the CG ($t = 3.31$, $p < 0.05$, $SD = 0.94$). Despite this, all participants in both groups were classified within the normal range, according to the test manual. Based on these results, all the following analyses will include age (in months) and the Raven score (standardized according to the manual) as covariables.

The reading task was analyzed by the general performance of participants and their performance in reading regular, irregular words and pseudowords. The analysis of total reading performance revealed, as expected, significantly higher scores in the CG (F [1; 49] = 96.17; $p < 0.001$; $\eta_p^2 = 0.68$). Next, the results obtained in the phonological processing and working memory assessments will be discussed.

In the Corsi cubes task, the two groups presented similar performances for forward (F [1; 45] = 0.24, $p = 0.63$, $\eta_p^2 = 0.005$), and backward retrieval (F [1; 45] = 3.78, $p = 0.06$, $\eta_p^2 = 0.08$), but with magnitude of effect between mild and moderate.

In the phoneme suppression task, the children in the DG presented a significantly lower performance than those in the CG (F [1; 45] = 129.30, $p < 0.001$, $\eta_p^2 = 0.74$). In the rhyme-judgment task, DG presented below-average performance compared with CG (F [1; 45] = 29.25; $p < 0.001$; $\eta_p^2 = 0.39$). The forward retrieval of the Digit Span task, the DG presented significantly lower scores than those in the CG (F [1; 45] = 16.36; $p < 0.001$; $\eta_p^2 = 0.27$). In backward retrieval, the same result was observed (F [1; 45] = 15.25; $p < 0.001$; $\mu^2 = 0.25$).

In the picture naming task, DG presented below-average performance compared with CG (F [1; 45] = 13.19, $p = 0.001$, $\eta_p^2 = 0.23$). In all RAN tasks, the children in the DG presented a higher mean reaction time than those in the CG. In the RAN picture naming task, there was a significant difference between the groups (F [1; 45] = 30.08; $p < 0.001$; $\eta_p^2 = 0.40$). In the RAN letter task, a significant difference was also observed (F [1; 45] = 34.25; $p < 0.001$; $\eta_p^2 = 0.43$). In the RAN color task, the results showed a significant effect (F [1; 45] = 19.89; $p < 0.001$; $\eta_p^2 = 0.30$). The RAN number task revealed a difference between groups (F [1; 45] = 19.09; $p < 0.001$; $\eta_p^2 = 0.30$). All tasks presented high magnitude of effects. To analyze the influence of syntactic complexity of dictated numbers on the performance of children, repeated-measures ANCOVA was used, adopting the numerical complexity as an intra-subject factor (2 to 7 transcoding rules), the group as a between-subject factor (CG and DG) and the school level (levels I, II or III). Since the school level factor correlates with age, only intelligence was included as a covariate. As the transcoding task has a different number of items in each level of syntactic complexity, the dependent variable of the analysis was the proportion of correct answers in each of these levels.

The analysis revealed a significant effect for syntactic complexity (F [5; 210] = 48.94; $p < 0.001$; $\eta_p^2 = 0.54$), with scores decreasing as syntactic complexity increased. A contrastive analysis revealed significant differences among all levels of complexity (all *p's* < 0.05).

A significant effect for school level (F [2; 42] = 12.01; $p < 0.001$; $\eta_p^2 = 0.36$) was also observed, with a contrast analysis revealing a significant increase in the scores between levels I and II of schooling ($p < 0.001$), but not between levels II and III of schooling ($p = 0.609$). A significant group-factor effect (F [1; 42] = 74.61; $p < 0.001$; $\eta_p^2 = 0.64$) revealed generally higher scores in the CG compared in the DG. In addition, the analysis revealed a significant interaction between syntactic complexity and the group (F [5; 210] = 26.28; $p < 0.001$; $\eta_p^2 = 0.38$), indicating that the complexity effect was different in each group. In order to investigate this interaction, ANCOVA was used separately for each group, without the group factor included. The effect of numerical complexity was significant in the CG (F [5; 95] = 5.74, $p < 0.05$, $\eta_p^2 = 0.23$) and in the DG (F [5; 110] = 35.64; $p < 0.001$; $\eta_p^2 = 0.62$), but revealed a higher magnitude in the second group. Finally, a significant interaction was also observed between the school level and the group (F [2; 42] = 11.64; $p < 0.001$; $\eta_p^2 = 0.36$), indicating that the effect of schooling was different in each group. This interaction was further investigated using two ANCOVAs for each group. The results of these analyses only revealed a significant effect for schooling level in the GD (F [2; 25] = 11.95; $p < 0.001$; $\eta_p^2 = 0.52$). Figure 1 shows the effects of numerical complexity, group and grades on the number transcoding task.

Linear regression models were tested to investigate the predictive power of phonological processing variables in number transcoding. For this analysis, standardized residual scores were used after removing the age effect (in months) from the phoneme suppression tasks, rhyme-judgment task, and the RAN number and picture naming tasks. The analysis was performed using the stepwise method.

The results revealed a significant model (F = 60.21, $p < 0.001$) explaining 71% of the variance (adjusted R^2). The variables with significant predictive power were the phoneme suppression task ($b = 0.58$, $t = 5.80$, $p < 0.001$) followed by the RAN letter task ($b = -0.36$, $t = 3.61$, $p < 0.01$). The same analysis was performed separately for the groups. In the CG, the model was significant (F = 6.14, $p < 0.05$, adjusted $R^2 = 0.19$), and the only significant predictor was the phoneme suppression task ($b = 0.08$, $t = 2.48$, $p < 0.05$). In the DG, the model was also significant (F = 12.26, $p < 0.001$, adjusted $R^2 = 0.47$), and the phoneme suppression task ($b = 0.54$, $t = 3.63$, $p < 0, 05$) and the RAN number task ($b = -0.36$, $t = 2.42$, $p < 0.05$) were significant predictors. As it can be seen, the phoneme suppression task was the only predictor present in the two groups that best explained the variance of the data (modified R^2 ranging from 0.11 to 0.64).

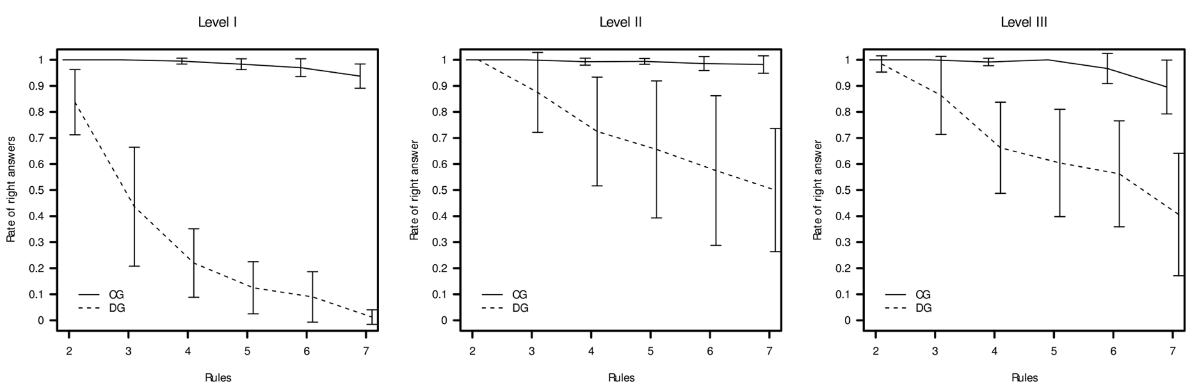

Figure 1. Effects of numerical complexity, group and educational level on number transcoding performance.

The errors in the number transcoding task were classified as syntactic and lexical errors. Lexical errors occur whenever a number is erroneously retrieved, for example, when ‘seven’ is written as ‘6’ or when ‘thirteen’ is written as ‘30’. Syntactic errors, in turn, occur due to the violation of principles in the syntactic composition of Arabic numbers, for example, when ‘three hundred’ is written as ‘30’, or when ‘one thousand three hundred twenty-nine’ is written as ‘1000300209’. These errors are usually more frequent in children and they are used as an indicator of the knowledge of the place-value syntax of the Arabic numbers (Camos, 2008; Moura et al., 2013).

In all, a total of 1149 errors were classified, of which 430 were lexical errors and 719 were syntactic errors. It is important to note that the same answer may contain more than one type of error, and therefore the number of errors analyzed is greater than the number of wrong answers obtained in the study.

In the CG, a total of 24 errors were committed, corresponding to approximately 2.0% of the total errors classified, which were divided into 16 lexical errors (66.7%) and 8 syntactic errors (33.3%). In the DG, in turn, 1125 errors were committed, approximately 98% of the total errors analyzed in this study, which were divided into 414 lexical errors (36.8%) and 711 syntactic errors (63.2%). A higher rate of lexical errors was observed in the CG compared with syntactic errors, but the opposite occurred in the DG, as the Fisher’s exact test revealed ($p < 0.01$, odds ratio = 3.43).

The repeated-measures ANCOVA was used, adopting the type of error as intra-subject factors (lexical or syntactic errors), and the group (GC and GD) and level of education (I, II and III) as a between-subjects factor. The Raven test was used as a covariate.

This analysis revealed a significant effect for error type (F [1; 42] = 12,34; $p < 0{,}01$; $\eta_p^2 = 0{,}23$), which indicated a higher frequency of syntactic errors; a group effect (F [1; 42] = 44.83, $p < 0.001$; $\eta_p^2 = 0.52$), which indicated a significantly higher frequency of errors observed in the DG, and a significant school level effect (F [2; 42] = 8, 77, $p < 0.01$, $\eta_p^2 = 0.29$). In the last effect, a contrast analysis indicated a significant difference between the first and second levels of schooling ($p < 0.001$), but not between the second and third levels ($p = 0.99$). A significant interaction between type of error and group (F [1; 42] = 5.80; $p < 0.05$; $\eta_p^2 = 0.12$) was observed, indicating that the effect of the type of error was different between the groups. Post-hoc tests with Bonferroni correction showed that in the CG there is a similar frequency of lexical and syntactic errors ($t = 1.36$, $p = 0.19$), while in the DG the frequency of syntactic errors is significantly higher than frequency of lexical errors ($t = 3.96$, $p = 0.001$). No other interactions reached statistical significance. (Figure 2)

Linear regression models were also tested to test the cognitive predictors of lexical errors in number transcoding. The analysis was performed by the stepwise method, following the same procedures for previous regressions. The analysis resulted in a significant model (F = 27.94, $p < 0.001$), explaining 53% of the variance. The RAN number task ($b = 0.46$, $t = 4.15$, $p < 0.001$) and phoneme suppression task ($b = -0.40$, $t = -3.62$, $p < 0.001$) were the variables that presented significant predictive power. Next, regression analysis was performed for the two groups separately. The CG did not present any significant predictors due to the reduced number of lexical errors in this group. In the DG the model (F = 12.88, $p < 0.001$, adjusted R^2 = 0.49) the predictive variables were forward retrieval of the Digit Span task ($b = -0.50$; $t = -3.36$; $p < 0.01$) and the RAN number task ($b = 0.41$, $t = 2.79$, $p = 0.01$).

A stepwise linear regression model was also used for syntactic errors. The model explained 67% of the variance (F = 33.22, $p < 0.001$). This model indicated that the best predictors were the phoneme suppression task ($b = -0.79$, t = -6.25, $p < 0.001$), the RAN number task ($b = 0.32$, $t = 3.44$, $p = 0.001$) and the rhyme-judgment task ($b = 0.28$, $t = 2.36$, $p < 0.05$). Then, a regression analysis was performed for CG and DG. The analysis revealed that the significant model in the CG (F = 14.44, $p = 0.001$) explained 38% of the

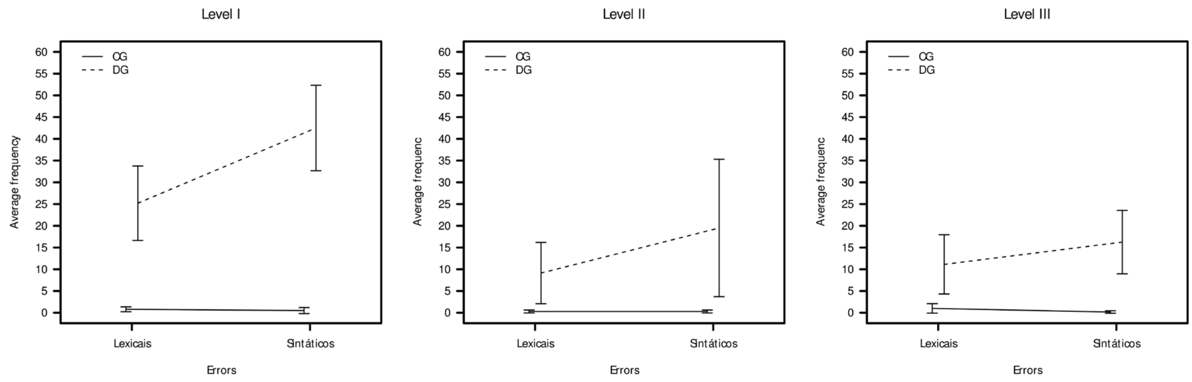

Figure 2. Lexical and syntactic errors observed per group and educational leve.

variance, indicating the phoneme suppression task as a significant predictor of syntactic errors (b = -0.64, t = -3, 80, p = 0.001). In the GD, the model was also significant and it explained 48% of the variance (F = 8.62, p = 0.001), and the predictors were the phoneme suppression task (b = -0.69, t = -2.82, p = 0.001), RAN number task (b = 0.34, t = 2.32, p < 0.05) and rhyme-judgment task (b = 0.39, t = 2.21, p < 0.05).

Discussion

This study sought to observe and understand the performance of children with DD in the number transcoding task. The results indicate that children with a dyslexic profile, which were characterized by significant phonological difficulties, difficulties in writing Arabic numbers, from the simplest to the most complex forms. Moreover, these difficulties cannot be explained by any differences in the intelligence or age of the groups. These results will be discussed in more detail below.

Our results showed that children with DD present a delay in learning the necessary procedures for transcoding syntactically more complex numbers. Furthermore, although children with DD had an increase in scores throughout school years, this difficulty seemed to persist during the first years of elementary school. The exception was simpler numbers, composed of 1 or 2 digits, for which the children with DD showed similar performance to the children with typical development after the first grade of elementary school.

The errors committed by the children in the transcoding task were classified as lexical and syntactic errors. No significant difference was observed in the frequency of lexical and syntactic errors in the CG, indicating that this group of children has no significant difficulties in writing numbers early in elementary school. This finding is not in agreement with other studies reported in the literature (Moura et al., 2013, Moura et al., 2015; Seron, Deloche, & Noël, 1992), which suggest that even children with typical performance do not present a ceiling effect in the first year of education and improve performance over the next few years. This difference in findings can be explained, in part, by the socioeconomic level of families or pedagogical differences among schools. These variables were not investigated in the present study and further research should be conducted. Children with DD, on the other hand, presented significantly higher rates in both classes of errors, and with a significantly higher proportion for syntactic errors compared with lexical errors. This finding is consistent with several other studies investigating children with typical development (Camos, 2008) and children with mathematics learning difficulties (Moura et al., 2013).

The linear regression models helped to further understand the observed errors. Regarding lexical errors, the performance of children with DD was better explained by verbal short-term memory and rapid automatized number naming. As for the short-term memory, this result is in agreement with the one predicted by the ADAPT model, which assumes that the first stage of processing involves storing the input in a phonological buffer. The presence of a predictor related to fast naming also finds support in the literature. Some models of phonological processing suggest that rapid automatized letter and number naming requires direct access to the lexicon where representations of these stimuli are stored (for an alternative proposal on the construct measured by fast-naming tasks, see Justi, Roazzi, and Justi (2014). This is the first publication that shows an association between the occurrence of lexical errors in number transcoding and lexical access difficulties and adds further evidence to the hypothesis that children with phonological deficits have difficulties in basic numerical skills, training or access to the numerical lexicon.

Regarding syntactic errors, the results observed also contribute to the scientific literature. In this case, in addition to fast naming, a general model indicated that phoneme suppression and rhyme-judgment tasks, which are widely acknowledged tasks that assess phonological processing, are important predictors. This finding is in line with, for example, findings that show the important role of phonological awareness in mediating between verbal working memory and number writing performance (Lopes-Silva et al., 2014). In the present study our conclusion argued that phonological awareness is more important as children process the syntactic composition of numbers during transcoding. In addition, the results in our analysis were similar for the two groups of children.

The present study suggests that children with DD present significant and persistent difficulties in number transcoding and that this deficit is strongly influenced by phonological processing. Similarly, the RAN letter and number tasks were important for the performance of number transcoding, as it plays an important role in the later mathematics performance, as it has been pointed out by scientific evidence (Hecht et al., 2001).

The present study has a strong applicability for transcoding to be investigated in clinical and educational contexts. Furthermore, studies with groups of different samples of dyslexic profiles, and studies with samples of children with reading and writing difficulties, and children with mathematics difficulties may more precisely indicate the specificities of the difficulties observed in each case.

Contributions

R.M. TEXEIRA worked on the study conception, data collection, data analysis, data interpretation and manuscript writing. R. MOURA worked on the study conception and design, data analysis, data interpretation and manuscript revision.

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