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Pauline Quemart, Laura Gonnerman, Jennifer Downing, S. Hélène Deacon. The development of morphological representations in young readers: a cross-modal priming study. *Developmental Science*, 2018, 21 (4), pp.e12607. 10.1111/desc.12607. hal-02340989

HAL Id: hal-02340989

<https://hal.science/hal-02340989>

Submitted on 19 Jul 2021

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Cite this article as: Quémart, P., Gonnerman, L. M., Downing, J., & Deacon, S. H. (in press).

The development of morphological representations in young readers: A cross-modal priming study. *Developmental Science*.

The Development of Morphological Representations in Young Readers: A Cross-Modal
Priming Study

Pauline Quémart^{a*},

Université de Poitiers and Centre National de la Recherche Scientifique, France

Laura M. Gonnerman^b,

School of Communication Sciences and Disorders, McGill University, Canada.

Jennifer Downing^c and S. Hélène Deacon^c

Department of Psychology, Dalhousie University, Canada

^a Centre de Recherches sur la Cognition et l'Apprentissage - UMR CNRS 7295 - Maison des Sciences de l'Homme et de la Société. 5, rue Théodore Lefebvre. TSA 21103. F-86073 Poitiers Cedex 9. France

E-mail address: pauline.quemart@univ-poitiers.fr; Tel: (+33)(0)5 49 45 46 19

^b School of Communication Sciences and Disorders, McGill University, 2001 McGill College Avenue, Suite 800, Montreal, QC, Canada H3A 1G1

E-mail address: laura.gonnerman@mcgill.ca

^c Department of Psychology, Dalhousie University, Life Sciences Centre, P.O. Box 15000, Halifax, Nova Scotia B3H 4R2, Canada. E-mail:

E-mail address: jn678452@dal.ca (Jennifer Downing) and sdeacon@dal.ca (Hélène Deacon)

* Corresponding author

Research Highlights

1. We compared the predictions of the localist and distributed accounts to explain the development of morphological representations in third and fifth grade children
2. The participants performed a cross-modal priming task in which we manipulated the degree of semantic similarity between morphologically related words
3. Priming effects were graded as a function of the convergence of form and meaning
4. Developing readers do not necessarily need to lexicalize morphological units to facilitate word recognition

Abstract

The way children organize words in their memory has intrigued many researchers in the past 20 years. Given the large number of morphologically complex words in many languages, the influence of morphemes on this organization is being increasingly examined. The aim of this study was to understand how morphemic information influences English-speaking children's word recognition. Children in grades 3 and 5 were asked to complete a lexical decision priming task. Prime-target pairs varied in semantic similarity, with low (e.g., *belly-bell*), moderate (e.g., *lately-late*), and high similarity relations (e.g., *boldly-bold*). There were also word pairs similar in form only (e.g., *spinach-spin*) and in semantics only (e.g., *garbage-trash*). Primes were auditory and targets were presented visually. Analyses of children's lexical decision times revealed graded priming effects as a function of the convergence of form and meaning. These results indicate that developing readers do not necessarily need to lexicalize morphological units to facilitate word recognition. Their ability to process the morphological structure of words depends on their ability to develop connections between form and meaning.

Keywords: Reading development; derivational morphology; cross-modal priming.

The Development of Morphological Representations in Young Readers: A Cross-Modal Priming Study

Words are represented in memory in terms of their abstract semantic, phonological, and orthographic properties; these refer to meanings, sounds and visual features, respectively. Most words that share these features are morphologically related in that they share morphemes, the smallest units of meaning in words (i.e., roots, prefixes and suffixes; e.g., *helpful, helpless, helpfulness, unhelpful*...). A core question lies in how these linguistic units are represented. Morphemes have been traditionally considered to be at the heart of lexical organisation and access (e.g., Marslen-Wilson, Tyler, Waksler, & Older, 1994; Taft & Forster, 1975). Connections between form (phonology and/or orthography) and meaning are established during the course of reading development. For example, both children and adults are faster to recognize *helpful* as a word when it is preceded by a morphologically-related word such as *helper* than by a word that is related by form or meaning alone (such as *helmet* or *supportive*, respectively; in children: Beyersmann, Castles, & Coltheart, 2011; Quémart, Casalis & Colé, for a review in adults, see Amenta & Crepaldi, 2012). In the present study, we provide an empirical contrast of two hypotheses to account for the development of morphological representations in developing readers. These hypotheses stem from two theoretical frameworks that offer diverging explanations of morphological facilitation during word recognition.

The first theoretical framework suggests that morphological facilitation arises from the activation of discrete and localized morphological representations (Giraud & Grainger, 2001; Grainger & Ziegler, 2011; Rastle & Davis, 2008; Schreuder & Baayen, 1995; Taft & Forster, 1975; Xu & Taft, 2015). According to this *localist account*, morphemes represented in the mental lexicon as discrete units. Morphological facilitation can therefore be viewed as a consequence of the activation of discrete morphological representations. For example, in a

priming task, the prime word *unforgettable* involves the activation of the root morpheme *forget*, leading to faster recognition of the subsequent target *forget* compared to an unrelated target. In the face of wide variation in the level of representation of morphological information and the factors that modulate such facilitation (Giraudo & Grainger, 2001; Grainger & Ziegler, 2011; Rastle & Davis, 2008; Schreuder & Baayen, 1995; Taft & Forster, 1975; Xu & Taft, 2015), proponents of this localist framework agree that the lexicon is organized around discrete morpheme units, and the activation of these units in the lexicon facilitates word recognition.

Alternatively, according to the *distributed account*, morphological facilitation reflects the co-activation of orthographic, phonological and semantic representations rather than the activation of a dedicated morphological level of representation (Gonnerman, Seidenberg, & Andersen, 2007; Kielar & Joanisse, 2011; Seidenberg & Gonnerman, 2000). As explained by Kielar and Joanisse (2011), many English words are quasi-regular in that they are not truly morphologically complex, but share some form and meaning properties with others (e.g., *dresser-dress*). From a linguistic point of view, there is no consensus as to whether these words can or cannot be decomposed into morphemes. But from a psychological perspective, quasi-regular words prime each other and the amount of priming depends on the degree of form-meaning convergence of primes and targets. With adults, Gonnerman et al. (2007) showed graded priming effects in a lexical decision task: Priming effects were larger when morphologically related prime-target pairs shared a high semantic relationship (e.g., *boldly-bold*) than when they shared a moderate semantic relationship (e.g., *lately-late*); this priming, in turn, was greater than when the pairs shared a low semantic relationship (e.g., *belly-bell*). These results were taken to suggest that the amount of priming can be predicted by the degree of semantic overlap rather than by the morphological status of the items (see also Devlin, Jamison, Matthews, & Gonnerman, 2004; Jared, Jouravlev, & Joanisse, 2017; Kielar &

Joanisse, 2011; Pastizzo & Feldman, 2009 for similar propositions). This framework questions the necessity to develop discrete morphological representations.

These two theoretical positions make conflicting predictions as to how children become sensitive to the morphological structure of words. On the one hand, according to the *localist* account, morphological processing requires children to develop a morphological level of representation that extends beyond phonology (or orthography) and semantics. The development of this level of representation requires the lexicalisation of morphemic units. Within the localist framework, two separate proposals have been developed to explain this lexicalisation process. The first proposal is that children rely on the form properties of morphemes (Rastle & Davis, 2003, 2008). According to this view, children exploit orthographic redundancy within words, either by analyzing the sequential probabilities of letter combinations to detect morphemic units or by grouping high frequency letter sequences—which often correspond to morphemes—into single units (e.g., “e” and “r” as in *brother* are more frequently associated in English than “e” and “l” as in *brothel*). The second proposal attributes an important role to the semantic properties of morphemes (Merkx, Rastle, & Davis, 2011; Schreuder & Baayen, 1995) to account for morpheme lexicalisation. According to this proposal, the acquisition of morphological representations occurs through a process of monitoring the lexicon for co-occurrences of form and meaning. When a reader detects that a given letter string is consistently associated with the same meaning, he or she develops a mental representation of this string (i.e., morpheme) in terms of both form (orthography and phonology) and meaning (Schreuder & Baayen, 1995). Whatever the proposed mechanism behind the lexicalization process, the localist framework is based on the notion that children must develop representations at the morphemic level within the lexicon.

On the other hand, according to the distributed account, morphemes do not need to be lexicalized to facilitate word recognition. Indeed, the mechanisms involved in the processing

of morphologically complex words are not specific to this type of word: the representations activated when processing morphologically complex words are similar to those involved in processing morphologically simple words. This connectionist perspective suggests that lexical representations are distributed across several processing units and words are stored in the weights on connections between phonological, orthographic and semantic representations. From a developmental perspective, children need to capture the partial regularities characteristic of many complex words to facilitate their recognition (Gonnerman et al., 2007). Children's ability to process the morphological structure of words during their recognition depends on their ability to develop connexions between orthography, phonology and semantics, and the level of activation of these three levels of representation determines morphological facilitation.

Despite the clear conceptual distinctions between these two theoretical accounts, localist and distributed, it has proved difficult to distinguish them empirically. Most of the studies conducted with children to date have shown that children do process the morphological structure of words during their recognition. The morphological priming paradigm has been widely used to this end. It has shown that morphologically related words (e.g., *turned-turn*) prime their base forms more than words that shared only the initial form only (e.g., *turnip-turn*) as early as in Grade 1 (Rabin & Deacon, 2008). Such effects have been observed in studies using visual primes and targets, where Grade 3 to 8 children were faster and/or more accurate to perform a lexical decision task on targets that were primed by a morphologically related word compared to an unrelated word (Beyersmann et al., 2011; Quémart et al., 2011) or an orthographically related word (Casalis, Dusautoir, Colé, & Ducrot, 2009; McCutchen, Logan, & Biangardi-Orpe, 2009). Auditory morphologically complex primes also influence subsequent written target completion (e.g., *needy – ne__*) in Grade 1 to 5 children (Rabin & Deacon, 2008; Feldman, Rueckl, DiLiberto, Pastizzo, &

Vellutino, 2002). Morphological facilitation has been observed in deep orthographies (English: Beyersmann et al., 2011) as well as in transparent orthographies (Italian: Burani, Marcolini, & Stella, 2002; Spanish: Lázaro, Camacho, & Burani, 2013).

These priming effects have generally been interpreted as reflecting the activation of a morphological level of representation in children (Beyersmann et al., 2011; Clahsen & Fleischhauer, 2014; Quémart et al., 2011). But to date, stimulus types have not been manipulated in research with children in a manner that can differentiate the role of distinct morphological relationships from that of form and meaning overlap. Quémart et al. (2011) conducted a time-course study with French-speaking third, fifth and seventh grade children. The authors presented participants with visual primes and targets for lexical decision. They dissociated the influence of the form and meaning properties of morphemes to determine whether morphological priming effects occur at the sublexical and/or supralexical level of processing. To this end, they contrasted priming effects of morphologically related (e.g., *tablette-table*, “little table – table”) and pseudoderived (e.g., *baguette-bague*, “French stick – ring”) pairs of words. They showed facilitation effects that were equivalent in the morphological and pseudoderived conditions when primes were presented at 60 ms, but facilitation effects decreased in the pseudoderivation condition when prime duration increased (250 and 800 ms). Priming effects in the morphological and pseudoderivation conditions could not be explained by form overlap between primes and targets, since no priming effect was observed in the orthographic control condition (e.g., *abricot-abri*, “apricot-shelter”).

Such dissociation in the influence of the form and meaning properties of morphemes indicates that a genuine morphological relationship is not necessary for priming effects to emerge: They were observed even when primes and targets were not morphologically related (i.e., in the pseudoderivation condition). This result questions the idea that morphological priming results from the activation of discrete morphemes, and suggests more research on

priming in children is warranted. Therefore, the aim of this study was to determine whether priming effects reflect the activation of a discrete level of morphological representations or the convergence of orthographic, phonological and semantic representations.

The present study

In the present study, we examined the extent to which morphological priming effects in children can be accounted for by the convergence of form and meaning information or the activation of discrete and localized morphological representations. This objective allowed us to contrast two theoretical hypotheses: The localized (Giraud & Grainger, 2001; Järviski & Pykkönen, 2011; Marslen-Wilson et al., 1994; Rastle & Davis, 2008; Taft & Forster, 1975) and distributed (Gonnerman et al., 2007; Kielar & Joanisse, 2011; Seidenberg & Gonnerman, 2000) accounts of morphology.

The procedure and material used in the study were as close as possible to Gonnerman et al.'s (2007) study. We used a cross-modal priming task with spoken presentation of primes and visual presentation of targets. The appropriateness of this procedure for children was recently demonstrated by Clahsen and Fleischhauer (2014); they showed significant cross-modal morphological priming effects in German-speaking children between the ages of 7 and 10. Another reason is that the cross-modal priming paradigm gives information regarding the modality of the representations activated during word recognition. This paradigm taps into modality-independent representations (Marslen-Wilson et al., 1994). Therefore, significant priming effects would reveal that the representations activated when performing the task are amodal (i.e., independent of processing in the visual and auditory modality).

We manipulated the form overlap between primes and targets (form only: *spinach-spin*; morphological: *boldly-bold* and semantic only: *garbage-trash*) as well as the degree of semantic similarity between morphologically related words (low semantic: *belly-bell*, moderate semantic: *lately-late*, or high semantic: *boldly-bold*; following on Gonnerman et al.,

2007). We used exactly the same method as Gonnerman et al (2007) to select the items, with adjustments to ensure the materials were appropriate for children. Critically, we ensured that the items were familiar to children by checking that they had a frequency at Grade 5 in a children's corpus database (Zeno, Ivens, Millard, & Duvvuri, 1995). We also ensured that the semantic relatedness manipulation was appropriate for children by collecting semantic ratings from a sample of same-aged children. Together, these modifications ensured that the items were appropriate to test our research questions with a child sample. In keeping with Gonnerman et al. (2007), the use of three levels of semantic similarity made it possible to evaluate the possibility of graded effects and to determine whether the amount of priming depends on the degree of semantic similarity between morphologically related words, rather than on their morphological status. In addition, we manipulated grade level to track the developmental trajectory of morphological processing across grades 3 and 5 when children are learning a great deal about derivational forms (Anglin, 1993; Nagy, Winsor, Osborn, & O'Flahavan, 1994). This age range is also at the lower end of existing data on use of this method with children (e.g., Clahsen & Fleischhauer, 2014).

If morphological priming results from high form-meaning consistency across morphologically related words, then we predict graded priming effects as a function of the degree of convergence between form and meaning. By contrast, if morphological priming effects result from the activation of a specific level of morphological representation, priming effects should be an all-or-none phenomenon.

Materials and Method

Participants

This study included 59 children in grade 3 (mean age = 8;11, $SD = 4$ months) and 49 children in grade 5 (mean age = 10;11, $SD = 3$ months). Children were recruited from a rural area of Canada. English was the first language for all participants and informed consent was obtained from the parents of all the children in the experiment.

Their development was reported as “typical” by the teachers: None of them were reported as having attention deficit disorder, neurological or emotional problems. To ensure that our results reflect typical reading development, participants performed the Word Identification subtest from the Woodcock Reading Mastery Tests—Revised (Woodcock, 1998). The participants who performed below the tenth percentile on these subtests were removed from the analysis ($N = 5$ in grade 5). Standardized scores for the remaining participants were 102.36 ($SD = 15.56$), and 98.22 ($SD = 11.79$), for Word Identification for each grade, respectively. These average scores and standard deviations are within the range of typically developing based on the test manual.

Materials

Semantic relatedness ratings pre-test.

A pre-test was conducted to evaluate the semantic similarity between pairs of words. A hundred pairs of words were selected, sharing three different relationships: form only (i.e., orthographic and phonological; e.g., *spinach* – *spin*), morphological (e.g., *boldest* – *bold*) or semantic only (e.g., *garbage* – *trash*). We asked thirty-eight children in Grade 4 ($n = 14$; mean age = 9.64 years, $SD = 0.36$) and 5 ($n = 24$; mean age = 10.68 years, $SD = 0.29$) to rate how similar in meaning the pairs were on a 7-point Likert scale, where 1 was “different in meaning” and 7 was “similar in meaning”. In the practice items, they were told the definitions

of each member of the example pair. For all items, they were asked to circle the number on the scale that they thought represented the similarity for each pair.

The ratings of semantic similarity (see Table 1 mean semantic ratings) were then used to allocate items to the three morphological conditions (low, moderate and high semantic), as well as in the form only and semantic only conditions. We also ensured that the items that were only related in form were not semantically related, and that the semantically related pairs of words were effectively semantically related according to the children.

Prime-target pairs.

Based on children's ratings, seventy prime-target pairs were selected and placed into the five priming conditions according to 1) the appearance of morphological structure and 2) the mean semantic ratings for each pair of words. The characteristics of the selected items are summarized in Table 1 and a complete list of the stimuli is presented in Appendix A. Each condition contained 14 prime-target pairs. In the three morphological conditions, the low semantic, moderate semantic and high semantic conditions consisted of items with a mean rating of less than three (e.g. *belly-bell*), between three and five (e.g. *lately-late*) and greater than or equal to five (e.g. *boldly-bold*; all scores are out of seven). The form only condition consisted of prime-target pairs that were form related. The items in this condition differed from those in the morphological low semantic condition in that the letter patterns of word endings did not look like actual suffixes (e.g. *-ach* in *spinach*). The semantic condition contained prime-target pairs that were highly related in meaning, but did not have form overlap (e.g. *garbage-trash*). By contrast, prime-target pairs in the three morphological conditions and in the form only condition overlapped in form (phonology and orthography).

[Insert Table 1 around here]

Item selection was confirmed through univariate ANOVAs. Mean semantic ratings of the selected pairs of items differed according to the conditions, $F(1, 65) = 294.65, p < .001, \eta^2 p = .95$. Post-hoc analyses showed similar levels of semantic relatedness between the pairs of the form only and those in the low semantic condition ($M = 1.83$ and $M = 2.09$, respectively). However, the semantic relatedness between the pairs was graded across the low semantic, moderate semantic ($M = 4.03$), high semantic ($M = 5.37$) and semantic only ($M = 6.05$) conditions, respectively. We confirmed that the same pattern of ratings emerged with the latent semantic analysis (LSA) ratings¹ (Landauer & Dumais, 1997); this provided independent validation for the children's semantic ratings. Word frequencies at the Grade 5 level (according to Zeno et al., 1995) were balanced across conditions for prime and target items (see Table 1). Prime words were indeed matched for length, frequency and number of phonemes and letters across the five conditions ($F_s < 1$). There were also no significant differences between the targets in terms of length, frequency, number of phonemes and number of letters ($F_s < 1$).

Following the standard approach for lexical decision priming tasks, an unrelated control prime was selected for each related test prime. Control primes matched test primes on their frequency and length ($F_s < 1$), and their morphological complexity. They were not phonologically, orthographically or semantically related to the target items.

Finally, 70 non-word target items were created by removing the suffix of a word and changing one letter. All of the non-word target items had plausible endings in English, based on a database of plausible English endings (Ziegler, Stone, & Jacobs, 1997). In order to mirror the construction of the prime-target word pairs, half of the word prime- non-word target pairs were related in form (e.g., *scary* – *SCAGE*) and the other half were unrelated in form (e.g.,

¹ LSA is a technique that provides the semantic relationships between words. It generates vector-based representations based on the occurrence of words in texts. The similarity between two words is assessed by computing the cosine between their vectors.

farmer – *CLASE*). In addition, half of the prime words were morphologically complex, the other half were morphologically simple. These items were presented in the same way as the real word conditions, in that a longer word primed a shorter non-word target.

The 140 prime-targets pairs were divided into two lists. Each list either contained the test prime (e.g., *boldly*) or the control prime (e.g. *fainter*), but both lists had the same target items (e.g., *bold*). Each child saw both lists, with the order of presentation randomized. We did so to ensure that we had adequate power to detect effects, particularly given the relatively small set of items that met all criteria.

Procedure

Children were tested individually and were seated in front of a Dell laptop computer. Primes were presented orally. First children were presented with a fixation cross in the center of a black screen for 1000 ms, followed by an auditory prime through headphones. The auditory prime was recorded by a female native English speaker. The target item appeared 100 ms after the end of hearing the word in the middle of the screen in lowercase size 40 white Arial font. Children were asked to determine if the target item was a word or a non-word. Immediately after the children made their decision, another fixation point appeared to commence a new trial. After 15% of the trials children were presented with a probe instructing them to repeat the word that they had just heard (following Gonnerman et al., 2007). This procedure ensured that the children were attending to the auditory primes.

Children made their lexical decisions by pressing a green “y” button on the keyboard with their dominant hand if the item was a word, and by pressing a red “n” button with their non-dominant hand if the item was not a word. Children were asked to respond as quickly and as accurately as possible for each target item. DirectRT (Jarvis, 2000) was used to present target items, and to record the responses of each participant.

Children were presented with two separate lists of items. To minimize repetition effects due to the presence of the targets in both lists, children completed a series of standardized reading tasks in between the administration of the first and second list. The Session effect was also included in the statistical analysis to ensure that it did not interact with the priming effects.

Results

Participants with error rates more than 2 standard deviations (SD) from the mean (i.e., below 56.63% of correct responses, namely four participants in Grade 3 and four participants in grade 5) were excluded from data analysis. In addition, the RTs were cleaned in several ways. First, data points below 300 ms and above 3000 ms were excluded. Then, all RTs above 3SD from the mean (i.e., 1.56% of the data) were also excluded from data analysis. And finally the RTs were log-transformed because of positive skew (Feldman, 2009; Quémart et al., 2011).

Log-transformed RTs were analyzed with linear mixed effect models using the `lmer()` function from the `lmerTest` package (Kuznetsova, Brockhoff, & Christensen, 2014) in the statistical analysis software R (R development core team, 2012). Log-transformed RTs were entered as the dependent variable in the model, while Grade (G3, G5), Condition (form only, low semantics, moderate semantics, high semantics, semantics only), Relationship (Related, Unrelated) and Session (1, 2) were the categorical independent predictors.

Model comparison was applied to evaluate whether inclusion of the three explicative variables and their interaction was validated by the data. Models were fit to the data using restricted maximum likelihood estimation. Model fitting was performed by initially specifying a model that included only the random factors (participants and items) and was progressively enriched by adding successively the fixed factors (i.e., the three explicative variables) and their interactions (the three two-ways interactions and the three-way interaction). The best

fitting model was defined as the most complex model that significantly improved the fit over the previous model. The results are reported for the best-fitting model. The final model included Grade, Relationship, Session and the interaction between condition and relationship as fixed effects, and Participants and Items as random factors. The addition of Grade as interaction term with Condition and Relationship did not significantly improve the model fit ($p = .57$), nor did the addition of Session as an interaction term with Condition and Relationship ($p = .22$). No analysis was conducted on accuracy, because of the low error percentages. Mean RTs and error percentages are presented in Table 2.

The model reveals a main effect of grade: RTs were overall faster in grade 5 ($M = 1049$ ms, $SD = 403$ ms) than in grade 3 ($M = 1236$ ms, $SD = 476$ ms), $F(1, 104) = 16.58, p < .001$. The main effect of condition was not significant, $F(4, 65) = 1.82, p < .001$ but the main effect of session was significant: RTs were faster in session 2 ($M = 1107$ ms, $SD = 454$ ms) than in session 1 ($M = 1188$ ms, $SD = 453$ ms), $F(1, 12356) = 16.00, p < .001$. Finally, the main effect of relationship was significant, $F(1, 12327) = 220.24, p < .001$: Mean RTs were also faster when targets were preceded by related primes ($M = 1107$ ms, $SD = 432$ ms) compared to unrelated primes ($M = 1178$ ms, $SD = 447$ ms) and this effect significantly interacted with condition, $F(4, 12326) = 8.93, p < .001$.

Decomposing the Condition x Relationship condition, the main effect of relationship was significant in the five conditions: Form only ($t = 3.66, p < .001$), Low semantics ($t = 4.03, p < .001$), Moderate semantics ($t = 6.84, p < .001$), High semantics ($t = 10.61, p < .001$) and Semantics only ($t = 7.16, p < .001$).

Based on our hypotheses, we then compared the amount of priming in the five conditions. The amount of priming in the form only condition was not significantly different from that of the low semantic condition ($t < 1$) but was lower than that of the moderate semantic ($t = 2.63, p = .011$), the high semantic ($t = 4.73, p < .001$) and the semantic only ($t =$

2.69, $p = .009$) conditions. Priming effects tended to be lower in the low semantics condition compared to the moderate semantics condition ($t = 1.96$, $p = .054$) and were significantly lower than in the high semantic condition ($t = 4.05$, $p < .001$) and in the semantic only condition ($t = 2.00$, $p < .001$). In the moderate semantic condition, priming effects were lower than in the high semantic condition ($t = 2.00$, $p = .049$) but were not different from the semantic only condition ($t = 0.01$, $p = .990$). And finally, the amount of priming in the high semantic condition was higher than that of the semantic only condition ($t = 2.07$, $p = .043$).

Discussion

Theoretical conceptualisations of morphological representation in children are far less explicit than those for adults, and the predictions that they do make have rarely been tested. In this study, we asked whether morphological effects reflect the activation of a discrete level of morphological representations (i.e. localized representations, Giraudo & Grainger, 2001; Järvikivi & Pyykkönen, 2011; Marslen-Wilson et al., 1994; Rastle & Davis, 2008; Taft & Forster, 1975) or the co-activation of orthographic, phonological and semantic information (i.e., distributed representations, Gonnerman et al., 2007; Kielar & Joanisse, 2011; Seidenberg & Gonnerman, 2000).

This question was addressed by manipulating the degree of semantic similarity between morphologically related words in a cross-modal priming experiment. Following Gonnerman et al. (2007), five different conditions were used in this experiment: Form only relationship (e.g., *spinach-spin*), Morphological relationship with low (e.g., *belly-bell*), moderate (e.g., *lately-late*) and high (e.g., *boldly-bold*) semantic relationship, and semantic only relationship (e.g., *garbage - trash*). We included children in Grades 3 and 5, to be able to track possible changes across these grades in morphological processing. The similarity between our method and the criteria for selection of items with that of Gonnerman et al.'s (2007) allows us to compare directly the results of the two studies.

Results showed priming effects in all five conditions in both grades. Importantly, the amount of priming depended on prime-target relationships. Priming effects were graded between the three morphological conditions: They were larger in the high semantic than in the moderate semantic condition, and tended to be larger in the moderate semantic than in the low semantic condition. In addition, priming effects did not significantly differ in size between the form only and low semantic conditions. And finally, priming effects were lower in the semantic only compared to the high semantic condition. This pattern of priming was not significantly influenced by grade level and was similar to that observed in adults (Gonnerman et al., 2007).

Morphological priming effects have already been reported in children (Beyersmann, Castles, & Coltheart, 2012; Casalis et al., 2009; Quémart & Casalis, 2014; Quémart et al., 2011; Schiff, Raveh, & Kahta, 2008) and are replicated here. The presentation of a morphologically related prime facilitates subsequent target recognition as early as in grade 3. These effects cannot be interpreted as the consequence of form or meaning overlap alone. In terms of semantic overlap, our results show graded effects as a function of semantic similarity in the three morphological conditions. However, there was less priming in the semantic only condition (e.g., *garbage-trash*) than in the high semantic condition (e.g., *boldly-bold*) despite a greater semantic overlap in the first condition ($M = 6.05$) compared to the second condition ($M = 5.37$). Therefore, semantic overlap alone cannot explain the priming effects. These effects cannot be attributed to form overlap alone either. Form overlap was indeed consistent in the three morphological conditions and in the form only condition. Despite this consistency, priming effects were larger in the moderate and high semantic conditions compared to the low semantic and form only conditions. To summarize, morphological priming effects are clearly distinct from semantic overlap alone or form overlap alone.

The comparison of the priming effects between the three morphological conditions informs us about the underlying processes involved in morphological priming in children: They provide theoretical arguments to shed light on the debate as to the localist or distributed nature of the representations of morphological information in children's memory. The graded priming effects observed in third and fifth graders are incompatible with localist theories that assume that morphological processing is an all-or-none process that occurs when a dedicated level of morphological representation has been activated. The results are clearly in-line with the distributed conception of morphological processing, according to which morphological priming results from the convergence between form and meaning.

The underlying principle of the distributed account of morphology is that morphological processing is the consequence of the coactivation of several levels of processing, with no necessity to develop a dedicated level of morphological processing (Gonnerman et al., 2007; Plaut & Gonnerman, 2000; Rueckl, Mikolinski, Raveh, Miner, & Mars, 1997). Morphological regularities constitute an inter-level of representation that reflects the convergence between form and meaning. The representations are distributed across several processing units and words are stored in the weights on connections between phonological, orthographic and semantic representations (Gonnerman et al., 2007). The mechanisms underlying the recognition of morphologically complex words are not qualitatively different from the mechanisms underlying the recognition of simple words. Patterns of priming reflect form and meaning similarity between primes and targets, independently of the morphological status of words. Therefore, in the present study, when we keep form overlap constant, semantically similar prime-target pairs yielded greater priming than semantically distant pairs.

Returning to the question that was originally posed in the introduction, our results show that developing readers do not necessarily need to lexicalize morphological units to

facilitate word recognition. Their ability to process the morphological structure of words during their recognition depends on their ability to develop connexions between form and meaning. With experience and learning, children develop connections between these representations as a function of the statistical properties of the language being learned. These representations are sufficiently connected within memory in third and fifth graders to resonate and facilitate subsequent word recognition. They have already captured the partial regularities characteristic of morphologically complex words, and the level of activation of these levels of representation determines morphological facilitation to facilitate their recognition. As explained by Gonnerman et al. (2007), morphological regularities may foster the development of interlevel representations that mediate mappings between form and meaning: Therefore, they give rise to greater priming than morphologically simple words.

Beyond the theoretical debate between localist and distributionist theories, these data provide empirical evidence for the influence of the semantic properties of words in their recognition. The dual route cascaded model (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) has implemented a semantic pathway in its model, but activation of this route is not mandatory for word recognition. The triangle model (Harm & Seidenberg, 2004; Plaut, McClelland, Seidenberg, & Patterson, 1996) also emphasizes the influence of semantic factors in the recognition of written words. According to this model, reading can be characterized as a 'division of labour' between a phonological pathway (consisting of mappings between phonological and orthographic representations) and a semantic pathway (consisting of connections between phonological, orthographic and semantic representations). Still, few studies have examined the influence of semantic characteristics of words, such as imageability, on the ease with which children process them. Laing and Hulme (1999) examined the influence of semantics through the spectrum of imageability. They showed that children are better able to learn abbreviated spellings for highly imageable words than for

lower imageable words. The influence of semantics has also been investigated through the influence of vocabulary: Oral vocabulary knowledge predicts word reading abilities (Duff & Hulme, 2012; Nation & Snowling, 2004; Ouellette & Beers, 2010), and more specifically exception word reading (Ricketts, Nation, & Bishop, 2007). Recently, Ricketts, Davies, Masterson, Stuart, and Duff (2016) showed that the influence of semantics goes beyond children's vocabulary: Semantic knowledge (a composite measure of oral vocabulary and knowledge of semantic relationships) supports reading of regular words and irregular words. In our study, we did not assess children's vocabulary and our semantic measure corresponded to how similar in meaning prime-targets pairs were according to 5th graders. Our results are in line with these data and reinforce the idea that semantic variables influence children's word recognition.

This study also sheds light on the issue of the modality of processing. Following Gonnerman et al. (2007), we used a cross-modal priming paradigm. This paradigm - in its form used in previous morphological priming studies (Gonnerman et al., 2007; Marslen-Wilson et al., 1994) – enables us to determine to what extent priming effects reflect the activation of modal or amodal representations: Significant priming effects when primes and targets are presented in different modalities (i.e., cross-modal priming) are taken as evidence of involvement of abstract representations (Giraudo & Grainger, 2001). Most of the priming studies conducted in children used visual primes and targets. To our knowledge, only one study indicated that morphological priming is not specific to the visual modality in children: Clahsen and Fleischhauer (2014) showed that 8- and 9-year-old German-speaking children benefit from auditory primes to process visual targets that are morphologically related (e.g., *gedruckt-drucke*). Our study reinforces this result and extends it to the processing of derivational morphology: The presentation of a morphologically complex auditory prime

facilitates subsequent root processing in third and fifth graders, indicating that the processing of morphological information is “modality-independent”.

We now turn to an intriguing aspect of our findings that deserves further exploration. The significant cross-modal priming effects observed in the form only condition (e.g., *spinach-spin*) have not been observed in prior studies with adults (Gonnerman et al., 2007; Kiehl & Joanisse, 2011; Longtin, Segui, & Hallé, 2003; Marslen-Wilson et al., 1994), nor in studies using masked priming with children (Beyersmann et al., 2012; Quémart et al., 2011). This finding is, however, compatible with prior evidence of the benefit of form overlap between primes and targets in cross-modal priming using the fragment completion task with children (Feldman et al., 2002; Rabin & Deacon, 2008). The discrepancy between masked priming and cross-modal priming in children may result from the sequential nature of spoken word processing. Prime-target pairs from the form only and low semantic conditions differ in terms of word ending only. In the low semantic condition, prime words end with a suffix ending (e.g., *y* in *belly*) whereas primes end with a non-suffix ending in the form only condition (e.g., *ach* in *spinach*). It may be that the participants benefit from the form overlap between primes and targets in these two conditions, independently of the presence of a suffix. Given that semantic overlap is similar in these two conditions, similar priming effects are observed. This result is not compatible with Quémart’s (2012) hypothesis that morphological decomposition is triggered by suffix endings. The nature of the processing involved in spoken word recognition (sequential) and written word recognition (parallel) may affect the type of unit that is critical to benefit from priming. More empirical results are needed to explore this issue and to test the effect of prime duration on priming effects with the same materials.

We also need to interpret the results of our experiments in tandem with their limitations. First, our research focused on items that did not change in sound between base and derived form to hold this variable constant. It would be useful for future research to

evaluate the influence of the degree of phonological relatedness between words on children's lexical representations (e.g. *natural-nature*, in which the *a* sound changes, with the addition of an ending; e.g., Gonnerman et al., 2007). This would provide an alternative test of distributed morphological processing in children. Second, we chose to conduct a cross-sectional study at grades 3 and 5 in part so that our results could be more directly contrasted with those of prior studies (e.g., Beyersmann et al., 2012; Quémart et al., 2011). This limited age range might reduce the ability to detect developmental differences, particularly at the outset of reading acquisition. It would be important for future research to explore the early origins of morphological processing, ideally in a longitudinal design.

To summarize, our findings resonate with the few morphological priming studies in adults implementing conditions with graded semantic overlap between pairs of words that have clearly shown graded priming effects, be they behavioral (Devlin et al., 2004; Gonnerman et al., 2007; Jared et al., 2017; Kielar & Joanisse, 2011; Pastizzo & Feldman, 2009) or electrophysiological (Kielar & Joanisse, 2011). The present study in children adds to this body of research and suggests that the overt processing of morphemes is not an all-or-none phenomenon, and might be better explained by the convergence of codes. Children benefit from any overlap in form and meaning during explicit word processing, and facilitation is even more important when these cues overlap. These effects mirror the pattern in Gonnerman et al. (2007)'s study with adults where the magnitude of the priming effect also depended on the degree of semantic similarity. The overall pattern of priming suggests that priming effects can be predicted by the degree of phonological and semantic overlap between primes and targets rather than their morphological relationship. Taken together, these results indicate that cross-modal morphological priming in developing children reflects the convergence of phonological and semantic codes, as with adults (Gonnerman et al., 2007) and are not modality-specific.

Acknowledgements

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Table 1

Mean prime and target frequency, number of letters, and semantic similarity (standard deviations in parentheses) according to the Condition.

| Condition | Example | Frequency | | Number of letters | | Semantic similarity | |
|-------------------|----------------------|-----------|---------|-------------------|--------|---------------------|-------------|
| | | Prime | Target | Prime | Target | Child ratings | LSA ratings |
| Form Only | <i>spinach-spin</i> | 18 (26) | 85 (83) | 6 (1) | 4 (0) | 1.83 (0.23) | .056 (.034) |
| Low Semantic | <i>belly-bell</i> | 20 (28) | 65 (47) | 7 (1) | 4 (1) | 2.09 (0.39) | .076 (.074) |
| Moderate Semantic | <i>lately-late</i> | 16 (16) | 71 (75) | 7 (1) | 4 (1) | 4.03 (0.63) | .279 (.256) |
| High Semantic | <i>boldly-bold</i> | 19 (33) | 71 (60) | 6 (1) | 4 (1) | 5.37 (0.27) | .447 (.188) |
| Semantic Only | <i>garbage-trash</i> | 23 (33) | 71 (95) | 6 (2) | 4 (1) | 6.05 (0.43) | .415 (.213) |

Note. Frequency is given by Zeno database (Zeno et al., 1995). LSA: Latent semantic analysis (Landauer & Dumais, 1997)

Table 2

Grade 3 and 5 mean reaction times (RTs), percentages of correct responses (% Corr) for unrelated and related primes and Priming Effect (in ms). Standard deviations are displayed in parentheses.

| Condition | Example | Unrelated | | Related | | Priming Effect |
|----------------------|----------------------|------------|---------------|------------|---------------|----------------|
| | | RTs | % Corr | RTs | % Corr | |
| Grade 3 | | | | | | |
| Form Only | <i>spinach-spin</i> | 1281 (503) | 88.57 (31.84) | 1234 (483) | 93.54 (24.60) | 47 |
| Low Semantic | <i>belly-bell</i> | 1257 (475) | 88.70 (31.68) | 1230 (483) | 93.04 (25.46) | 27 |
| Moderate Semantic | <i>lately-late</i> | 1292 (479) | 79.87 (40.12) | 1240 (474) | 88.32 (32.13) | 52 |
| High Semantic | <i>boldly-bold</i> | 1269 (479) | 88.57 (31.84) | 1159 (469) | 93.91 (23.92) | 110 |
| Semantic Only | <i>garbage-trash</i> | 1232 (470) | 88.45 (31.99) | 1168 (442) | 92.30 (26.68) | 64 |
| Grade 5 | | | | | | |
| Form Only | <i>spinach-spin</i> | 1080 (426) | 94.60 (22.61) | 1059 (408) | 96.51 (18.37) | 21 |
| Low Semantic | <i>belly-bell</i> | 1089 (417) | 94.60 (22.61) | 1033 (413) | 95.08 (21.65) | 56 |
| Moderate Semantic | <i>lately-late</i> | 1136 (415) | 89.05 (31.25) | 1039 (422) | 93.97 (23.83) | 97 |
| High Semantic | <i>boldly-bold</i> | 1080 (426) | 93.65 (24.40) | 946 (369) | 97.94 (14.23) | 134 |
| Semantic Only | <i>garbage-trash</i> | 1063 (403) | 93.97 (23.83) | 966 (355) | 97.46 (15.75) | 97 |
| All grades collapsed | | | | | | |
| Form Only | <i>spinach-spin</i> | 1187 (469) | 91.22 (28.31) | 1153 (458) | 94.84 (22.12) | 34*** |
| Low Semantic | <i>belly-bell</i> | 1177 (456) | 93.94 (23.87) | 1140 (463) | 91.29 (28.21) | 37*** |
| Moderate Semantic | <i>lately-late</i> | 1216 (455) | 83.91 (36.76) | 1146 (461) | 90.80 (28.91) | 70*** |
| High Semantic | <i>boldly-bold</i> | 1181 (465) | 95.68 (20.34) | 1062 (439) | 90.80 (28.91) | 119*** |
| Semantic Only | <i>garbage-trash</i> | 1153 (448) | 94.56 (22.68) | 1075 (416) | 90.87 (28.81) | 78*** |

Note. *** $p < .001$

Appendix A

Detailed list of the stimuli

| Form only | | | Low semantic | | | Moderate semantic | | |
|-----------|--------|--------------------|--------------|--------|--------------------|-------------------|--------|--------------------|
| Prime | Target | Semantic Rating | Prime | Target | Semantic Rating | Prime | Target | Semantic Rating |
| bucket | buck | 2.00 | apartment | apart | 1.94 | barely | bare | 3.40 |
| campaign | camp | 1.70 | bandage | band | 1.61 | burner | burn | 4.28 |
| captain | cap | 2.06 | basement | base | 2.39 | costly | cost | 4.45 |
| cartoon | cart | 1.44 | belly | bell | 1.55 | directly | direct | 4.85 |
| dragon | drag | 1.67 | bully | bull | 1.85 | entirely | entire | 4.61 |
| freeze | free | 1.80 | coaster | coast | 2.33 | folder | fold | 3.22 |
| lesson | less | 1.90 | fasten | fast | 2.05 | former | form | 3.50 |
| market | mark | 1.90 | message | mess | 1.83 | inner | inn | 3.33 |
| pumpkin | pump | 2.22 | million | mill | 2.10 | lately | late | 4.50 |
| rocket | rock | 1.95 | mister | mist | 1.67 | poorly | poor | 4.39 |
| spinach | spin | 1.50 | officer | office | 2.65 | roller | roll | 4.15 |
| ticket | tick | 1.80 | passive | pass | 2.89 | stiffly | stiff | 3.80 |
| triple | trip | 2.05 | pigment | pig | 2.22 | suitable | suit | 3.06 |
| turnip | turn | 1.60 | waiter | wait | 2.17 | tightly | tight | 4.85 |