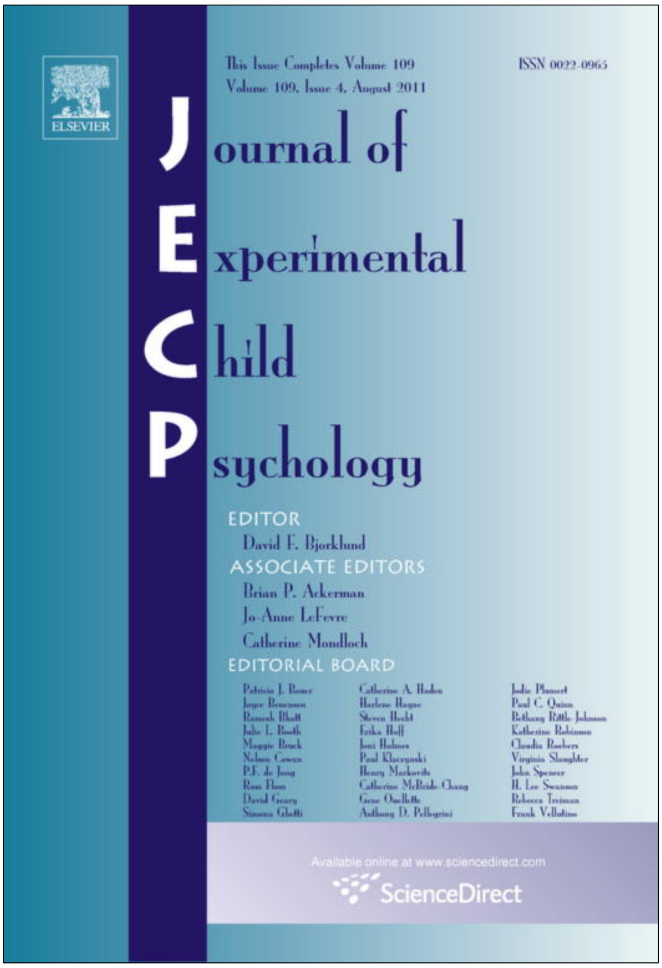
ELSEVIER
This Issue Completes Volume 109
Volume 109, Issue 4, August 2011
ISSN 0022-0965
Journal of Experimental Child Psychology
EDITOR
David F. Bjorklund
ASSOCIATE EDITORS
Brian P. Ackerman
Jo-Anne LeFevre
Catherine Mondloch
EDITORIAL BOARD
Available online at www.sciencedirect.com
ScienceDirect

Journal of Experimental Child Psychology 109 (2011) 478–496

Contents lists available at ScienceDirect

Journal of Experimental Child Psychology

journal homepage: www.elsevier.com/locate/jecp

The role of form and meaning in the processing of written morphology: A priming study in French developing readers

Pauline Quémart [a], Séverine Casalis [a,*], Pascale Colé [b]

[a] Laboratoire URECA (EA 1059), Université Lille Nord de France, 59653 Villeneuve d'Ascq, France
[b] Laboratoire de Psychologie Cognitive (UMR 6146), Université Aix-Marseille, 13331 Marseille, France

ARTICLE INFO

Article history:
Received 13 October 2010
Revised 8 February 2011
Available online 17 March 2011

Keywords:
Reading development
Morphology
Visual priming
Lexical decision
Pseudoderivation
Semantics

ABSTRACT

Three visual priming experiments using three different prime durations (60 ms in Experiment 1, 250 ms in Experiment 2, and 800 ms in Experiment 3) were conducted to examine which properties of morphemes (form and/or meaning) drive developing readers' processing of written morphology. French third, fifth, and seventh graders and adults (the latter as a control group) performed lexical decision tasks in which targets were preceded by morphological (e.g., *tablette–TABLE*, "little table–table"), pseudoderived (e.g., *baguette–BAGUE*, "little stick–ring"), orthographic control (e.g., *abricot–ABRI*, "apricot–shelter"), and semantic control (e.g., *Tulipe–FLEUR*, "tulip–flower") primes. Across all groups, different patterns of priming were observed in both morphological and orthographic/semantic control conditions, suggesting that they all process morphemes as units when reading. In developing readers, the processing of written morphology is triggered by the form properties of morphemes, and their semantic properties are activated later in the time course of word recognition. In adults, patterns of priming were similar except that the activation of the form properties of morphemes decreased earlier in the time course of word recognition. Taken together, these findings indicate that French developing readers process both the form and meaning properties of morphemes when reading and support a progressive quantitative change in the development of morphological processing over the course of reading development.

* Corresponding author. Fax: +33 0 320416032.
E-mail address: severine.casalis@univ-lille3.fr (S. Casalis).

0022-0965/$ - see front matter © 2011 Elsevier Inc. All rights reserved.
doi:10.1016/j.jecp.2011.02.008

Introduction

In alphabetic writing systems such as English and French, written units represent phonemes. As a consequence, considerable attention has been drawn to the importance of phonological processing in the acquisition of reading skills (Goswami & Bryant, 1990; Share, 1995; Sprenger-Charolles, Siegel, Béchennec, & Serniclaes, 2003; Ziegler & Goswami, 2005). But alphabetic writing systems also represent morphemes, the smallest units of meaning in words. For example, the word *singer* is composed of two morphemes – the base word *sing*- and the suffix -*er* – and therefore is morphologically complex. Because a large proportion of the new words children encounter in print are analyzable into their morphemic constituents (Nagy & Anderson, 1984), taking into account the morphemic structure of complex words may help children to deal with many of the new words they encounter in print.

There is mounting evidence that children's ability to manipulate the internal structure of words, or morphological awareness, is significantly related to reading skills beyond phonological awareness (Carlisle, 1995; Carlisle & Nomanbhoy, 1993; Deacon & Kirby, 2004; Fowler & Liberman, 1995; Roman, Kirby, Parrila, Wade-Woolley, & Deacon, 2009). However, numerous questions remain as to whether, when, and how developing readers process morphologically complex words through their morphemic constituents when *reading*. Morphological processing not only may enhance reading speed and accuracy, because morphemic units are generally more frequent and more likely to be represented in the lexicon, but also may improve reading comprehension, because the activation of morphemes' meaning helps developing readers to infer the meaning of these new complex words.

Although there is wide agreement that skilled adult readers process morphologically complex words through their constituents during recognition (see Rastle & Davis, 2008, for a review), models of reading development generally do not assign a *specific* role (i.e., distinct from orthography and semantics) to morphological processing in the acquisition of reading skills. Instead, they consider that children progressively learn to process morphemes in the same way as any orthographic unit larger than graphemes to recognize words faster and more accurately (Ehri, 2005; Frith, 1985). The only model that gives a specific role to morphemes as processing units in developing readers was proposed by Seymour (1997, 2005). Very briefly, he argued that reading acquisition is a four-phase process involving the establishment of logographic and alphabetic foundations that contribute to the subsequent development of orthographic and morphographic processing systems. The morphographic processing system consists of whole-word forms and combinations of morphemes, and its activation enables readers to process morphologically complex words through their constituents when reading.

Studies investigating children's processing of written morphology have demonstrated that their reliance on morphemes is not limited to the processing of sublexical orthographic features. English-speaking second and third graders have been shown to read words with real suffixes (e.g., *hilly*) faster and more accurately than simple words matched for orthography (e.g., *silly*) (Carlisle & Stone, 2005; Laxon, Rickard, & Coltheart, 1992). Similarly, French second graders are more accurate when reading aloud pseudowords made up of morphemes (e.g., *mordage,* where an equivalent in English could be "bitage") than pseudowords with only a suffix (e.g., *soumage,* where an equivalent in English could be "somage") (Marec-Breton, Gombert, & Colé, 2005). Morphological processing in reading has also been evidenced in Hebrew morphology in third and seventh graders (Schiff, Raveh, & Kahta, 2008) and in the Italian regular orthography in third to fifth graders (Burani, Marcolini, & Stella, 2002).

Although these data indicate that developing readers decompose morphologically complex words into their constituent morphemes during word recognition, additional investigation is needed to understand which properties of morphemes children rely on during this processing. Indeed, morphologically related words tend to have similar forms and are related in meaning. Two hypotheses have been formulated regarding the role of morphemes' form and meaning properties in children's word recognition. According to Rastle and Davis (2008) (see also Seidenberg, 1987, for a similar proposition), the segmentation of printed words into morphemic constituents is driven by the orthographic properties of morphemes. To acquire morphologically structured orthographic representations, children rely on distributional probabilities that enable them to discover which letter sequences cohere as morphemic units in print. For example, the frequency of the bigram *pf* is so low that it straddles a morpheme boundary in the word *helpful.* In contrast, Schreuder and Baayen (1995) suggested that morphological processing works toward the goal of computing meaning from the constituent elements through the activation of subwords that systematically share form and meaning properties. They describe the acquisition of affixal representations as a progressive amodal monitoring of the mental lexicon for correspondences between form and meaning. When the system detects patterns of form and meaning that are systematically coactivated, it creates an independent concept node and an access representation for this form–meaning pattern. Thus, according to this account, the development of the processing of written morphology is based on the progressive discovery of form–meaning correspondences.

Still, to our knowledge, the role of morphemes' form and meaning properties in children's processing of written morphology has never been directly tested. In adults, the priming paradigm has helped to dissociate these properties and to track their activation by comparing priming effects for morphologically related pairs (e.g., *singer–SING*) and for pseudoderived pairs (e.g., *corner–CORN,* where "corner" is built with two morphemes but is not semantically related to "corn") according to the time course of word recognition (in English: Feldman, O'Connor, & Moscoso del Prado Martin, 2009; Marslen-Wilson, Bozic, & Randall, 2008; Rastle, Davis, Marslen-Wilson, & Tyler, 2000; in French: Diependaele, Sandra, & Grainger, 2005; Longtin, Segui, & Hallé, 2003; Meunier & Longtin, 2007). Typically, evidence suggests two hierarchically organized processing stages in adults (Diependaele et al., 2005; Meunier & Longtin, 2007; Rastle & Davis, 2008). The *morpho-orthographic* stage characterizes the earliest stages of visual word recognition and is activated whenever the visual input is fully decomposable into a root and a suffix independent of morphemes' meaning (e.g., both *singer* and *corner* are decomposed into morphemes). In contrast, the *morpho-semantic* stage is activated later in visual word recognition when the visual input is fully decomposable and, at the same time, shares semantic features with its base word (e.g., only *singer* is decomposed into morphemes).

In developing readers, the priming paradigm has proved to be a valuable tool for investigating children's processing of written morphology. Studies using this paradigm associated with a fragment completion task (Feldman, Rueckl, DiLiberto, Pastizzo, & Vellutino, 2002; Rabin & Deacon, 2008) have shown that first to fifth graders were more likely to correctly complete a fragment with the base form (e.g., *need*) if they had been primed with a morphologically complex word (e.g., *needy*) than if they had been primed with a word related in form only (e.g., *needle*). This finding was taken as evidence that the processing of written morphology is not bound to the processing of sublexical orthographic features of words. Furthermore, in a primed lexical decision task among French fourth graders, Casalis, Dusautoir, Colé, and Ducrot (2009) manipulated prime duration (75 and 250 ms) to track the activation of orthographic and morphological representations. Each target was primed by a word that shared either a morphological relationship (e.g., *bougie–BOUGEOIR,* "candle–candleholder"), an orthographic relationship (e.g., *bouger–BOUGEOIR,* "to move–candleholder"), or no relationship (e.g., *testament–BOUGEOIR,* "testament–candleholder"). Although priming effects were comparable in the morphological and orthographic conditions at the 75-ms prime duration, they were different at the 250-ms prime duration. This dissociation in priming between the morphological and orthographic conditions according to prime duration reinforces the idea that children's processing of morphemes is not bound to the processing of sublexical orthographic features.

However, the pseudoderivation condition (e.g., *corner–CORN*), which has been widely used in adult studies (see Rastle & Davis, 2008, for a review), has not been included in child studies of morphological processing. This experimental condition is critical to dissociate the role of morphemes' form and meaning properties because it differs from the morphological condition (e.g., *singer–SING*) in only one dimension: the semantic overlap between primes and targets. For their part, primes in the orthographic control condition used to date in child priming studies (Casalis et al., 2009; Feldman et al., 2002; Rabin & Deacon, 2008) are not built with two morphemes (e.g., *spinach–SPIN,* where *ach* is not a morpheme). As a consequence, they differ from morphological primes in two dimensions, absence of suffix ending and semantic overlap, and make it possible only to investigate whether the processing of morphemes goes beyond the processing of sublexical orthographic properties.

The current study

In this study, we used the priming paradigm with a lexical decision task to examine the role of form and meaning in French developing readers' processing of written morphology and the developmental dynamic of morphological processing.

This issue is particularly relevant in French for several reasons. First, like English and Hebrew words, most French words are morphologically complex (75% according to Rey-Debove, 1984) and can be analyzed in terms of morphemic constituents. Because these words are generally long and infrequent, it may be particularly helpful for children to process them via their constituents, which are shorter and usually more frequent and, thus, more likely to have an orthographic representation. Second, because French derivational morphology is fairly transparent, the processing of complex words through their morphemic constituents can be easily triggered. Third, a particularity of French orthography is that it is more consistent from spelling to phonology than from phonology to spelling. Indeed, many words end with a silent letter motivated by morphology (*bavard,* "talkative", where the derived form is *bavardage,* "chattering"). For this reason, it may be argued that morphological processing is relevant for spelling (Pacton & Deacon, 2008; Sénéchal, 2000) more than for reading. But reading and spelling skills are known to be very closely related (Adams, 1990; Fayol, Zorman, & Lété, 2009; Treiman, 1993), and children may benefit from their ability to spell according to morphology when reading complex words. Fourth, children's morphological awareness has also proved to be an independent predictor of early reading ability development in French beyond phonological awareness (Casalis & Louis Alexandre, 2000).

We conducted three priming experiments among French developing readers (third, fifth, and seventh graders), each with a different prime duration (60 ms in Experiment 1, 250 ms in Experiment 2, and 800 ms in Experiment 3) but with the same four priming conditions: morphological (e.g., *tablette–TABLE,* "little table–TABLE", where an equivalent in English could be *singer–SING*), pseudoderivation (e.g., *baguette–BAGUE,* "French stick–RING", where an equivalent in English could be *corner–CORN*), orthographic control (e.g., *abricot–ABRI,* "apricot–SHELTER", where an equivalent in English could be *spinach–SPIN*), and semantic control (e.g., *tulipe–FLEUR,* "tulip–FLOWER"). As a control measure, we also conducted the two first experiments[1] with skilled adult readers to replicate, with our stimuli, previously observed patterns of priming in adults.

The examination and comparison of priming effects in the morphological and pseudoderivation conditions according to prime duration makes it possible to investigate the role of form and meaning in the processing of written morphology. If developing readers rely on morphemes as orthographic units, as proposed by Rastle and Davis (2008), we expected significant and comparable priming effects in both the morphological and pseudoderivation conditions. In contrast, if developing readers process morphemes as the smallest units of form *and* meaning, as proposed by Schreuder and Baayen (1995), we expected priming effects only in the morphological condition. Finally, if both types of properties are successively activated in the time course of word recognition, as already found in adults, we expected a dissociation between morphological and pseudoderivation priming depending on prime duration.

The orthographic and semantic conditions were included as controls to confirm whether French developing readers process morphemes as units. Although there is already evidence that the processing of morphemes is not limited to the exploration of orthographic sublexical properties in French fourth graders (Casalis et al., 2009), to date no semantic control condition has been used to examine the extent to which the processing of morphemes is limited to a semantic overlap between primes and targets. If developing readers process morphemes as units, we expected a dissociation in priming among the morphological, orthographic and semantic control conditions.

We conducted each of these studies among third, fifth, and seventh graders to explore the developmental dynamic of morphological processing. The inclusion of three different grades would enable us to determine whether a processing of morphemes characterizes early reading development (e.g.,

[1] Adult skilled readers did not perform Experiment 3, with a prime duration of 800 ms, because reading procedures are likely to be under strategic control with this long prime duration. In addition, long-term morphological priming has been shown to be resistant to intervening items, whereas semantic priming has not (Bentin & Feldman, 1990).

third grade) or only advanced levels of reading and whether young and more advanced readers extract the same properties of morphemes (form and meaning) when processing morphologically complex words.

Finally, as a control measure, we also conducted these experiments with skilled adult readers. We expected to replicate previously observed patterns of priming, namely priming effects in both the morphological and pseudoderivation conditions at 60 ms and in both the morphological and semantic control conditions at 250 ms.

Experiment 1: 60-ms prime duration in developing readers and in adults

Method

Participants and background measures

A sample of 60 French developing readers (21 third graders, 19 fifth graders, and 20 seventh graders) participated in this experiment. The mean chronological age for each grade is reported Table 1. Participants attended primary and secondary schools around the city of Lille in northern France.

For inclusion in the experimental group, children needed to meet four criteria:

1. Their reading level corresponded to their chronological age, according to the French reading test "l'Alouette" (Lefavrais, 1967). This test involves 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 3 min) and accuracy. To make it possible to examine the grade effect, we needed to limit the overlap in reading age among the three grades. To do so, we excluded from the analysis children with a reading lag of 18 months below expectation for age, corresponding to the maximum tolerated delay before the children are considered as poor readers. We also excluded 8 children (overall across the three experiments) with a remarkable advance in reading skills (more than 30 months above expectation for age).
2. Their nonverbal reasoning skills were not below the 25th percentile, as assessed by Raven's Coloured Progressive Matrices (Raven, Court, & Raven, 1995) in third and fifth graders and Raven's Advanced Progressive Matrices (Raven, Raven, & Court, 1998) in seventh graders.
3. They needed to be native speakers of French.
4. Parental consent needed to be obtained before the experiment started.

Details on the background measures are reported in Table 1.

Table 1
Chronological age, reading age, and nonverbal reasoning of developing readers participating in Experiments 1, 2, and 3.

	Experiment 1		Experiment 2		Experiment 3	
	M (*SD*)	Range	*M* (*SD*)	Range	*M* (*SD*)	Range
Chronological age[a]						
Third graders	8;10 (4.30)	8;0–9;3	8;9 (5.00)	8;5–9;10	8;11 (5.52)	8;3–9;8
Fifth graders	10;11 (7.32)	9;0–11;11	10;11 (4.91)	9;11–11;5	10;4 (7.71)	9;8–11;6
Seventh graders	12;0 (10.70)	11;3–13;1	12;4 (7.54)	11;11–13;4	12;8 (5.66)	11;6–13;4
Reading age[b]						
Third graders	9;3 (13.78)	7;8–10;3	9;3 (16.70)	7;1–10;10	8;7 (9.11)	7;9–10;8
Fifth graders	10;11 (14.60)	9;8–13;0	10;6 (13.50)	9;9–12;10	10;8 (13.59)	9;0–12;10
Seventh graders	12;3 (15.30)	10;2–14;3	12;6 (15.75)	10;9–14;3	12;8 (14.41)	11;4–14;3
Nonverbal reasoning[c]						
Third graders	32.38 (2.49)	28–36	31.91 (3.72)	26–36	31.71 (2.55)	28–36
Fifth graders	33.58 (3.02)	30–36	32.95 (2.73)	30–36	33.43 (2.62)	30–36
Seventh graders	41.30 (5.48)	38–50	43.40 (6.13)	34–54	46.00 (3.73)	40–54

[a] Chronological age in years and months (years;months). Standard deviations are in months.
[b] Reading age in years and months (years;months) according to *Test de l'Alouette* (Lefavrais, 1967). Standard deviations are in months.
[c] Standard score on the nonverbal reasoning test (Raven et al. 1995, 1998).

The adult participants were 17 undergraduate students from the University of Lille. All participants were native speakers of French and reported normal or corrected-to-normal vision. They participated voluntarily, and no credit was given for participation.

Materials

The materials (listed in Appendix Table 1A) included four sets of 16 prime–target pairs. In the *morphological* condition, the primes were morphologically related to their targets (e.g., *tablette–TABLE,* ''little table–table''). The morphological status of the primes was determined using the ''Brio'' French dictionary, which analyzes the lexical morphology of French (Rey-Debove, 2004).

Primes in the *pseudoderivation* condition appeared to contain two morphemes – a base word (the target) and a suffix – but the prime's meaning was unrelated to that of the target (e.g., *baguette–BAGUE,* ''French stick–ring''). Although prime–target pairs were not semantically related in this condition, they could have a historical morphological relationship that is no longer apparent.

For each pair in the morphological and pseudoderivation conditions, the relationship between prime and target was orthographically transparent; the derived words contained the entire stem with no consonant or vowel changes. The semantic relatedness of these pairs was tested by means of a pretest where 112 undergraduate students were asked to rate the semantic similarity of each pair on a scale ranging from 1 (*surely unrelated*) to 4 (*surely related*). Mean similarity ratings were calculated for each pair of words. Only pairs with a mean rate of at least 3.50 of 4 ($M = 3.86$, $SD = 0.12$) were included in the morphological condition. Conversely, only pairs with a mean rate of 1.50 of 4 or below ($M = 1.24$, $SD = 0.07$) were included in the pseudoderivation condition.

In the *orthographic control* condition, primes were orthographically but not morphologically related to the target. The target word was embedded in them (e.g., *abricot–ABRI,* ''apricot–shelter''), but contrary to the pseudoderivation condition, their ending was not suffixal (''cot'' is not a suffix in French).

Finally, prime–target pairs in the *semantic control* condition were semantically but not morphologically related (e.g., *tulipe–FLEUR,* ''tulip–FLOWER''). Among the 16 prime–target pairs, 9 shared an associative relationship and 7 shared a categorical relationship.

We ensured that the semantic relatedness of the morphological and semantic pairs was not statistically different using latent semantic analysis (LSA) (Landauer & Dumais, 1997). This technique is used to extract semantic representations of words through the analysis of French written texts. The strength of the semantic relatedness of primes and targets in the morphological ($M = 0.33$) and semantic control ($M = 0.26$) conditions was not significantly different, $t(30) = 1.11$, $p = .273$.

Prime–target pairs were matched as closely as possible across the four conditions for length, frequency, and neighborhood size (Manulex-infra: Peereman, Lété, & Sprenger-Charolles, 2007). Primes were matched for length (number of letters, $F < 1$), print frequency ($F < 1$), and neighborhood size (N size), $F(3, 124) = 1.11$, $p = .35$. We selected frequent targets that were likely to be known by developing readers. They were matched for frequency ($F < 1$) but could not be perfectly matched for length, $F(3, 60) = 3.47$, $p = .02$. Indeed, targets in the morphological condition were longer than targets in the orthographic condition (5.25 vs. 4.25 letters, $p = .02$), but this mismatch biases the items against the hypothesis under investigation (i.e., longer targets should take longer to be processed). In addition, because of the constraints imposed by the main design variables, we could not fully match the neighborhood size of targets across conditions, $F(3, 60) = 7.02$, $p < .001$. Targets from the semantic condition (mean N size = 1.88) had fewer orthographic neighbors 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.

In total, 64 unrelated control primes were selected for the 64 target words. They bore no morphological, semantic, or orthographic relationship to the targets, and they were matched in length and frequency with the related primes (both Fs < 1).

In addition, 16 unrelated prime–target pairs were included as fillers to reduce the proportion of related prime–target pairs in the experiment to 44%, leading to a total of 144 prime–word target pairs.

The mean values of these variables are shown in Table 2.

In total, 144 morphologically simple pseudoword targets were selected for the ''no'' responses of the lexical decision task. Pseudoword targets were orthographically and phonologically legal sequences created by changing one or two letters in existing words. Of these 144 pseudoword targets,

Table 2
Stimulus properties across test conditions.

Condition	*n*		Length		Frequency		N size	
			Prime	Target	Prime	Target	Prime	Target
Morphological		*M*	7.25	5.25	20.97	105.66	0.63	4.50
(e.g., *Tablette–TABLE*)	16	(*SD*)	(0.86)	(1.00)	(19.50)	(85.88)	(1.02)	(2.78)
Pseudoderivation		*M*	7.19	4.44	20.56	97.72	1.31	6.06
(e.g., Baguette–BAGUE*)*	16	(*SD*)	(0.98)	(0.81)	(20.08)	(73.51)	(1.66)	(2.89)
Orthographic control		*M*	7.06	4.25	19.67	98.12	0.69	5.25
(e.g., Abricot–ABRI*)*	16	(*SD*)	(0.93)	(1.06)	(20.72)	(52.75)	(1.40)	(3.17)
Semantic control		*M*	7.00	4.75	19.17	100.23	0.69	1.88
(e.g., Tulipe–FLEUR)	16	(*SD*)	(1.10)	(0.86)	(12.12)	(48.28)	(0.70)	(1.96)

64 were preceded by a related word and 80 were preceded by an unrelated word, as for word items. Among these prime words, half appeared to contain morphemes (derived or pseudoderived words) and half did not.

In total, there were 288 prime–target pairs, 144 of which contained word targets and 144 of which contained nonword targets. Prime–target pairs were divided into two lists with 72 word targets and 72 pseudoword targets in each list. Among the 72 target words appearing in each list, 32 were associated with a related prime (8×4 conditions), whereas the other 40 were associated with an unrelated prime. Words that were preceded by a related prime in one list were preceded by an unrelated prime in the other list, so that we could examine reaction time (RT) differences to targets according to priming condition (related or unrelated).

Procedure

We used a masked priming procedure, as in Forster and Davis (1984), with a prime duration of 60 ms. This prime duration is slightly longer than the 57-s one usually used in visual priming studies with children (Castles, Davis, Cavalot, & Forster, 2007; Castles, Davis, & Letcher, 1999) because our primes were longer (five to nine letters). Each trial consisted of a sequence of four stimuli. First, a fixation cross (+) was displayed in the middle of a screen for 1000 ms (which also served as the intertrial interval). This was followed by an 800-ms forward mask consisting of a row of eight hash marks (########). Next, the prime stimulus was displayed for 60 ms in lowercase letters, followed immediately by the target stimulus in uppercase letters (this also served as a backward mask), which remained on the screen until a response was given (for a maximum of 5000 ms). Primes and targets were displayed in 25-point Courier New font in black on a white background. The letters on the screen were 10 mm high and 8 mm wide. Stimulus presentation and data collection were controlled using the E-Prime software package version 1.0 (Schneider, Eschmann, & Zuccolotto, 2002) running on a Dell Latitude 131L laptop computer.

Children were tested in a quiet room at their school building during regularly scheduled school hours. Adults were tested individually in a quiet room at the University of Lille. Children and adults were seated in front of a computer screen at a distance of approximately 30 cm from their eyes. They were told that they would see a series of letter strings presented one at a time and that they would be required to decide, as quickly and accurately as possible, whether or not each string was a French word.

Responses were recorded via the "p" and "q" keys on a computer keyboard, on which we glued two removable stickers: one for right responses and one for false responses. Stickers were placed so that participants used their dominant hand for "Right" responses. Given the short prime duration, the presence of a visual prime was never mentioned. Following the instructions, participants completed a practice session of 10 trials (half word targets and half pseudoword targets) where feedback was given and then completed the experimental session without feedback.

We used a within-participants procedure, with each participant completing the two experimental lists. This enabled us to directly compare the influence of the prime on target processing in each participant. The order of presentation of the items within the two lists was randomized, and the order of

Table 3
Experiment 1 (60-ms prime): mean RTs, priming effects, and percentage errors for developing readers and adults as a function of the condition.

Condition	RT (ms)			Errors (%)	
	Related	Unrelated	Priming	Related	Unrelated
Third graders					
Morphological	1304 (235)	1357 (248)	53	3.88 (5.03)	4.17 (5.52)
Pseudoderived	1232 (224)	1294 (202)	62	6.59 (8.32)	4.37 (6.81)
Orthographic control	1301 (248)	1287 (226)	−14	5.96 (5.47)	5.20 (5.24)
Semantic control	1230 (216)	1251 (236)	21	5.40 (6.34)	4.46 (7.03)
Fifth graders					
Morphological	1011 (151)	1085 (186)	74	5.14 (5.00)	5.60 (4.75)
Pseudoderived	975 (152)	1054 (196)	79	4.81 (5.51)	1.88 (3.12)
Orthographic control	1084 (179)	1056 (212)	−28	7.29 (6.31)	5.61 (5.26)
Semantic control	952 (119)	964 (167)	12	4.66 (5.36)	4.17 (4.79)
Seventh graders					
Morphological	927 (195)	972 (206)	45	3.13 (4.91)	3.13 (4.42)
Pseudoderived	890 (173)	936 (190)	46	4.07 (4.65)	4.55 (6.22)
Orthographic control	945 (184)	929 (189)	−16	4.07 (6.11)	4.13 (5.29)
Semantic control	915 (183)	890 (150)	25	3.17 (5.39)	1.41 (2.72)
Adults					
Morphological	604 (73)	629 (65)	25	0.74(2.08)	4.04 (3.79)
Pseudoderived	584 (64)	609 (73)	25	1.96 (3.92)	1.18 (2.62)
Orthographic control	614 (66)	609 (61)	−5	5.49 (4.85)	3.14 (3.43)
Semantic control	606 (77)	597 (58)	−9	1.21 (5.39)	1.10 (3.30)

Note: standard deviations are in parentheses.

presentation of each list was counterbalanced. To ensure that target repetition did not influence priming effects, we entered the order of list presentation into the statistical analysis. Mean RTs according to the order of list presentation are reported in Appendix Table 1B.

In children, reading and nonverbal reasoning tests were completed in alternation with the lexical decision task to maintain children's attention and interest and to prevent possible repetition effects.

Data treatment

Latency and error data were collected and cleaned in several ways. Latency data for incorrect responses (error percentages reported in Table 3) and invalid responses were excluded from the analysis. Latencies were considered as invalid when the response was premature (<500 ms as accuracy fell below 50% when participants responded faster) or longer than 3000 ms. The lower cutoff led to the exclusion of 0.72% of trials (1.65% in third graders, 0.67% in fifth graders, 0.54% in seventh graders, and 0% in adults), and the upper cutoff led to the exclusion of 2.62% of trials[2] (7.03% in third graders, 2.07% in fifth graders, 1.34% in seventh graders, and 0.03% in adults). Two targets were removed from the analysis (*mou,* "soft", from the pseudoderived condition, and *char,* "tank", from the orthographic control condition) because the percentage of errors with these items was more than 2.5 standard deviations from the mean. Finally, response latencies were log-transformed to correct for the skewed latency distributions.

Results

Analyses of variance (ANOVAs) were carried out on log-transformed response latencies[3] separately in developing readers and adults. In developing readers, grade was treated as an unrepeated factor (three

[2] Although this procedure seems to imply the exclusion of a lot of data in third graders, we adopted this cutoff to exclude no more than 5% of invalid responses overall (all experiments collapsed).

[3] No analysis was conducted on the accuracy measures because of ceiling effects.

levels: third, fifth, and seventh graders), whereas priming (two levels: related and unrelated), condition (four levels: morphological, pseudoderived, orthographic control, and semantic control), and order of list presentation (two levels: 1 and 2) were treated as repeated factors. In adults, priming (two levels: related and unrelated), condition (four levels: morphological, pseudoderived, orthographic control, and semantic control), and order of list presentation (two levels: 1 and 2) were treated as repeated factors. However, because we were specifically interested in the effects of grade, condition, and order of list presentation on priming, we report only the effects concerning the grade and priming variables and the interaction among grade, priming, condition, and order of list presentation. In each experiment, we also compared the amount of priming (mean latencies to unrelated primes – mean latencies to related primes) in the morphological and pseudoderivation conditions using a paired (two-tailed) *t* test.

The mean RTs and error rates for developing readers and adults are displayed in Table 3.

Results in developing readers

There was a main effect of grade, $F(3, 52) = 20.4$, $p < .001$, $\eta_p^2 = .44$, indicating that third graders ($M = 1282$ ms) made slower lexical decisions than fifth graders ($M = 1023$ ms) and seventh graders ($M = 925$ ms). There was also a significant main effect of priming (related vs. unrelated) indicating a priming effect overall, $F(1, 52) = 13.0$, $p < .001$, $\eta_p^2 = .20$. This main effect of priming was modulated by an interaction with condition, $F(3, 156) = 8.5$, $p < .001$, $\eta_p^2 = .14$, but the interaction among priming, condition, and grade and that among priming, condition, and order of list presentation were not significant (*F*s < 1).

As a consequence, planned comparisons were conducted to examine priming effects according to condition. They indicate that related primes speeded up lexical decisions compared with unrelated primes in both the morphological condition ($M = 49$ ms), $F(1, 52) = 15.08$, $p < .001$, $\eta_p^2 = .22$, and the pseudoderivation condition ($M = 64$ ms), $F(1, 52) = 20.98$, $p < .001$, $\eta_p^2 = .29$, but not in the orthographic control ($M = -19$ ms) and semantic control ($M = 4$ ms) conditions (*F*s < 1). In addition, the *t* test indicates that the amount of priming did not differ in the morphological and pseudoderivation conditions ($t < 1$).

Results in adults

The main effect of priming was not significant, $F(1, 16) = 2.55$, $p = .13$, $\eta_p^2 = .14$. There was a significant interaction between priming and condition, $F(3, 48) = 3.31$, $p = .02$, $\eta_p^2 = .17$, but not among priming, condition, and order of list presentation ($F < 1$).

Planned comparisons showed that related primes speeded up lexical decisions compared with unrelated primes in the morphological condition, $F(1, 16) = 4.67$, $p = .04$, $\eta_p^2 = .23$, and in the pseudoderivation condition, $F(1, 16) = 9.23$, $p = .008$, $\eta_p^2 = .37$. However, related orthographic control and semantic control primes did not speed up lexical decisions compared with unrelated primes (*F*s < 1). As in developing readers, the *t* test indicates that the amount of priming in the morphological and pseudoderivation conditions is not different ($t < 1$).

Discussion

In this experiment, we investigated the relative role of form and meaning in the processing of morphologically complex words in a cross-sectional perspective. We used a masked priming procedure with a 60-ms prime duration, guaranteeing that the effects observed derive from the earliest stages of word recognition.

The different priming effects observed in the morphological condition, on the one hand, and in the orthographic and semantic control conditions, on the other, are consistent with the view that morphemically structured representations – as evidenced across several studies in children (Feldman et al., 2002; Rabin & Deacon, 2008) – are activated quickly and automatically when reading complex words. We replicated Casalis and colleagues' (2009) results here even in younger readers (third graders) and also showed that the processing of morphemes is not limited to the activation of semantic properties.

Furthermore, our data clearly indicate significant and comparable priming effects in the morphological and pseudoderivation conditions across all grades. This result suggests that shared meaning between the prime and the target is not necessary to give rise to priming effects and that developing readers rely on the form properties of morphemes to recognize morphologically complex words through their constituents.

The current experiment does not show any developmental trend in the processing of morphemes given that the patterns of priming do not change across grades. Thus, morphological processing is already available and driven by the form properties of morphemes from third grade. In adults, priming effects are similar to those already reported in the literature (in French: Longtin & Meunier, 2005; Longtin et al., 2003; in English: Marslen-Wilson et al., 2008; Rastle et al., 2000); namely, they are specific to morphemes and driven by orthographic properties. Our replication of these results with our material confirms their validity.

Overall, these data support the view that the processing of morphologically complex words through their constituents is efficient as early as third grade and requires the automatic activation of form but not meaning properties of morphemes. This result is in line with Rastle and Davis's (2008) suggestion that the orthographic properties of morphemes trigger processing of written morphology even in developing readers. Experiment 2 provides a further analysis of the influence of the form and meaning properties of morphemes on word reading later in the time course of word recognition using the same procedure with a prime duration of 250 ms.

Experiment 2: 250-ms prime duration in developing readers and in adults

Method

Participants and background measures

A new sample of 63 developing readers (22 third graders, 21 fifth graders, and 20 seventh graders) from elementary schools and middle schools around the city of Lille participated in this experiment. Children were selected on the basis of the same four criteria as in Experiment 1, and details of participants are provided in Table 1.

The adult participants were 14 undergraduate students at the University of Lille. They all were native speakers of French, reported normal or corrected-to-normal vision, and participated voluntarily. They received no credit for their participation.

Procedure and materials

The procedure and materials were the same as in Experiment 1. However, for the experimental task, the primes were presented for 250 ms instead of 60 ms and their presence was explicitly mentioned.

Data treatment

We applied the same cleaning procedure as in Experiment 1. The lower cutoff (500 ms) led to the exclusion of 1.56% of trials (2.59% in third graders, 0.75% in fifth graders, 1.34% in seventh graders, and 0% in adults), and the upper cutoff (3000 ms) led to the exclusion of 3.78% of trials (7.70% in third graders, 2.27% in fifth graders, 1.37% in seventh graders, and 0% in adults). The same target items were excluded from data analysis as in Experiment 1 (*mou* and *char*), and RTs were also log-transformed.

Results

The research design was the same as in Experiment 1. Table 4 shows mean RTs and error rates for developing readers and adults.

Results in developing readers

The ANOVA reveals a main effect of grade on RTs, $F(3, 55) = 14.8$, $p < .001$, $\eta_p^2 = .35$, indicating that third graders ($M = 1273$ ms) were slower than fifth graders ($M = 1098$ ms) and that fifth graders were slower than seventh graders ($M = 964$ ms). The main effect of priming was significant, $F(1, 55) = 25.1$, $p < .001$, $\eta_p^2 = .31$, indicating an overall priming effect. The interaction between priming and condition was significant, $F(3, 165) = 4.6$, $p = .003$, $\eta_p^2 = .07$, but the interaction among priming, condition, and grade and that among priming, condition, and order of list presentation were not significant (Fs < 1).

Table 4
Experiment 2 (250-ms prime): mean RTs, priming effects, and percentage errors for developing readers and adults as a function of the condition.

Condition	RT (ms)			Errors (%)	
	Related	Unrelated	Priming	Related	Unrelated
Third graders					
Morphological	1261 (273)	1318 (228)	57	2.87 (5.48)	6.99 (10.25)
Pseudoderived	1216 (190)	1257 (194)	41	5.65 (6.98)	2.37 (4.15)
Orthographic control	1334 (220)	1335 (254)	1	7.62 (5.25)	6.41 (7.41)
Semantic control	1246 (240)	1219 (235)	27	4.28 (4.92)	5.65 (7.09)
Fifth graders					
Morphological	1030 (185)	1139 (203)	109	7.08 (7.96)	6.65 (6.99)
Pseudoderived	1094 (252)	1117 (205)	23	5.70 (6.24)	5.65 (9.12)
Orthographic control	1124 (201)	1153 (226)	29	9.19 (13.70)	5.83 (7.62)
Semantic control	1053 (209)	1072 (190)	19	6.92 (10.35)	7.13 (7.50)
Seventh graders					
Morphological	916 (117)	1013 (195)	107	1.34 (2.77)	2.85 (3.82)
Pseudoderived	942 (122)	968(188)	26	7.82 (8.84)	4.56 (6.37)
Orthographic control	1026 (227)	1034 (175)	8	3.82 (4.16)	6.86 (7.51)
Semantic control	878 (150)	934 (200)	56	2.21 (4.68)	4.21 (5.21)
Adults					
Morphological	571 (68)	627 (64)	56	1.79 (3.82)	4.46 (5.16)
Pseudoderivation	612 (91)	599 (59)	–13	4.29 (4.97)	3.33 (6.27)
Orthographic control	593 (80)	607 (85)	14	6.67 (5.23)	5.71 (8.62)
Semantic control	575 (70)	588 (74)	13	4.28 (4.92)	5.65 (7.09)

Note: standard deviations are in parentheses.

Planned comparisons were conducted to examine priming effects according to condition and regardless of grade. Related primes speeded up responses to targets compared with unrelated primes in both the morphological condition (M = 86 ms), $F(1, 55) = 31.30$, $p < .001$, $\eta_p^2 = .36$, and the pseudoderivation condition (M = 31 ms), $F(1, 55) = 4.6$, $p = .04$, $\eta_p^2 = .08$, but not in the orthographic control condition (M = 9 ms) ($F < 1$) and the semantic control condition (M = 24 ms), $F(1, 55) = 1.6$, $p = .21$, $\eta_p^2 = .03$. However, the t test indicates larger priming effects for the morphological condition than for the pseudoderivation condition, $t(57) = 2.52$, $p = .015$, $d = 0.38$.

Results in adults

The main effect of priming was significant, $F(1, 13) = 27.31$, $p < .001$, $\eta_p^2 = .68$, indicating that lexical decisions were faster when targets appeared after related primes than after unrelated primes. In addition, the priming effect significantly interacted with the condition, $F(3, 39) = 5.43$, $p = .003$, $\eta_p^2 = .29$, but the interaction among priming, condition, and order of list presentation did not reach significance ($F < 1$).

Planned comparisons were conducted to examine the effect of priming across the four conditions. They showed that related primes speeded up lexical decisions compared with unrelated primes in both the morphological condition, $F(1, 13) = 40.07$, $p < .001$, $\eta_p^2 = .79$, and the semantic condition as a trend, $F(1, 13) = 3.19$, $p = .09$, $\eta_p^2 = .20$, but not in the pseudoderivation condition, $F(1, 13) = 2.37$, $p = .15$, $\eta_p^2 = .15$, and the orthographic control condition ($F < 1$). Furthermore, the paired t test indicates that the priming effects were larger for the morphological condition than for the pseudoderivation condition, $t(13) = 4.50$, $p < .001$, $d = 1.73$.

Discussion

The same material as in Experiment 1 but with a longer prime duration led to nearly similar patterns of priming in developing readers but not in adults. In developing readers, priming effects are significant in the morphological condition but not in the orthographic control and semantic control conditions, reinforcing the idea that the processing of morphemes is not limited to orthographic or semantic overlap between primes and targets. With respect to the role of form and meaning properties of morphemes, priming effects are significant in both the morphological and pseudoderivation conditions, although they are larger in the first condition than in the second one. These effects indicate that the semantic overlap between morphologically related prime–target pairs strengthens priming effects at this point in the time course of visual word recognition even if developing readers do not necessarily need to activate the semantic properties of morphemes to benefit from priming.

In adults, the picture is a little different. Although morphological processing does not appear to be limited to orthographic overlap, priming effects are no longer significant in the pseudoderivation condition. Thus, the simultaneous presence of a base and a suffix in the prime is not sufficient to give rise to priming effects, and morphological processing also requires activation of the semantic properties of morphemes. In line with this finding are the marginally significant priming effects in the semantic control condition, reinforcing the idea that adults activate the semantic properties of primes when they are presented for 250 ms.

An important issue now is to examine whether developing readers still rely on the orthographic properties of morphemes to recognize complex words through their components later in the time course of word recognition. Thus, we conducted a third experiment using the same procedure as in Experiments 1 and 2 but with a prime duration of 800 ms.

Experiment 3: 800-ms prime duration in developing readers

Method

Participants and background measures

A new sample of 66 French developing readers (21 third graders, 21 fifth graders, and 24 seventh graders) participated in this experiment. They all attended primary and secondary schools around the city of Lille.

Children were selected on the basis of the four criteria presented in Experiment 1. Details of participants are provided in Table 1.

Procedure and materials

The procedure and materials were the same as in Experiments 1 and 2 except that the prime duration was 800 ms.

Data treatment

The same cleaning procedure as in Experiments 1 and 2 was applied. The lower cutoff (500 ms) led to the exclusion of 3.23% of the data (5.01% in third graders, 2.72% in fifth graders, 1.98% in seventh graders, and 0% in adults), and the upper cutoff (3000 ms) led to the exclusion of 3.62% of the data (7.20% in third graders, 2.29% in fifth graders, 1.36% in seventh graders, and 0% in adults). The same target items were excluded from data analysis as in Experiments 1 and 2 (*mou* and *char*), and RTs were log-transformed.

Results

The research design was the same as in Experiments 1 and 2. Table 5 shows mean RTs and error rates for developing readers.

The ANOVA shows a main effect of grade on RTs, $F(3, 53) = 19.87$, $p < .001$, $\eta_p^2 = .43$. Third graders ($M = 1310$ ms) were slower to accept words than fifth graders ($M = 1009$ ms) and seventh graders ($M = 906$ ms). The main effect of priming was significant, $F(1, 53) = 40.05$, $p < .001$, $\eta_p^2 = .43$, indicating an overall priming effect. This effect interacted with condition as a trend, $F(3, 159) = 2.36$, $p = .07$, $\eta_p^2 = .04$, but the interaction among priming, condition, and grade and that among priming, condition, and order of list presentation were not significant (Fs < 1).

Table 5
Experiment 3 (800-ms prime): mean RTs, priming effects, and percentage errors for developing readers as a function of the condition.

Condition	RT (ms)			Errors (%)	
	Related	Unrelated	Priming	Related	Unrelated
Third graders					
Morphological	1266 (281)	1374 (314)	108	5.37 (7.62)	6.95 (7.80)
Pseudoderived	1290 (260)	1331 (295)	41	7.10 (7.20)	8.31 (7.81)
Orthographic control	1313 (291)	1408 (332)	95	12.23 (10.44)	9.60 (9.24)
Semantic control	1226 (294)	1274 (332)	48	6.98 (6.88)	9.29 (7.44)
Fifth graders					
Morphological	974 (187)	1033 (209)	59	3.06 (5.11)	4.49 (5.83)
Pseudoderived	974 (210)	995 (200)	21	4.23 (5.95)	4.49 (6.29)
Orthographic control	1035 (223)	1072 (189)	37	5.43 (5.19)	6.14 (6.57)
Semantic control	968 (198)	1021 (190)	53	5.05 (5.22)	4.56 (8.35)
Seventh graders					
Morphological	863 (160)	940 (218)	77	0.60 (1.88)	2.23 (3.25)
Pseudoderived	902 (172)	905 (183)	3	3.56 (4.66)	2.32 (4.66)
Orthographic control	933 (215)	939 (155)	6	6.17 (6.70)	3.93 (4.61)
Semantic control	844 (193)	920 (183)	76	1.23 (2.60)	1.87 (3.63)

Note: standard deviations are in parentheses.

Planned comparisons were conducted to examine priming effects according to condition and independent of grade. Related primes speeded up lexical decisions compared with unrelated primes in the morphological condition ($M = 87$ ms), $F(1, 53) = 27.97$, $p < .001$, $\eta_p^2 = .35$, the semantic control condition ($M = 53$ ms), $F(1, 53) = 15.11$, $p < .001$, $\eta_p^2 = .22$, and the orthographic control condition ($M = 49$ ms), $F(1, 53) = 5.57$, $p = .02$, $\eta_p^2 = .09$, but not in the pseudoderivation condition ($M = 20$ ms), $F(1, 53) = 2.30$, $p = .14$, $\eta_p^2 = .04$. Finally, the t test indicates that the priming effects were larger in the morphological condition than in the pseudoderivation condition, $t(55) = 2.49$, $p = .016$, $d = 0.62$.

Discussion

A different pattern of results emerges in developing readers in Experiment 3 compared with Experiment 2. Although developing readers still benefit from a morphologically related prime to process the target, priming effects are no longer significant when primes and targets share a relationship of pseudoderivation. The orthographic sharing of morphological units between primes and targets is no longer sufficient with this long prime duration to process morphologically complex words through their constituents and the activation of the semantic properties of morphemes is required.

Another important finding consistent with this interpretation is the significant priming effect when primes and targets share a semantic control relationship, which occurs across all grades. This confirms that developing readers are able to activate the semantic properties of the prime when it is presented for a long duration and that this activation facilitates target recognition as reported previously (in French: Bonnotte & Casalis, 2009; in English: Simpson & Foster, 1986).

The significant priming effect in the orthographic control condition was unexpected. A closer inspection of the data reveals that the overall priming effect observed in this condition is due mainly to a large priming effect in third graders that might reflect a trade-off between latencies and errors. An index of this trade-off is provided by the RT/error ratio, which is lower in the related condition than in the unrelated condition in the orthographic control condition, $t(17) = 2.26$, $p = .037$, whereas this is not the case in the morphological condition, $t(17) = 1.19$, $p = .25$, the pseudoderivation condition ($t < 1$), and the semantic control condition, $t(17) = 1.12$, $p = .28$. Thus, third graders emphasized speed over accuracy in the related orthographic control condition, which precludes interpretation of the observed orthographic facilitation in RTs.

General discussion

Although a large proportion of the new words that children encounter in print are morphologically complex (Nagy & Anderson, 1984), models of reading acquisition have generally focused on the processing of the phonological, orthographic, or semantic properties of whole words in the acquisition of reading skills. Therefore, numerous questions remain as to whether and how developing readers process these words through their morphemic constituents when reading.

The aim of the current study was to clarify this issue of morphological processing in developing readers. More precisely, we investigated the role of the form and meaning properties of morphemes in the recognition of morphologically complex words and the developmental dynamic of morphological processing. To this end, we used the priming paradigm because it allows examining activation of properties associated with morphemes at different stages of word processing.

The main results can be summarized as follows. Evidence of significant morphological priming was found in both developing readers and adults in all three experiments. In the pseudoderivation condition, priming effects were significant when primes were presented for 60 and 250 ms in developing readers and only for the shortest (60-ms) primes in adults. There was no priming effect in the orthographic control condition except in developing readers when the prime duration was 800 ms, but as mentioned in the Discussion of Experiment 3, this result is not interpretable. Finally, in the semantic control condition, priming effects were significant when primes were presented for 800 ms in developing readers and were marginally significant when primes were presented for 250 ms in adults.

Because morphological priming was evident whatever the prime duration, contrary to orthographic and semantic control priming, our study confirms that developing readers process morphemes as units during visual word recognition. This finding supports the view that not only is the developing lexicon organized around morpheme units, as already evidenced by Feldman and colleagues (2002) and Rabin and Deacon (2008) in English, but also developing readers activate these morphological representations directly when *reading* morphologically complex words as early as third grade. Furthermore, morphological information appears to be available very early in the time course of word recognition because priming effects were observed with a very short prime duration (i.e., 60 ms).

The dissociation in priming between the morphological and pseudoderivation conditions indicates that the form and meaning properties of morphemes make separate contributions to morphological processing. At the earliest steps of word recognition (until 250 ms), developing readers are sensitive to the co-occurrence of base and suffix in words, but the activation of the semantic properties of morphemes is not necessary to process complex words through their constituents. Although these semantic properties are already activated at 250 ms, as evidenced by larger priming effects for the morphological condition, they play a crucial role in morphological processing only later in the time course of word recognition (800 ms).

The current study provides evidence for the first time that the written processing of morphologically complex words through their constituents is triggered by their form properties in developing readers. This finding supports Rastle and Davis's (2008, pp. 952–956) orthographic-based hypothesis of morphological processing, holding that developing readers rely on the orthographic properties of morphemes to process morphologically complex words through their decomposed form. Because the semantic properties of morphemes are activated later in the time course of word recognition, our results are not inconsistent with Schreuder and Baayen's (1995) proposal, according to which the goal of morphological processing is to compute meaning from the constituent elements. However, the sharing of form *and* meaning is not necessary to trigger morphological processing.

Models of reading acquisition need to deal with the mechanisms that underlie reading development and, more specifically, with developmental changes in the activation of linguistic information. As mentioned before, current models do not assign a specific role to morphology in the acquisition of reading skills. Because our data clearly indicate that the processing of complex words through their constituents facilitates word identification as early as third grade, they suggest that morphology should be integrated into models of reading development. However, even though we did not find any evidence of a developmental trend in the specificity or nature of morphological processing in developing readers, one should be cautious in data interpretation because this may be due to a limited number of participants in each grade, possibly reducing the power of statistical analyses.

Furthermore, even though patterns of priming are comparable in developing readers and in adults, the semantic properties of morphemes play a crucial role in morphological processing earlier in adults than in developing readers. A simple explanation of this temporal delay is based on reading expertise. Because developing readers are likely to have less experience with written materials, they might benefit from the morphological overlap between pseudoderived prime–target pairs for a longer time. A slightly different but related explanation is couched in terms of the strength of the connections between the form and meaning properties of morphemes in the lexicon. Following Schreuder and Baayen (1995), Rastle and Davis (2008) suggested that "the two forms of decomposition observed behaviourally (orthographically based and semantically based) reflect decomposed representations at two separate levels of processing in visual word recognition" (p. 965). These two forms of decomposition have already been evidenced in oral tasks in developing graders (Carlisle & Fleming, 2003; Derwing & Baker, 1979). First to third graders rely more on phonological relations than on semantic relations when they need to judge whether two words are related or not (e.g., *doll–dollar*), whereas third to sixth graders activate the semantic properties of morphemes to perform this task. The two separate levels of processing may nevertheless be less connected in developing readers, and the form properties of morphemes may exert significant influence on children's word recognition for a longer time compared with adults.

This article provides evidence for the important role of form properties of morphemes when processing morphologically complex words through their constituents. What are these form properties of morphemes on which children rely? This processing is not limited to the extraction of base word properties given that no facilitation is observed in the orthographic control condition where primes and targets share only a base word (e.g., *abricot–abri,* where an equivalent in English could be *spinach–spin*). This clearly shows that the co-occurrence of base and suffix is fundamental to the processing of complex words through their constituents. One possibility is that the decomposition of morphologically complex words into their constituents is triggered by suffix endings. Consistent with this hypothesis are the error percentages in the orthographic control condition, which tend to be higher than those in the other conditions at the descriptive level. Even if we did not conduct statistical analyses on error percentages, this puzzling error rate might point out children's difficulty in processing orthographically related words without a morphological structure.

Our results differ slightly from those of Casalis and colleagues (2009), who did not find any difference between the morphological and orthographic conditions with a short prime duration of 75 ms, whereas such a difference emerged with a longer prime duration (250 ms). One difference between the current study and Casalis and colleagues' study lies in the linguistic status of the targets, which were morphologically complex words in their study and base words in the current study. The presentation of complex words as targets involves an additional base extraction, which might reduce the benefit related to morphological priming (Marslen-Wilson, Tyler, Waksler, & Older, 1994). Another difference lies in target frequency, which was much lower in Casalis and colleagues' study (i.e., 12.6 occurrences per million) than in the current study. Hence, their words may have been unknown to children and thus had no lexical representation, leading first to a strong processing of their sublexical properties and only later to the processing of morphemes.

An important but open issue is how these affix units have acquired a specific status in children's lexicon. The literature on adult morphological processing has proposed a wide range of factors that might enable readers to develop morphologically structured orthographic representations. Among these factors, the likelihood of an affix occurring as a processing unit in a given language has been shown to be influenced by *affixal salience* (Laudanna & Burani, 1995). This salience depends both on the distributional (e.g., length, frequency) and linguistic (e.g., productivity, orthographic transparency, suffix allomorphy) (Järvikivi, Bertram, & Niemi, 2006) properties of morphemes. Additional experiments are needed in developing readers to examine the role of these factors in the development of morphemes as processing units.

Arguably, the relative role of form and meaning may be influenced by the language under consideration. Indeed, the role of form may depend on the properties of the derivational system. In languages such as Turkish and Finnish, the pronunciation of the base never changes in the derived form, whereas in other languages such as English, the derivation often involves a modification of the base (e.g., *nature–natural, five–fifth*). These modifications are likely to delay or alter the development of morphemes as processing units and, more specifically, the representation of the form properties of morphemes. Morphological productivity may also be a determining factor in this development because it affects the probability of readers encountering morphemic units in print.

Furthermore, the role of meaning may be influenced by orthographic consistency. In the framework of the triangle model (Plaut, McClelland, Seidenberg, & Patterson, 1996), learning to read requires the establishment of links between orthography and phonology (phonological pathway) and between orthography and semantics (semantic pathway). An important characteristic of this model is that the contribution of the semantic pathway is supposed to be greater when the phonological pathway is compromised, namely when grapheme–phoneme correspondences are inconsistent (Harm & Seidenberg, 2004). In adults, the involvement of semantics in reading aloud has been found to be particularly great when words contain irregular mappings between spelling and sound (McKay, Davis, Savage, & Castles, 2008). Thus, it may be argued that the influence of the semantic properties of morphemes may be particularly great in irregular orthographies such as English, where the correspondence between written and spoken morphemes is often less transparent. Precisely understanding the impact of orthographic transparency will be critical in the wider goal of formulating a complete theory of children's processing of written morphology.

Because the younger participants in our study were third graders, it precludes the establishment of a complete picture of morphological processing starting at the onset of literacy. This choice was due to the fact that the lexical decision task is rather complex for second graders and that first and second graders tend to generate many false positives or to produce exceptionally long response times. In addition, we assumed that they would not exhibit automatic priming effects with such a short prime duration because the primes were morphologically complex words that are long by nature (at least six letters) and therefore unlikely to be captured by these children's visual system. Nevertheless, as stated earlier, first graders' oral morphological representations are specified mostly in terms of form and are progressively enriched with semantic and syntactic information with reading exposure (Carlisle & Fleming, 2003; Derwing & Baker, 1979). Thus, an area of future research would be to use another experimental method to shed light on developmental aspects of morphological processing in younger readers.

In conclusion, the results of this study provide support for the role of both form and meaning properties of morphemes when reading complex words in French as early as third grade. The priming paradigm has demonstrated a dissociation between the involvement of these properties, indicating that they are successively activated in the time course of word recognition. Thus, linking the knowledge of form properties of morphemes with their semantic or syntactic properties may allow developing readers to process complex words faster and facilitate their reading comprehension.

Acknowledgments

This research was completed while the first author was a doctoral student at the University of Lille North of France. We would like to thank the children who participated in this study. This work was supported by the French Ministry of Research and Technology (award to P. Quémart) and by the French National Agency of Research (project "Lect Morpho", award to S. Casalis).

Appendix A

See Table 1A.

Table 1A
Detailed list of related prime–target pairs.

Morphological		Pseudoderivation		Orthographic control		Semantic control	
Prime	Target	Prime	Target	Prime	Target	Prime	Target
sagesse	SAGE	mouette	MOU	abricot	ABRI	poitrine	CORPS
poirier	POIRE	coupable	COUPER	ecureuil	ÉCURIE	biberon	BÉBÉ
amical	AMI	champion	CHAMP	troupe	TROU	tulipe	FLEUR
poulet	POULE	repasser	REPAS	féroce	FER	chandelle	BOUGIE
chasseur	CHASSE	lunette	LUNE	rossignol	ROSE	vêtement	ROBE
coffret	COFFRE	panneau	PANNE	huître	HUIT	banane	SINGE
pêcheur	PÊCHE	chouette	CHOU	cachalot	CACHE	guidon	VÉLO
grillage	GRILLE	dentelle	DENT	potiron	POT	serrure	CLÉ
mariage	MARIER	Rater	RAT	sanglier	SANG	meuble	CHAISE
visiteur	VISITE	mortier	MORT	second	SEC	ménage	BALAI
tablette	TABLE	toilette	TOILE	torture	TORTUE	acteur	FILM
plumage	PLUME	fouet	FOU	chardon	CHAR	carotte	LAPIN
fermier	FERME	pommade	POMME	soldat	SOL	bouillon	SOUPE
saladier	SALADE	bouleau	BOULE	tombola	TOMBE	fraise	FRUIT
feuillage	FEUILLE	courage	COUR	joindre	JOIE	chiffre	SEPT
armure	ARME	baguette	BAGUE	vendredi	VENDRE	chapiteau	CIRQUE

Appendix B

See Table 1B.

Table 1B
Mean RT (ms) for each experiment according to the list order, the relationship, and the group.

	Experiment 1 (60 ms)				Experiment 2 (250 ms)				Experiment 3 (800 ms)			
List order	1		2		1		2		1		2	
Relationship	R	U	R	U	R	U	R	U	R	U	R	U
Third graders												
Morphological	1351	1416	1239	1298	1322	1354	1177	1265	1309	1438	1173	1268
Pseudoderived	1291	1336	1161	1244	1285	1322	1151	1185	1350	1389	1198	1227
Orthographic C	1336	1336	1251	1228	1393	1407	1265	1254	1328	1495	1243	1267
Semantic C	1271	1325	1173	1174	1332	1296	1144	1131	1299	1337	1129	1152
Fifth graders												
Morphological	1073	1095	946	1081	1079	1169	977	1092	993	1073	957	990
Pseudoderived	1018	1085	933	1023	1147	1182	1028	1047	1027	1052	937	950
Orthographic C	1159	1113	999	988	1169	1240	1091	1069	1091	1123	994	1019
Semantic C	983	977	912	940	1142	1136	950	1015	1018	1057	915	995
Seventh graders												
Morphological	907	976	945	962	919	1076	915	951	868	987	858	876
Pseudoderived	915	941	862	934	1010	1004	880	925	930	910	877	900
Orthographic C	988	957	906	905	1120	1060	928	1007	964	987	910	896
Semantic C	951	913	872	867	929	967	824	894	893	939	800	892
Adults												
Morphological	619	646	589	611	581	638	561	614	–	–	–	–
Pseudoderived	601	622	566	595	659	631	567	567	–	–	–	–
Orthographic C	639	640	591	579	628	629	562	586	–	–	–	–
Semantic C	634	620	579	574	587	616	563	558	–	–	–	–

Note: R, related; U, unrelated; Orthographic C, orthographic control; Semantic C, semantic control.

References

Adams, M. (1990). *Beginning to read: Thinking and learning about print*. Cambridge, MA: MIT Press.

Bentin, S., & Feldman, L. B. (1990). The contribution of morphological and semantic relatedness to repetition priming at short and long lags: Evidence from Hebrew. *Quarterly Journal of Experimental Psychology A, 42*, 693–711.

Bonnotte, I., & Casalis, S. (2009). Semantic priming in French children with varying comprehension skills. *European Journal of Developmental Psychology, 7*, 309–328.

Burani, C., Marcolini, S., & Stella, G. (2002). How early does morpholexical reading develop in readers of a shallow orthography? *Brain and Language, 81*, 568–586.

Carlisle, J. F. (1995). Morphological awareness and early reading achievement. In L. B. Feldman (Ed.), *Morphological aspects of language processing* (pp. 189–209). Hillsdale, NJ: Lawrence Erlbaum.

Carlisle, J. F., & Fleming, J. (2003). Lexical processing of morphologically complex words in the elementary years. *Scientific Studies of Reading, 7*, 239–253.

Carlisle, J. F., & Nomanbhoy, D. M. (1993). Phonological and morphological awareness in first graders. *Applied Psycholinguistics, 14*, 177–195.

Carlisle, J. F., & Stone, C. A. (2005). Exploring the role of morphemes in word reading. *Reading Research Quarterly, 40*, 428–449.

Casalis, S., Dusautoir, M., Colé, P., & Ducrot, S. (2009). Morphological effects in children word reading: A priming study in fourth graders. *British Journal of Developmental Psychology, 27*, 761–766.

Casalis, S., & Louis Alexandre, M. F. (2000). Morphological analysis, phonological analysis, and learning to read French: A longitudinal study. *Reading and Writing, 12*, 303–335.

Castles, A., Davis, C., Cavalot, P., & Forster, K. I. (2007). Tracking the acquisition of orthographic skills in developing readers: Masked priming effects. *Journal of Experimental Child Psychology, 97*, 165–182.

Castles, A., Davis, C., & Letcher, T. (1999). Neighbourhood effects on masked form priming in developing readers. *Language and Cognitive Processes, 14*, 201–224.

Deacon, S. H., & Kirby, J. R. (2004). Morphological awareness: Just "more phonological"? The roles of morphological and phonological awareness in reading development. *Applied Psycholinguistics, 25*, 223–238.

Derwing, B. L., & Baker, W. J. (1979). Recent research on the acquisition of English morphology. In P. Fletcher & M. Garman (Eds.), *Language acquisition: Studies in first language development* (pp. 209–223). Cambridge, UK: Cambridge University Press.

Diependaele, K., Sandra, D., & Grainger, J. (2005). Masked cross-modal morphological priming: Unravelling morpho-orthographic and morpho-semantic influences in early word recognition. *Language and Cognitive Processes, 20*, 75–114.

Ehri, L. C. (2005). Development of sight word reading: Phases and findings. In M. J. Snowling & C. Hulme (Eds.), *The science of reading: A handbook* (pp. 135–154). Oxford, UK: Blackwell.

Fayol, M., Zorman, M., & Lété, B. (2009). Associations and dissociations in reading and spelling French: Unexpectedly poor and good spellers. *British Journal of Educational Psychology, 6*, 63–75.

Feldman, L. B., O'Connor, P. A., & Moscoso del Prado Martin, F. (2009). Early morphological processing is morphosemantic and not simply morpho-orthographic: A violation of form-then-meaning accounts of word recognition. *Psychonomic Bulletin and Review, 16*, 684–691.

Feldman, L. B., Rueckl, J., DiLiberto, K., Pastizzo, M. J., & Vellutino, F. R. (2002). Morphological analysis by child readers as revealed by the fragment completion task. *Psychonomic Bulletin and Review, 9*, 529–535.

Forster, K. I., & Davis, C. (1984). Repetition priming and frequency attenuation in lexical access. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 10*, 680–698.

Fowler, A. E., & Liberman, I. Y. (1995). The role of phonology and orthography in morphological awareness. In L. B. Feldman (Ed.), *Morphological aspects of language processing* (pp. 157–188). Hillsdale, NJ: Lawrence Erlbaum.

Frith, U. (1985). Beneath the surface of developmental dyslexia. In K. E. Patterson, J. C. Marshall, & M. Coltheart (Eds.), *Surface dyslexia: Neuropsychological and cognitive studies of phonological reading* (pp. 301–330). London: Lawrence Erlbaum.

Goswami, U., & Bryant, P. (1990). *Phonological skills and learning to read*. London: Lawrence Erlbaum.

Harm, M. W., & Seidenberg, M. S. (2004). Computing the meanings of words in reading: Cooperative division of labor between visual and phonological processes. *Psychological Review, 111*, 662–720.

Järvikivi, J., Bertram, R., & Niemi, J. (2006). Affixal salience and the processing of derivational morphology: The role of suffix allomorphy. *Language and Cognitive Processes, 21*, 394–431.

Landauer, T. K., & Dumais, S. T. (1997). A solution to Plato's problem: The latent semantic analysis theory of acquisition, induction and representation of knowledge. *Psychological Review, 104*, 211–240.

Laudanna, A., & Burani, C. (1995). Distributional properties of derivational affixes: Implications for processing. In L. B. Feldman (Ed.), *Morphological aspects of language processing* (pp. 345–364). Hillsdale, NJ: Lawrence Erlbaum.

Laxon, V., Rickard, M., & Coltheart, M. (1992). Children read affixed words and non-words. *British Journal of Psychology, 83*, 407–423.

Lefavrais, P. (1967). *Test de l'Alouette*. Paris: Editions du Centre de Psychologie Appliquée.

Longtin, C.-M., & Meunier, F. (2005). Morphological decomposition in early visual word processing. *Journal of Memory and Language, 53*, 26–41.

Longtin, C.-M., Segui, J., & Hallé, P. A. (2003). Morphological priming without morphological relationship. *Language and Cognitive Processes, 18*, 313–334.

Marec-Breton, N., Gombert, J.-E., & Colé, P. (2005). Traitements morphologiques lors de la reconnaissance des mots écrits chez les apprentis lecteurs [Morphological processing in beginning readers' written word recognition]. *L'Année Psychologique, 105*, 9–45.

Marslen-Wilson, W. D., Bozic, M., & Randall, B. (2008). Early decomposition in visual word recognition: Dissociating morphology, form, and meaning. *Language and Cognitive Processes, 23*, 394–421.

Marslen-Wilson, W. D., Tyler, L. K., Waksler, R., & Older, L. (1994). Morphology and meaning in the English mental lexicon. *Psychological Review, 101*, 3–33.

McKay, A., Davis, C., Savage, G., & Castles, A. (2008). Semantic involvement in reading aloud: Evidence from a nonword training study. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 34*, 1495–1517.

Meunier, F., & Longtin, C.-M. (2007). Morphological decomposition and semantic integration in word processing. *Journal of Memory and Language, 56*, 457–471.

Nagy, W. E., & Anderson, R. C. (1984). How many words are there in printed school in English? *Reading Research Quarterly, 19*, 304–330.

Pacton, S., & Deacon, S. H. (2008). The timing and mechanisms of children's use of morphological information in spelling: A review of evidence from English and French. *Cognitive Development, 23*, 339–359.

Peereman, R., Lété, B., & Sprenger-Charolles, L. (2007). Manulex-infra: Distributional characteristics of grapheme–phoneme mappings, and infralexical and lexical units in child-directed written material. *Behavior Research Methods, 39*, 579–589.

Plaut, D. C., McClelland, J. L., Seidenberg, M. S., & Patterson, K. (1996). Understanding normal and impaired word reading: Computational principles in quasi-regular domains. *Psychological Review, 103*, 56–115.

Rabin, J., & Deacon, S. H. (2008). The representation of morphologically complex words in the developing lexicon. *Journal of Child Language, 35*, 453–465.

Rastle, K., & Davis, M. H. (2008). Morphological decomposition based on the analysis of orthography. *Language and Cognitive Processes, 23*, 942–971.

Rastle, K., Davis, M. H., Marslen-Wilson, W. D., & Tyler, L. K. (2000). Morphological and semantic effects in visual word recognition: A time-course study. *Language and Cognitive Processes, 15*, 507–537.

Raven, J. C., Court, J. H., & Raven, J. (1995). *Raven manual: Coloured progressive matrices*. Oxford, UK: Oxford Psychologists Press.

Raven, J., Raven, J. C., & Court, J. H. (1998). *Raven manual: Standard progressive matrices*. Oxford, UK: Oxford Psychologists Press.

Rey-Debove, J. (1984). Le domaine de la morphologie lexicale [The domain of lexical morphology]. *Cahiers de Lexicologie, 45*, 3–19.

Rey-Debove, J. (Ed.). (2004). *Le Robert Brio: Analyse comparative des mots* [The Robert Brio: A comparative analysis of words] Paris: Dictionnaires Le Robert.

Roman, A. A., Kirby, J. R., Parrila, R. K., Wade-Woolley, L., & Deacon, S. H. (2009). Toward a comprehensive view of the skills involved in word reading in Grades 4, 6, and 8. *Journal of Experimental Child Psychology, 102*, 96–113.

Schiff, R., Raveh, M., & Kahta, S. (2008). The developing mental lexicon: Evidence from morphological priming of irregular Hebrew forms. *Reading and Writing, 21*, 719–743.

Schneider, W., Eschmann, A., & Zuccolotto, A. (Eds.). (2002). *E-Prime reference guide*. Pittsburgh, PA: Psychology Software Tools.

Schreuder, R., & Baayen, R. H. (1995). Modeling morphological processing. In L. B. Feldman (Ed.), *Morphological aspects of language processing* (pp. 131–154). Hillsdale, NJ: Lawrence Erlbaum.

Seidenberg, M. S. (1987). Sublexical structures in visual word recognition: Access units or orthographic redundancy? In M. Coltheart (Ed.), *Attention and performance 12: The psychology of reading* (pp. 245–263). Hillsdale, NJ: Lawrence Erlbaum.

Sénéchal, M. (2000). Morphological effects in children's spelling of French words. *Canadian Journal of Experimental Psychology, 54*, 76–86.

Seymour, P. H. K. (1997). Foundations of orthographic development. In C. Perfetti, L. Rieben, & M. Fayol (Eds.), *Learning to spell* (pp. 319–337). Mahwah, NJ: Lawrence Erlbaum.

Seymour, P. H. K. (2005). Early reading development in European orthographies. In M. J. Snowling & C. Hulme (Eds.), *The science of reading: A handbook* (pp. 296–315). Oxford, UK: Blackwell.

Share, D. L. (1995). Phonological recoding and self-teaching: Sine qua non of reading acquisition. *Cognition, 55*, 151–218.

Simpson, G. B., & Foster, M. R. (1986). Lexical ambiguity and children's word recognition. *Developmental Psychology, 22*, 147–154.

Sprenger-Charolles, L., Siegel, L. S., Béchennec, D., & Serniclaes, W. (2003). Development of phonological and orthographic processing in reading aloud, in silent reading, and in spelling: A four-year longitudinal study. *Journal of Experimental Child Psychology, 84*, 194–217.

Treiman, R. (1993). *Beginning to spell: A study of first-grade children*. New York: Oxford University Press.

Ziegler, J. C., & Goswami, U. (2005). Reading acquisition, developmental dyslexia, and skilled reading across languages: A psycholinguistic grain size theory. *Psychological Bulletin, 131*, 3–29.