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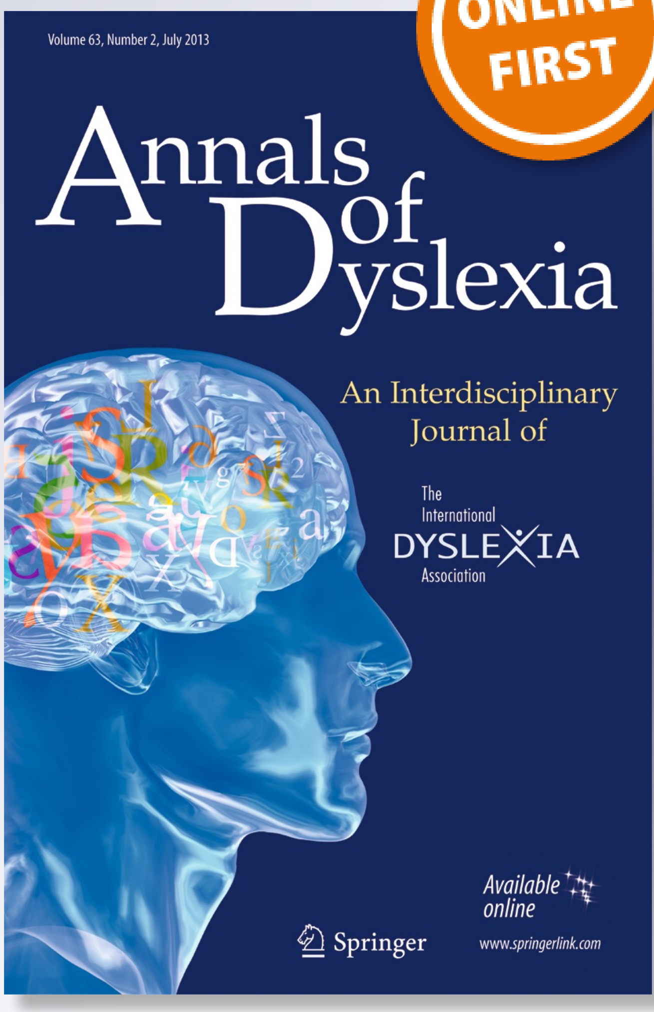

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Beyond decoding deficit: inhibitory effect of positional syllable frequency in dyslexic Spanish children

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Abstract This study explores whether activation and inhibition word processes contribute to the characteristic speed deficits found in transparent orthographies (Wimmer, Appl Psycholinguist 14:1–33, 1993). A second and fourth grade sample of normal school readers and dyslexic school readers participated in a lexical decision task. Words were manipulated according to two factors: word frequency (high vs. low) and syllable frequency (high vs. low). It has been repeatedly found that words with high-frequency syllables require extra time for deactivating the lexical syllabic neighbors: the so-called inhibitory effect of positional frequency syllable (Carreiras et al., J Mem Lang 32:766–780, 1993). We hypothesized that dyslexic readers would show a stronger inhibitory effect than normal readers because they are slower decoders and they may also be slower at the activation and inhibition of word representations that are competing (i.e., syllabic candidates). Results indicated an interaction between word and syllable frequency (i.e., a strong inhibitory effect was found in the low-frequency word condition). According to our hypothesis, the inhibitory effect size was almost three times bigger in dyslexics than in the normal readers. This difference shows an alteration, not a developmental lag. Interestingly, the inhibitory effect size did not interact with school grade. Thus, reading experience did not impact the lexical processes involved on the inhibitory effect. Our outcomes showed how activation and/or inhibition of lexical processes can contribute to the lack of speed beyond decoding deficit.

Keywords Dyslexia · Lexical access · Reading processes · Speed deficit · Syllable

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Abbreviations
SFE Syllable frequency effect
PSF Positional syllable frequency

The predominant etiological view of dyslexia postulates that reading problems are caused by a cognitive phonological deficit (e.g., Snowling, 2000). This deficit exists prior to reading acquisition, and it has been demonstrated in three areas not related to reading (Wagner & Torgesen, 1987): phonological awareness (e.g., Liberman & Shankweiler, 1985; Mann & Liberman, 1984), retrieval of phonological codes from long-term memory (rapid automatized naming) (e.g., Bowers & Swanson, 1991), and verbal short-term memory (e.g., Catts, 1989; Mann & Liberman, 1984). Given that the deficit seems to be specific to the representation and processing of sounds (Lyon, Shaywityz, & Shaywitz, 2003), the efficient learning of the decoding procedures has been signaled as the key difficulty for dyslexics (e.g., Snowling, 1980; 1981; Snowling, Goulandris, & Defty, 1996; Ziegler & Goswami, 2005). But even when it has been widely accepted that the accuracy deficit occurs at the decoding step, other processes can be involved and need to be studied.

It has been assumed that dyslexics in transparent orthographies struggle with a characteristic reading speed impairment (Wimmer, 1993). This speed deficit, however, is proven difficult to explain (Davies, Cuetos, & González-Seijas, 2007) and it could stem from higher levels of representations and processing occurring once graphemes-to-phoneme conversions are completed. These processes could be also part of the phonological component and could include both sublexical (i.e., syllabic units) and lexical representations (i.e., density and number of phonological neighbor words) (e.g., Conrad, Grainger, & Jacobs, 2007; López-Zamora, Luque, Álvarez, & Cobos, 2012; Perry, Ziegler, & Zorzi, 2010). The syllabic units, for instance, or the phonological lexicon are primarily oral language representations, and they are incorporated to the reading circuit during literacy. As abovementioned, the phonological deficit seems to exist prior to reading acquisition. Thus, these representations and their associated processes could suffer their own previous deficits. The main objective of this paper is to investigate whether these phonological processes—beyond the decoding phase—contribute to the characteristic speed deficits found in transparent orthographies (Wimmer, 1993, 1996a, b), such as Spanish (Davies et al., 2007; Jiménez & Hernández, 2000; Serrano & Defior, 2008).

While it is easy to determine the source of an accuracy deficit, a speed deficit may stem from multiple causes (Davies et al., 2007). First, a possible “locus” could be situated on the phonological route. Grapheme–phoneme conversion processes might become more accurate as dyslexics get older; however, phonological decoding speed remains significantly slower in dyslexics relative to non-dyslexics (Francis, Shaywitz, Stuebing, & Shaywitz, 1996; Shaywitz, 2003). Children with dyslexia may never acquire an automatic decoding speed, regardless of the orthography in which they are learning to read (e.g., Ziegler & Goswami, 2005). In addition, a developmental delay of some phonological representations that are larger than the phoneme, such as syllables, could also explain the slower decoding speed. The role of these larger sublexical units has been studied on school readers and in languages with transparent orthographies, such as French and Spanish (Colé, Magnan, & Grainger, 1999; Jiménez, García, O’Shanahan, & Rojas, 2010; Jiménez & Hernández, 2000; Jiménez, Guzman, & Artiles, 1997; Jiménez & Rodrigo, 1994; Maïonchi-Pino, Magnan, & Écalle, 2010a, b; Chetail & Mathey, 2009; Goicoetxea, 2005). There have been found facilitatory and inhibitory syllabic effects. Nevertheless, the first emergence of the inhibitory effect is a controversial issue (i.e., Jiménez & Hernández, 2000 vs. Goicoetxea, 2005). We will extend on this idea further on.

A second locus could be related to visual route representations. The lack of speed may be due to an insufficient development of visual–orthographic representations. Share (1995) proposed that the visual–orthographic representations of words are constructed by the repeated exercising of the phonological route. Therefore, less reading experience or fewer self-teaching opportunities result in poorer development of orthographic representations. Moreover, this dynamic relationship between the two routes has specific characteristics in the case of dyslexic readers. Following Shaywitz, Morris, and Shaywitz (2008), neuroimaging studies focusing on the mechanisms of reading indicate that poor readers rely on memory rather than understanding how letters are linked together. Dyslexic readers memorize words and can read them relatively accurately but not automatically; therefore, they read slowly and with greater effort. Thus, memorizing words as a compensatory strategy is not sufficient to close the gap caused by a phonological-specific speed deficit. Finally, Nicholson and Fawcet (1990) proposed another explanation based on a general skill automatization deficit. However, Wimmer, Mayringer, and Landerl (1998) showed that even in regular orthographies, difficulties in learning to read are due to a phonological deficit and not to a general skill automatization deficit.

Notwithstanding the foregoing, there are other phonological representations and processes that are working while we read a word. Once the grapheme phoneme conversion takes place, phonemes converge on larger sublexical units, such as syllables, as previously commented. When a syllable is pronounced, some words are activated from the phonological lexicon. An interesting approach to investigating the role of syllables and their associated lexical processes began 20 years ago in Spain with adult readers (Carreiras, Álvarez, & de Vega, 1993). The main finding has been called the "Inhibitory effect of positional syllable frequency" (i.e., words composed of frequent syllables produce longer reaction times than words with less frequent syllables). Using a classical lexical decision task with two levels of both variables, word frequency and syllable frequency, it is easy to replicate the effect. It is worth noting that the increment of the lexical decision time in high syllable frequency conditions is explained as a consequence of lexical activation and competition processes. So, this lexical decision task and the inhibitory effect could be a fair opportunity to study what is happening just after the phonological decoding processes.

Let us consider the inhibitory effect in detail. Conrad, Grainger, and Jacobs (2007) have explained the inhibitory effect as follows. When a printed word is presented, a sublexical orthographic code generates activation in the appropriate set of phoneme representations, which then converge on syllabic representations. It must be noted that syllable units receive bottom-up input via phoneme representations and are, therefore, phonologically defined syllables. The syllable representations then control activation at the level of whole-word representations, and the polysyllabic words that share the first syllable are activated. If this first syllable is a high-frequency syllable, then it is shared by more words that compete for recognition. The co-activated word representations interfere with the recognition of the target word, and the lateral inhibition of these lexical candidates is necessary. In support of this theoretical explanation, it has also been found that the number of higher frequency syllabic neighbors is essential to account for the inhibitory syllable frequency effect (Álvarez, Carreiras, & Taft, 2001; Perea & Carreiras, 1998). It should be noticed that the effect is greater and clearer in low-frequency words than in high-frequency words, as high-frequency words are less affected by the frequency of the activated syllabic neighbors that compete for recognition compared to low-frequency words (Álvarez et al., 2001; Carreiras et al., 1993; Perea & Carreiras, 1998).

The inhibitory effect of the positional syllable frequency (PSF) has been studied almost exclusively in adults and normal readers. Studies of Spanish schoolchildren are scarce, and results have commonly found facilitation frequency effects, this is, high syllable frequency words are read faster than words with a low-frequency syllable at the first position (Jiménez & Hernández, 2000; Jiménez et al., 1997). Facilitation effects have also been found in some French studies, but these studies used a different experimental paradigm (Maïonchi-Pino et al., 2010a). These facilitatory effects have been considered as pure sublexical, being the case that processing more frequent syllabic units is faster than less frequent ones, without lexical activation taking place, as happens in naming tasks (e.g., Perea & Carreiras, 1998). A Spanish study verified the inhibitory effect with a sample of 8- to 13-year-old children (Jiménez & Rodrigo, 1994). Chetail and Mathey (2009) found similar results with 10-year-old French schoolchildren. These results are consistent with the standard explanation of the inhibitory effect. Inhibitory effect would be found when the letter–sound recoding procedures become automatic. This way, the indirect phonological route would be sufficiently rapid to surpass the processing speed of the direct route or the subsequent information input. Given that the phonological route must be automatic and getting ahead to orthographic word representations, it has been readily accepted that the inhibitory effect does not appear in younger school readers, let alone in dyslexics.

However, the results found by Goikoetxea (2005) challenge the idea that inhibitory effect is a late acquisition. Goikoetxea used a masked priming paradigm following a design used by Carreiras and Perea (2002), but participants were children from kindergarten (age M= 6 years 1 month; SD=3.1 months) and grade 1 (age M=6 years 9 months; SD=4.3 months). Her results were outstanding and they showed—such as in the studies with adults (Carreiras & Perea, 2002)—that lexical decision responses to a word are inhibited when this word is preceded by a brief masked presentation of another word sharing the same first syllable. Goikoetxea (2005) stated that beginning readers use a syllabic level of representation to lexical access from the early steps of literacy, and furthermore, she claimed that initial access to the mental lexicon could be attained through the first syllable. Therefore, although the first syllable activation process is not as fast as it is in adults, the inhibitory effect could happen under other conditions. The inhibitory effect may not be the result of the high-speed activation of lexical candidates, but it could be the consequence of the temporal relationship between the activation produced by the first syllable and the input of subsequent information. It would be necessary for the second syllable or subsequent information input to occur late enough and not stop the massive activation of lexical candidates. In addition, the results by Goikoetxea (2005) show that it is not necessary to develop a whole orthographic lexicon to get an inhibition source. Thus, the first syllable would activate some high word frequency candidates, while the second syllable would complete the activation of the low word frequency target word. This way, all the competing items could come from phonological lexicon. This claim is consistent with the theoretical explanation offered by Conrad et al. (2007). In addition, this alternative view is compatible with some computational models with syllabic representation levels (e.g., Perry et al., 2010).

Accordingly, we predict that it is possible to find inhibitory effects in younger school readers. Moreover, if our rationale is correct, the inhibitory effect could also be found in dyslexic school readers. Indeed, dyslexics could even reach a larger effect than normal school readers, since activation and competition lexical processes would be mainly based on the phonological component. The phonological difficulties could influence in several ways. First, given their slow decoding skills, the temporal interval between the first and the second syllable would be longer in dyslexic school readers than in normal school readers, so the dyslexics could reach a larger inhibitory effect. Second, dyslexics could also show a slower lexical processing than normal school readers, as RAN tests have shown (e.g., Bowers & Swanson, 1991). Furthermore, activation or competition lexical processes could be altered.

In addition to our two hypotheses, we are interested in exploring two questions about the nature of the inhibitory effect. First, since we are predicting an interaction between the inhibitory effect and the different groups (dyslexics vs. normal readers), we want to specify the nature of this interaction. In other words, could the possible differences be considered a delay or an alteration? To answer this question, control age and control reading-level groups will be considered. Second, it is known that adult dyslexics retain the speed deficit throughout their lifespan, so it would be interesting to explore how the inhibitory effect is affected by reading experience. In this sense, we will pay attention to the differences between the second and fourth grades.

In summary, we hypothesize that a global inhibitory effect will be found: each group will confirm the inhibitory effect. Our second hypothesis states that the inhibitory effect will be greater in dyslexic school readers than in normal school readers. If we detected these differences, then we want to know whether they are a developmental lag or a deficit. Finally, we propose to study how the reading experience could affect the inhibitory effect.

Method

Participants

For this study, we selected a sample of 158 participants from 14 schools in the province of Málaga in southern Spain. Selected schools covered a full range of socioeconomic statuses, including public and private schools. All the schools taught reading using a phonic method. The TECLE test (Marín & Carrillo, 1997; see the description below) was administered to an initial sample of 1,158 participants; they were all the children of second and fourth grade from the 14 schools. We needed to select children with clear reading difficulties, as well as children with clearly average or superior reading skills based on their age group. Therefore, the second and fourth grade normal readers groups (NR) included children with efficiency measures between the mean and the mean+1.0 SD of the TECLE test scores. Two dyslexic groups (DYS) were selected for the second and fourth grade. Each dyslexic group included children whose performance did not reach the mean—1.5 SD on the TECLE test. We ensured that the fourth grade dyslexic group was matched with the reading level of the normal reading children in the second grade. Thus, the second grade NR was used as a reading level control group when necessary. No children were included in the sample that had been diagnosed with neurological, auditory perception, visual perception, and sensory–motor deficits or other problems that were used as exclusionary criteria for a specific learning disability diagnosis. Table 1 shows the main sample characteristics.

Table 1 Sample characteristics

Groups	No.	Age in months (SD)	TECLE % success rate means (SD)
2nd grade DYS	43	91.84 (4.8)	8.80 (5.47)
2nd grade NR	43	93.76 (5.6)	31.48 (4.48)
4th grade DYS	32	119.67 (6.8)	22.64 (7.07)
4th grade NR	40	116.35 (2.9)	54.88 (6.77)

Measures

Reading efficiency test

For each participant, global reading ability was assessed with the TECLE, a forced-choice sentence completion test (Marín & Carrillo, 1997). The test consisted of 64 sentences that had a missing word. Four options were proposed for each sentence, and the participant had to choose the correct option. All of the incorrect options were orthographically similar to the target: two were pseudowords, and the third was a real word (e.g., for the correct response "problema" (problem) the pseudoword foils were "probrema" and "proglema" and the word foil was "protesta" (protest)). Participants read silently and completed as many sentences as they could in 5 min. Each participant's score was the number of correct responses. As the participant progressed through the test, the complexity of each task increased: sentences became longer, words became less frequent, and syntactic, cognitive and pragmatic aspects of the sentences became more complex. For example, the first sentence was "Tu pelota es de color… rogo, roco, robo, rojo" (The color of your ball is… red) and the last sentence was "Ten mucho cuidado para que la máquina no caiga al agua, ya que no es… sumergible, sumengible, sunergible, sustituirle" (Be very careful the machine does not fall into the water because it is not… submersible). Before the test began, two examples were shown to each participant. The reliability of this test was evaluated using the test–retest technique on 376 primary schoolchildren with an interval of about 1 month between tests (Cuadro, Costa, Trias, & Ponce de León, 2009). The correlation was substantial and significant (r=0.880, p<0.001). Cuadro, Costa, Trias, and Ponce de León (2009) also calculated the predictive validity: the correlation between the total score and the expert criterion of teacher. The correlation showed a significant correlation, positive and moderate (r=0.402**) between teacher assessment and test results.

Materials for the lexical decision task

For the reading lexical decision task, a list of 120 disyllabic items (60 words and 60 pseudowords) between four and six characters in length was used. The items were selected from the Spanish corpus Buscapalabras (Davis & Perea, 2005). Two factors were manipulated in the items selection: the token syllable frequency of the first syllable (high vs. low) and the word frequency (high vs. low) in a 2×2 experimental design. The high-frequency syllabic condition included words that had a first syllable with a token syllable frequency between 1,974 and 5,535 per million (m=4,647). The low-frequency syllabic condition included words that had a first syllable with a token syllable frequency between 7 and 386 (m=180). The frequency of the second syllable was controlled as much as possible by selecting, in each condition, words with a similar second syllable frequency. The word frequency was calculated using the standard measure Log10, obtained from the base 10 logarithm of the total word frequency per million of the corpus (Davis & Perea, 2005). The high word frequency condition included words between 75 and 398 (m=175.6), and the low word frequency condition included words between 1.4 and 6.4 (m=3.9). The pseudowords were constructed by this procedure: we took the first syllables of the experimental words list and, then, we added second syllables forming items that resembled real words but did not actually exist in the Spanish language.

Procedure

The TECLE test was collectively administered to each classroom. Children listened to instructions and received two example trials. They were told that the test would take only 5 min and that they must answer as many items as they could.

The reading lexical decision task was individually administered, and the task was performed on personal computers. Reaction times (RTs) and error rates were measured using the E-Prime 1.02 experimental software. The participants were instructed to pay attention to the written stimuli that appeared on the screen. They had to press a certain key if the visual stimulus was a word (e.g., "madre") or a pseudoword (e.g., "mapel") as quickly and accurately as possible. Each trial began with a fixation point (*****) in the center of the screen that lasted 1,500 ms until the experimental item appeared. The item remained on the screen until the participant responded by pressing a key, and then the next trial began. Prior to the experimental test, the participants underwent a training of the task in which the participant was required to correctly answer 80 % of the presentations. Otherwise, the experiment would not start.

Analyses were conducted separately regarding the RTs and error rates of the words, both by participants and by items. Incorrect answers were removed from the analyses of RTs following the next criteria: times less than 150 ms and more than 7,000 ms, and RTs either greater or less than 2.0 standard deviations (11.5 % of the data).

The words were analyzed according to a $2 \times 2 \times 2 \times 2$ design, including two between-participant factors: school grade (second and fourth) and group (normal readers and dyslexic), and two within-participant factors: syllable frequency (SF, high and low) and word frequency (WF, high and low).

Results

A ($2 \times 2 \times 2 \times 2$) group (dyslexic vs. normal readers) × school grade (second and fourth grades) × lexical frequency (high vs. low) × syllable frequency (high vs. low) mixed analysis of variance was performed on the RTs and error rates.

First, the reaction time analysis of the SF factor was not significant for the item analysis [$F1(1, 154)=4.020$, $p<0.047$; $F2(1, 127)=14.258$, $p=0.275$], while in the error analyses, it was significant for both participants and items [$F1(1, 154)=68.688$, $p<0.000$; $F2(1, 56)=0.283$, $p=0.021$]. The WF was significant for the reaction time analysis [$F1(1, 154)=95.532$, $p<0.000$; $F2(1, 56)=24.949$, $p=0.000$] but was not significant for the error measure. School grade and group factors were significant in the reaction times [$F1(1, 154)=50.478$, $p<0.000$; $F2(1, 56)=889.644$, $p=0.000$; $F1(1, 154)=118.296$, $p<0.000$; F2(1, 56)=1,050.730, $p=0.000$], but they were not significant in the error analyses. We do not include a detailed explanation of these main effects because several interactions were also significant, as it will be commented next. Mean reaction times and error rate of the lexical decision task can be found in Table 2 and Table 3, respectively.

Second, the interaction between SF and WF was significant [$F1(1, 154)=59.332$, $p<0.000$; $F2(1, 56)=14.258$, $p=0.000$]. For low-frequency words, the high SF words reached greater reaction times than the low SF words, but for high-frequency words, the pattern was the opposite. Furthermore, the inhibitory effect was stronger than the facilitation effect. The error analyses showed a similar pattern, but this result was not confirmed on the items analysis, $F1(1, 154)=110.869$, $p<0.000$; $F2(1, 56)=3.605$, $p=0.063$. There was another significant interaction between WF and group factors in the reaction time measure [$F1$(1,

Table 2 Mean reaction times (in millisecond) of the lexical decision task

	Words								Pseudo words			
	High lexical frequency				Low lexical frequency							
	High syllabic freq.		Low syllabic freq.		High syllabic freq.		Low syllabic freq.		High syllabic freq.		Low syllabic freq.	
Group	*M*	SD	*M*	SD	*M*	SD	*M*	SD	*M*	SD	*M*	SD
2nd grade DYS	2,197	639	2,357	583	2,641	704	2,381	655	2,841	713	3,038	734
2nd grade NR	1,458	368	1,491	389	1,658	465	1,565	423	1,806	464	1,962	521
4th grade DYS	1,574	436	1,725	558	2,087	556	1,810	424	2,228	480	2,445	527
4th grade NR	1,095	217	1,151	238	1,273	201	1,183	208	1,353	265	1,399	127

154)=13.436, $p<0.000$; $F2(1, 56)=12.941$, $p=0.001$], as the dyslexic participants showed greater differences between high and low-frequency words compared to normal reader participants.

A second-order interaction between the SF, WF, and group factors reached significance [$F1(1, 154)=15.644$, $p<0.000$; $F2(1, 56)=13.445$, $p=0.001$]. There was a distinct pattern of processing concerning the syllabic frequency depending on the group: dyslexic or normal readers and depending on word frequency. Dyslexic participants showed a greater inhibitory effect in the low-frequency word condition than normal readers. For the high-frequency words, the facilitation effect of SF seemed to be restricted to the dyslexic group. The error analysis was not significant (all $p>0.05$). Reaction time analyses did not reach significance when the interaction between SF, WF, and school grade factors was considered. The reaction times associated with the SF effects did not show changes that were related to the increment of instructional time between the second and fourth school grades. In the error analysis, the second grade children made significantly more mistakes than the fourth grade children ($F1(1, 154)=8.149$, $p<0.005$; $F2(1, 56)=4.369$, $p=0.041$). No third-order significant interaction was found. Given the complexity of this triple interaction, we consider that an evaluation of the pattern of results for each group is more informative.

For the second grade dyslexic group, the main effect of WF was significant for the reaction time and error analyses [$F1(1, 42)=25.848$, $p<0.000$; $F2(1, 56)=17.556$, $p=0.000$;

Table 3 Error rate (in percent) of the lexical decision task

	Words								Pseudo words			
	High lexical frequency				Low lexical frequency							
	High syllabic freq.		Low syllabic freq.		High syllabic freq.		Low syllabic freq.		High syllabic freq.		Low syllabic freq.	
Group	*M*	SD	*M*	SD	*M*	SD	*M*	SD	*M*	SD	*M*	SD
2nd grade DYS	15.2	10.3	20.6	10.3	31.3	12.6	16.8	8.0	20.6	12.7	39.5	15.0
2nd grade NR	10.1	5.9	12.7	8.5	25.1	12.1	11.4	6.9	9.7	6.5	23.1	14.2
4th grade DYS	14.0	8.2	14.4	8.7	25.6	11.4	14.9	10.0	15.4	9	39.2	18.2
4th grade NR	14.4	4.4	10.3	6.2	18.5	7.3	10.3	6.8	6.5	3.6	25.8	16.0

$F1(1, 42)=17.769$, $p<0.000$; $F2(1, 56)=4.603$, $p=0.036$]. This group was slower and made more mistakes in the low-frequency words. The interaction between WF and SF was significant [$F1(1, 42)=18.363$, $p<0.000$, $F2(1, 56)=14.844$, $p=0.000$]. We observed a facilitation effect of SF on the high-frequency words [$F1(1, 42)=6.552$, $p<0.014$; $F2(1, 28)=4.968$, $p=0.034$] and inhibition in the low-frequency words [$F1(1, 42)=10.698$, $p<0.002$; $F2(1, 28)=9.971$, $p=0.004$]. The error analysis also confirmed the interaction of WF and SF [$F1(1, 42)=54.064$, $p<0.000$; $F2(1, 56)=5.166$, $p=0.027$] in the same direction.

For the second grade normal readers, the main effect of WF was significant [$F1(1, 42)=15.834$, $p<0.000$; $F2(1, 56)=13.460$, $p=0.001$], with longer RTs for low-frequency words. The error analysis was significant [$F1(1, 42)=33.380$, $p<0.000$; $F2(1, 56)=5.572$, $p=0.022$], as more errors were found in the low WF condition. The interaction between WF and SF was not confirmed in the analysis by items [$F1(1, 42)=5.168$, $p<0.028$; $F2(1, 56)=2.723$, $p=0.105$]. The pattern was the same for the second school grade dyslexic group, but the differences between high and low SF words were less apparent than for normal readers. The error analysis of the interaction of SF by WF was significant [$F1(1, 42)=32.065$, $p<0.000$; $F2(1, 56)=4.349$, $p=0.042$].

The fourth grade dyslexic group showed a significant main effect on WF in the same direction as the second school grade groups, both for reaction time and error measures [$F1(1, 31)=28.445$, $p<0.000$; $F2(1, 56)=22.021$, $p<0.000$; $F1(1, 31)=19.613$, $p<0.000$; $F2(1, 56)=5.072$, $p=0.028$]. The interaction between WF and SF was also significant [$F1(1, 31)=27.626$, $p<0.000$; $F2(1, 56)=12.226$, $p=0.001$]. We observed a facilitation effect of SF on words with high frequency [$F1(1, 31)=6.862$, $p<0.0.014$; $F2(1, 28)=5.368$, $p=0.028$] and inhibition of SF on words with low frequency [$F1(1, 31)=21.121$, $p<0.000$; $F2(1, 28)=7.062$, $p=0.013$]. The error analysis was not significant ($p>0.05$).

Finally, in the fourth grade normal readers, the main effect of WF was significant for the reaction time analysis [$F1(1, 39)=50.65$, $p<0.000$; $F2(1, 56)=14.028$, $p<0.000$], and there was a marginal effect for the error measures [$F1(1, 39)=28.669$, $p<0.000$; $F2(1, 56)=3.837$, $p=0.055$]. The results showed a significant interaction between WF and SF [$F1(1, 39)=15.434$, $p<0.000$; $F2(1, 56)=8.471$, $p=0.005$]. An effect of inhibition of SF was found only in the low WF condition [$F1(1, 39)=13.282$, $p<0.001$; $F2(1, 28)=5.144$, $p=0.031$].

To summarize, the group analyses indicated that the inhibitory effect of SF was common to all groups in the low WF condition, whereas a facilitation effect was verified only in the dyslexic groups in the high WF condition.

Discussion

A speed deficit is a hallmark of dyslexics who are learning to read in transparent orthographies. The main objective of this study was to explore whether at least part of the variance in speed deficit could be due to lexical processes beyond the decoding process. To study the role of lexical processes, we carried out a standard lexical decision task manipulating two factors: WF and SF, specifically in terms of the frequency of the first syllable. This manipulation has consistently produced a phenomenon known as the inhibitory effect of positional syllable frequency: words that begin with high-frequency syllables yield greater reaction times than those that begin with low-frequency syllables (Carreiras et al., 1993). Given that words containing high-frequency syllables are read more slowly than words starting with low-frequency syllables, the decoding time of the syllables does not appear to be responsible for this delay. The accepted interpretation of this inhibitory effect is that lexical activation and competition processes cause the increment in the reaction time (e.g., López-Zamora et al., 2012). So, inhibitory effect could offer a suitable window to observe the role of lexical processes during word reading.

From this framework, we predicted that in school readers the inhibitory effect should arise but in a different way than observed for adults. Our second hypothesis stated that this effect would indeed be greater for dyslexic school readers due to their slow decoding and lexical processing skills. Finally, if the second hypothesis was confirmed, then we proposed to study the nature of this difference, in terms of both severity (delay vs. alteration) and developmental course.

The main results associated with these four goals can be summarized as follows. First, a global inhibitory effect of SF was found. Moreover, each group confirmed the inhibitory effect. As we proposed in the introduction, getting a full-automatic phonological route is not a necessary condition, neither a well-developed lexical route, in order to produce the inhibitory effect. This means that the inhibitory effect can be based mainly on phonological components of the word reading. Second, there was a second-order interaction between group, SF, and WF variables. Dyslexic school readers showed a three times greater inhibitory effect than the normal school readers. So, the inhibitory effect has a particular impact on the dyslexic readers. Third, differences between fourth grade dyslexics and their age and reading level control groups were significant. Thus, the differences related with the inhibitory effect must be considered a deficit and not a developmental lag. This result reinforces the former idea about the particular impact of the inhibitory effect on dyslexic readers. Fourth, the inhibitory effect of PSF did not interact with the school grade factor. This is an astonishing result because fourth grade participants have two more years of reading experience. However, this 2 years of reading instruction did not improve their lexical processes underlying the inhibitory effect. If we look at Table 2, at the low word frequency condition, it can help us to understand the main findings. We can calculate the magnitude of the inhibitory effect subtracting the mean of the low syllable frequency items from the high syllable frequency means. The magnitude of the inhibitory effect for the second and fourth dyslexic groups was 260 and 277 ms, respectively. While the magnitude for the second and fourth normal reader groups was 93 and 90 ms, respectively. We think these calculations provide a clear description of the four before-mentioned results.

First, let us deal with the global inhibitory effect found. Three components or processes can explain the reaction times: the syllable decoding times, the activation of lexical candidates, and the competition between the candidates. First, syllable input produces the activation of lexical candidates, whereas subsequent information input primarily deactivates the non-target candidates. This competition process could be addressed by the second syllable input or by information from the lexical route. Following Conrad et al. (2007), syllable representations produce the activation at the whole-word level for both orthographic and phonological lexical representations. It is plausible that children had activation and competitive lexical processes mostly based on phonological word representations, while a greater weight of whole-word orthographic representations are expected with adult performances. Therefore, this finding does not contradict previous explanations about adult performances but rather suggests a different dynamic relation. We propose that this dynamic relation could change as the readers gain reading experience.

Regarding the second hypothesis, why did dyslexic school readers show a three times longer inhibitory effect than normal school readers? There are at least two possible explanations. First, Álvarez, Carreiras, and de Vega (2000) concluded that Spanish adult normal readers processed disyllabic words in a sequential way, with a bias toward initial syllables. Our dyslexic school readers took longer RTs than normal school readers in the lexical decision task. Thus, it could be the case that sequential processing time for the first and second syllabic inputs was proportionally longer. Then, first syllable would get more time to either activate more numbers of lexical candidates or produce a stronger activation of the candidates. This explanation claims that a longer inhibitory effect is a direct consequence of the slower decoding processes. Therefore, the inhibitory phenomenon would be beyond the decoding step, but the effect would be directly produced by the decoding speed deficit. However, there was not a linear relationship between the inhibitory effect size and the RTs in the lexical decision task. In fact, the fourth grade groups, dyslexics and normal readers, were faster than their matched second grade groups, but the inhibitory effect remained the same for each experimental condition. Thus, the increment of sequential processing time does not offer a satisfactory explanation, since the second grade groups should have shown a greater inhibitory effect than the fourth grade counterparts. Moreover, Ramus and Szenkovits (2008) have recently proposed that the deficit of dyslexics could be an access problem to phonological representations, including lexical ones. Then, although dyslexic school readers take longer sequential processing times, they could not activate more lexical candidates or produce stronger activations than normal school readers. Ultimately, this lack of linear correlation means that the magnitude differences of inhibitory effects are independent of the decoding times of syllables. The explanation for the differences in the inhibitory effect must be sought one step after decoding processes.

The second explanation must consider the speed of the lexical processes (activation and competition). Our data have showed unequivocal results. There was a second-order interaction between group, WF, and SF factors. The inhibitory effect reached the triple size in the dyslexic readers. This difference is revealed as a deficit and not as a developmental lag. So we have found a speed deficit in the lexical processes implicated on word reading that could be considered as our major finding. It is important to note that the deficit in lexical processes has been primarily found in oral language tasks. Dyslexics perform some oral tasks that require access to phonological representations of words slower than normal readers (Swan & Goswami, 1997; Bowers & Wolf, 1993; Wolf & Bowers, 2000; Carrillo & Alegría, 2009a). They have also been shown to be less productive in verbal fluency tasks within a fixed time frame, in which they were asked to say as many names as possible that belong to a semantic field (e.g., animal names) or that are defined phonologically (e.g., names beginning with /s/) (Maillart, van Reybroeck, & Alegría, 2005). Our experimental study has revealed how lexical processes, originally of an oral nature, are incorporated into the reading network, thus preserving the differences between dyslexics and normal readers. So the inhibitory effect could be an alternative way to study the phonological lexical deficits shown by RAN and fluency tasks, while these lexical processes are taking part in a reading task.

A primary constraint must be also noted, however. The experimental design cannot discern which of these processes, activation or inhibition, alone or in interaction, is responsible for the reaction times obtained. We should not rule out the possibility of a deficit in the activation process. However, it would not be the first time that inhibition is claimed as a main cause of reading difficulties. Gernsbacher (1990) explained the principal deficit of poor comprehenders to the role of the suppression mechanism, following her terminology. She stated that less-skilled comprehenders were plagued by less-efficient suppression mechanisms, and then, they were less able to suppress the contextually inappropriate meanings of ambiguous words. This lack of inhibition would produce a noise or overload of working memory, and this overload would hinder reading comprehension (see Gernsbacher, 1990, for a full explanation). Similarly, our experimental paradigm has demonstrated how less-efficient phonological lexical processes affect dyslexics in a particular way. It is therefore reasonable to suppose that this phonological difficulty could reduce working memory resources. In any case, it would be interesting to plan some new experiments to clarify the role of activation and competition processes. The manipulation of the density of lexical neighbors may be useful for elucidating this issue (e.g., Perea & Carreiras, 1998).

Apart from the main explanation, a corollary can be obtained from our results: dyslexics show a slow but functional connection between phonemes, syllables, and words. It should be noted that this is true even for 7-year-old children with specific reading difficulties. If this interpretation is correct, then it also suggests that the functional connection between phonemes, syllables, and words in Spanish is acquired earlier than in French, since no inhibitory effect has been found until 10 years old in French samples (Maïonchi-Pino et al., 2010a, b; Chetail & Mathey, 2009).

We also believe that our results could have some implications for applied issues. On one hand, dyslexics solve the problem of decoding with relative ease and accuracy measures soon lose their discriminative value in transparent orthographies such as Spanish (Carrillo & Alegría, 2009b; Carrillo, Alegría, Miranda, & Sánchez, 2011; Jimenez & Hernández, 2000; Serrano & Defior, 2008). Moreover, RAN tests have been shown to be better predictors than phonological awareness in terms of reading acquisition of transparent orthographies, such as Dutch and German (e.g., de Jong & van der Leij, 1999; Wimmer, Mayringer, & Landerl, 2000). All the above mentioned is consistent with an early evolution from a decoding deficit to a speed deficit. Our results have shown that slow phonological lexical processes also contribute to this speed deficit. This contribution was shown as independent from the decoding influence. So, a specific intervention is required to this lexical deficit. On the other hand, the lack of interaction between the inhibitory effect and the school grade factor emphasizes an intriguing result: there were no significant changes in lexical processing, despite that the fourth grade groups had 2 years more of reading experience. Nevertheless, the inhibitory effect changes when we consider a larger temporal period. Normal adult readers are reaching the inhibitory effect when the difference between high and low-frequency syllable conditions is around 50 ms (e.g., Carreiras et al., 1993). Our normal school readers will diminish approximately half the size of their inhibitory effects. So, normal school readers need a large amount of standard reading experience to reach the adult level. If it is hard for normal school readers, it should be even more for school readers with dyslexia. In summary, there is a specific speed deficit affecting phonological lexical processes. The lexical deficit is independent from other decoding deficits. Standard reading experience hardly produces much more than a slow improvement of the RTs speed. Consequently, only a specific and long-term intervention program seems proper for these conditions. It is a reasonable conjecture that interventions focusing on word reading automatization and fluent reading could produce some impact in the size of the inhibitory effect. Since high-frequency words are less affected by the frequency of the activated syllabic neighbors, intervention on word reading automatization could diminish the magnitude of the inhibitory effect. Not only the increment of visual–orthographic lexical representations could impact on inhibitory effect. If the inhibitory effect is the consequence of the temporal relationship between the activation produced by the first syllable and the input of subsequent information, this gap could decrease in the extent in which reading fluency increases. Thus, our results would entail more support to introduce fluency tasks in Spanish intervention programs.

Finally and concluding, we have shown that some lexical processes involved in reading words contribute to the dyslexic speed deficit in a meaningful way. This deficit in lexical processes has proved independent from the decoding deficit. Furthermore, it appears a severe deficit, since it was shown as an altered profile and not just as a developmental delay. We think this lexical deficit is related with phonological impairments originally detected by RAN tests, though further research will be necessary to deeply understand its true nature.

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