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# Automatic activation of phonology in silent reading is parallel: Evidence from beginning and skilled readers

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## Abstract

The picture–word interference paradigm was used to shed new light on the debate concerning slow serial versus fast parallel activation of phonology in silent reading. Prereaders, beginning readers (Grades 1–4), and adults named pictures that had words printed on them. Words and pictures shared phonology either at the beginnings of words (e.g., *DOLL–DOG*) or at the ends of words (e.g., *FOG–DOG*). The results showed that phonological overlap between primes and targets facilitated picture naming. This facilitatory effect was present even in beginning readers. More important, from Grade 1 onward, end-related facilitation always was as strong as beginning-related facilitation. This result suggests that, from the beginning of reading, the implicit and automatic activation of phonological codes during silent reading is not serial but rather parallel.

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## Introduction

An important part of reading development has to do with learning associations between letter strings and their corresponding phoneme sequences, a process often referred to as

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*phonological decoding* (Frith, Wimmer, & Landerl, 1998; Share, 1995). Phonological decoding in children typically is studied by having children read aloud words and/or pseudo-words (Frith et al., 1998; Goswami, Ziegler, Dalton, & Schneider, 2003; Treiman, Goswami, & Bruck, 1990). Research using the reading aloud paradigm has shown that beginning readers initially rely on a slow and sequential process by which graphemes are mapped onto their corresponding phonemes—the so-called alphabetic stage of reading development (Frith, 1985).

Phonological decoding is at the heart of reading acquisition because it provides a self-teaching device that allows children to decode novel words (e.g., Ehri, 1992; Share, 1995; Ziegler & Goswami, 2005). As beginning readers become more skilled, phonological decoding becomes less serial (i.e., more parallel). The hallmark of this developmental change is the disappearance of the word length effect. That is, beginning readers tend to show strong length effects, for which naming latencies increase with each additional letter in a quasilinear fashion (Goswami, Ziegler, Dalton, & Schneider, 2001; Ziegler & Goswami, 2005). However, as children become more skilled readers, the length effect becomes much smaller and eventually disappears, at least for familiar words (Di Filippo, De Luca, Judica, Spinelli, & Zoccolotti, 2006; Weekes, 1997; but see Perry, Ziegler, & Zorzi, 2007).

This literature suggests that beginning readers compute phonology from print in a rather slow and serial manner. However, this conclusion is based largely on reading aloud tasks in which phonology is activated in an explicit and controlled fashion. In a recent series of experiments, Booth, Perfetti, and MacWhinney (1999) challenged this conclusion by studying automatic orthographic and phonological activation in the brief identification paradigm. In their task, children (Grades 2–6) were presented with an uppercase prime (for 30 ms) followed by a lowercase target (for 60 ms) and a pattern mask (XXXX). The instruction was to identify the target word. For a target word such as *tomb*, primes were pseudowords that shared either phonology (*tume*) or orthography (*tams*) with the target or that were unrelated to the target. Booth and colleagues showed orthographic and phonological priming effects despite the fact that primes and targets were presented so briefly that children were not fully aware of the stimuli. These findings provided strong evidence in favor of a quick, automatic, and general activation of phonological codes in beginning readers.

Contrasting these two lines of research, there seems to be a conflicting view about how beginning readers activate phonological codes from print. Naming data suggest that phonological activation initially is slow and serial, whereas perceptual identification data suggest that phonological activation can be extremely rapid and general. Unfortunately, brief perceptual identification tasks have been subject to various criticisms highlighting the influence of sophisticated control strategies on the participants' performance (Perry & Ziegler, 2002; Verstaen, Humphreys, & Olson, 1995).

### ***Incidental reading in the picture–word paradigm***

To adjudicate between these two apparently conflicting views, one would need a task that is not affected by guessing strategies and in which reading is not achieved in an explicit and controlled manner. These conditions are met by the picture–word interference paradigm (Rosinski, Michnick-Golinkoff, & Kukish, 1975). In this paradigm, participants' main task is to produce the name of a pictured object as quickly as possible. At the same time, they are asked to ignore a distractor word printed on the picture. The incidental

processing of ignored distractors automatically produces activation that influences naming latencies. More specifically, word production models assume that the incidental processing of the distractor word automatically activates its corresponding representations such that, when these representations coincide with those of the target picture, naming responses are facilitated. Manipulating the relation between the distractor and the picture name, therefore, can be used to understand how the distractor word is processed. Given that participants' task is picture naming and not word reading, the paradigm can be administered to prereaders as well as readers at various levels of reading expertise. Therefore, the current paradigm seems ideal for studying reading development from the very beginning of reading acquisition.<sup>1</sup>

### *Phonological facilitation in the picture–word paradigm*

A relevant manipulation of the distractor word concerns its orthographic or phonological overlap with the target name. A standard observation is that participants are quicker to produce the picture name in related conditions (e.g., *doll–dog*) than in unrelated conditions (e.g., *bell–dog*). Several reasons motivate a phonological interpretation, rather than an orthographic interpretation, of this effect. First, participants are producing oral responses. Therefore, their task requires retrieving the target's phonology to articulate it, not retrieving the target's orthography to write it down. Alario, Perre, Castel, and Ziegler (2007) investigated a possible influence of the orthographic properties of words that are spoken on the verbal latencies. They asked adult speakers to name pictures in blocks. The picture names in a block were either phonologically related or unrelated. Moreover, the picture names in phonologically related blocks could be either orthographically related or unrelated. Replicating previous studies, Alario and colleagues observed a facilitation effect for all phonologically related blocks. In contrast, despite careful analysis, there was no trace of a modulation of the phonological effect by the orthographic overlap among pictures in a block. This result was taken as evidence that the orthographic properties of words to be named do not affect picture naming latencies. Second, a facilitatory effect has been observed when heterographic homophones and pseudohomophones are used. These distractors share their complete phonology with the target while having a more limited orthographical overlap (e.g., *wail–whale*). The facilitatory effect produced by these kinds of distractor must be attributed to their phonological overlap (see also below). Finally, when the orthographic similarity and phonological similarity are manipulated orthogonally, phonological similarity has a significant effect over and above that of orthographic similarity (Lupker, 1982). In short, there is converging evidence suggesting that the most important part of the picture–word priming effect is phonological in nature. (For a thorough discussion of the activation pathways involved in this phenomenon in adults, see Lupker, 1982; Roelofs, Meyer, & Levelt, 1996; Starreveld & La Heij, 1996).

Posnansky and Rayner (1977) found that 6- to 12-year-olds named pictures more quickly in the presence of words and pseudowords that were heterographic homophones of the picture name (e.g., *wail–whale*) than in the presence of unrelated words (e.g., *sock–whale*). This facilitation effect was not modulated by grade. Similar results were reported by

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<sup>1</sup> Global naming performance (e.g., absolute naming latencies) might vary with age or reading level. The advantage of the current paradigm, however, is that we do not look at the absolute differences; instead, we look at the relative effects of different types of distractors on the incidental reading performance of children.

Briggs and Underwood (1982, 1987), who used several types of distractor words, including homophones of the target's name. Contrary to Posnansky and Rayner (1977), they manipulated reading skill in children and adults rather than grade. Phonological conditions produced facilitation effects when compared with unrelated conditions. Reading skill did not influence the facilitatory effect of phonologically related distractors. Note, however, that the manipulation of reading skill might not have been strong enough to influence the phonological effect in those studies. Only two groups (good readers vs. poor readers) were compared within the adult and child population. Moreover, the children were not in the earliest stages of learning (mean reading ages 14.4 vs. 9.9 years). In both groups, reading proficiency might not have varied enough to find subtle developmental effects.

### *Beginning-related versus end-related phonological facilitation*

The slow serial and fast parallel hypotheses make different predictions about phonological facilitation occurring at the ends of words. According to the slow serial hypothesis, end phonology should be computed later than should beginning phonology, and therefore end overlap should produce a relatively smaller priming effect than should beginning overlap. According to the fast parallel hypothesis, end phonology would be computed as efficiently as would beginning phonology. One way to arbitrate between these hypotheses, then, is to assess the developmental modulation of a phonological effect that is carried solely by the ends of words (e.g., phonological end-related distractors). Underwood and Briggs (1984) reported that the ends of words can produce a phonological facilitation effect in the picture–word paradigm. Lupker (1982) reported end-related orthographic and phonological effects with adults. Coltheart, Woollams, Kinoshita, and Perry (1999) showed that beginning-related overlap produced stronger facilitatory priming effects than did end-related overlap in adults performing the Stroop paradigm. Just as in the picture–word paradigm, participants in the Stroop task are asked to produce a verbal response (naming a color) while ignoring a printed distractor. Also similar to the picture–word task, shorter color naming latencies have been observed when the printed distractor and the target color name share one phoneme than when they are unrelated. Thus, Coltheart and colleagues' results would favor the serial hypothesis, at least at the final stage of development.

Note that for end-related effects to be visible, one condition needs to be met: The picture naming response must not be triggered by the speech production system before the whole target word has been phonologically encoded and/or buffered. If speech was triggered on the basis of partial phonological encoding or partial buffering of the target word, the extra-activation received by the end of the word would go unnoticed in the response onset times. Previous studies have addressed this issue. Meyer and Schriefers (1991) tested adults with beginning- and end-related phonological distractors that were presented auditorily. They observed that both beginning- and end-related conditions produced facilitation. Brooks and MacWhinney (2000) tested children (5–7 and 9–11 years of age) as well as adults. They obtained beginning effects at all ages but found end effects only for 5- to 7-year-olds. They attributed the disappearance of the end effect to the ability to start speech before encoding or buffering whole words. Note, however, that the adult results of Brooks and MacWhinney stand in contrast to those of Meyer and Schriefers (1991) and that Brooks and MacWhinney's interpretation stands in contrast to a number of proposals according to which adult phonological buffering spans at least one word in this kind of paradigm (e.g., Alario, Costa, & Caramazza, 2002; Costa & Caramazza, 2002). In summary, the available evidence

indicates that verbal responses are not triggered before a whole word is encoded and that the ground is safe for testing the parallel automatic hypothesis with phonological end-related distractors.

### *The current experiment*

We addressed the issue of parallel versus serial activation of phonology by comparing two kinds of prime: a *beginning* prime that shares the initial CV with the picture name (e.g., *doll–dog*) and an *end* prime that shares the final VC with the picture name (e.g., *fog–dog*). The experiment also included an identity condition (distractors were the picture names) and an unrelated baseline condition. The identity condition was used as an indicator of the sensitivity of the paradigm. We predicted that as soon as reading instruction has started, the identity condition should induce a facilitation effect with respect to the unrelated baseline. The two critical comparisons concern the beginning- and end-related conditions. If the implicit and automatic computation of phonology from print initially is slow and serial (i.e., left-to-right phonological decoding), we should obtain greater beginning priming than rhyme priming in beginning readers. In contrast, if the implicit and automatic computation of phonology from print is parallel from the beginning of reading development, we should obtain similar priming effects for beginning primes as well as rhyme primes.

These predictions can be refined by considering the possibility that the rhyme plays a special role in certain aspects of lexical or phonological processing. Goswami (1986, 1990; see also Treiman, 1985; Treiman, Mullennix, Bijeljac-Babic, and Richmond-Welty, 1995) suggested that rhymes are important units in early reading development because they are phonologically salient and provide useful analogies in novel word reading. Accordingly, rhyme (end) overlap could be more helpful than beginning overlap in a picture–word naming paradigm. One controversial issue is whether such a rhyme effect would exist from the beginning of reading or whether these effects would arise only at a later stage of reading development, that is, the “small units first” versus “large units first” debate (for discussions, see Brown & Deavers, 1999; Duncan, Seymour, & Hill, 1997; Perry & Ziegler, 2000; Ziegler & Goswami, 2005). Notice also that all of the studies cited previously were conducted in English. Given that our study was conducted in French, the arguments outlined previously would apply only if the rhyme were a phonologically salient unit even in French. There is ample evidence that this is the case. First, in French, rhyme awareness develops naturally prior to reading (Gombert, 1990). Second, rhyme neighbors are more frequent in French than are all other types of phonological neighbors (see Fig. 3 in Ziegler & Goswami, 2005). Third, there is more cohesiveness and interdependence between the vowel and the final consonant cluster than between the onset and the vowel (for relevant analyses, see Peereman & Content, 1997).

In summary, for prereaders (reception year), we did not predict any facilitatory effect between the word and the picture. For developing readers (Grades 1, 2, and 4), we expected three possible outcomes: (a) beginning effects only (this finding would be in favor of serial activation), (b) rhyme effects only (this finding would be in favor of a special role of the rhyme in reading development), and (c) beginning and rhyme effects (this finding would be in favor of a parallel activation of phonology in silent reading). We also tested skilled adult readers to see whether we could replicate Coltheart and colleagues' (1999) finding of a serial effect in skilled readers.

## Method

### Participants

A total of 20 adults and 90 children volunteered for this experiment. All were native speakers of French. None of them had previously been diagnosed with a written or spoken language impairment. The adults were students of psychology at the Université de Provence (Aix-en-Provence, France) and were between 20 and 25 years of age.

The children were divided into four groups: 19 from reception year (11 boys and 8 girls, mean chronological age = 5 years 9 months,  $SD = 4$  months), 24 from Grade 1 (12 boys and 12 girls, mean chronological age = 6 years 9 months,  $SD = 4$  months), 24 from Grade 2 (11 boys and 13 girls, mean chronological age = 7 years 9 months,  $SD = 3$  months), and 23 from Grade 4 (13 boys and 10 girls, mean chronological age = 9 years 10 months,  $SD = 3$  months). The group sizes differ between grades due to the different compositions of class groups in the schools.

The children attended public primary schools in the southeast of France when testing took place (between April and May 2004). Children in reception had received metaphonological training but no formal reading instruction. The other children were exposed mainly to a phonics method that explicitly taught how to use letter-to-sound correspondences to read words in texts with selected vocabulary. Each child outside reception received the standardized French reading test *L'Alouette* (Lefavrais, 1965). Reading ages were as follows: Grade 1, 6 years 11 months; Grade 2, 7 years 11 months; and Grade 4, 9 years 0 months. All children received a standardized vocabulary test, *Échelle de Vocabulaire en Images Peabody* (Dunn, Thériault, & Dunn, 1993) (mean score = 100,  $SD = 15$ ). Vocabulary ages were as follows: reception, 5 years 0 months; Grade 1, 7 years 8 months; Grade 2, 9 years 8 months; and Grade 4, 11 years 9 months.

### Materials

We selected 20 black and white pictures of common objects from the Alario and Ferrand (1999) database. The pictures' names were monosyllabic and had a mean rated age of acquisition of 1.85 years (on a scale from 1 to 5, with 1 = learned between 0 and 3 years of age and 2 = learned between 3 and 6 years of age). Hence, the picture names presumably were known by the children who participated.

For each picture (e.g., *TABLE*, meaning *table*), we selected four different distractor words: (a) the name of the picture itself, (b) a monosyllabic word that shared its two or three first phonemes with the target name (e.g., *TARTE*, meaning *tart*), (c) a monosyllabic word that shared its two or three last phonemes with the target name (e.g., *FABLE*, meaning *tale*), and (d) a monosyllabic word that shared no segments with the target name (e.g., *SUCRE*, meaning *sugar*). Except for the picture's name itself, the distractor words were semantically unrelated to the picture's name. The four distractor words of a given picture were matched on the following psycholinguistic variables: child word frequency,  $F < 1$  (Lété, Sprenger-Charolles, & Colé, 2004); adult word frequency,  $F < 1$  (New, Pallier, Ferrand, & Matos, 2001); length in letters,  $F(3, 16) = 1.76$  non significant and phonemes,  $F < 1$ . The percentages of phonemes and letters shared with the target word were similar for the beginning- and end-related conditions: phonemes,  $t(16) < 1$ ; letters,  $t(16) = 1.26$ ,  $p = .23$ . As described subsequently in Results, some items needed to

Table 1  
Summary of material used

Condition	Example	Child frequency	Adult frequency	Number of letters	Shared letters (%)	Number of phonemes	Shared phonemes (%)
Identity	Table	88	59	5.1	100	3.4	100
Beginning related	Tarte	89	74	4.8	46	3.3	67
End related	Fable	103	68	5.1	58	3.3	65
Unrelated	Sucre	106	101	4.8	14	3.4	0

be excluded from the analysis and are not included in these counts. A summary of these variables is given in Table 1.

The experimental pictures were created by printing the distractor words on the pictures in black uppercase (Arial font size 30 points). For each experimental picture, five different files were created: one with each of the four distractor words and one in alphanumeric characters (e.g., %\$#£). The alphanumeric trials were considered as fillers. Overall, 60% of the trials were “related” trials and 40% were “unrelated” trials. Six other pictures were selected from the same database, paired with unrelated distractors, to be used in training and warm-up trials.

### Design

There were two factors: grade (manipulated between participants and within items) and picture–distractor relatedness (manipulated within participants and within items). The grade factor had five levels: four groups of children of differing grades plus a group of adults. The relatedness factor had four levels: identity, beginning related, end related, and unrelated. All participants saw all of the pictures in these four experimental conditions as well as in the filler condition (alphanumeric).

We created a total of 10 lists of experimental stimuli. We first created 5 lists, each consisting of five blocks. In each of the blocks, each picture appeared only once. There was an even number of items of each condition in each of the blocks. The order within each block was quasirandom with the following constraints: Two successive pictures were not of the same semantic category, two successive pictures did not begin or end with the same phoneme, and no more than two trials of the same experimental condition occurred in a row. Each experimental block started with a series of two warm-up trials consisting of a filler picture and an unrelated word. To create the 5 other lists, the order of the experimental items was reversed.

### Procedure

The experiment was controlled by the software *DmDX* (Forster & Forster, 2003). Participants were tested individually. Before the experiment proper, they were familiarized with the materials. They were presented with the pictures once without any distractor word. They were asked to provide the most appropriate name, and they were corrected if this was not the intended name. Then participants were familiarized with the experimental procedure. This familiarization was done with 15 filler pictures. The experimental trials were identical to those of the experiment proper (see also below).

During a trial of the experiment proper, each participant first saw a blank screen for 300 ms, followed by a fixation point for 500 ms. Then the target picture was presented. The picture remained on the screen until the participant's response was detected or a deadline of 2000 ms was reached, whichever came first. After the participant's response was detected, a question mark appeared on the screen until the space bar was pressed so as to start the next trial. Response latencies were measured from the onset of picture display to the onset of articulation, as detected by the software voice key of the controlling software. Digital recordings, time-locked to picture onset, were also recorded for later inspection and verification. The experimenter stayed in the same room as the participant to control the experiment and to note the participant's naming errors. After the experiment was completed, the recorded sound files and the measured voice onset were checked visually with sound editing software. Automatic software voice key measurements were corrected when appropriate. This analysis was blind with regard to the experimental conditions under investigation. Here we report the corrected values for the naming latencies.

## Results

Due to a programming error, the data corresponding to four of the pictures were not recorded properly during the children's testing. These items (pictures of peigne, pelle, poire, and pomme) were excluded from the analysis. In the interest of homogeneity, these items were also excluded from the adult data (this decision did not affect the pattern of results for adults). After exclusion of these items, errors and outliers were identified according to the following criteria. Reaction times were considered as outliers, and excluded from further treatment, when they were less than 300 ms, when they were greater than the deadline limit of 2000 ms, or when they were more than 3 standard deviations from the mean of the participants (488 outliers, 8% of the trials). Trials in which participants produced the expected name incorrectly (e.g., phonologically deviant responses), a word different from the intended name, or other verbal responses were considered as errors (634 errors, 10.5 % of the data). A summary of the data of this experiment is given in Table 2.

We conducted  $F_1$  and  $F_2$  analyses of variance (ANOVAs) by participants and items on the error rates and the naming latency data. An alpha level of .05 was used for all statistical tests. The error rate decreased with grade,  $F_1(4, 105) = 24.9, p < .01$ , and  $F_2(4, 60) = 33.2, p < .01$ . There was also a significant effect of relatedness,  $F_1(3, 315) = 10.2, p < .01$ , and  $F_2(3, 45) = 11.3, p < .01$ . The unrelated condition produced the largest error rate, followed by the end-related, beginning-related, and identity conditions. The interaction between the two factors was significant only in the analysis by items,  $F_1(12, 315) = 1.29$  and  $F_2(12, 180) = 1.90, p = .04$ . These results are consistent with the analysis of naming latency reported next.

The analysis of naming latency data yielded the following results. There was a significant effect of grade,  $F_1(4, 105) = 45.2, p < .001$ , and  $F_2(4, 60) = 29.9, p < .001$ . There was a significant effect of relatedness,  $F_1(3, 315) = 86.4, p < .001$ , and  $F_2(3, 45) = 76.2, p < .001$ . The significant interaction between the two factors,  $F_1(12, 135) = 8.65, p < .001$ , and  $F_2(12, 180) = 13.5, p < .001$ , indicated that the effect of the distractor words varied with the participants' grade. Accordingly, we conducted separate one-way ANOVAs for each grade. Relatedness was treated as a within-participants and within-items factor. Within each of the grades where relatedness showed a significant main effect (i.e., all grades except reception), we then assessed the specific effects of each distractor type with two-tailed

Table 2  
Summary of naming latency (ms) and accuracy data in the experiment

Grade		Condition				Difference with unrelated		
		Beginning	End	Identity	Unrelated	Beginning	End	Identity
Reception	<i>M</i>	1159	1114	1162	1132	–26	18	–30
	<i>SD</i>	137	146	174	133			
	Error %	23	25	22	23	0	–2	1
1	<i>M</i>	1051	1059	1000	1180	129	121	180
	<i>SD</i>	147	189	140	223			
	Error %	7	9	5	11	4	2	6
2	<i>M</i>	960	999	859	1154	194	155	295
	<i>SD</i>	132	138	132	168			
	Error %	9	11	5	15	6	4	10
4	<i>M</i>	924	896	781	1102	177	206	321
	<i>SD</i>	144	110	89	139			
	Error %	4	5	1	4	0	1	3
Adults	<i>M</i>	678	664	603	761	83	97	158
	<i>SD</i>	112	121	84	121			
	Error %	3	1	0	4	1	3	4

Note. Means and standard deviations are in milliseconds (ms).

Student's *t* tests. These pairwise comparisons always were conducted according to the ordering of the conditions in the mean naming latencies.

In reception, the effect of relatedness was not significant,  $F_1(3, 54) = 1.19$ , and  $F_2(3, 45) = 1.33$ . In Grade 1, the effect of relatedness was significant,  $F_1(3, 69) = 12.2$ ,  $p < .001$ , and  $F_2(3, 45) = 13.6$ ,  $p < .001$ . The identity condition was faster than the beginning-related condition,  $t_1(23) = 2.05$ ,  $p < .05$ , and  $t_2(15) = 2.16$ ,  $p < .05$ . The beginning- and end-related conditions did not differ from one another,  $ts < 1$ . The end-related condition was significantly faster than the unrelated condition,  $t_1(23) = 3.72$ ,  $p < .01$ , and  $t_2(15) = 4.29$ ,  $p < .01$ .

In Grade 2, the effect of relatedness was significant,  $F_1(3, 69) = 30.7$ ,  $p < .01$ , and  $F_2(3, 45) = 50.6$ ,  $p < .001$ . The identity condition was faster than the beginning-related condition,  $t_1(23) = 4.93$ ,  $p < .001$ , and,  $t_2(15) = 3.50$ ,  $p < .05$ . The beginning- and end-related conditions did not differ from one another,  $t_1(23) = 1.70$ , and  $t_2(15) = 1.53$ . The end-related condition was significantly faster than the unrelated condition,  $t_1(23) = 4.39$ ,  $p < .001$ , and  $t_2(15) = 6.72$ ,  $p < .001$ .

In Grade 4, the pattern was very similar to that in Grade 2. There was an effect of relatedness,  $F_1(3, 66) = 61.6$ ,  $p < .001$ , and  $F_2(3, 45) = 78.3$ ,  $p < .001$ . The identity condition was faster than the end-related condition,  $t_1(22) = 6.68$ ,  $p < .001$ , and  $t_2(15) = 9.79$ ,  $p < .001$ . The end- and beginning-related conditions did not differ from one another,  $t_1(22) = 1.24$ , and  $t_2(15) < 1$ . The beginning-related condition was significantly faster than the unrelated condition,  $t_1(22) = 7.03$ ,  $p < .001$ , and  $t_2(15) = 8.52$ ,  $p < .001$ .

Finally, adults also showed a pattern similar to that of second and fourth graders. There was an effect of relatedness,  $F_1(3, 57) = 40.3$ ,  $p < .001$ , and  $F_2(3, 45) = 32.2$ ,  $p < .001$ . The identity condition was faster than the end-related condition,  $t_1(19) = 4.05$ ,  $p < .001$ , and  $t_2(15) = 4.09$ ,  $p < .001$ . The beginning- and end-related conditions did not differ from one another,  $t_1(19) = 1.36$ , and  $t_2(15) < 1$ . The end-related condition was significantly faster than the unrelated condition,  $t_1(19) = 4.96$ ,  $p < .001$ , and  $t_2(15) = 3.96$ ,  $p < .001$ .

In these analysis, the beginning- and end-related conditions never differed from one another. If the grouping of the children by grade is averaging out a reading skill modulation of these two effects, such a modulation should be observed when reading age is taken as the independent classifying variable. In a post hoc analysis, children from grades in which priming was found (Grades 1–4) were assigned to one of the three groups according to their reading age (on the basis of the 33 and 66% percentiles of the reading age distribution). The priming effects in the three conditions were computed post hoc for these three groups and were normalized using  $z$  scores by group. As is shown on Fig. 1, the amount of priming increased with reading skill, yet there was no difference in priming between the beginning- and end-related conditions.

## Discussion

The results of this experiment are straightforward. First, naming latencies decreased with grade. Second, the significant interaction between grade and relatedness indicated a modulation of priming effects across grades. Priming was nonexistent for reception and was largest for Grade 4. Third, there were differences in the evolution of the three priming effects. Children in their reception year showed no priming. First graders showed similar amounts of priming in the beginning- and end-related conditions and a slightly larger effect in the identity condition. Finally, second and fourth graders, as well as adults, showed significantly larger priming in the identity condition than in the two other related conditions, which did not differ from one another.

In short, identity priming was statistically different from beginning- and end-related priming from Grade 2 onward, and the beginning- and end-related conditions never differed from one another. This pattern of results indicates that throughout the develop-

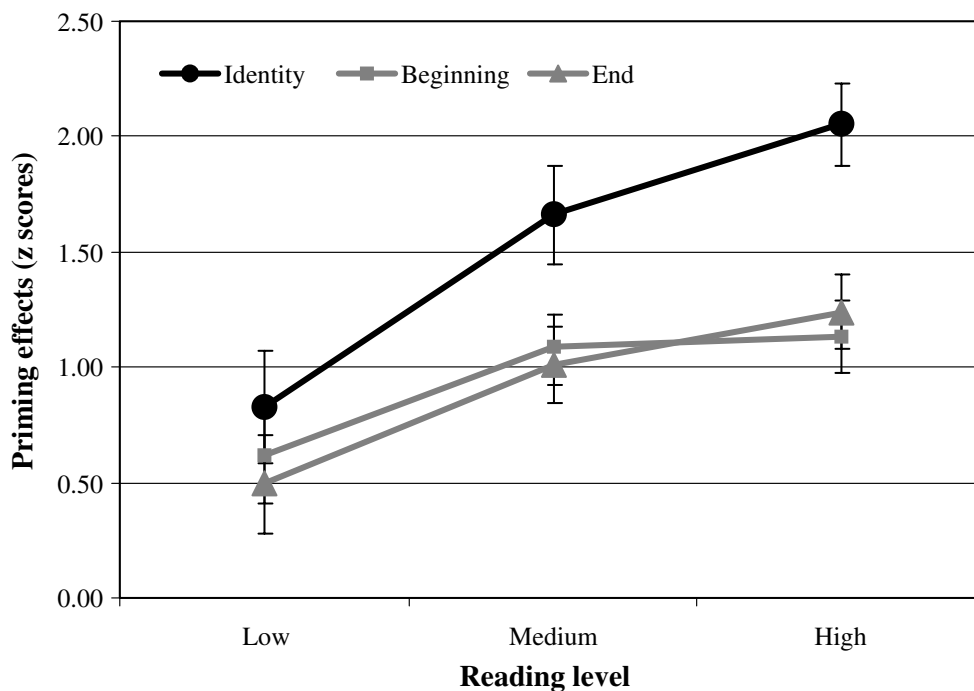


Fig. 1. Normalized priming effects ( $z$  scores) in the identity, beginning-related, and end-related conditions versus the unrelated condition, plotted as a function of estimated reading level defined post hoc (see text for details). Whiskers represent standard errors around effect sizes normalized by participants.

ment of reading in this population, both beginnings and rhymes are equally important with regard to the automatic computation of phonology from print. According to the rationale presented in the Introduction, this result suggests that the automatic extraction of phonology from print can proceed automatically in parallel from the early stages of reading acquisition.

Our finding of a parallel activation of phonology stands somewhat in contrast to results obtained by Coltheart and colleagues (1999). One important difference between the two studies could explain this empirical discrepancy. Coltheart and colleagues used pseudowords as distractor stimuli. Pseudowords typically produce stronger serial effects than do words (Weekes, 1997; Ziegler, Perry, Jacobs, & Braun, 2001). Therefore, observing differential beginning- and end-related facilitation effects when pseudowords, rather than words, are used as distractors is not necessarily inconsistent with our developmental data.

Typically reading development is studied by having children read aloud words and pseudowords (e.g., Frith et al., 1998; Goswami et al., 2001, 2003). Data from the reading aloud paradigm suggest that beginning readers compute phonological codes in a serial and rather slow fashion. These data stand in contrast to results from masking or priming paradigms, which suggest that phonological activation in beginning readers can be quick, automatic, and parallel (Booth et al., 1999). There are a number of problems with the exclusive reliance on the reading aloud paradigm for the understanding of reading development. First, it is difficult to obtain reliable data from the earliest stages of reading development by using the reading aloud task. This task can be used only to the extent that children are already relatively good decoders, a stage that most children (at least English-speaking children) do not reach before Grade 2 or 3 (Frith et al., 1998; Seymour et al., 2003; Ziegler & Goswami, 2005). Second, the most sensitive variable in reading aloud is reading latency, yet when the error rate is still quite high, as in beginning readers, latency data seldom are reliable. Finally, the investigation of reading aloud taps the explicit and overt computation of phonology while leaving untested the possible specificities of silent reading, for example, the hypothesis according to which the implicit computation of phonology is not serial and slow.

In an attempt to overcome these problems, the current study investigated the implicit and automatic computation of phonology in a task that does not rely on overt reading aloud and that can be used from the earliest moments of reading. The baseline task we used, picture naming, is performed easily by prereaders and older children. To test word processing, we asked participants to name pictures while ignoring printed distractor words that were phonologically related or unrelated to the picture names. Importantly, the baseline task itself yielded a comparable level of performance across grade levels (picture naming latencies in the unrelated condition did not differ much across grades).

The serial hypothesis predicted a greater advantage for beginning-related distractors, especially in beginning readers. The rhyme hypothesis predicted a greater advantage for the end-related distractors (i.e., distractors having a rhyme overlap). Finally, the parallel hypothesis predicted similar effects for both beginning- and end-related distractors. For prereaders (reception), no priming effects were obtained. From Grade 1 onward, the beginning and end conditions yielded similar facilitation effects. The beginning-related priming effect is consistent with previous research (Briggs & Underwood, 1982, 1987; Posnansky & Rayner, 1977; Underwood & Briggs, 1984). The finding of an end-related priming effect in this population is new. We interpret these results as an indication that, for the ends of words, phonological encoding is automatic even from the beginning of reading. These

results also go beyond previous observations (Briggs & Underwood, 1982) in showing that the size of the priming effect increased with reading skill (grade). The absence of such an effect in previous investigations can be attributed to a lack of strength in the reading skill manipulation.

The finding that the beginning- and end-related conditions produce similar priming effects provides strong support in favor of the parallel processing hypothesis. According to this hypothesis, the implicit activation of phonology is quick, automatic, and parallel even in beginning readers (Booth et al., 1999; Van Orden, Stone, & Pennington, 1990). Notice that such a conclusion would seem to contradict the results observed in reading aloud experiments suggesting a rather serial and slow activation of phonology (Rastle & Coltheart, 1999). Several clarifications are in order to reconcile these two views. First, reading aloud probably exaggerates serial effects because reading aloud requires overt articulation, which is a slow and highly serial motor process. In fact, even in skilled readers, serial effects are much stronger in reading aloud than in the lexical decision task (Balota, Cortese, Sergent-Marshall, Spieler, & Yap, 2004). Second, reading a word out loud requires a fully specified explicit phonological code. In contrast, the implicit activation of phonology we tested might not require such a complete specification. For example, the strong phonological theory of reading (Frost, 1998) postulates that phonology always is activated even if it is not always fully specified. Our beginning- and end-related priming effects might reflect such a general and automatic, yet underspecified, activation of phonology. A more detailed description of this view could be that a quick initial forward pass computes the most reliable spelling–sound correspondences in parallel (e.g., Berent & Perfetti, 1995; Brown & Deavers, 1999). Because beginning and end units tend to be more consistent than vowels<sup>2</sup> (Treiman, Mullennix, Bijeljac-Babic, & Richmond-Welty, 1995), both beginning- and end-related priming effects are expected.

The idea that implicit phonological activation in silent reading is automatic but somewhat underspecified is consistent with previous explanations of the differences between good and poor readers (Briggs & Underwood, 1982) and the literature on skilled reading. For example, in literate adults, regularity/consistency effects<sup>3</sup> are present in naming but absent in lexical decision (Berent, 1997). In line with Frost's (1998) strong phonological theory, Berent (1997) argued that in lexical decision the computation of phonology in silent reading is impoverished due to a coarse coding. This proposal is supported by the fact that regularity/consistency often is manipulated with regard to the vowel unit (e.g., *ea* in *pear* vs. *tear*), and hypothetically the vowel unit might not get computed initially due to its generally greater inconsistency (see previous paragraph). In contrast, consistency/regularity effects should, and in fact do, show up in reading aloud because reading aloud requires the full specification of phonology, including the vowel. Indeed, Berent showed that the absence of regularity/consistency effects in lexical decision could not be taken to suggest that there was no fast phonological computation. The participants in her study showed robust phonological priming in the lexical decision task, whereas they did not show regularity/consistency effects in exactly the same task.

<sup>2</sup> Even in French, CV and VC units help to disambiguate the vowel. That is, for French monosyllables, the consistency of the VC unit is .95, whereas the consistency of the V unit alone is only .91 (Peereman & Content, 1997).

<sup>3</sup> The regularity/consistency effect reflects the finding that words with exceptional (i.e., irregular/inconsistent) spelling-to-sound correspondences (e.g., PINT) take longer to name and produce more errors than do words with regular or consistent spelling-to-sound correspondences (for an extensive review, see Perry et al., 2007).

In summary, our developmental results clearly are consistent with the strong phonological theory (Frost, 1998; Van Orden et al., 1990), according to which phonological codes in silent reading are computed automatically and in parallel but might be underspecified. The presence of end-related priming effects from the beginning of reading suggests that there is no systematic transition from slow serial decoding to fast parallel processing in silent reading. Instead, even in learning readers, development shows signs of fast parallel activation of phonology, at least in tasks that do not require a fully specified phonological output.

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