How orthographic transparency affects morphological processing in young readers with and without reading disability

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This study investigates how orthographic modifications to the stems of complex words affect morphological processing in proficient young Spanish readers and children with reading deficits. In a definition task all children, irrespective of their reading skill, were worse at defining derived words that had an orthographic alteration of the base stem than words with no orthographic alteration. In a go/no-go lexical decision task, an interaction between base frequency and orthographic alteration was found: base frequency affected derived words with no orthographic alteration more than words with alterations, irrespective of reading skill. Overall, results show that all children benefit from a high frequency base, skilled children outperform children with reading deficits and morphological processing is affected by orthographic alterations similarly in proficient and impaired readers.

Key words: Base frequency, dyslexia, morphology, morpho-orthographic segmentation.

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INTRODUCTION

Morphological processing has become a major issue in the investigation of oral and written language development. Findings to date show that morphological processing not only has a facilitatory role in visual word recognition in adults (e.g., Dominguez, Alija, Rodriguez-Ferreiro & Cuertos, 2010; Dünabetia, Laka, Perrea & Carreiras, 2008; Giraudo & Grainger, 2000; Marslen-Wilson, Bozic & Randall, 2008), but also in typically developing children and children with reading deficits (e.g., Burani, De Luca, Marcolini & Zoccollotti, 2008; Burani, Marcolini & Stella, 2002; Mann & Singson, 2003; Quémart, Casalis & Duncan, 2012).

Evidence concerning morphological processing in children was obtained with different methodologies (e.g., naming task, lexical decision task) and materials (e.g., morphologically complex words and pseudowords) by using morphologically complex stimuli that were both orthographically and semantically opaque or transparent (see, e.g., Beyersmann, Castles & Coltheart, 2012a; Schiff, Raveh & Figel, 2012). It has been argued that shifts in phonology/orthography and/or semantics in the base of a complex word may reduce the benefits of morphological processing (Reichle & Perfetti, 2003); but contrary to this hypothesis, one study conducted on English (McCormick, Rastle & Davis, 2008) suggested that adult skilled readers are insensitive to orthographic alterations in the stems of derived words at an early stage of word processing. McCormick and co-workers (2008) carried out four masked priming lexical decision experiments in which word primes with some orthographic alterations were introduced (e.g., duplicated consonants as in dropper-DROP, or missing “e” as in adorable-ADORE). Results showed similar facilitation of targets by morphologically-related primes, regardless of whether there were any differences between word primes and targets as a function of orthographic alterations. McCormick et al. (2008) concluded that in proficient adult processing morpho-orthographic segmentation is not affected by orthographic alteration of morphemes.

It might be assumed, however, that adult readers develop morphological relationships between derived words and their bases as a consequence of numerous encounters (in print) with those words, which are related in meaning and morphology but may not be fully transparent in orthography. By contrast, because of limited exposure to words of this type in print, developing readers might be unable to efficiently recognize the relationship between a base word and a derived word when the latter does not include the base form in its entirety. Thus, one might expect that any orthographic alteration in a derived word would negatively affect children’s performance in word recognition tasks, because the word’s morphological constituency is less transparent in a derived word whose base has undergone an orthographic shift.

This hypothesis is consistent with the results of both Quémart and Casalis (2014) and Carlisle, Stone and Katz (2001). These studies, carried out in languages with opaque orthographies (i.e., French and English, respectively) showed that children’s visual word recognition performance was a function of the phonological and orthographic relationships between derived words and their bases. Quémart and Casalis (2104) submitted third, fourth and fifth grade typically developing children and adults to a lexical decision task in which the base words were preceded by a derived word prime presented for a duration of 60 ms. (Experiment 1) or 250 ms. (Experiment 2) in four different conditions of a prime-target relationship. In the first condition, prime and target shared a morphological relationship without any form shift in the base (as in nuageux-NUAGE). In the second condition the morphological
relationship involved a phonological but not an orthographic modification of the base (as in bergerie-BERGER). In the third condition the relationship between base and derived word involved an alteration that was both phonological and orthographic (as in soigneur-SOIN). The fourth condition was a control in which primes and targets just had an orthographic overlap (as in fourmi-FOUR). The results of the first experiment (60 ms. prime) showed that in children there was a significant priming effect only in the first condition. In the second experiment (250 ms. prime), however, all three conditions of morphological relatedness showed a significant priming effect. Adults showed significant priming for the three morphological conditions in both the first and the second experiment. These results suggest that allomorphic variations may prevent lexical activation of bases at the fastest word exposures in children but not in adults. According to the authors, children need more time to activate a base in the case of a phonological or an orthographic shift because activation of the bases is not yet automatized.

Carlisle et al. (2001) ran two experiments, that is, a naming task and an unprimed lexical decision task. Two groups of young readers with and without reading difficulties (with ages ranging from 10.75 years to 15.75 years) and a group of adults performed the tasks. They were presented with stable words (in which no phonological alteration occurred between bases and derived words, as in cultural), shift words (in which a phonological alteration occurred, as in majority) and foils. Results showed an effect of phonological transparency in all groups, confirming that it takes longer to respond to complex words with a phonological alteration in the base than to complex words without a phonological alteration. Contrary to what could be expected on the basis of McCormick et al.’s (2008) results, adult readers were also sensitive to the phonological manipulation. Similarly to the conclusions of Quémart and Casalis (2014), the results of Carlisle et al. (2001) strongly suggest that phonological alterations between bases and derived words make it more difficult to benefit from access to the base in performing the experimental tasks.

Whether orthographic changes in the base affect children’s processing of morphologically complex words in languages with transparent orthographies and whether these alterations affect children with reading disabilities and typically developing readers to the same extent has to be further explored. In principle, any orthographic alteration in a derived word should affect both proficient young readers and children with reading deficits. Children with reading deficits might, however, be more affected by orthographic modifications because they are usually less exposed to print than typically developing readers and are likely to have phonological difficulties (Scarborough, Dobrich & Hager, 1991; Vellutino, Fletcher, Snowling & Scanlon, 2004).

In the present study we focused on the role of orthographic alterations of the stem in morphological processing in Spanish children with and without reading deficits. Spanish has a very transparent orthography. Phonomes are consistently assigned to graphemes, thus reading is systematically predictable once one knows the phoneme that corresponds to a given grapheme. For this reason children who are exposed to a transparent orthography (such as Spanish) learn to read faster than children exposed to an opaque orthography (Ziegler, Bertrand, Tóth et al., 2010). On the other hand, in the Spanish language, unlike Germanic languages such as German, Dutch or English, new words tend to be created through derivational morphology, not through composition. This implies that the productivity of certain derivational suffixes is very high.

In this study two experiments were run. In the first one a word manipulation task was performed on Spanish derived words in which the stem of the base word did or did not undergo an orthographic alteration. In the second one, a lexical decision task was performed on the two kinds of derived words, that is, with or without an orthographic alteration of the stem. The latter experiment assessed whether the effect of base frequency (i.e., words with a high-frequency base are more easily recognized than words with a low-frequency base) held for both words with or without orthographic alteration or only for words that included an unaltered stem.

Our prediction was that children (especially those with reading deficits because of their limited exposure to print and poor ability to derive phonology from print) would have difficulty accessing the base of a morphologically-complex word when the base had undergone some morpho-orthographic alteration as a consequence of the derivational process, namely, when the derived word could not be exactly segmented into its morphemic components. Accordingly, when defining the meaning of a derived word, children would be less likely to benefit from the meaning of its stem if it had undergone some orthographic alteration than if the stem had undergone no orthographic modification (Experiment 1). Children’s lexical access to a derived word would also show reduced facilitation by the frequency of the base after orthographic alteration (Experiment 2).

EXPERIMENT 1

In the first experiment a definition task was carried out on suffixed derived words. This task had been adopted in previous studies with Finnish (Bertram, Laine & Virkkala, 2000a) and Italian (Burani, Bimonte, Barca & Vicari, 2006) young readers. In these studies, children of different ages (ranging from second to fourth grade and including young people with Williams syndrome) defined a low-frequency word better when it included a known stem and a derivational suffix than when the word was non-derived (i.e., it did not include a derivational suffix). These results indicate that children use and combine knowledge of stems and suffixes to understand the meaning of an unfamiliar derived word.

In a pseudoword definition task Lázaro (2012b) observed that Spanish children with reading deficits and young proficient readers were similarly sensitive to the morphological constituency of a pseudoword and interpreted its meaning more accurately when the pseudoword included a familiar stem rather than an unfamiliar one. However, Lázaro (2012b) also observed an effect of children’s reading ability, namely, children with reading deficits scored lower than controls. Nevertheless, orthographic alterations in the stems were not controlled in the aforementioned study. Therefore, it is unclear whether they affected children’s performance. In Spanish as well as in several other languages, when an affix is attached to a stem, changes in the stem commonly occur so that the affix does not concatenate perfectly
to the stem. For example, the final vowel of a stem is sometimes deleted when concatenating the affix (e.g., *cola + -eta → coleta* (tail → pigtail)). This is a phonological alteration motivated by morphology, i.e., it is a morpho-phonological adjustment (Malkiel, 1958) that also results in an orthographic modification of the printed stem.

In the present experiment the definition task was adopted to gain information about the role of orthographic alterations in word processing. A three group (children with reading deficits, skilled readers matched for chronological age and skilled readers matched for vocabulary level) by two orthographic alterations (lost or preserved diphthong) factorial design was used.

**METHOD**

**Participants**

Sixty children were selected from three different public schools in a middle-class neighborhood of Talavera de la Reina, a city with an average socioeconomic level for Spain. All children and parents were born in Spain and were native Spanish speakers.

Twenty children with reading deficits but no other linguistic or cognitive difficulty were selected for reading treatment from those attending the speech and language service of the schools. All of them were submitted to the Prolec-R test (Cuetos, Rodriguez, Ruano & Arribas, 2007), which is commonly used to measure reading ability and has been adopted to assess reading difficulties in previous studies (see Aguilar, Navarro, Menacho, Alcace, Marchena & Ramiro, 2010; González, López, Vilà & Rodríguez, 2013; Lázaro, Camacho & Burani, 2013). The Prolec-R test is validated for Spanish children between 6 and 12 years and consists of eight different exams of performance on written stimuli: letter identification, same-different, word reading aloud, pseudoword reading aloud, grammatical structures, punctuation marks, simple sentence comprehension and text comprehension. Performance on each sub-test is evaluated as normal, slightly below normal or well below normal. The children selected for the present study failed to obtain normal results on any of the test measures assessing performance on written stimuli. Table 1 shows the distribution of total scores obtained by the group of children with reading deficits on the different subtests of the Prolec-R test.

Twenty skilled readers matched for chronological age with the children with reading deficits were selected from the school population. Care was taken not to choose any child who had previously received treatment for language or speech disorders. Parents and teachers were asked to confirm that no child had language, hearing, speech, attention or motor skills issues. A third group of children was created by selecting children who were 10 to 18 months younger than the children in the first two groups. The third group was expected to differ for vocabulary from the older skilled children and to be similar to the children with vocabulary deficits, in line with Spanish data reported in previous studies (see Lázaro, 2012b; Lázaro et al., 2013).

The mean age for the group of children with reading deficits was 102 months (SD 8.3), that is, eight years and six months; it was 105 months (SD 5.8), eight years and nine months for the skilled readers matched for chronological age, and 92 months (SD 4), seven years and eight months for the skilled children matched for vocabulary level. Age differences between the first two groups were not significant (t(19) = -1.06, p > 0.08); the difference between the younger children and the children with reading deficits was significant (t(19) = -4.71, p < 0.001).

As in Ouellette and Been’s (2010) and Lázaro’s (2012b) studies, we submitted all children to the Peabody picture vocabulary test (Spanish version by Dunn, Dunn & Arribas, 2006) to assess their receptive vocabulary size. As expected, skilled readers matched for chronological age obtained significantly higher vocabulary scores (138; SD 8) than the reading disabled group (120; SD 10; t(19) = 4.73, p < 0.001). The youngest group’s scores (118; SD 16) were similar to those of the children with reading deficits on the Peabody test (t(19) = -0.44, p > 0.5), but lower than those of the older skilled readers (t(19) = -6.3, p < 0.001).

To further assess differences among groups, all children performed a phonological test (see, e.g., Casalís, Cole & Sopo, 2004; Ramus, 2003). All children performed the PECO test for the evaluation of phonological knowledge developed by Ramos and Cuadrado (2006). This test is commonly used by speech and language therapists in Spain; it measures children’s phonological ability in adding and deleting phonemes and syllables from given items. The PECO takes about 20 minutes to complete. The scores were 29.65 (SD 0.5) for children matched for chronological age, 28.85 (SD 1.2) for children matched for vocabulary size and 23.75 (SD 4.4) for children with reading deficits. Statistical analyses showed that the group of children with reading deficits scored below the group with the same chronological age (t(19) = 5.9, p < 0.001) and below the group of children matched for vocabulary level (t(19) = 5.1 p < 0.001). The children matched for chronological age scored higher than the children matched for vocabulary level (t(19) = -2.8, p < 0.05).

**Stimuli**

A set of 40 suffix derived words was created. Half of the words consisted of a suffix concatenated to a stem with no orthographic alteration. The other half of the words included orthographic alterations. We selected complex words in which the diphthong of the stem was transformed into a single vowel when concatenating the suffix (e.g. *diente → dentista* “tooth → dentist”; *muerte → mortal* “death → mortal”). All words had a low frequency. The following variables were controlled across the two sets: word surface frequency, base frequency, orthographic N-size, letter length and suffix productivity (see Table 2). Values for the controlled variables were taken from Martínez and García’s (2004) database, which is based on written words for children between six and twelve years. Suffix productivity was controlled using Bosque and Pérez’s (1987) reverse dictionary, which lists words in the reverse order (starting from the last letter) and is especially useful in morphological studies. All stimuli are reported in Table A1 in the Appendix.

**Procedure**

As in previous studies (Bertram et al., 2000a; Burani et al., 2006; Krott & Nicoladis, 2005; Lázaro, 2012b; Nicoladis & Krott, 2007), the definition task required the children to give a verbal definition of the target stimulus. Each word was written on a plastic card. The experimenter presented the cards to the children one-by-one in random order. If they did not provide a definition, the children were asked to try once more. If again they made no response, the next card was presented. Three training trials were performed prior to the start of the experiment to ensure that the children understood the task; none of the training stimuli were used in the experimental task. Responses were audio-recorded and later transcribed. As in Burani et al. (2006), Lázaro (2012b) and Nicoladis and Krott

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<th>Grammatical structures</th>
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(2007), responses were scored on a scale from 0 to 2. If the children explicitly mentioned the stem of the word in the definition, they were given 2 points. If they responded with a word from the stem’s morphological family, they were also given 2 points (e.g., *donde se entierra a la gente* “where people are buried” when the word *terrario* ‘t errarium’, from the stem *tierra* ‘soil’, was presented). If the stem was not mentioned but the response suggested they had some comprehension of the stem, they scored 1 point (e.g., *son los músculos* “it’s the muscles” when the word *corporal* ‘bodily’ was presented, deriving from the stem *cuerpo* ‘body’). A score of 0 was given if the children did not respond or defined the word in a way that was unrelated to the stem, even if there was some phonological overlap between the target word and the word used in the response (e.g., *el mes de febrero* “the month of February” was the response to *febril* ‘feverish’ from the stem *fieber* ‘fever’).

Coding was carried out by the second author of this paper. As in the studies of Nicoladis and Krott (2007) and Lázaro (2012b), to check the reliability of the scoring an independent rater coded the responses of some of the children (six children, in our case, who were randomly selected from all three groups). Between-rater agreement was very high (95%), therefore we decided not to ask for further collaboration and proceeded with our own scores.

**RESULTS**

Results of the definition task for each group of children are reported in Fig. 1. Results showed a strong effect of orthographic alteration in both the analyses by participants (F(1, 57) = 451.33, MSe = 0.037, p < 0.001, $\eta^2 = 0.88$) and by items (F(1, 38) = 31.69, MSe = 0.53, p < 0.001, $\eta^2 = 0.45$); performance was lower on words with an orthographic alteration than on words without it. The effect of group was significant (F(1, 57) = 3.69, MSe = 0.108, p = 0.031, $\eta^2 = 0.15$; F(1, 38) = 20.06, MSe = 0.019, p = 0.05, $\eta^2 = 0.34$). Planned comparisons (Bonferroni post hoc test) showed that the younger group of skilled readers scored below the older group (p = 0.001). Children with reading deficits also scored below skilled readers of the same chronological age (p = 0.000). No difference was found between younger skilled children and children with reading deficits (p = 0.4). The interaction between group and orthographic alteration was not significant (F(1, 57) = 1.97, MSe = 0.4, $g^2 = 0.34$), thereby suggesting no difference in children’s performance irrespective of their reading ability. This effect should be expected considering that the

![Fig. 1. Total scores on the definition task for each group of children in each condition. Error bars show the standard error in each condition.](image)
orthographic overlap between a stem and the complex word is greater when no orthographic alteration is present.

Results also showed that children with reading deficits performed worse than typically developing readers of the same chronological age. As shown in Fig. 1, the older skilled children defined the derived words better than both children with reading deficits and younger skilled children, who did not differ from each other. The lack of difference between the latter two groups, despite the better phonological ability of the younger skilled children, may suggest that phonological ability does not play a relevant role in performance on the definition task, which mainly relies on semantic processing. However, a Pearson-correlation analysis showed a low, but significant, correlation between performance on one subtest of the PECO test and results obtained in the definition task \( r = 0.44, p < 0.001 \). Analyses split by groups revealed a significant correlation for children with reading deficits \( r = 0.69, p < 0.001 \) and non-significant correlations for typically developing readers \( r = 0.37, p = 0.11 \), for younger readers, and \( r = 0.34, p = 0.14 \), for older readers). However, when the data of the two groups of skilled readers were considered together, the correlation became significant \( r = 0.27, p = 0.04 \). Overall these results suggest that the performance at definition is to some extent predicted by phonological skills in all children. However, the data also suggest that phonology may be a stronger predictor of the definition performance in children with reading deficits than in typically developing readers. Thus it can be speculated that definition performance is more related to phonological skills when it does not reach a sufficient level of proficiency, as in the case of children with reading deficits. In accounting for the results, one must keep in mind the characteristics of the definition task, which is performed without a time limit. In this task children with reading deficits can benefit from having sufficient time to access the orthographic forms that correspond to morphemes, process their meanings and the meaning of the resulting combination and thus compensate for the phonological difficulties with extra time. A different time-limited task, in which rapid orthographic processing is crucial for accessing the lexicon and semantic processing is not involved to the same extent as in the word definition task, might provide additional evidence of difficulty in children with reading deficits in accessing morphology in words that include orthographically altered stems. An example of such a task is the on-line lexical decision task (see, e.g., Balota & Chumbley, 1984; Plaut, 1997), which we adopted in the second experiment with the same children.

EXPERIMENT 2

In the second experiment, we exploited the base frequency (BF) effect in interaction with orthographic-phonological opacity. BF has been frequently used to investigate morphological processing. It refers to the summed frequency of a base word and its inflected and derived words. When a word such as worker is considered, for example, the base frequency is obtained by summing the frequencies of work, works, workable, workout, etc. In several languages, such as Dutch (Bertram, Schreuder & Baayen, 2000b), English (Baayen, Wurm & Aycock, 2007; Ford, Davis & Marslen-Wilson, 2010), Italian (Burani & Caramazza, 1987) and Spanish (Lázaro, 2012a), high-frequency constituent morphemes facilitate adult readers’ recognition of a complex word. The morphemic effect suggests that readers process complex words not only through whole-word representations but also via their morphological constituents. The simultaneous processing of whole-word and morphemic representations is considered to maximize the possibility of successful word recognition (Beyersmann, Coltheart & Castles, 2012b).

Some studies have shown that children with and without language difficulties (including children with Down syndrome: Lázaro, Moraleda & Garayzábal, 2013; and Williams syndrome: Burani et al., 2006) benefit from the effect of the frequency of morphemic constituents. When confronted with a complex word that has a high-frequency base, children with reading deficits performed better on definition tasks (Lázaro, 2012b; Lázaro, Schreuder & Aceituno, 2011) and more quickly and accurately on lexical decision and naming tasks (Carlisle & Katz, 2006; Lázaro et al., 2013; Traficante, Marelli, Luzzatti & Burani, 2014; Verhoeven & Schreuder, 2011) than when they processed complex words with a low-frequency base. These results indicate that both young proficient readers and children with dyslexia use morphemes to achieve comprehension and reading fluency (see also Burani et al., 2008; Marcolini, Traficante, Zoccolotti & Burani, 2011).

As previous research showed a relevant effect of BF in children, in the present experiment we aimed to assess the role of BF in the context of orthographic shifts in the stem of a derived word. We focused on how orthographic-phonological alteration modulates the BF effect and thus affects morphological processing of the base.

We adopted the online lexical decision task in a go/no-go version (see Procedure below). Using this task, we expected to find larger differences between reading disabled and skilled readers than in the definition task. In comparison to the definition task, online lexical decision is very demanding for reading disabled children, because rapid orthographic processing is needed to access the lexical representation of a letter string. When performed under time pressure, lexical decision imposes heavy constraints on disabled readers who have a limited capacity to build the correct word form to access the lexicon. This makes the discrimination process particularly difficult.

METHOD

Participants

The same 60 children who participated in the first experiment also took part in this experiment. The order of the test administration was counterbalanced; therefore, half of the children performed experiment one first and the other half performed experiment two first.

Stimuli

A pool of 100 derived words was created with base frequencies ranging from 1 to 500 frequency per million. Half of the 50 words in each group had an orthographic alteration in the base and the other half were words in which the concatenation of affixes to stems did not involve any orthographic alteration. In this experiment, we assessed the effect on processing of the morphophonological adjustment that forces the
elimination of the last vowel of stems when affixes are concatenated (as in the case of obrag-obrares: “work-worker”; see Table A2 in the Appendix for the list of stimuli). The values of the variables were controlled using the same databases as in Experiment 1. Pseudowords were created by changing one or two letters in the stems of real complex words. There was a total of 100 pseudowords.

Procedure
A lexical decision task was carried out. But, instead of the classical yes/no task, we adopted the go/no-go task, analogously to Schmalz, Marinus and Castles (2013). Participants were instructed to judge as quickly as possible whether the presented letter strings were real words, while avoiding errors. When the letter string constituted a real word, participants had to press a button on the keyboard as quickly as possible; when the letter string did not constitute a real word participants were told not to press any key. This procedure is similar to a classical lexical decision task, but pseudowords are not responded to. In both versions of the lexical decision task the cognitive processes involved are basically the same, as shown by Perea, Gómez and Fraga (2010). Therefore, the go/no-go task should be sensitive to the same effects (e.g., semantic priming, repetition priming, word frequency, neighborhood size) as the yes/no lexical decision task (Gómez, Ratcliff & Perea, 2007; Perea, Rosa & Gómez, 2002; 2003). By using the go/no-go task we aimed to diminish error rates, accelerate response latencies and decrease variability in latency data (Moret-Tatay & Perea, 2011) relative to when the yes/no lexical decision task is administered to children (e.g., Laxon, Coltheart & Keating, 1988; Lázaro et al., 2013).

Participants sat about 50 cm away from a laptop screen in a quiet room. The screen showed a fixation point “+” for 1 second, followed by a word or pseudoword target for 3 seconds or until participants responded. After a response or time out, a blank screen was displayed for 500 ms. The order of presentation of the stimuli was randomized.

Prior to the experiment, ten trials (half words and half pseudowords) were presented in this same manner. None of the stimuli presented in the training session were used in the experiment.

RESULTS
Latencies and error rates were analyzed using mixed-effects models (Baayen, Davidson & Bates, 2008; Jaeger, 2008). The models were fitted in R software (version 3.0, RDevelopmentCoreTeam, 2008) using the lme4 package (Bates, Maechler, Bolker & Walker, 2014). P-values were obtained using the lmerTest package version 2.0 (Kuznetsova, Brockhoff & Christensen, 2014). Surface frequency, N, Letter length, BF, Suffix productivity, Group and Morpho-orthographic alteration of the bases were introduced as fixed factors. Participants and items were introduced as random effects. Response latencies were log-transformed to reduce skewness in the distribution. Main factors as well as the interactions between them were tested. The analysis started with a full factorial model, which was progressively simplified by removing the variables and the interactions that did not significantly contribute to the model. It was inspected through the results of the likelihood ratio test by comparing the model before and after removing the effect of each non-significant variable (for similar likelihood estimate procedures see Kuperman, Bertram & Baayen, 2010; Traficante et al., 2014).

For the sake of simplicity we only report data with significant p values (p < 0.05). The results show a significant effect of Group (t = −6.16, p < 0.001). Children with reading deficits responded slower than both younger and older typically developing readers (mean RTs were 1917, 1625 and 1250 ms, respectively). The results also show a significant effect of morpho-orthographic alteration (t = 1.96, p = 0.05). Complex words with morpho-orthographic alterations showed longer reaction times than complex words without morpho-orthographic shifts (1598 vs. 1555 ms.). Importantly, the interaction between BF and orthographic alteration was significant (t = −2.02, p < 0.05). To better understand this interaction, two different analyses were carried out for the two conditions of morpho-orthographic alteration. The results show that the effect of base frequency is smaller in the case of orthographic alteration (t = −2.43, p = 0.015) than in the case of no alteration (t = −4.57, p < 0.001).

Error rates were analyzed by means of generalized linear mixed models fit by the Laplace approximation for binomial data with the same fixed factors as in the analyses of RTs. Participants and items were introduced as random effects. The results showed three significant factors: Group (t = −5.8, p < 0.001), surface frequency (t = −7.3, p < 0.001) and BF (t = −2.5, p < 0.001), with no significant interactions. Children with reading deficits made more errors than control children and there were more errors with low surface frequency words and low base frequency words.

Discussion
The data showed that children with reading disabilities were the slowest and made more errors in performing the task and that orthographic alterations in the base affected performance. As expected, rapid lexical decision resulted in slow latencies for children with reading deficits. However, the lack of significance of the interaction between group and orthographic alteration indicates that children with reading disabilities were not more affected by the orthographic manipulation than the other groups. Consequently, although the reading disabled children were slower than the other readers, they demonstrated that they were able to parse morphologically complex words into morphemes when the stem was familiar enough, even if its orthographic form had been partially altered.

The interaction between BF and orthographic alteration indicates that the effect of BF was stronger for words with preserved bases than modified bases. Thus, the BF effect is qualified by the orthographic transparency of the base: access via the stem of the derived word is more likely to succeed when the stem is both of high frequency and orthographically transparent, i.e., when it is highly familiar and fully visible in the derived word. However, the analysis of error rates shows that high-frequency bases drive successful access to derived words in all young readers of differing reading abilities, irrespective of the orthographic alteration of the stem.

General discussion
The results of both experiments indicated that morphological processing is less beneficial when an orthographic alteration of the base stem is present: Word definition scores decreased (Experiment 1) and response times in a go/no-go lexical decision task increased (Experiment 2) when an orthographic alteration was present in the stem of a complex derived word. Furthermore,
in the second experiment the effect of base frequency (BF) was present for all derived words, but it was greater for words with preserved bases than for words with orthographically modified bases. This finding suggests that all complex words are addressed morphologically (presumably because of the presence of a suffix) independently of their surface form, but morphological analysis is a stronger determinant of word identification when the stem is not modified.

Results were consistent in the two experiments; in both tasks – definition and lexical decision – children’s reading ability as well as orthographic shifts in the stem had significant effects with no evidence of an interaction between them. This indicates that the orthographic alteration in a derived word plays an essential role irrespective of the task proposed and the readers’ skill. In 7–9 year-old developing readers with different reading abilities, the orthographic transparency of the morphological structure of a word is critical for accessing morphological representations and meaning.

This conclusion is in line with the interpretations of Beyersmann et al. (2012a) and Schiff et al. (2012), according to which morphological representations become more independent of orthography with increasing reading ability and word exposure. This is also consistent with the conclusions of Quémart and Casalis (2014), which we reported in the Introduction. In the early stages of reading development, readers rely heavily on the orthographic and semantic consistency of a stem to successfully identify the derived word, and in later stages, with increased exposure to written language and increased reading ability, a certain level of generalization develops in the mental lexicon. Words that share a stem become represented as related even in the absence of a shared orthographic form or a shared meaning, thus showing no effect of orthographic alteration in adult readers (McCormick et al., 2008). The idea that orthographic processing abilities are in part determined by print exposure is also consistent with findings reported in the classical study by Cunningham and Stanovich (1990).

The findings of our experiments indicate that children’s access to the morphological lexicon in tasks such as word recognition or definition is constrained by orthographic alterations in the derived word’s morphemes. It still remains to be assessed, however, whether these orthographic alterations might also negatively affect word recognition in the very early stages of stimulus processing; a lexical decision task performed under masked priming conditions might shed light on this issue. Some studies provide evidence consistent with this possibility (Quémart & Casalis, 2014; Schiff, Raveh & Kahta, 2008). Schiff et al. (2008) conducted a study on naming in masked priming conditions in Hebrew third- and seventh-grade children and found effects of morphological facilitation on targets when primes and targets contained all three letters of the root. However, no morphological facilitation was found when primed and targets did not overlap in the surface forms of the root. Two other studies investigated the earliest stages of word recognition in child readers of English (Beyersmann et al., 2012a) and Hebrew (Schiff et al., 2012), respectively. Both studies tested a different property of morphologically related words, that is, the semantic relatedness between a target word and its prime. In both studies, conducted in 8- to 9-year-olds (as in the present study), morphological facilitation effects were obtained only when the prime had a semantically transparent morphological relationship with the target word. Target recognition was facilitated by a semantically opaque (but morphologically related) prime only in older children (around 12.5 years). The authors concluded that a form-based morpho-orthographic decomposition mechanism is not yet automated in 8- to 10-year-olds and does not become automated until a later stage in reading development (see also Beyersmann et al., 2012a; McCormick et al., 2008). According to the authors, morphological representations become more abstract and depend more on the formal morphological structure of the root rather than its semantic properties only in the lexicon of skilled readers (Schiff et al., 2012).

In our study, the morphological and orthographic characteristics of words affected the performance of all children to similar extents, showing that access to word morphology occurs similarly in children with differing reading abilities. However, children with reading deficits were overall slower and scored worse than skilled readers of the same chronological age. This pattern of findings indicates that the main difficulties of children with reading deficits on the definition and lexical decision tasks have more to do with slower and less accurate processing of the written stimuli than with qualitatively different access and use of lexical-semantic information (see also, e.g., Davies, Cueto & Glez-Seijas, 2007; Paizi, De Luca, Zoccolotti & Burani, 2013; Zoccolotti, De Luca, Judica & Spinelli, 2008).

Finally, the results should be of great interest to clinicians. As pointed out by Lázaro and Calvo (2013), Traficante (2012) and in the reviews by Bowers, Kirby and Deacon (2010) and Goodwin and Ahn (2010), children with reading deficits can benefit from morphological instructions when they are given by experts. The fact that these children are able to process morphology similarly to skilled readers opens a window for this kind of teaching, namely, using morphology to compensate for a phonological deficit.

This work is dedicated to Rob Schreuder in memoriam. The authors are very grateful to Daniela Traficante for her advice in the statistical analysis of the second experiment. We acknowledge the support the first author received from the European Science Foundation (ESF) in the context of the “European Network on Word Structure: Cross-disciplinary Approaches to Understanding Word Structure in the Languages of Europe.” We also acknowledge the support the second author received from the Ministerio de Economía y Competitividad to collaborate in this study.

NOTE

1 Note that the condition without orthographic alteration included three different cases: (i) suffix attached perfectly to the stem, as in jardín-jardiner “garden-gardener”; (ii) same last vowel of the stem and first letter of the affix; thus one of the two was dropped, as in semana-semanal “week-weekly”; and (iii) the base was a verbal root and, consequently, the inflectional suffix had to be deleted when concatenating a new affix, as in cantar-cantante “sing-singer”.

REFERENCES


**APPENDIX**

Table A1. *Stímuli for Experiment 1*

<table>
<thead>
<tr>
<th>Orthographic alteration</th>
<th>No orthographic alteration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meloso (Honeyed)</td>
<td>Salino (Saline)</td>
</tr>
<tr>
<td>Herbario (Herbal)</td>
<td>Ayudante (Helper)</td>
</tr>
<tr>
<td>Fibril (Febrile)</td>
<td>Jardinero (Gardener)</td>
</tr>
<tr>
<td>Fortaleza (Fortitude)</td>
<td>Papeleria (Paper bin)</td>
</tr>
<tr>
<td>Pedrada (Blow from a stone)</td>
<td>Semanal (Weekly)</td>
</tr>
<tr>
<td>Certero (Accurate)</td>
<td>Colorista (Colorist)</td>
</tr>
<tr>
<td>Terrario (Terrarium)</td>
<td>Vigilante (Watchman)</td>
</tr>
<tr>
<td>Fososo (Spiritid)</td>
<td>Azacarillo (piece of sugar)</td>
</tr>
<tr>
<td>Invernadero (Greenhouse)</td>
<td>Lechería (Milkshop)</td>
</tr>
<tr>
<td>Soñador (Dreamer)</td>
<td>Avioneta (Plane)</td>
</tr>
<tr>
<td>Cordaje (Rigging)</td>
<td>Deportista (sporter)</td>
</tr>
<tr>
<td>Dentista (Dentist)</td>
<td>Cantante (Singer)</td>
</tr>
<tr>
<td>Herrera (Smith)</td>
<td>Florista (Florist)</td>
</tr>
<tr>
<td>Mortal (Mortal)</td>
<td>Lenguaje (Language)</td>
</tr>
<tr>
<td>Centena (Hundred)</td>
<td>Pobreza (Poverty)</td>
</tr>
<tr>
<td>Serpentina (Serpentine)</td>
<td>Cabezazo (Header)</td>
</tr>
<tr>
<td>Corporal (Corporal)</td>
<td>Cochero (Coachman)</td>
</tr>
<tr>
<td>Celeste (Celestial)</td>
<td>Musculoso (Muscular)</td>
</tr>
<tr>
<td>Portero (Porter)</td>
<td>Carrero (Ram)</td>
</tr>
<tr>
<td>Concertista (Concertist)</td>
<td>Estacazo (Blow with a club)</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>High BF with orthographic alteration</th>
<th>High BF without orthographic alteration</th>
<th>Low BF with orthographic alteration</th>
<th>Low BF without orthographic alteration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Letrero (Signboard)</td>
<td>Corredor (Runner)</td>
<td>Soplón (Informer)</td>
<td>Armador (Shipowner)</td>
</tr>
<tr>
<td>Libreta (Notebook)</td>
<td>Cristalero (Glazier)</td>
<td>Caldero (Cauldron)</td>
<td>Vigilante (Watchman)</td>
</tr>
<tr>
<td>Cocinero (Cook)</td>
<td>Ayudante (Helper)</td>
<td>Bombero (Fireman)</td>
<td>Habitante (Inhabitant)</td>
</tr>
<tr>
<td>Obreño (worker)</td>
<td>Lechero (Milkman)</td>
<td>Pulsera (Bracelet)</td>
<td>Aceitera (Oil can)</td>
</tr>
<tr>
<td>Otonal (Autumnal)</td>
<td>Jardiner (Gardener)</td>
<td>Tramposo (Cheat)</td>
<td>Cucharada (Spoonful)</td>
</tr>
<tr>
<td>Telefonista (Telephonist)</td>
<td>Papeler (Paper bin)</td>
<td>Guitarista (Guitarist)</td>
<td>Violinista (Violinist)</td>
</tr>
<tr>
<td>Diner (a lot of money)</td>
<td>Semanal (Weekly)</td>
<td>Pianista (Pianist)</td>
<td>Puñalada (Stab)</td>
</tr>
<tr>
<td>Grandioso (grandiose)</td>
<td>Florista (Florist)</td>
<td>Oficinista (Clerk)</td>
<td>Salero (Saltshaker)</td>
</tr>
<tr>
<td>Vivero (vivarium)</td>
<td>Colorista (Colorist)</td>
<td>Cerebral (Cerebral)</td>
<td>Mohosó (Moldy)</td>
</tr>
<tr>
<td>Camiset (t-shirt)</td>
<td>Carnero (Ram)</td>
<td>Molinero (Miller)</td>
<td>Peatonal (Pedestrian)</td>
</tr>
<tr>
<td>Espejismo (mirage)</td>
<td>Azucarillo (Piece of sugar)</td>
<td>Pantanal (Marshland)</td>
<td>Patinador (Skater)</td>
</tr>
<tr>
<td>Ventanilla (Window)</td>
<td>Relojero (Watchmaker)</td>
<td>Espesura (Thickot)</td>
<td>Temeroso (Fearful)</td>
</tr>
<tr>
<td>Frutería (greenery)</td>
<td>Avioneta (Plane)</td>
<td>Artista (Artist)</td>
<td>Borrador (Draft)</td>
</tr>
<tr>
<td>Orejera (Earmuff)</td>
<td>Futbolista (Footballer)</td>
<td>Accidental (Accidental)</td>
<td>Motorista (Motorcyclist)</td>
</tr>
<tr>
<td>Montanero (Mountaineer)</td>
<td>Comprador (Buyer)</td>
<td>Pistolero (Gunner)</td>
<td>Saludable (Healthy)</td>
</tr>
<tr>
<td>Manzanero (Apple tree)</td>
<td>Cantante (Singer)</td>
<td>Novelista (Novelist)</td>
<td>Bestial (Bestial)</td>
</tr>
<tr>
<td>Quesero (cheesemaker)</td>
<td>Monstruo (Monstrous)</td>
<td>Carterista (Pickocket)</td>
<td>Cazador (Hunter)</td>
</tr>
<tr>
<td>Flautista (Flutist)</td>
<td>Marino (Sailor)</td>
<td>Tintero (Inkwells)</td>
<td>Domador (Tamer)</td>
</tr>
<tr>
<td>Secano (Rainfed)</td>
<td>Musculos (Muscular)</td>
<td>Jarrón (Vase)</td>
<td>Habilidad (Hability)</td>
</tr>
<tr>
<td>Enfermero (Nurse)</td>
<td>Hablador (Talkative)</td>
<td>Cigarrillo (Cigarette)</td>
<td>Tribunal (Court)</td>
</tr>
<tr>
<td>Pescadero (Fishmonger)</td>
<td>Buscador (Seeker)</td>
<td>Tropical (Tropical)</td>
<td>Ocasion (Occasional)</td>
</tr>
<tr>
<td>Sillón (Armchair)</td>
<td>Pasteler (Baker)</td>
<td>Fichero (File)</td>
<td>Limpiador (Cleaner)</td>
</tr>
<tr>
<td>Manual (Manual)</td>
<td>Pobreza (Poverty)</td>
<td>Minero (Miner)</td>
<td>Profesional (Professional)</td>
</tr>
<tr>
<td>Batista (Bather)</td>
<td>Cabezazo (Hit with one’s had)</td>
<td>Intimidad (Privacy)</td>
<td>Leñador (Woodcutter)</td>
</tr>
<tr>
<td>Ropero (Wardrobe)</td>
<td>Cherner (Coachman)</td>
<td>Mentiros (Liar)</td>
<td>Alarmante (Alarming)</td>
</tr>
</tbody>
</table>