Dyslexia and reading development in transparent orthographies

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Abstract

In an opaque orthography like English, phonological coding errors are a prominent feature of dyslexia. In a transparent orthography like Spanish, reading difficulties are characterized by slower reading speed rather than reduced accuracy. In previous research, the reading speed deficit was revealed by asking children to read lists of words. However, speed in list reading sums the time required to initiate an utterance (reaction time, RT) with the time required to say it (response duration, RD). Thus, the dyslexic speed deficit in transparent orthographies could be driven by slow RTs, by slow RDs or both. The distinction is especially important if developmental readers rely on phonological coding to achieve lexical access because the whole word would have to be encoded before it could be identified. However, while the factors that affect reading RT have been extensively investigated, no attention has been paid to RD. We studied the performance of typically developing and dyslexic Spanish children in an oral reading task. We analyzed the impact of word frequency and length on reading accuracy, RT and RD. We found that both RT and RD were affected by word frequency and length for both control and dyslexic readers. We observed interactions between effects of reader group (dyslexic, typically developing (TD) younger or TD older readers) and effects of lexicality, frequency and word length. Our results show that in transparent orthographies children are capable of reading strategy flexibility, using lexical and non-lexical coding processes.

[abstract = 240 words]

Keywords: reading; development; dyslexia; transparent; orthography; speed

Reading development in transparent orthographies

Developmental reading difficulties in transparent orthographies are characterized by speed not accuracy problems, in contrast to dyslexic reading in opaque orthographies for which accuracy problems are much more prominent (Wimmer, 1993). The observation that dyslexic reading in transparent orthographies is not characterized by accuracy problems is explained by assuming the same cause used to explain, also, the observation that reading acquisition happens more quickly in transparent than in opaque orthographies: spelling-sound consistency. Numerous studies have shown that where spelling-sound mappings are highly consistent, as in transparent orthographies like Spanish, Italian and so on, there the typical course of reading development ends in accurate foundation level reading within the first school year (Seymour, Aro, & Erskine, 2003): a much faster rate than that seen in English (see, also, consistent results obtained in cross-linguistic comparisons reported by Bruck, Genesee, & Caravolas, 1997; Ellis & Hooper, 2001; Frith, Wimmer, & Landerl, 1998; Goswami, Gombert, & Barrera, 1998; Wimmer & Goswami, 1994). The explanation for the difference in acquisition rate, as for the apparent limitation of reading difficulties to speed problems, is that transparent orthographies permit accurate phonological coding just so long as grapheme-phoneme correspondences are mastered. In comparison, in an opaque orthography like English, mastering grapheme-phoneme correspondences does not afford accurate coding of irregular exception words, due to the variation in, especially, the pronunciation of vowel letters.

Wimmer's (1993) observation that dyslexics reading in German were distinguished by slower reading speed not by lesser reading accuracy, in comparison to controls, has been repeated in a number of studies (e.g. Wimmer & Mayringer, 2002), and in other languages (Dutch, Yap & Van der Leij, 1993; Greek, Porpodas, 1999; Italian, Zoccolotti, De Luca, Di Pace, Judica, & Orlandi, 1999; Spanish, Davies, Cuetos, & Glez-Seijas, 2007; Gonzalez & Valle, 2000). Wimmer and colleagues (Bergman & Wimmer, 2008; Wimmer et al., 2010) have suggested that slowed dyslexic reading in a transparent orthography like German results from the slow activation of phonology. In terms of the dual-route model of reading (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001), Bergman and Wimmer (2008) blamed slowed reading on both (1.) slower lexical phonological coding, *i.e.*, slower activation of phonological word representations given orthographic word activation, and (2.) slower grapheme to phoneme conversion in the sub-lexical route.

The speed deficit account of dyslexia in transparent orthographies ties slower reading to slower phonological coding but it is not clear what factors determine the rate of coding. The lack of clarity comes, in part, from the conflation of response latency and response duration. The original observations showing the speed deficit in various languages relied on the list reading task, in which children are asked to read words printed as a list on the page (e.g. in Spanish, Davies et al., 2007; in German, Wimmer, 1993). This task has the advantage that it mimics natural reading. However, list reading times sum both the time between stimulus onset and response onset (response latency or reaction time, RT) and the time required to produce the response (response duration, RD). While there is substantial evidence concerning the factors that affect reading RTs, including those recorded for children, there is no evidence on the factors that influence RDs in developmental reading in any language, let alone in Spanish. The first aim of our investigation, therefore, was to examine the effects of item attributes on reading RTs and RDs.

What should our expectations be? There is ample evidence to suggest that RT is influenced by lexical and sub-lexical factors in children's reading in transparent orthographies. Though most of the relevant data come from work in Italian, the results should adequately delimit our expectations concerning Spanish given the similarity of the Italian and Spanish orthographies, as well as the congruence of indications from other measures of reading performance in Spanish. Burani, Marcolini and Stella (2002) found that word frequency and length affected the reading of 8- and 10-year old Italian children in lexical decision and word naming tasks (see, for consistent results on frequency in an older developmental sample, Barca, Burani, Di Filippo, & Zoccolotti, 2006). For word naming, Burani et al. (2002) observed that while the frequency effect did not vary by age, the length effect was found to be smaller for older children. The decrease in length effect with increasing age was also observed by Zoccolotti, de Luca, Di Pace, Gasperini, Judica and Spinelli (2005; see, also, De Luca, Barca, Burani, & Zoccolotti, 2008; Zoccolotti et al., 1999), who tested dyslexic (mean age = 8.4 years) and typically developing readers (aged 6.8 – 8.7 years).

The frequency effect is argued to reflect the functioning of a lexical phonological coding route, with frequency scaling the activation function for lexical units in the dual-route model of reading (Coltheart et al., 2001; see Seidenberg & McClelland, 1989, and Adelman, Brown, & Quesada, 2006, for alternate accounts of the frequency effect). Zoccolotti et al. (2005) proposed that the Burani et al. (2002) findings on frequency suggest that a lexical reading route is already functioning by the third grade. The frequency effect appears to be smaller in more skilled readers, when comparing dyslexic with typically developing children (Barca et al., 2006). However, frequency effects continue to be observed in the reading of Italian-speaking adults (Barca, Burani, & Arduino, 2002; Burani, Arduino, & Barca, 2007), suggesting that a lexical reading route is established fairly early and then remains in operation through the lifetime of a reader in a transparent orthography.

The length effect has been argued to reflect the serial phonological coding of graphemes by the non-lexical reading route (Coltheart et al., 2001; Weekes, 1997). Zoccolotti et al. (2005) suggested that because the length effect diminished substantially between first and second grade readers, lexical coding largely displaces non-lexical in determining RTs in word naming. And because the length effect in dyslexic readers resembled that seen in younger controls, non-lexical coding may remain a dominant strategy for children with reading difficulties.

Findings in Spanish indicate similar effects on other performance measures compared to those reported for Italian reading RT. Defior, Justicia and Martos (1996) reported effects of both word frequency and length on reading accuracy in typically developing and dyslexic Spanish-speaking children aged 6-12 years. An effect of frequency on accuracy was also noted for the reading of Spanish dyslexic children (aged 9-10 years) by Rodrigo López and Jiménez González (1999). And Davies et al. (2007) reported effects of word frequency, length, and orthographic N-size on word list reading times. These effects are largely replicated in analyses of Spanish-speaking adults' reading RTs (Cuetos & Barbón, 2006), indicating the development and continuing use of lexical and non-lexical reading routes in Spanish.

We are not aware of any study of the factors that influence response duration in developmental reading in any language. However, some previous research does offer clues as to what effects can be expected. Firstly, it appears that the duration of whole word spoken responses in reading are shortened if target words are preceded by semantically related primes (Balota, Boland & Shields, 1989; see, also, Kawamoto, Goeltz, Agbayani, & Groel, 1998). Secondly, it has been reported that the duration of a spoken word response in a lexical decision task is shorter for high compared to low frequency words (Balota & Abrams, 1995). To be clear, in Balota and Abrams's (1995) study, stimulus words varied in frequency but participants were required to say a single word (e.g. "normal" in E3) in response to a stimulus, and it is the duration of that response that varied with stimulus frequency. Nevertheless, taken together, these findings contradict the separation between response preparation and response execution that is usual in reading models. The frequency effect on response duration is inconsistent with the assumption that the frequency effect is confined to a locus, in lexical activation, 'upstream' of the events surrounding response execution (Balota & Abrams, 1995) because lexical frequency continues to influence response execution even after response onset. And the priming effect on response duration is inconsistent (in Kawamoto et al.'s, 1998, account) with the assumption that a response is initiated (as in the dual-route model, Coltheart et al., 2001) when phonological coding has been completed and all phonemes are available, *i.e.*, when the activation of all is above threshold. This is because priming should not influence pronunciation if pronunciation is simply the articulation of a phonological code, a set of phonemes simultaneously and entirely activated at response onset. Results like those reviewed imply a cascaded flow of activation from stages dominated by access to and processing of lexical representations to later stages focused on response production (Balota & Yap, 2006). For our study, previous research suggested we should find word frequency and length effects in word naming RDs.

<u>The present study</u>

In the present study we examined the factors that influence oral reading performance in Spanish-speaking children. We presented words or non-words in discrete trials rather than word lists. For the first time, to the best of our knowledge, both reaction time and response duration measures of children's reading performance were subject to analysis. Our analyses were designed to estimate the effect on RT, RD and accuracy of item attributes, including length for all items, as well as frequency for words. We examined reading in Spanish dyslexic children and in two groups of typically developing readers, one matched on chronological age to the dyslexic readers, and the other composed of younger readers (in the first grade of primary school).

Method

Subjects

We recruited nine dyslexic children (7 males, 2 females) and 20 children of typically developing reading ability (12 females, 8 male) from schools in the city of Oviedo and surrounding areas. Participant characteristics are summarized in Table 1. The nine dyslexic children attended the speech and language therapy clinic managed by PS, where they were receiving remedial instruction in reading or spelling averaging one hour per week. The 20 controls were recruited from public schools in Oviedo. For these children, selection to the study was based on teacher ratings of typical literacy development. No child was included if she was known to have received a diagnosis of neurological abnormality.

(Table 1, about here)

We collected information on children's reading level and intelligence using the word and non-word sub-tests of the PROLEC-R standardized literacy test (Cuetos, Rodríguez, Ruano, & Arribas, 2007) and the Spanish version of the Wechsler Intelligence Scale for Children-R (WISC-R; Wechsler, 1974), the EIWN-R (Wechsler, 1982). No child scored less than 80 on the performance scale of the EIWN-R.

In the PROLEC-R reading sub-test, a list of 40 printed words, varying in length, frequency and syllable structure, and a list of 40 non-words, varying in length and syllable structure, is presented for reading aloud. Reading accuracy and speed are measured for each list. The dyslexic children in our study were found to read words aloud at a level of accuracy less than the mean minus 2 SD recorded for the standardization sample for their school year. The word reading accuracy for all control children was within normal limits according to the same criterion. All but one of the dyslexic children read non-words at a level of accuracy less than the standardization sample mean minus 2 SD for their age (the exception child's non-word accuracy was less than the mean for his age minus 1.5 SD). All the control group children read within normal limits according to the same criterion.

The typically developing (TD) children were split into two groups of ten children each: a chronological age match (older TD) group and a younger group (younger TD). The older TD children were matched to the dyslexic children on age and intelligence (EIWN-R, general, verbal and performance indices), $p > 0.10$ for all comparisons. However the older TD children were significantly more accurate and faster in PROLEC-R word and non-word reading ($p < 0.001$ for each comparison) than the dyslexic children. The younger TD controls were in the first year of primary school, compared to the dyslexic and older TD children, who were mostly in the fifth or sixth years. The younger TD children were significantly younger than the dyslexic or the older TD children ($p < 0.001$) but did not differ from either of the other groups on intelligence (all ps > 0.05). The younger TD children were significantly faster and more accurate in word and non-word reading than the dyslexic children ($p < 0.001$ for each comparison).

The TD younger cannot be said to present an ability match to the dyslexic children. However, we could not have found ability matches to our sample of dyslexic children without testing pre-school readers, entailing an unacceptable confound between comparison groups and differences in experience of instruction. It was better, in our view, to bring younger TD readers into the sample in order to afford a cross-sectional comparison between younger and older typically developing readers. In addition, we were able to make a comparison between older dyslexic and younger TD readers that would align reading performance in the dyslexic group with the performance of typical readers in the first year of primary school.

Materials

We selected 80 words and constructed 80 non-words for use in our study. The stimulus words were four, five, six or seven letters in and were of high or low frequency, with ten words selected for each cell in a fully factorial, length by frequency, design. The stimulus non-words were constructed from a set of base-words matched to the stimulus words on frequency and length. Four or five letter words and non-words were two syllables in length, six and seven letter items were three syllables in length. Non-word construction was by single letter substitution preserving the onset bigram of the base-word. Words and base-words consisted of monomorphemic nouns, verbs and adjectives; most items were nouns.

The estimates of lexical frequency values for words and for the base-words corresponding to non-word stimuli were taken from an analysis of texts given to children for reading in school (Martínez & García, 2004). We used as our index of lexical frequency the estimates of the accumulated frequency of occurrence of words experienced in print up to the sixth grade, when children are 11-12 years old in Spain.

Several other item attributes were controlled across the four manipulated cells, including the imageability and Age-of-Acquisition (AoA) of words, as well as the orthographic neighbourhood size of both words and non-words. Imageability data were gathered from the Valle-Arroyo (2001) norms which include average values obtained from the ratings of 135 adults on a 7-point scale. We collected AoA ratings for words (on a 7-point scale) from 20 adult volunteers, undergraduates attending the University of Oviedo. Estimates of the orthographic neighbourhood size (N-size) of words and non-words computed using the BuscaPalabras database (Davis & Perea, 2003). In BuscaPalabras, neighbourhood size is determined by counting the number of words that can be formed by substituting a single letter at any of the letter positions within a word or non-word string, counting as neighbours only entries in the LEXESP adult frequency corpus (Sebastían, Martí, Carreiras, & Cuetos, 2000). Characteristics of the real words presented are summarized in Table 2.

(Table 2, about here)

Words and non-words did not differ on length nor on N-size ($F(1,158) = 0.89$, $p = 0.35$). Words of different length conditions (two or three syllables) did not differ on frequency ($F(1,78) = 0.68$, $p = 0.411$), AoA ($F(1,78) = 1.3$, $p = 0.256$), imageability ($F(1,78) = 0.857$, $p = 0.357$) or N-size ($F(1,78) = 0.51$, $p = 0.822$).

To improve the sensitivity of our analyses and militate against the effect of skew in variable distributions, we transformed word frequency measures to log10(frequency + 1).

Apparatus and procedure

The children were tested in two sessions, in which standardized reading or intelligence tasks were also administered. They saw each critical word or non-word stimulus twice: once in pure lists of word or non-word trials only and once in mixed lists of word and non-word trials. Children were instructed to read items as quickly and as accurately as possible. They were warned if they were going to read words in a pure or a mixed block.

Stimuli were presented and responses recorded using DMDX (Forster & Forster, 2003) on a Windows XP laptop. Stimuli were presented in Arial 10-point type. Children were seated at 30cm from the display screen. The stimuli subtended an average of 4.29 degrees of visual angle at that distance.

Each item was presented twice throughout the experiment, once in each of the two test sessions. Four experimental programs were created. Within each experimental program, 80 items were presented in two blocks of 40 trials each. Items were pseudorandomly assigned to the two blocks such that stimuli high or low in (word or base-word) frequency and length were equally likely to be represented in each block, for each program. The order of administration of the four experimental programs was counterbalanced across participants using a Latin Square design. Then, for each participant, in each test session, the order of presentation of trials within each block and of the blocks themselves was randomized.

Two programs were administered in each test session. A short break was permitted between each block. Each experimental program began with six practice trials. Practice items were selected to have similar characteristics to the critical items. The experimenter answered any questions the participants had following the practice but no further feedback was given thereafter.

An experimental trial had the following sequence of events (timed with respect to screen refreshes): Firstly, there appeared a blank screen for 512ms (event timing is coordinated by DMDX with respect to screen refresh rates or ticks). Then, a black asterisk was presented in the centre of a grey field screen for 512ms. The stimulus replaced the asterisk and was presented for 3072ms. Responses made during the three second response intervals were recorded digitally to hard disk. Each test session lasted 30 minutes in total.

Results

Data extraction

We recorded a total of 9,280 responses. We analyzed sound spectrograms of the recorded responses, using the CheckVocal application (Protopapas, 2007), to extract accuracy, reaction time (RT) and response duration (RD). We analyzed the RTs and RDs of correct responses only.

Analysis strategy

Our investigation had a repeated measures design, with the same items presented to different participants, requiring the use of mixed-effects modelling to accurately estimate effects of theoretical interest while properly accounting for error variance (Baayen, 2008; Baayen, Davidson & Bates, 2008). Mixed-effects models estimate both fixed effects, that is, replicable effects of theoretical interest e.g. of word frequency or reader ability, and random effects, *i.e.*, unexplained effects due to random variation between items or between participants. Mixed-effects modelling supports accurate estimation of interactions between reader type and item attribute effects without running the risk of spurious over-additivity due to differences between readers or between groups of readers in average RT or RD (see Faust, Balota, Spieler, & Ferraro, 1999).

Analysis of accuracy

A summary of the accuracy percentages obtained by each participant group in each condition is presented in Table 3. It can be seen that the level of accuracy in word naming is very high (comparable to that seen e.g. in Seymour et al., 2003), above 80% in all conditions for all children, largely above 90% for the control group TD children.

(Table 3, about here)

We analyzed the accuracy of responses to words or non-words using Generalized-Mixed effects Modelling (GLMM), that is, the mixed-effects extension of multiple logistic regression (Baayen, 2008) in which the aim is to estimate the log odds that a response would be accurate given a set of predictors. Random (intercepts) effects of both subjects and items were required for all reported models.

We first analyzed the accuracy of responses to both words and non-words: reader group (dyslexic, younger TD and older TD children), lexicality (words, nonwords) and word length (in letters) were included as predictors in this model, together with interaction terms representing the interaction between effects of reader group or item attribute. A summary of the results is presented in Table 4. Note that in the tabled model summary, z values indicate that a response is more likely to be correct for unit change in the corresponding factor whereas negative z values indicate that a response is less likely to be correct for unit change.

(Table 4 about here)

We found that older but not younger TD children were significantly more likely to produce correct responses to words or to non-words than dyslexic children. Correct responses were more likely to be elicited by words than by non-words, and shorter items (words and non-words) were more likely to be read correctly than longer items. We also found an interaction such that the lexicality effect on accuracy was greater for older TD children compared to dyslexic readers.

We conducted a separate analysis of childrens' responses to words alone (Table 4). Lexical frequency was now included as a predictor in this analysis, and lexicality was dropped. The accuracy of responses to words was affected by frequency alone: more frequent words were more likely to elicit correct responses.

<u>Analysis of reaction times and response durations</u>

We report, firstly, our analysis of RTs then our analysis of RDs. We transformed the raw RT and RD scores to log (base 10) values, before analysis, to militate against the influence of the marked skew associated with chronometric data (following e.g. Baayen, Feldman, & Schreuder, 2006). We analyzed the RT and RD data using linear mixed-effects modelling. Random (intercepts) effects of both subjects and items were required for all reported models.

Analyses of RTs

Following the same procedure used in the analysis of accuracy data, we first analyzed the latency of all 8,522 correct responses to words or non-words considered together . For models of chronometric data, where t statistics associated with effects are positive this indicates that, in comparison to the overall average, the logRT or logRD increased for unit increase in the predictor variable. Where t statistics are negative this indicates that the logRT or logRD decreased for unit change in the predictor. Following Baayen (2008), we report Markov chain Monte Carlo (MCMC)-derived p-values for effects. We note that MCMC- and t-derived p-values for our analyses largely coincide but the former are slightly more conservative than the latter (Baayen et al., 2008).

A summary of the models of RT is presented in Table 4. We first analyzed the effects on correct response RTs to both words and non-words of reader group (dyslexic, younger TD and older TD children), lexicality (words, nonwords) and item (words and non-words) length in letters, as well as the interaction between effects of reader group or item attribute. We found that, compared to dyslexic readers, response latencies tended to be shorter if readers were older TD but not if they were younger TD children. Words elicited shorter latencies than non-words, on average. A length effect was also obtained with short items eliciting shorter RTs in all the groups. In addition, we found interaction effects such that, compared to dyslexic readers, the effect of item length was less for older TD readers, while the effect of lexicality was less for younger TD readers.

We then analyzed the latency of 4,384 correct responses to just words (Table 4). We found that, compared to dyslexic readers, response latencies to words tended to be shorter if readers were older TD but not if they were younger TD children. We found both word length and frequency effects: shorter and more frequent words tended to elicit shorter RTs. We again found an interaction between the effect of item (word) length and reader group such that the length effect was smaller, compared to dyslexic readers, for older TD readers.

Analyses of RDs

We examined, firstly, the effects on the durations of correct responses to words and non-words of reader group (dyslexic, younger TD and older TD children), lexicality (words, nonwords) and item (words and non-words) length in letters, as well as the interaction between effects of reader group or item attribute (Table 4). We found no effect of reader group but we found significant effects of lexicality and item length. Words elicited shorter RDs than non-words. Shorter items, words and non-words, also tended to elicit shorter durations. These effects were modulated by interactions involving reader group. The effect of item length on RDs was, compared to dyslexic readers, significantly smaller for older TD readers. And the effect of lexicality was, compared to dyslexic readers, significantly smaller for both control groups.

We then analyzed the duration of correct responses to just words. We found no effect of reader group on response duration. We found both word length and frequency effects: shorter and more frequent words tended to elicit shorter RDs. We again found an interaction between the effect of item (word) length and reader group such that the length effect was smaller, compared to dyslexic readers, for older TD readers. We also found an interaction between the effect of word frequency and reader group such that the frequency effect was smaller, compared to dyslexic readers, for older TD readers.

Discussion

Our study explored the factors that influence reading aloud in typically developing and dyslexic readers in a transparent orthography, Spanish. The presentation of words and non-words as well as the manipulation of length and frequency allowed us to estimate effects of lexicality and item attributes, addressing important questions about the reading strategies employed by children reading in transparent orthographies. We found effects of lexicality, item length and word frequency in all analyses, demonstrating the use of both a sub-lexical reading route (whose function is reflected in the length effect) and a lexical route (reflected in the frequency effect) in developmental reading in Spanish. These results are consistent with previous observations on Italian children (e.g. Burani et al., 2002) and adults (e.g,. Burani et al., 2007). The combination of evidence for a lexicality effect with evidence for a frequency effect – for a sample of stimuli that was selected to control an extensive range of confounding variables – conclusively demonstrates the impact of lexical knowledge on reading in a transparent orthography. The observation of these effects in RDs as well as RTs indicates that that lexical influence extends beyond the initiation of responses, consistent with the view that activation cascades through the phonological process in reading (Balota & Yap, 2006).

The length of the items, both words and non-words, appeared to affect accuracy, RTs and RDs of the three groups of participants, reflecting the use of serial non-phonological coding processes (Coltheart et al., 2001; Weekes, 1997) by readers of a transparent orthography. This finding is consistent with a great deal of evidence previously reported for Italian and other languages by Zoccolotti and colleagues (e.g. Zoccolotti et al., 2005), among others. However, the analysis of only word reading revealed that the pattern of effects was a bit more complicated. Word reading RDs were affected by letter length in all groups of participants, implying that not even the more experienced children could avoid the effect of the number of letters on the time needed to pronounce words. Note that item length measured in letters very precisely corresponds to item length in phonemes in transparent orthographies. Older TD readers, however, showed a significantly smaller effect of word length on their reading RTs. The effect on word reading latencies of the interaction between reader group and length suggests that the use of non-lexical information and sequential coding processes, when confronted with words, is more prominent in these younger and less skilled readers than in the older and more skilled TD group.

The analyses of the influence of lexical frequency on reading performance also revealed interesting results, complementary to those obtained by the analysis of the length effect. Word reading RTs for all three groups were affected by lexical frequency. A frequency effect was also observed to influence the duration of the responses of the younger TD and dyslexia groups but not the older TD group. Frequency affected the accuracy of the dyslexic group alone. Thus, frequency seems to be a strong predictor of reading speed in younger typical or older dyslexic developing readers of Spanish. These results demonstrate the use of lexical information in the preparation and execution of phonological coding in a transparent orthography. However, the frequency effect on RDs evidently decreased for older TD readers. We think that this indicates that the reading expertise of the older TD participants tended to be associated with a greater coding efficiency consequent on learning from accumulated reading experience. A diminishing frequency effect with increasing experience is reported by Zevin and Seidenberg (2002) in a connectionist simulation of reading development, and is attributed to the gradual optimization of connection weights, a process of adaptation to experience that tends to narrow the space in which the frequency effect can appear.

When considering the influence of lexical frequency on RTs in developmental reading in Italian, in comparisons of younger and older TD children, the evidence is inconsistent. Whereas Barca et al. (2007) reported a larger frequency effect for younger compared to older TD children, Burani et al. (2002) observed no significant interaction between the effects of frequency and age group or relative reading skills. Those results were obtained with respect to RT. Our results suggest that other dependent measures, like RD, might be more sensitive to the impact of reader age or ability on the frequency effect in reading.

In sum, just as has been found in healthy adults reading in transparent orthographies, in children reading performance depends on a mixture of lexical and sub-lexical knowledge. This is not altogether surprising if one moves away from the emphasis on reading accuracy that has perhaps stemmed, historically, from the accident of beginning the study of reading with the study of reading in English (Share, 2008) a peculiarly difficult, inconsistent, alphabetic orthography. It makes perfect sense if one focuses on reading fluency, here, measured with respect both to the time it takes to prepare an oral response (RT) and the time it takes to say a word (RD), a point that has been made by a number of other authors (since e.g. Wimmer, 1993). Our work extends the evidence base by showing the subtlety of such item attribute effects, and how they are modulated both by differences between readers and by the circumstances of the task.

The RD observations have wider and quite practical implications, however. If lexical access to meaning proceeds at least initially in development through phonological coding of printed words (see Harm & Seidenberg, 2004, for a review of relevant evidence) dyslexic readers will then – in transparent orthographies – have slower access to meaning as a consequence of their slower phonological coding. If response initiation can occur before the phonological code for a word has been completely mapped to response execution processes then, provided meaning access depends on phonological coding, the rate of access to meaning from print will be limited by the capacity of the reader to compute a phonological code for any printed word. In dyslexic readers in transparent orthographies, according to the speed deficit account, and as shown in our data that phonological coding capacity is slow.

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Table 1. Summary of participant characteristics

Test		dyslexic *n = 9* mean	*(SD)*	older TD *n= 10* mean	*(SD)*	younger TD *n = 10* mean	*(SD)*
	age (mths, rounded to nearest mth)	132	*(12)*	124	*(11)*	77	*(6)*
EIWN-R	general intelligence	107.1	*(16.3)*	112.0	*(11.3)*	100.9	*(14.8)*
EIWN-R	verbal intelligence	108.7	*(24.6)*	111.8	*(13.0)*	102.0	*(12.0)*
EIWN-R	performance intelligence	101.3	*(9.4)*	107.9	*(10.6)*	99.4	*(15.7)*
PROLEC-R	word reading accuracy (total correct/40)	29.7	*(5.0)*	39.6	*(0.5)*	38.9	*(0.9)*
PROLEC-R	word reading speed (s)	81.6	*(27.6)*	25.4	*(2.9)*	51.0	*(12.3)*
PROLEC-R	non-word reading accuracy (total correct/40)	25.6	*(6.2)*	37.5	*(0.5)*	37.0	*(0.9)*
PROLEC-R	non-word reading speed (s)	105.8	*(42.9)*	43.6	*(7.1)*	70.7	*(9.0)*

Participant group

Table 2. Summary of the psycholinguistic characteristics of the presented words

	Low Freq.-Short	**Low Freq.-Long**	**High Freq. - Short**	**High Freq. - Long**
Letters (syllables)	4-5 (2)	6-7 (3)	4-5 (2)	6-7 (3)
Frequency: mean (SD)	38.3 (16)	31.7 (16.2)	276.6 (88.1)	235.2 (95)
n	20	20	20	20
AoA: mean (SD)	3.7 (0.6)	3.9 (0.6)	2.9 (0.7)	3.1 (0.7)
Imageability: mean (SD)	5 (0.6)	4.6 (0.9)	5 (1)	4.9 (1.3)
Neighborhood size: mean (SD)	2.6 (1.7)	2.6 (1.3)	2.6 (1.6)	2.7 (1.6)

Table 3. Number and percentages of correct responses as well as means and standard deviations of reaction times and response durations per group and lexicality

DYSLEXIA GROUP

	Words		non-Words		*Total Dyslexia Group*	
Accuracy	1291	(89.7%)	1201	(83.4%)	*2492*	*(86.5%)*
Mean(s.d.) RT	1159	(457.46)	1335	(499.32)	*1247*	*(478.1)*
Mean(s.d.) RD	606	(245.1)	674	(273.88)	*640*	*(259.49)*

YOUNGER TD

	Words		non-Words		*Total Young TD*	
Accuracy	1499	(93.7%)	1392	87.0%	*2891*	*(90.4%)*
Mean(s.d.) RT	1144	(439.76)	1211	(447.44)	*1178*	*(443.6)*
Mean(s.d.) RD	715	(270.6)	771	(296.97)	*743*	*(283.78)*

OLDER TD

	Words		non-Words		*Total Old TD*	
Accuracy	1594	(99.6%)	1545	(96.6%)	*3139*	*(98.1%)*
Mean(s.d.) RT	718	(182.37)	821	(241.72)	*769*	*(212.05)*
Mean(s.d.) RD	560	(112.06)	590	(135.54)	*575*	*(123.8)*

Table 4. Generalized linear mixed effects models of log odds accuracy as well as linear mixed effects models of logRTs and logRDs of correct responses

Accuracy	Words and non-Words		Words only	
	z value		z value	
(Intercept)	6.532	***	3.559	***
Dyslexia vs. Old TD	2.565	*	0.719	
Dyslexia vs. Young TD	-0.537		0.225	
letters	-3.378	***	-1.857	
lexicality	4.484	***		
frequency			3.279	**
group (Dys. vs. Old)*letters	-0.834		0.229	
group (Dys. vs. Young)*letters	1.103		1.032	
group (Dys. vs. Old)*lexicality	3.38	***		
group (Dys. vs. Young)*lexicality	0.783			
group (Dys. vs. Old)*frequency			0.623	
group (Dys. vs. Young)*frequency			-1.172	
Reaction Times				
	t value		t value	
(Intercept)	104.83	***	92.82	***
Dyslexia vs. Old TD	-4.27	***	-3.83	***
Dyslexia vs. Young TD	-0.94		-1.18	
letters	6.26	***	4.87	***
lexicality	-11.48	***		
frequency			-4.97	***
group (Dys. vs. Old)*letters	-3.58	***	-3.01	**
group (Dys. vs. Young)*letters	-0.47		1.19	
group (Dys. vs. Old)*lexicality	1.83			
group (Dys. vs. Young)*lexicality	6.29	***		
group (Dys. vs. Old)*frequency			1.67	
group (Dys. vs. Young)*frequency			1.76	
Response Durations				
(Intercept)	93.47	***	72.76	***
Dyslexia vs. Old TD	1.07		0.43	
Dyslexia vs. Young TD	1		1.41	
letters	21.62	***	14	***
lexicality	-7.5	***		
frequency			-3.13	**
group (Dys. vs. Old)*letters	-7.66	***	-4.35	***
group (Dys. vs. Young)*letters	1.9		1.24	
group (Dys. vs. Old)*lexicality	5.75	***		
group (Dys. vs. Young)*lexicality	3.62	***		
group (Dys. vs. Old)*frequency			2.59	**
group (Dys. vs. Young)*frequency			-0.08	

*** if p =< 0.001; ** if p =< 0.01