Visual Processing of Derivational Morphology in Children with Developmental Dyslexia: Insights from Masked Priming

(Short title: Morphological Processing in Dyslexic Children)

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Abstract

We investigated whether children with dyslexia rely on derivational morphology during visual word recognition, and how the semantic and form properties of morphemes influence this processing. We conducted two masked priming experiments, in which we manipulated the semantic overlap (Experiment 1) and the form overlap (Experiment 2) between morphologically related pairs of words. In each experiment, French dyslexic readers as well as reading-level matched and chronological-age matched children performed a lexical decision task. Significant priming effects were observed in all groups, indicating that their lexicon is organized around morpheme units. Furthermore, the dyslexics' processing of written morphology is mainly influenced by the semantic properties of morphemes, whereas children from the two control groups are mainly influenced by their form properties.

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Key-words

developmental dyslexia ; derivational morphology ; visual word recognition ; masked priming

Introduction

Developmental dyslexia is a failure to acquire word recognition skills which affects around 5% of the population despite adequate intelligence, education and social background (Lyon, 1995; Snowling, 2000; Stanovich, 1982; Vellutino, 1979). A leading hypothesis to explain the dyslexics' difficulties with word recognition is that it results from a deficient representation and use of phonological information (Goswami & Bryant, 1990; Griffith & Snowling, 2002; Rack, Snowling, & Olson, 1992; Sprenger-Charolles, Colé, & Serniclaes, 2006; Ziegler & Goswami, 2005), which interferes with the ability to establish grapheme-phoneme correspondences. These deficient phonological skills delay the development of orthographic knowledge (Hultquist, 1997) and the ability to process orthographic information (Marinus & De Jong, 2010), preventing the dyslexics from developing rapid and automatic word recognition skills (Share, 1995).

Although these phonological processing difficulties persist into adulthood (Bruck, 1990, 1992; Felton, Naylor, & Wood, 1990), the dyslexics make progress in learning to read (Deacon, Parrila, & Kirby, 2006; Pennington, Van Orden, Smith, Green, & Haith, 1990) and some of them succeed at university. However, very little is known about the mechanism by which the dyslexics learn to read. As a substitute for their inefficient decoding abilities, Stanovich (1980) has proposed that they use their adequate semantic knowledge to recognize words in a top-down process (see Hulme & Snowling, 1992, for a similar proposition). The dyslexics have also been assumed to process complex orthographic patterns more easily than spelling-age controls (Lefly & Pennington, 1991; Pennington, McCabe, Smith, Lefly, Bookman, Kimberling et al., 1986) and to develop superior awareness of the orthographic structure of words than typically-developing readers (Siegel, Share, & Geva, 1995).

In a pioneering work, Elbro and Arnbak (1996) have suggested that dyslexic readers are particularly prone to rely on morphemes, the smallest units of meaning in words, during visual word recognition. There are at least two reasons why the processing of written morphology could be particularly appropriate for dyslexic readers. First, morphemes are larger units than graphemes. Thus, their processing does not require the activation of fine-grained phonological representations, which are underspecified in dyslexics (e.g., Ziegler & Goswami, 2005). Second, a large proportion of the new words encountered in print are morphologically complex (Nagy & Anderson, 1984), and these complex words are generally very long and unfrequent, thereby unlikely to be represented in the lexicon. As dyslexic readers have difficulties in reading long words (Martens & de Jong, 2006) and new words (Rack et al., 1992), the possibility to decompose morphologically complex words into morpheme-size units may facilitate word recognition.

In spite of these arguments, only a few studies have investigated the issue of morphological processing during visual word recognition in dyslexic readers. The present study is designed to examine whether children with developmental dyslexia rely on morphemes during visual word recognition, and on which properties of morphemes they rely to do so.

Morphology, Word Recognition and Developmental Dyslexia

Over the last decade, an increasing body of research has demonstrated that developing readers rely on morphemes during the processing of morphologically complex words and pseudowords (in English: Carlisle & Stone, 2003, 2005; in French: Colé, Bouton, Leuwers, Casalis, & Sprenger-Charolles, 2012; Quémart, Casalis, & Duncan, 2012; in Italian: Burani, Marcolini, & Stella, 2002) as early as in second grade.

However, there is little agreement as to whether the ability to process written morphology can develop in spite of decoding difficulties. Some authors have argued that the processing of small-size units such as graphemes is required to process large-size units such as rhymes (Duncan, Seymour, & Hill, 1997; 2000), suggesting that the processing of written morphemes should not be possible when the application of grapheme-phoneme correspondences is impaired. Nevertheless, the psycholinguistic grain-size theory considers that reading development does not necessarily involve a small-to-large unit progression and that grain-size units depend on orthographic consistency as well as on the availability of spoken units in a given language (Ziegler & Goswami, 2005). In line with this argument, Hatcher and Snowling (2002) suggest that the establishment of relationships between orthography and phonology occurs at a coarse-grained level in dyslexics, i.e. at a multi-letter level or at a morphemic level.

Studies investigating the ability of readers with dyslexia to make use of morphemes during visual word recognition have revealed inconsistent results. Children with dyslexia benefit from the presence of morphemes when reading aloud Italian complex words (e.g., *cassiere*, “cashier”) and pseudowords (e.g., *donnista*, “womanist”; Burani, Marcolini, De Luca, & Zoccolotti, 2008; Traficante, Marcolini, Luci, Zoccolotti, & Burani, 2011). In Danish, they are more efficient when they can move a text window morpheme-by-morpheme than syllable-by-syllable, contrary to their reading age matched peers (Elbro & Arnbak, 1996). Significant priming effects in a lexical decision task have also been evidenced by Leikin and Zur Hagit (2006) in Hebrew-speaking adults with dyslexia. By contrast, Deacon, Parrila and Kirby (2006) found that, contrary to their age matched peers, high-functioning English-speaking adult dyslexics were not influenced by the morphological complexity of words when performing a lexical decision task. A lack of sensitivity to the morphological structure of words has also been reported by Schiff and Raveh (2007) in a primed word fragment completion task in adult Hebrew readers with dyslexia (see also Raveh & Schiff, 2008 for similar results in a primed visual lexical decision task).

These inconsistencies might result from methodological differences between studies with respect to the tasks used and the control groups selected for comparison. Indeed, the dyslexics' reliance on derivational morphemes in a naming task indicates that they have established connections between orthography and phonology at larger grain sizes than single letters, which might supplement inefficient grapheme-phoneme decoding. By contrast, the lexical decision task sheds light on how the lexical system encodes morphological information and how it recognizes morphologically complex words. In addition, given the absence of a reading-age matched control group in many experiments, one cannot exclude that the different patterns of results observed in dyslexics may be the consequence of their general reading delay rather than a specific deficit in morphological processing. Thus, the lack of convergence between the studies conducted so far demonstrates the need to further investigate the processing of written morphology in dyslexics.

Nature of Morphological Processing

As morphemes encode both form and meaning information, the present paper also seeks to clarify the influence of each of these properties in the dyslexics' processing of written morphology. Both hypotheses (form-driven and meaning-driven processing) have been proposed. According to Burani et al. (2008, see also Marcolini, Traficante, Zoccolotti, & Burani, 2011; Traficante et al., 2011), children with dyslexia are better able to grasp morphemic than graphemic units when reading long and unfrequent words, because morphemes are larger units than graphemes and easily catchable. This form-driven hypothesis assumes that the processing of written morphology does not necessarily require the activation of semantic knowledge when reading aloud. In contrast, Elbro and Arnbak (1996, see also Casalis, Colé, & Sopo, 2004, for a similar proposition) consider that the dyslexics' activation of morphemes' meaning is central in morphological decomposition when reading aloud. In line with this meaning-driven hypothesis are the more accurate reading scores of the dyslexics when morphologically complex words are semantically transparent (e.g. *sunburn*) than opaque (e.g., *window;* Elbro & Arnbak, 1996).

The form-based and meaning-based hypotheses of morphological decomposition have never been directly compared in dyslexic readers. The priming paradigm associated to a lexical decision task has been successfully used to investigate this issue in adult skilled readers (in English: Feldman, Soltano, Pastizzo, & Francis, 2004; Marslen-Wilson, Tyler, Waksler, & Older, 1994; Rastle, Davis, Marslen-Wilson, & Tyler, 2000; in French: Giraudo & Grainger, 2000; Longtin, Segui, & Hallé, 2003; See Rastle & Davis, 2008, for a review) and in typically developing readers (Casalis, Dusautoir, Colé, & Ducrot, 2009; Quémart, Casalis, & Colé, 2011). In particular, the manipulation of the semantic overlap between morphologically related prime-target pairs, as well as the manipulation of prime duration, has made it possible to examine the influence of form and meaning in the processing of written morphology.

In adult skilled readers, when the prime is presented so fast that it cannot be explicitly perceived (i.e., masked priming), priming effects have been observed when prime-target pairs share a morphological relationship (e.g., *cleaner – clean*) and a pseudoderivation relationship (i.e. morphological relationship with no semantic overlap, e.g., *corner – corn*). This result is taken as evidence that the processing system is not influenced by the semantic properties of morphemes at the earliest steps of word recognition (in English: Marslen-Wilson, Bozic, & Randall, 2008; Rastle, Davis, & New, 2004; in French: Longtin & Meunier, 2005; Longtin et al., 2003). However, when the prime is presented for more than 200 ms, priming effects are not observed in the pseudoderivation condition anymore (Marslen-Wilson et al., 2008; Longtin et al., 2003; Meunier & Longtin, 2007), indicating that the activation of the semantic properties of morphemes is essential to observe morphological decomposition later in the time course of visual word recognition.

Similar results have been observed in typically developing readers, except that the influence of the semantic properties of morphemes was perceptible later in the time course of word recognition than in adults. Indeed, in a study using three different prime durations, Quémart et al. (2011) found that third to seventh grade children benefit from a prime that shares a morphological relationship (i.e. *tablette – TABLE*, "little table – table") and a pseudoderivation relationship (i.e. *baguette – BAGUE*) when the prime is presented for 60 ms and 250 ms. However, with a prime duration of 800 ms, priming effects were not significant in the pseudoderivation condition anymore, indicating that form overlap is not sufficient to process morphologically complex words through their components at this prime duration[1].Instead, the significant priming effects observed in both the morphological and semantic conditions were taken as evidence that developing readers are mainly influenced by the semantic overlap between primes and targets when recognizing words at this 800 ms prime duration.

These patterns of priming have led to the conclusion that morphological decomposition is first driven by the form properties of morphemes (*morpho-orthographic processing*) and then driven by the semantic properties of morphemes (*morpho-semantic processing*). This double-mechanism, the *form-then-meaning account*, assumes that morpho-orthographic processing is a sine-qua-non to morphological decomposition, and that the activation of the semantic properties of morphemes occurs only when words have been decomposed into smaller components on the basis of their form properties.

Nevertheless, the necessity to decompose morphologically complex words into smaller orthographic units prior to the activation of morphemes' meaning has been put into question fairly recently (Diependaele, Duñabeitia, Morris, & Keuleers, 2011; Diependaele, Sandra, & Grainger, 2005, 2009; Feldman, O'Connor, & Moscoso del Prado Martin, 2009; but see Davis & Rastle, 2010, for an alternative view). The authors suggest that the semantic properties of morphemes influence morphological decomposition very early in the time course of word

[1] Note, however, that priming effects were significant in the "orthographic control" condition in this experiment; this effect was due to a speed-accuracy tradeoff and could not be interpreted as a significant orthographic priming effect.

recognition. Their assumption is based on a systematic review of the adult literature on morphological masked priming as well as on empirical data, whereby the amount of priming is larger when prime-target pairs share a morphological relationship that is semantically transparent (i.e. related in meaning) than semantically opaque (i.e. unrelated in meaning). To explain these results, Diependaele et al. (2009) have proposed an hybrid model of morphological processing, according to which morpho-orthographic and morpho-semantic representations are activated in parallel during word recognition. The morpho-orthographic and morpho-semantic levels are interconnected via feedback connections and resonate with each other when the words that are presented to the system activate the two processing levels. These feedback connections explain why larger amounts of priming have been observed when morphological relationship is semantically transparent than opaque.

The existence of form-driven and meaning-driven hypotheses of morphological processing when reading aloud in the dyslexic literature, as well as the lack of consensus regarding the triggering factors of morphological decomposition in the adult literature, prompted the need to address whether and how children with developmental dyslexia rely on morphemes during visual word recognition.

The Present Study

The existing work thus leaves two important questions open regarding the processing of derivational morphology in children with developmental dyslexia:

1. Do children with dyslexia activate morphological information during visual word recognition?

2. What is the influence of morphemes' meaning and form properties in this processing?

In this paper, we attempt to address these questions through the study of the influence of semantic information (Experiment 1) and form information (Experiment 2) on French dyslexics' morphological decomposition. Morphologically related pairs of words were included in a visual masked priming paradigm, which consists in presenting the primes so fast that they cannot be explicitly perceived. Thus, contrary to the unmasked priming paradigm, which makes it possible to activate strategies in the recognition process, the masked priming paradigm is a powerful tool for investigating rapid and automatic word recognition, and to explore a processing which is not under strategic control (Forster, 1998).

Although on-line priming studies have already been conducted in adults with dyslexia (Leikin & Zur Hagit, 2006; Raveh & Schiff, 2008; Schiff & Raveh, 2007), such studies have never been carried out in dyslexic children. The priming paradigm has nonetheless already been exploited in the "garden variety" of poor readers. Significant phonological (Betjemann & Keenan, 2008) and semantic (Assink, Van Bergen, Van Teeseling, & Knuijt, 2004; Simpson, Lorsbach, & Whitehouse, 1983) unmasked priming effects have been reported in this population, as well as phonological and orthographic masked priming effects (Booth, Perfetti, & MacWhinney, 1999). In the latter study, Booth and colleagues have shown that poor readers are slower in activating orthographic and phonological information than good readers, but pseudohomophone priming effects (e.g., *kyte - KITE*) and orthographic priming effects (e.g., *kute – KITE*) were already reliable when primes where presented for 60 ms. Following Booth et al. (1999), we decided to use a 60 ms prime duration in the two experiments presented below.

In order to examine the influence of primes on target processing, we asked the participants to perform a lexical decision task on the targets. This task is more appropriate than the naming task for the purpose of this study because we sought to investigate whether dyslexic children activate morphological representations during visual word recognition. In addition, lexical decision times are influenced to a greater extent by morphological and semantic information than word naming times (Baayen, Feldman, & Schreuder, 2006).

In each Experiment, we compared patterns of priming observed in dyslexics (DYS) to patterns of priming of children matched for Reading Level (RL) and of children matched for Chronological Age (CA). We included a group of adult skilled readers in Experiment 2 only, as the effect of semantic transparency on French adult skilled readers' morphological processing has been demonstrated in several studies (see for example Longtin et al., 2003).

Experiment 1: Influence of the semantic properties of morphemes

Experiment 1 was specifically designed to examine whether dyslexic children rely on morphemes during visual word recognition, and, if so whether this reliance is driven by the semantic properties of morphemes. To do so, we selected prime-target pairs that could share four relationships: morphological (e.g., *tablette – TABLE*, "little table – TABLE"), pseudoderivation (i.e. morphological without semantic overlap, e.g., *baguette – BAGUE*, "French stick – ring"), orthographic control (i.e. orthographic overlap with no morphological relationship, *abricot – ABRI*, "apricot – shelter") and semantic control (e.g., *tulipe – FLEUR*, "tulip – FLOWER").

If children with dyslexia process the morphological structure of words during their recognition, they should benefit from morphological priming and we expect to observe different priming effects in the orthographic control and semantic control conditions. With respect to the nature of this processing, two assumptions can be formulated on the basis of naming patterns observed in previous studies. If morphemes' meaning is not involved in morphological processing in dyslexic readers, as suggested by the form-driven hypothesis, then we should observe significant priming effects in the morphological and pseudoderivation conditions. However, if dyslexic readers rely on the semantic properties of morphemes to process derivational morphology, as proposed by the meaning-driven hypothesis, we expect significant priming effects in the morphological condition only. Finally, we did not expect significant priming effects in the semantic control condition in both groups, as semantic priming typically characterises later stages of visual word recognition (Bonnotte & Casalis, 2010; Nievas & Justicia, 2004).

Method

Participants.

The dyslexics (n = 16, 7 boys and 9 girls, mean age = 13;6) the RL control participants (n = 16, 9 boys and 7 girls, mean age = 9;8) and the CA control participants (n = 16, 8 boys and 8 girls, mean age = 13;1) were recruited while they were involved into a larger experiment on morphological processing in good and poor readers in regular schools in the area of Lille (Northern France) and in a specialised school for children with dyslexia in the area of Arras (Pas de Calais, France).

All the dyslexic participants were impaired in both pseudoword and irregular word reading, and were therefore classified as having a mixed profile of dyslexia by a multidisciplinary team including a speech therapist and an education psychologist. Their nonverbal IQ was within normal range and they all had at least 24 months reading delay.

None of the control participant reported language impairments, hearing impairments or neurological disorders and all the participants had French as their first language.

Background measures.

The children completed a battery of five tasks in order to provide a more complete picture on cognitive and metalinguistic skills of both groups of participants. The complete battery was administered in one session between the two lists of the experimental task. The tasks were administered individually to participants in a quiet room in their schools and they were administered in the same order to all participants. The mean scores for each of the measures for each group are given in Table 1.

Reading skills. Word reading ability was assessed with the Alouette French reading test (Lefavrais, 1967), which was administered individually. This test is the most commonly used reading test in France. It consists in reading a text of 265 words aloud as quickly and accurately as possible. The final score provides a reading age taking into account both speed (how many words are read during three minutes) and accuracy. This reading age enables to ensure that the dyslexics' reading age is at least 18 month behind their chronological age. Although the reliability of this test has not been directly assessed, it compares favorably with other reading tests in terms of sensitivity, specificity and efficiency (Bertrand, Fluss, Billard, & Ziegler, 2010).

***Nonverbal reasoning*.** Nonverbal reasoning was assessed by Raven's Coloured Progressive Matrices (Raven, Court, & Raven, 1995) in children under the age of 12, and Raven's Standard Progressive Matrices (Raven, Raven, & Court, 1998) in children older than 12 years old. The score provided is the raw score (number of correct responses[2]). The reliabilities of the Raven Coloured and Standard Progressive Matrices are respectively .90 and .88.

***Receptive Vocabulary*.** Receptive vocabulary of the participants was measured with the French version of the Peabody Picture Vocabulary Test (EVIP: Echelle de Vocabulaire en Images Peadbody, Dunn, Theriault-Whalen & Dunn, 1993). This test consists of 170 words of increasing difficulty. For each word, children need to choose the corresponding image from four alternatives. Because of time constraints, a shorter version of the test has been administered. For each child, we selected a subset of images depending on their chronological age. This subset included images ranging from two years below up to two years above their chronological age. For example, 8-year old children completed the test between 6 and 10-year-old. The score was the percentage of correct answers within a given age range. The reliability of the EVIP test is .80.

[2] Note that the number of items included in the Coloured Progressive Matrices (specifically designed for children under the age of 12) is different from the number of items included in the Standard Progressive Matrices (36 *vs*. 60).

Phonological Decoding. We assessed the phonological decoding skills of the participants by means of a pseudoword reading task. It consisted in reading a set of 12 short pseudowords (mean number of letters = 4.67; *SD* = 0.49) and 20 long pseudowords (mean number of letters = 8.95; *SD* = 0.51) as fast and accurately as possible. The pseudowords were created by substituting one or two letters from an existing word. This task is a good indicator of phonological skills, and is particularly deficient in readers with dyslexia (Rack et al., 1992). Inter-item reliability was .82.

Morphological Awareness. Finally, as a control measure, we assessed morphological awareness through a sentence completion task, adapted from Carlisle (1988). The participants were orally provided with a sentence and had to add the appropriate derivational suffix at the end of a base word to complete the sentence correctly (e.g., *Une petite fille est une* ____ *[fillette]*). The whole task consisted of ten sentences, each with one target word. Half of the derivations involved no phonological change (e.g., fille / fillette) and half of the derivations involved a phonological change (e.g., forêt / forestier). The mean spoken frequency of the base was 90.14 and the mean spoken frequency of the whole word was 4.08, as indicated by the French Lexical database Lexique[3] (New, Brysbaert, Veronis, & Pallier, 2007).Participants performed two practice trials prior to receiving the ten test trials. Inter-item reliability was .92.

Insert Table 1 about here

The DYS were matched to the group of RL children (n = 16, 9 boys and 7 girls) in terms of reading age ($t < 1$) and to the group of CA children (n = 16, 8 boys and 8 girls) in receptive vocabulary ($t < 1$) and in non-verbal reasoning, $t(30) = 1.77$, ns. However, because of recruitment constraints, DYS could not be perfectly matched to CA children in terms of

[3] These spoken word frequencies are provided for information only because they are based on film and television subtitles. No child database of spoken word frequency is available in French.

chronological age and were slightly older than their normal-reading peers, $t(30) = 2.08$, $p = .046$.

Reading accuracy in the pseudoword reading task depended on the group, $F(2, 91) = 3.18$, $p = .046$. Paired-sample *t*-tests indicate that the dyslexics were less accurate than the RL children, $t(62) = 1.82$, $p = .037$, and the CA children, $t(60) = 2.30$, $p = .025$, when reading pseudowords. Regarding morphological awareness, there was a significant effect of the group on the percentage of correct derivations, $F(2, 45) = 6.54$, $p = .003$. The DYS were more accurate than the RL matched children when completing sentences with the correct derived form, $t(30) = 3.05$, $p = .004$, and their performance was not different from the CA matched children ($t < 1$).

Stimuli and design.

Four experimental conditions were created, including 16 prime-target pairs in each condition. The conditions were the following:

Morphological (e.g., *tablette – TABLE*, "little table – TABLE"). Prime-target pairs were morphologically related, and the morphological status of the primes was determined using the ''Brio'' French dictionary (Rey-Debove, 2004), which analyzes the lexical morphology of French. An equivalent in English could be *cleaner – CLEAN*.

Pseudoderivation (e.g., *baguette – BAGUE*, ''French stick – RING'')**.** The primes could be parsed into existing morphemes ("bague" and "-ette") but were semantically unrelated to the target. An equivalent in English could be *corner – CORN*.

Orthographic control (e.g., *abricot – ABRI*, ''apricot – SHELTER''). The primes were orthographically related to the target, as their beginning word included the target, but could not be parsed into existing morphemes (i.e. "cot" is not a suffix-ending in French). An equivalent in English could be *brothel – BROTH*.

Semantic control (e.g., *tulipe – FLEUR*, "tulip – FLOWER"). Primes-target pairs were semantically but not morphologically or orthographically related.

The semantic relatedness between morphological and pseudoderivation pairs was evaluated by 112 undergraduate students from the University of Lille (Northern France) on a scale ranging from 1 (surely unrelated) to 4 (surely related). Prime-target pairs in the morphological condition had a mean rate of at least 3.50 out of 4 (M = 3.86, SD = 0.12) while in the pseudoderivation condition the prime-target pairs had a mean rate of 1.50 out of 4 or below (M = 1.24, SD = 0.07). In addition, the semantic relatedness between primes and targets was not different in the morphological (M = 0.33) and semantic (M = 0.26) conditions ($t(30)$ = 1.11, p = .273) as determined by the Latent Semantic Analysis (LSA, Landauer & Dumais, 1997).

The distributional characteristics of selected items were provided by the French lexical database Manulex-infra (Peereman, Lété, & Sprenger-Charolles, 2007) and are summarized in Table 2. Primes were matched for print frequency, length and neighbourhood size (Fs < 1.11). Targets were matched for print frequency (F < 1) but could not be perfectly matched for length, $F(3, 60) = 3.47$, $p = .02$, as morphologically related targets were longer than orthographically related targets (5.25 vs. 4.25 letters, $p = .02$). Because of constraints on item selection, we could not fully match the targets in neighbourhood size, $F(3, 60) = 7.02$, $p <$ .001. Targets from the semantic condition (mean N size = 1.88) had fewer orthographic neighbours than targets in the morphological (mean N size = 4.50), pseudoderived (mean N size = 6.06), and orthographic control (mean N size = 5.25) conditions. Finally, the orthographic overlap between primes and targets tended to be higher in the morphological and pseudoderivation conditions than in the orthographic control condition. A complete list of the stimuli is presented in Appendix A.

Insert Table 2 about here

Each of the 64 targets was associated to an unrelated prime, which served as a baseline to assess priming effects. These 64 prime-target pairs shared no morphological, semantic, or orthographic relationship.

An additional set of 16 unrelated prime-target pairs was included as fillers in the experiment, in order to reduce the proportion of related prime–target pairs to 44%, leading to a total of 144 prime–word target pairs.

For the purpose of the lexical decision task, 144 prime-target pairs with pseudowords as targets and words as primes were included in the experiment. Pseudowords consisted of legal orthographic and phonological sequences created by changing one or two letters of an existing word. In analogy to the word condition, 64 pseudoword targets were preceded by an orthographically related word and 80 were preceded by an orthographically unrelated word. In addition, half of these primes were derived or pseudoderived words, and half were not.

The 288 prime-target pairs were divided into two lists of 144 items, with 72 word targets and 72 pseudoword targets in each list. Among the 72 target words from each list, 32 were associated with a related prime (8 from each of the 4 conditions) and 32 were associated to an unrelated prime. A target word preceded by a related prime in one list was preceded by an unrelated prime in the other list.

Procedure and apparatus.

The presentation of the stimuli and recording of response times were controlled using the E-Prime software package version 1.0 (Schneider, Eschmann, & Zuccolotto, 2002) running on a Dell Latitude 131L laptop computer. The items were displayed in 25-point Courier New font and appeared on the screen as black characters on white background. Each trial consisted of the following sequence of four stimuli: First, a fixation cross (which also served as inter-trial interval) was displayed on the middle of the screen for 1000 ms. Next, a forward mask consisting of a row of eight hash marks was presented for 800 ms, followed immediately by the prime stimulus in lowercase letters for 60 ms, followed immediately by the target stimulus in uppercase letters. The target remained on the screen until the participants responded, and for a maximum of 5000 ms. Reaction times were measured from target onset until the participants' response.

Child participants were tested in a dedicated room at their school building during regularly scheduled school hours. They were instructed to respond as rapidly and as accurately as possible whether the target was a real word or not, and had to respond by pressing the *p* ("yes" answer for right-handed children[4]) or *q* ("no" answer for right-handed children) keys on a computer keyboard. The presence of a prime was not mentioned. Each participant completed 10 practice trials, representative of the experimental stimuli, and then completed the two experimental lists without feedback.

We used a within-participants design, in order to eliminate inter-individual differences. Therefore, each participant completed the two experimental lists, but the background tests were completed between the two experimental lists in order to minimize repetition effects. In addition, to ensure that target repetition did not influence priming effects, we entered the order of list presentation into the statistical analysis. The order of presentation of the items within the two lists was randomized, and the order of presentation of each list was counterbalanced.

Results

Table 3 shows the mean error percentages and mean RTs for correct responses in each group. A 3 (group: DYS versus RL versus CA) X 4 (condition: morphological versus pseudoderivation versus semantic versus orthographic) X 2 (priming: related versus

[4] Left-handed children did the opposite.

unrelated) X 2 (order of list presentation: 1 versus 2) repeated-measures analysis of variance was computed using log-transformed RTs as dependant variable. RTs faster than 500 ms (0.24 % of the data) and slower than 3500 ms (2.30 % of the data) were considered as outliers and removed from data analysis. Two targets were also excluded from data analysis because error rates were beyond 2 SD of the mean (“mou”: 19.19%; “char”: 15.07%[5]).;

Insert Table 3 about here

The analysis of variance indicated a main effect of group, $F(2, 45) = 10.69$, $p < .001$, $\eta^2_p = .32$. Post-Hoc comparisons showed that the RL children were slower than the DYS and the CA, but reaction times were not different between the DYS and the CA. The main effect of priming was also significant, $F(1, 45) = 6.91$, p .012, $\eta^2_p = .13$, indicating that RTs were faster when targets were preceded by related than unrelated primes. This priming effect interacted with the group, $F(2, 45) = 3.73$, $p = .03$, $\eta^2_p = .14$, showing that the amount of priming differed across the three groups. The main effect of the order of list presentation was significant, $F(1, 45) = 59.34$, $p < .001$, $\eta^2_p = .57$, as RTs were faster in the second testing session than in the first, but the three-way interaction between order of list presentation, condition and priming did not achieve significance ($F < 1$) and will not be discussed further. Finally, the three-way interaction between group, priming and condition was not significant, $F(6, 135) = 1.05$, $p = .39$, $\eta^2_p = .04$. The significant interaction between group and priming led us to perform planned comparisons on this interaction in each group.

The DYS showed significant priming effects in the morphological condition, $F(1, 15) = 8.90$, $p = .009$, $\eta^2_p = .37$ but not in any of the three other conditions (pseudoderivation: $F < 1$; orthographic control: $F(1, 15) = 2.65$, $p = .12$, $\eta^2_p = .12$, semantic control: $F(1, 15) = 2.00$,

[5] The stimuli remained matched across all factors after excluding these items

$p = .18$, $\eta^2_p = .12$). By contrast, the RL and CA control groups showed priming effects in the morphological ($F(1, 15) = 5.94$, $p = .028$, $\eta^2_p = .28$ in RL, $F(1, 15) = 5.15$, $p = .038$, $\eta^2_p = .26$ in CA) and in the pseudoderivation ($F(1, 15) = 18.37$, $p < .001$, $\eta^2_p = .55$ in RL, $F(1, 15) = 8.90$, $p = .009$, $\eta^2_p = .35$ in CA) conditions. No significant priming effects were observed in these groups for the orthographic control ($F(1, 15) = 1.36$, $p = .26$, $\eta^2_p = .08$ in RL, $F < 1$ in CA) and semantic control ($F_S < 1$ in RL and in CA) conditions.

Discussion

Experiment 1 was conducted in order to answer two questions related to morphological processing in dyslexic readers. The first question was whether dyslexic children rely on morphemes during visual word recognition. Results show significant morphological priming effects in the dyslexic group of participants, as well as in the two control groups. However, priming effects were not significant in the orthographic control and semantic control conditions. These patterns of priming indicate that children with dyslexia benefit from the presence of a morphologically related prime to process a target, and that this processing can be distinguished from priming attributable to form or meaning overlap alone. This result reinforces the hypothesis according to which the dyslexics are able to process morphemic units in spite of their decoding difficulties, as already proposed by Elbro and Arnbak (1996) and Burani et al. (2008). The use of a masked priming procedure has also made it possible to evidentiate that the activation of morphological representations is rapid and automatic in dyslexic readers.

The second question was whether semantic overlap between morphologically related words is necessary for dyslexics to trigger morphological decomposition during visual word recognition. Our results indicate that the dyslexics and control groups are influenced differently by semantic properties of the combination of morphemes. Indeed, contrary to their matched peers, children with dyslexia do not exhibit significant priming effects when prime-target pairs share a pseudoderivation relationship. Thus, form overlap is not sufficient to process morphologically complex words into smaller components in dyslexic readers. Morphological representations of dyslexics appear to be specified at the morpho-semantic level of representation rather than at the morpho-orthographic level, which confirms the hypothesis of semantically-structured morphological representations in dyslexics already suggested by Elbro and Arnbak (1996, see Casalis et al., 2004, for a similar proposition).

A noteworthy aspect of the current results is that priming effects in dyslexic readers were significant in the morphological condition only. This finding supports the hypothesis that morphological decomposition is not necessarily only driven by the orthographic properties of morphemes at the earliest steps of word recognition, and that the semantic properties of morphemes also have a role to play at this step of visual word recognition. Slightly larger priming effects in morphological than pseudoderivation conditions had already been evidenced in adult skilled readers (Feldman et al., 2009, Diependaele et al., 2005, 2009, 2011) but the hypothesis according to which the semantic overlap between morphologically related primes influences word recognition very early in the time course of word recognition has received only little support so far. Our results in the dyslexic population are in line with this hypothesis, in that they indicate that an early and efficient activation of the morpho-semantic procedure can assist inefficient morpho-orthographic decomposition at the earliest steps of word recognition.

In summary, the processing of written morphology is more influenced by the semantic properties than by the form properties of morphemes in dyslexic readers. In order to further support this finding, we conducted a second experiment in which we manipulated the phonological and orthographic overlap between morphologically related primes and targets, while keeping semantic overlap constant.

Experiment 2: Influence of the form properties of morphemes

Morphological derivation often implies slight form modification of the base word, that can be phonological (e.g., *direct*/*direction*) and/or orthographic (e.g., *divide/division*). These modifications do not appear to be a barrier to efficient morphological decomposition in adult skilled readers, as they benefit from masked priming even when the derivation involves a slight orthographic alteration of the base word (e.g., *wranish* – *WARN*, Beyersmann, Castles, & Coltheart, 2011, Duñabeitia, Perea, & Carreiras, 2007, McCormick, Rastle, & Davis, 2008).

However, developing readers in third and fifth grade have more difficulty in naming derived forms when they undergo phonological and orthographic modifications than when they do not (Carlisle, 2000). In addition, ten-year-old children are more accurate when performing a primed fragment completion task when morphological overlap between primes and targets is orthographically transparent (e.g., *messy* – *MESS*) than opaque (e.g., *chosen* – *CHOOSE*; Feldman, Rueckl, DiLiberto, Pastizzo, & Vellutino, 2002). Thus, morphological decomposition appears to be less flexible and more sensitive to form overlap between morphologically related words in developing readers than in skilled readers.

The probability to be penalized by form modifications of the base also depends on phonological skills. Indeed, poor readers have more difficulties naming words whose base word undergoes a phonological shift when a suffix is added ("shift words", e.g., *natural*) than words that are phonologically transparent ("stable words", e.g., *cultural*) and this effect is more pronounced in poor readers than in average readers (Carlisle, Stone & Katz, 2001). Nevertheless, using the same stimuli, Carlisle et al. (2001) found that poor readers' latencies were less penalized by phonological shift in a lexical decision task, suggesting that the impact of phonological transparency depends – at least partially – on task demands.

In this study, we aimed at verifying to what extent a semantic overlap between morphologically related words is sufficient to trigger morphological decomposition in children with dyslexia. To this end, we manipulated the phonological and orthographic overlap between morphologically complex words and kept semantic overlap constant. If children with dyslexia activate rapidly and automatically the semantic properties of morphemes during visual word recognition, as already evidenced in Experiment 1, then we expect them to benefit from morphological priming independently of the phonological and orthographic modifications of the base word. Regarding the control groups, results from Experiment 1 indicate that morphological decomposition is triggered by the form properties of morphemes at the earliest steps of word recognition. As a consequence, we expect the RL and the CA children to be penalized by these form modifications of the base word, and to exhibit morphological priming only when there is no modification of the base word. Finally, we expected the adults to exhibit priming effects in the three morphological conditions, given that morphological processing has been shown to be robust to form modifications in this population (Beyersmann et al., 2011; Duñabeitia et al., 2007; McCormick et al., 2008).

Method

Participants and background measures.

A new pool of participants involved in the same large-scale study as in Experiment 1 participated in Experiment 2. Based on the background measures presented in Experiment 1, we constituted a group of DYS, (n = 14, 5 boys and 9 girls) a group of RL matched children (n = 14, 7 boys and 7 girls) and a group of CA matched children (4 boys and 10 girls). As in Experiment 1, the inclusion in the DYS group was justified by their reading age, their scores in nonverbal reasoning and receptive vocabulary.

Insert Table 4 about here

The mean scores of these background measures as well as the accuracy in pseudoword decoding and morphological awareness are provided in Table 4. The DYS were matched to RL in reading age ($t < 1$) and matched to CA in non-verbal reasoning and receptive vocabulary, ts < 1.However, because of recruitment constraints, DYS could not be perfectly matched to CA in terms of chronological age, $t(26) = 2.47$, $p = .020$.

Regarding pseudoword decoding, mean accuracy scores depended on the group, $F(2, 79) = 3.19$, $p = .047$. Accuracy was lower in the DYS than in the CA matched children, $t(52) = 2.37$, $p = .011$ but was not different in the DYS than in the RL matched children ($t < 1$). With respect to morphological awareness, correct sentence completion did not depend on the group, $F(2, 39) = 1.74$, $p = .19$. Finally, it is important to note that the DYS from Experiment 1 and from Experiment 2 were matched for reading age, pseudoword reading accuracy and morphological awareness (all ts < 1).

Fifteen undergraduate students at the University of Lille also participated in the experiment in order to constitute a group of adult participants. All were native speakers of French and reported normal or corrected-to-normal vision. They had no history of learning disabilities and/or neurological impairments. No credit was given for their participation.

Materials.

We selected four new sets of 16 prime–target pairs that were divided into four groups, including three morphological conditions and one orthographic control condition. These conditions are presented below:

Morphological transparent (e.g., *nuageux – nuage*, “cloudy – CLOUD”). The prime words were derived forms of the target, and the derivation did not involve any phonological or orthographic modification of the base word. Nevertheless, contrary to McCormick et al. (2008), we did not consider a missing “e”, or shared “e” at the end base words as an orthographic alteration, as most of the French words end with a silent “e” that is very often preserved (e.g., *nuageux – nuage*) or replaced by another vowel (e.g., *policier – police*) in the derived form . In English, *cloudy – CLOUD* would have been a good example of this condition.

Morphological with phonological shift of the base (“morphological P-shift”, e.g., *bergerie – BERGER*, “sheepfold – sheep”). This condition consisted of morphologically related pairs of words whose base word had a phonological shift of the base when it appeared in the derived form. The phonological shift corresponded to the pronunciation of a silent letter for half of the items (e.g., *dentiste – dent*, “dentist – tooth”), or to the voicing of the vowel and consonant that constitute a nasal vowel at the end of the base for the other half of the items (e.g., *moulinet – MOULIN*, “reel – mill”). An equivalent of this condition in English could be *direction – DIRECT*.

Morphological with phonological and orthographic shift of the base[6] (“morphological PO-shift”, e.g., *soigneux – SOIN*, “careful – CARE”). In this condition, primes were morphologically related to the target but the derivation involved both a phonological and orthographic shift of the base word, for different reasons: First, primes and targets could be allomorphic forms of the same root (e.g. *soigneux – soin*, “carefull – CARE”). Second, the derivation could require the addition of an additional letter between the base and the suffix (e.g., *magicien – magie*, “magician – MAGIC”). Finally, the form modifications could be explained by the necessity to transform final letters of the base to respect the orthographic conventions of French language (e.g., *banquette – banc*, “seat – bench”). An equivalent of this condition in English could be *division – DIVIDE*.

As in Experiment 1, the morphological relationship between primes and targets was determined using the “Brio” French dictionary (Rey-Debove, 2004).

[6] For reasons related to French language, it has not been possible to include a condition where the shift of the base word was only orthographic (such as daily – day in English).

Orthographic control (e.g., *fourmi – FOUR*, “ant – OVEN”). This control condition was equivalent to the one used in Experiment 1, but included a new set of prime-target pairs. An equivalent in English could be *spinach – SPIN*.

Primes were matched for frequency, length and orthographic neighbourhood (Fs < 1.18). Targets were matched for frequency ($F < 1$) but could not be matched perfectly in length, $F(3, 60) = 2.35$, $p = .08$, as the mean number of letters in the target words of the morphological transparent condition tended to be higher than in that of the orthographic control condition. In addition, the mean number of orthographic neighbours of the targets also depended on the condition, $F(3, 60) = 3.61$, $p = .02$. Targets from the orthographic control condition had on average more orthographic neighbours than targets from the morphological transparent condition. Mean values for each of these variables are shown in Table 5.

Insert Table 5 about here

As in Experiment 1, each target was associated to an unrelated prime that was neither morphologically nor semantically, nor orthographically related. Sixteen unrelated prime-target pairs were also included as fillers to dilute the proportion of related items encountered in the experiment. One hundred and forty-four pseudoword targets were included in the experiment for the “no” responses of the lexical decision task. They were created the same way as in Experiment 1, and were preceded by a prime word that could be orthographically related (n = 64) or unrelated (n = 80).

The design of the experiment was the same as in Experiment 1: The total of 288 prime target-pairs (144 with words as targets and 144 with pseudowords as targets) was divided into two lists of 144 pairs of items, with equal number of words and pseudowords in each list.

Each target word was preceded by a related prime in one list, and by an unrelated prime in the other list.

A complete list of the stimuli included in each condition is presented in Appendix B

Procedure and apparatus.

The procedure and apparatus of Experiment 2 was exactly the same as that of Experiment 1.

Results

We used the same trimming procedure as in Experiment 1. RTs faster than 500 ms (0.81% of the data) and slower than 3500 ms (0.98% of the data) were removed from data analysis in the dyslexic and control children group[7]. In all groups, four items were excluded from data analysis because of high error rates ("odeur": 9.52%; "mare": 19.05%, "ras": 48.24%, "fier": 23.17%[8]). Error percentages and mean latencies for correct responses for each group are presented in Table 6.

Insert Table 6 about here

Analyses of variance were carried out separately in the group of dyslexics and control children and in adults.

Results in dyslexics and control children.

A 3 (group: DYS versus RL versus CA) X 4 (condition: morphological transparent versus morphological P-shift versus morphological OP-shift versus orthographic control) X 2 (priming: related versus unrelated) X 2 (order of list presentation: 1 versus 2) repeated-measures analysis of variance was computed using log-transformed RTs as dependant variable.

[7] We did not remove outliers in adults because most of their RTs lied between 400 and 800 ms
[8] The stimuli remained matched across all factors after excluding these items

The analysis of variance showed a main effect of group, $F(2, 39) = 37.70$, $\eta^2_p = .66$, $p < .001$. Post-Hoc comparisons indicated that the RL children were slower than the DYS, and that the DYS were slower than the CA. The main effect of priming was also significant, $F(1, 39) = 25.60$, $\eta^2_p = .46$, $p < .001$, as RTs were faster when targets were preceded by related prime than when preceded by unrelated primes. There was a significant interaction between group and priming, $F(2, 39) = 5.70$, $\eta^2_p = .23$, $p = .006$, indicating that the amount of priming differed across the three groups. The effect of order of list presentation was also significant, $F(1, 39) = 39.9$, $p < .001$, $\eta^2_p = .51$, as RTs were faster in the second session than in the first. However, the three-way interaction between order of list presentation, condition and priming was not significant ($F < 1$) and will therefore not be discussed further. Finally, the three-way interaction between group, condition and priming did not achieve significance, $F(6, 117) = 1.4$, $p = .20$, $\eta^2_p = .07$. Nevertheless, as the group by priming interaction was significant, we performed planned comparisons to test our specific hypotheses.

The DYS showed significant priming effects in the three morphological conditions, namely transparent, $F(1, 13) = 15.93$, $p = .001$, $\eta^2_p = .55$, with P-shift, $F(1, 13) = 6.49$, $p = .024$, $\eta^2_p = .33$, and with PO-shift, $F(1, 13) = 7.76$, $p = .015$, $\eta^2_p = .37$. No significant priming effect was observed in the orthographic control condition, $F(1, 13) = 1.56$, $p = .233$, $\eta^2_p = .11$. In RL children, priming effects were significant in the morphological transparent condition, $F(1, 13) = 11.79$, $p = .004$, $\eta^2_p = .48$, but were not significant in the three other conditions (morphological P-shift: $F < 1$, morphological PO-shift: $F(1, 13) = 1.82$, $p = .200$, $\eta^2_p = .12$, orthographic control: $F < 1$). Finally, in CA children, priming effects were significant in the morphological transparent condition, $F(1, 13) = 4.70$, $p = .049$, $\eta^2_p = .27$ and in the morphological P-shift condition, $F(1, 13) = 6.63$, $p = .023$, $\eta^2_p = .34$. Priming effects in the morphological PO-shift condition and in the orthographic control condition did not achieve significance, Fs < 1.

Results in adults.

A 4 (condition: morphological transparent versus morphological P-shift versus morphological OP-shift versus orthographic control) X 2 (prime: related versus unrelated) X 2 (order of list presentation: 1 versus 2) repeated-measures analysis of variance was computed on log-transformed RTs.

There was a main effect of priming, $F(1, 14) = 37.08$, $p < .001$, $\eta^2_p = .73$, indicating that related targets were processed faster than unrelated targets. The interaction between condition and priming was also significant, $F(3, 42) = 4.11$, $p = .012$, $\eta^2_p = .23$, suggesting that priming effects depended on the condition. The main effect of the order of list presentation was significant, $F(1, 14) = 14.99$, $p = .002$, $\eta^2_p = .52$, as RTs were faster at the second presentation than at the first, but the critical three-way interaction between order of list presentation, priming and condition was not significant ($F < 1$).

Planned comparisons indicated significant priming effects in the morphological transparent condition, $F(1, 14) = 39.99$, $p < .001$, $\eta^2_p = .74$, in the morphological P-shift condition, $F(1, 14) = 10.17$, $p = .007$, $\eta^2_p = .42$ as well as in the morphological OP-shift condition, $F(1, 14) = 8.26$, $p = .012$, $\eta^2_p = .37$. However, priming effects were not significant in the orthographic control condition, $F(1, 14) = 1.97$, $p = .18$, $\eta^2_p = .12$.

Discussion

The results of Experiment 2 clearly indicate that the dyslexic children benefit from priming in the three morphological conditions, independently of the phonological and orthographic shifts of the base word. Such results corroborate the finding of Experiment 1 that dyslexic readers rely on morphemes during visual word recognition, and that the probability to process morphologically complex words through their components depends more on semantic overlap between morphologically related words than on form overlap.

A different pattern of priming emerged in the two control groups and in the dyslexics. In the RL group, morphological priming was significant only in the morphological transparent condition, indicating that morpho-orthographic decomposition evidenced in Experiment 1 requires phonological and orthographic overlap between morphologically related words. Turning to the CA group, priming effects were significant in the morphological transparent and morphological with phonological shift conditions. This finding suggests that the CA children are not influenced by phonological alterations of the base, whereas orthographic alterations prevent them from decomposing morphologically complex words into smaller components. Thus, the only developmental difference between the RL and CA children occurs in the morphological condition with phonological shift. This result can be accounted for by the fact that the connections between phonology and orthography are not sufficiently developed in RL children, preventing them from benefiting from the orthographic overlap between morphologically related words. As developing readers mainly rely on form overlap to decide whether two words are morphologically related or not (Carlisle & Fleming, 2003), the lack of phonological overlap between the words included in the phonological shift condition might have prevented morphological decomposition.

Priming effects were significant in the three morphological conditions in adult skilled readers. This result suggests that their processing of written morphology is flexible to phonological and orthographic shifts of the base word, as already evidenced in English (Beyersmann et al., 2011; McCormick et al., 2008) and in Spanish (Duñabeitia et al., 2007). Adult models of morphological processing will be considered in the General Discussion.

General Discussion

The present study investigated whether and how French dyslexic children rely on the morphological structure of words during their visual recognition. Following the studies of Elbro and Arnbak (1996) and Burani et al. (2008), we were specifically interested in testing the influence of form and meaning properties of morphemes in the dyslexics' processing of morphologically complex words. To this end, we conducted two masked priming experiments in which we manipulated the semantic overlap (Experiment 1) and the form overlap (Experiment 2) between morphologically related pairs of words.

In this section, we summarize the main results in relation to the two aims of the study and we relate these findings to reading procedures in dyslexics. We also interpret our findings in light of the current models of morphological processing.

The significant morphological priming effects observed across the two experiments in dyslexic children indicate that they rely on derivational morphemes during visual word recognition. Although several studies indicate that French typically-developing readers make use of the morphological structure of words during their recognition (Casalis et al., 2009; Quémart et al., 2011, 2012), we report that such processing is also at work in French dyslexics. A morphological facilitation when naming words and pseudowords had already been evidenced in the dyslexic population by Burani et al. (2008), Traficante et al. (2011) as well as Elbro and Arnbak (1996), suggesting that in spite of their decoding difficulties, dyslexic readers are able to grasp larger units such as morphemes to decode words faster. The present study extends those results by indicating that morphological processing also characterizes visual word recognition. Such an automatic processing is remarkable in the sense that dyslexic readers are generally assumed to be very slow when processing linguistic information (Pennington, 2006). Nevertheless, adequate speed of processing of the primes emerges in these readers when tapping automatic and unconscious processes with the masked priming paradigm, which corroborates Bonifacci and Snowling (2008)'s finding that speed of information processing is normal in dyslexic children.

Turning to the nature of this processing, the patterns of priming observed in Experiment 1 and in Experiment 2 suggest that dyslexic readers are mainly influenced by the semantic properties of morphemes during the identification of morphologically complex words, whereas their reading level and chronological age matched peers are essentially influenced by the form properties of morphemes. Thus, the semantic interpretability of base and suffix combinations is the triggering factor of morphological decomposition in dyslexic readers. The important role of morphemes' meaning in morphological processing confirms the hypothesis of Elbro and Arnbak (1996) and Casalis et al. (2004) that dyslexic readers take advantage of their relatively preserved semantic skills to develop a morpho-semantic level of representations. Adequate morphological awareness abilities observed in dyslexic children in Experiments 1 and 2 reinforce this hypothesis. Furthermore, the activation of this morpho-semantic level of representation evidenced with a new task – the primed lexical decision task – fosters the semantic hypothesis by showing that this processing is not specific to the naming task. By contrast, priming effects observed in Experiment 2 in the two control groups strengthen Quémart et al. (2011)'s proposition that morphological processing is firstly form-driven in typically developing readers. Finally, results in adult skilled readers suggest that they are not penalized by slight orthographic or phonological shifts of the base word when decomposing morphologically complex words. A flexibility of morpho-orthographic processing has already been evidenced by several studies (Beyersmann et al., 2011; Duñabeitia et al., 2007; McCormick et al., 2008) but had never been reported in French language. The difference in patterns of priming between chronological-age matched children and adult skilled readers in the morphological OP-shift condition point out that 13-year-old children are not as yet flexible as adults to process the orthographic properties of morphemes.

Integrating Morphological Processing to other Reading Strategies in Dyslexic Readers

The dyslexics' higher reliance on semantic than form properties of morphemes is in line with the general idea that these readers are prone to implement a semantic reading strategy. As proposed in Stanovich's (1980) interactive-compensatory model, dyslexic readers may use their adequate semantic skills when recognizing words through a top-down process, as a substitute for their inefficient decoding abilities (see Hulme & Snowling, 1992, for a similar account). Indeed, readers with low-quality lexical representations tend to use contextual information to bolster their word recognition by selecting the appropriate lexical entry as a function of the semantic context (Frith, 1980), whereas good readers with high-quality representations retrieve lexical and semantic information using bottom-up information (Perfetti & Hart, 2001). Empirical evidence supporting a particular reliance on semantic information in readers with dyslexia has been provided across several studies, where they have been shown to make more use of context when decoding words compared with normal readers (Ben-Dror, Pollatsek, & Scarpati, 1991; Bruck, 1988; Nation & Snowling, 1998) and to mostly rely on the semantic pathway during word naming (Hennessey, Deadman, & Williams, 2011).

We do not advocate here that the dyslexics only benefit from the semantic overlap between morphologically related words during visual word recognition, especially because we did not observe priming effects in the semantic control condition. Morphemes are units of form and meaning, and young readers rely on the convergence between form and meaning when developing mental representations of morphemes (Schreuder & Baayen, 1995). In addition, derived words that belong to the same morphological family typically share form characteristics. However, the activation of morpho-orthographic information is inefficient in dyslexics and they quickly activate the semantic properties of morphemes to try to compensate for their difficulty in processing orthographic information. .

An additional assumption is that the dyslexics' processing of written morphology is coarse-grained, in that they do not appear to code letter position or identity within morphemes in a strict fashion. The hypothesis of a coarse-grained coding of spelling-sound correspondences in dyslexics has already been proposed by Hatcher and Snowling (2002; see

Burani et al., 2008, for a similar proposition). Developmental dyslexia is characterized by difficulties in the development of phonemic representations that imply difficulties in the development of phonemic decoding. However, Hatcher and Snowling argue that children with dyslexia establish connections between orthography and phonology at a coarse-grained level, namely between units larger than graphemes and phonemes. Results of this study extend this conceptualization by indicating that dyslexic readers are also able to rely on morpheme-size units during visual word recognition.

Theoretical Implications

Morpho-orthographic versus morpho-semantic processing.

Two sets of hypotheses about the influence of form and meaning in the processing of written morphology have been formulated. According to the form-then-meaning account, morphological processing is a two-stage serial process, involving first the decomposition of morphologically complex words into morpho-orthographic units, and second the activation of the semantic properties of morphemes (Rastle & Davis, 2008). This hypothesis is supported by significant masked priming effects in adult skilled readers when prime-target pairs share morphological or pseudoderivation relationships, and by an absence of pseudoderivation priming when primes are fully visible. However, according to the hybrid model of morphological processing (Diependaele et al., 2009), the two levels of morphological representations (morpho-orthographic and morpho-semantic) are activated in parallel. Truly derived words can be recognized along both processing routes, as morphologically related words share both form and meaning properties. However, pseudoderived words are only able to activate the morpho-orthographic level, since the meaning of their components in not related to that of the whole word. Finally, the feedback connections between the morpho-semantic and morpho-orthographic levels of representation explain the greater priming effects for morphologically related words than pseudoderived words observed in adult skilled readers (Feldman et al., 2009).

The present results fit nicely with the hybrid model of morphological processing. Indeed, the significant morphological priming effects in absence of pseudoderivation priming show that the morpho-semantic route is already involved in the recognition of morphologically complex words at the earliest steps of word recognition, and that an automatic activation of form properties of morphemes is not mandatory to trigger morphological decomposition. Thus, the dyslexics' specific sensitivity to the semantic properties of morphemes indicates that the activation of their morpho-semantic level of representation supplies an inefficient activation of the morpho-orthographic level of processing in this population.

Such a conception of morphological processing in dyslexic readers is akin to the supralexical model of derivational morphology proposed by Giraudo and Grainger (2000, 2001). In this model, morphological representations are located between whole-word representations forms and higher-level semantic representations. When a morphologically complex word is presented to the cognitive system (e.g., *departure*), the whole word activates the representation of the corresponding morphemes (*depart*- and *–ure*) that send back activation to all whole-word representations that are compatible with those morphemes (e.g., *depart*, *departing*…) but not to those who are only orthographically related (e.g., *department*). Although this model of supralexical processing lacks a morpho-orthographic level of representation in order to explain morphological processing in typically developing readers and adult skilled readers, it enables to understand how the system works when the morpho-orthographic processing level is deficient. In particular, it explains why priming occurs only when primes and targets are morphologically and semantically related, as evidenced in Experiment 1. In addition, as these supra-lexical representations are located at an abstract level in the architecture of the model, morphological processing is not influenced by surface phonological or orthographic modifications of the base word. Therefore, priming effects emerge even though primes and targets are not completely overlapping in dyslexics, as indicated by the significant priming effects in the three morphological conditions of Experiment 2.

Fine-grained versus coarse-grained processing of written morphology.

Morphological processing is flexible to surface form modifications of the base in dyslexic readers, but much less flexible in the two control groups. This difference can be accounted for by the dual route approach to orthographic processing recently outlined by Grainger and Ziegler (2011). In this model, word recognition is thought to be achieved via two routes, the *fine-grained route* and the *coarse-grained route*. The first processing route is involved in the precise coding of letter position in strings, whereas the second processing route enables to rapidly access semantic representations through a flexible orthographic processing system that does not encode letter position. With respect to morphological processing, the authors argue that morpho-orthographic decomposition occurs via the fine-grained route, as it requires a precise letter position coding in order to differentiate between morphemes that differ in only one letter (e.g., *-age* vs *-ale* in French). By contrast, morpho-semantic processing is supposed to be achieved along the coarse-grained coding route, which enables to access very rapidly morphological representations. The two types of constraints (fine-grained and coarse-grained) interact with each other in order to optimize the recognition of morphologically complex words. Nevertheless, Grainger and Ziegler (2011) report significant masked transposed letter priming for derived words (e.g., *signer – SING*) but not for pseudoderived words (e.g., *conrer – CORN*). As transposed-letter priming is possible only via the coarse-grained processing route, the lack of priming effect in the pseudoderivation condition shows that such words are not processed via the coarse-grained route.

Within this framework, the insensitivity of dyslexic readers to slight orthographic modifications of the base word points out the specific involvement of the coarse-grained route during their visual word recognition. As this route is selectively involved in morpho-semantic processing (Grainger & Ziegler, 2011), this finding also reinforces the idea that dyslexic readers activate only morpho-semantic representations when processing written morphology. In addition, the dyslexics' results are in accordance with the lexical tuning hypothesis (Castles, Davis, Cavalot, & Forster, 2007) according to which orthographic representations become finely tuned as a function of the growing orthographic lexicon. As the orthographic representations of the dyslexics are not sufficiently detailed, priming effects occur even when the orthographic matching between primes and targets is not perfect (see Marinus & de Jong, 2010, for a similar explanation).

The lack of flexibility of the control groups' word recognition system evidenced in Experiment 2 shows that their orthographic processing is principally achieved along the fine-grained route, which is supposed to be involved in morpho-orthographic decomposition (Grainger & Ziegler, 2011). This result is in accordance with the findings of Quémart et al. (2011) that morphological decomposition is essentially triggered by the form properties of morphemes in developing readers from grade 3 to grade 7. However, if the semantic properties of morphemes are activated later in the time course of word recognition, as evidenced by Quémart et al. (2011), then morphological processing should be more flexible with a longer prime duration than with a short prime duration. Additional studies are needed to explore this hypothesis.

Conclusion

The present study brings new evidence that dyslexic readers have developed representations for written morphology, and indicates that they activate these representations rapidly and automatically during the recognition of morphologically complex words. These representations are located at the morpho-semantic level, and their access occurs along a coarse-grained route of orthographic processing. By contrast, morphological representations of reading-level and age matched participants are located at the morpho-orthographic level, and are accessed via a fine-grained processing system that is sensitive to form modifications. Finally, these results confirm that form and meaning make separate contribution to the processing of written morphology.

Appendix A

Target and prime words used in Experiment 1

Morphological		Pseudoderivation		Orthographic control		Semantic control	
Prime	target	Prime	target	Prime	Target	prime	target
amical	ami	baguette	bague	Abricot	abri	poitrine	corps
armure	arme	bouleau	boule	Cachalot	cache	biberon	bébé
chasseur	chasse	champion	champ	Chardon	char*	tulipe	fleur
coffret	coffre	chouette	chou	Écureuil	écurie	chandelle	bougie
fermier	ferme	coupable	couper	Féroce	fer	vêtement	robe
feuillage	feuille	courage	cour	Huître	huit	banane	singe
grillage	grille	dentelle	dent	Joindre	joie	guidon	vélo
mariage	marier	fouet	fou	Potiron	pot	serrure	clé
pêcheur	pêche	lunette	lune	Rossignol	rose	meuble	chaise
plumage	plume	mortier	mort	Sanglier	sang	ménage	balai
poirier	poire	mouette	mou*	Second	sec	acteur	film
poulet	poule	panneau	panne	Soldat	sol	carotte	lapin
sagesse	sage	pommade	pomme	Tombola	tombe	bouillon	soupe
saladier	salade	rater	rat	torture	tortue	fraise	fruit
tablette	table	repasser	repas	joindre	joie	chiffre	sept
visiteur	visite	toilette	toile	vendredi	vendre	chapiteau	cirque

Note. The targets marked with an asterisk have been excluded from data analysis.

Appendix B

Target and prime words used in Experiment 2

Morphological transparent		Morphological P-shift		Morphological PO-shift		Orthographic control	
Prime	Target	Prime	Target	Prime	Target	Prime	Target
Amoureux	amour	Bergerie	berger	aviateur	avion	boutique	bout
Boulette	boule	Bordure	bord	baignoire	bain	bulletin	bulle
Clocher	cloche	dangereux	danger	banquette	banc	centre	cent
Courageux	courage	dentist	dent	chaleur	chaud	chandelle	chant
Équipage	équipe	jardinage	jardin	clarté	clair	collège	colle
Fierté	fier*	longueur	long	curiosité	curieux	contexte	conte
Jeunesse	jeune	marine	marin	douceur	doux	formule	forme
Joliment	joli	moulinet	moulin	famine	faim	fourmi	four
Nombreux	nombre	patinage	patin	langage	langue	marraine	mare*
Nuageux	nuage	plombier	plomb	liberté	libre	ministre	mine
Oreiller	oreille	précision	précis	lumineux	lumière	pharmacie	phare
Policier	police	rangement	rang	magicien	magie	pistolet	piste
Princesse	prince	rasoir	ras*	musicien	musique	radical	radis
Règlement	règle	régional	région	odorat	odeur*	septembre	sept
Rêveur	rêve	sachet	sac	pianiste	piano	troupe	trou
Tristesse	triste	voisinage	voisin	soigneux	soin	vagabond	vague

Note. The targets marked with an asterisk have been excluded from data analysis.

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Notes

[1] Note, however, that priming effects were significant in the "orthographic control" condition in this experiment; this effect was due to a speed-accuracy tradeoff and could not be interpreted as a significant orthographic priming effect.

[2] Note that the number of items included in the Coloured Progressive Matrices (specifically designed for children under the age of 12) is different from the number of items included in the Standard Progressive Matrices (36 *vs*. 60).

[3] These spoken word frequencies are provided for information only because they are based on film and television subtitles. No child database of spoken word frequency is available in French.

[4] Left-handed children did the opposite

[5] The stimuli remained matched across all factors after excluding these items

[6] For reasons related to French language, it has not been possible to include a condition where the shift of the base word was only orthographic (such as daily – day in English).

[7] We did not remove outliers in adults because most of their RTs lied between 400 and 800 ms

[8] The stimuli remained matched across all factors after excluding these items

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Table 1

Mean background measures (and standard deviations) according to the group in Experiment 1

Reading group	RL (n = 16)	DYS (n = 16)	CA (n = 16)
Chronological age	8;10 (4)	12;8 (7)	12;1 (10)
Reading age	9;6 (14)	9;5 (14)	12;1 (20)
Non-verbal reasoning	32.37 (2.66)	38.13 (4.35)	41.13 (5.16)
Vocabulary (% correct)	85.94 (7.12)	89.17 (7.65)	91.90 (9.13)
Pseudoword reading (% correct)	92.66 (11.78)	86.67 (14.47)	93.94 (9.79)
Morphological awareness (% correct)	81.25 (10.25)	90.62 (6.80)	91.88 (9.81)

Note. RL = Reading Level matched children; DYS = dyslexic children; CA = Chronological Age matched children. Chronological and reading age in years and months, raw scores for nonverbal reasoning (max = 36 in RL; max = 60 in DYS and in CA).

Table 2

Stimulus properties across test conditions of Experiment 1

Condition	Length		Frequency		N size	
	Prime	Target	Prime	Target	Prime	Target
Morphological	7.25 (0.86)	5.25 (1.00)	20.97 (19.50)	105.66 (85.88)	0.63 (1.02)	4.50 (2.78)
Pseudoderivation	7.19 (0.98)	4.44 (0.81)	20.56 (20.08)	97.72 (73.51)	1.31 (1.66)	6.06 (2.89)
Orthographic control	7.06 (0.93)	4.25 (1.06)	19.67 (20.72)	98.12 (52.75)	0.69 (1.40)	5.25 (3.17)
Semantic control	7.00 (1.10)	4.75 (0.86)	19.17 (12.12)	100.23 (48.28)	0.69 (0.70)	1.88 (1.96)

Note. N size corresponds to the mean number of orthographic neighbours. Lexical frequency is given by the French database "Manulex Infra" (Peereman et al., 2007) and has been calculated from a corpus of 42422 words.

Table 3

Experiment 1: Mean RTs (in ms) and error percentages (standard deviations in parentheses) of the three groups according to the condition and to the priming relationship.

	RL		DYS		CA	
	RT	Err %	RT	Err %	RT	Err %
			Morphological			
Related	1269 (225)	3.65 (5.24)	1027 (245)	3.39 (5.69)	938 (201)	3.52 (5.09)
Unrelated	1337 (261)	3.65 (4.12)	1112 (309)	4.09 (5.87)	997 (228)	3.52 (4.55)
Priming effect	68*	0	85**	0.7	59*	0
			Pseudoderivation			
Related	1199 (222)	7.32 (10.10)	1039 (226)	2.11 (3.24)	902 (197)	4.17 (4.79)
Unrelated	1300 (227)	4.67 (6.99)	1032 (310)	5.00 (6.21)	949 (196)	4.23 (6.00)
Priming effect	101***	-2.65	-7	2.89	47**	0.06
			Semantic control			
Related	1207 (246)	4.38 (6.12)	1003 (217)	4.82 (5.88)	922 (186)	3.18 (5.62)
Unrelated	1243 (249)	5.13 (6.99)	961 (244)	4.32 (6.75)	896 (153)	1.95 (3.76)
Priming effect	36	0.75	-42	-0.50	-26	-1.23
			Orthographic control			
Related	1256 (230)	6.11 (5.75)	1009 (216)	7.83 (8.68)	940 (195)	4.17 (6.38)
Unrelated	1237 (215)	5.67 (4.68)	1073 (303)	6.51 (8.62)	963 (186)	4.64 (5.40
Priming effect	-19	-0.44	64	-1.32	23	0.47

Note. * $p < .05$; ** $p < .01$; *** $p < .001$. RL = Reading Level matched children; DYS = Dyslexic children; CA = Chronological Age matched children.

Table 4

Mean background measures (and standard deviations) according to the group in Experiment 2

Reading group	RL	DYS	CA
Chronological age	9;8 (11)	13;6 (6)	13;1 (4)
Reading age	9;9 (12)	9;9 (12)	13;6 (10)
Non-verbal reasoning	33.57 (2.95)	42 (5.60)	43.28 (3.97)
Vocabulary (% correct)	77.86 (13.26)	87.86 (11.22)	90.00 (9.61)
Pseudoword reading (% correct)	88.04 (10.24)	84.82 (15.77)	92.82 (7.02)
Morphological awareness (% correct)	83.57 (16.46)	89.29 (7.30)	91.43 (8.64)

Note. RL = Reading Level matched children; DYS = dyslexic children; CA = Chronological Age matched children. Chronological and reading age in years and months, raw scores for nonverbal reasoning (max = 36 in RL; max = 60 in DYS and in CA).

Table 5

Stimulus properties across test conditions of Experiment 2

Condition	Length		Frequency		N size	
	Prime	Target	Prime	Target	Prime	Target
Morphological						
Transparent	7.88 (0.96)	5.44 (0.96)	22.04 (24.53)	103.69 (65.19)	0.38 (0.81)	1.94 (2.52)
P-shift	7.88 (0.81)	4.94 (1.13)	18.15 (24.30)	102.46 (109.87)	0.69 (0.95)	3.94 (2.73)
PO-shift	7.56 (0.81)	5.13 (0.89)	21.36 (15.79)	100.43 (53.82)	0.38 (0.62)	3.00 (2.05)
Orthographic control	7.63 (1.02)	4.56 (0.51)	20.93 (14.83)	97.97 (89.90)	1.13 (1.78)	5.81 (3.69)

Note. N size corresponds to the mean number of orthographic neighbours. Lexical frequency is given by the French database “Manulex Infra” (Peereman et al., 2007) and has been calculated from a corpus of 42422 words.

Table 6

Experiment 2: Mean RTs (in ms), priming effects (in ms) and error percentages (standard deviations in parentheses) of the three groups of children and the adults according to the condition and to the priming relationship.

	RL		DYS		CA		Adults	
	RT	Err %	RT	Err %	RT	Err %	RT	Err%
				Morphological transparent				
Related	1085(183)	5.85(8.18)	954(169)	2.53(3.53)	728(80)	2.26(3.99)	556(45)	0.89(2.35)
Unrelated	1209(287)	4.47(3.49)	1056(160)	3.84(4.33)	758(91)	3.18(4.12)	615(66)	2.22(4.82)
Priming	124**	-1.38	102***	1.31	30*	0.92	59***	1.33
				Morphological P-shift				
Related	1188(196)	8.57(9.22)	985(176)	8.74(9.36)	718(72)	2.60(4.59)	582(80)	0.89(2.35)
Unrelated	1153(228)	13.55(10.44)	1069(139)	10.99(8.09)	748(66)	3.81(5.68)	621(58)	3.56(4.95)
Priming	-35	4.98	84*	2.25	30*	1.21	39**	2.67
				Morphological PO-shift				
Related	1105(241)	4.46(5.96)	881(129)	5.85(7.87)	715(80)	2.36(3.30)	564(71)	1.33(2.76)
Unrelated	1144(234)	6.70(7.85)	984(162)	2.38(4.22)	728(70)	1.82(3.86)	590(68)	3.56(4.95)
Priming	39	2.24	103*	-3.47	13	-0.54	26*	2.23
				Orthographic control				
Related	1252(267)	5.80(8.30)	1020(171)	10.46(8.41)	790(106)	5.35(4.71)	607(69)	4.00(4.91)
Unrelated	1204(216)	9.02(5.89)	1049(153)	10.00(8.57)	787(93)	7.21(8.04)	618(58)	3.56(4.27)
Priming	-48	3.22	29	-0.46	-3	1.86	11	-0.44

Note. * $p < .05$; ** $p < .01$; *** $p < .001$. RL = Reading Level matched children; DYS = Dyslexic children; CA = Chronological Age matched children.