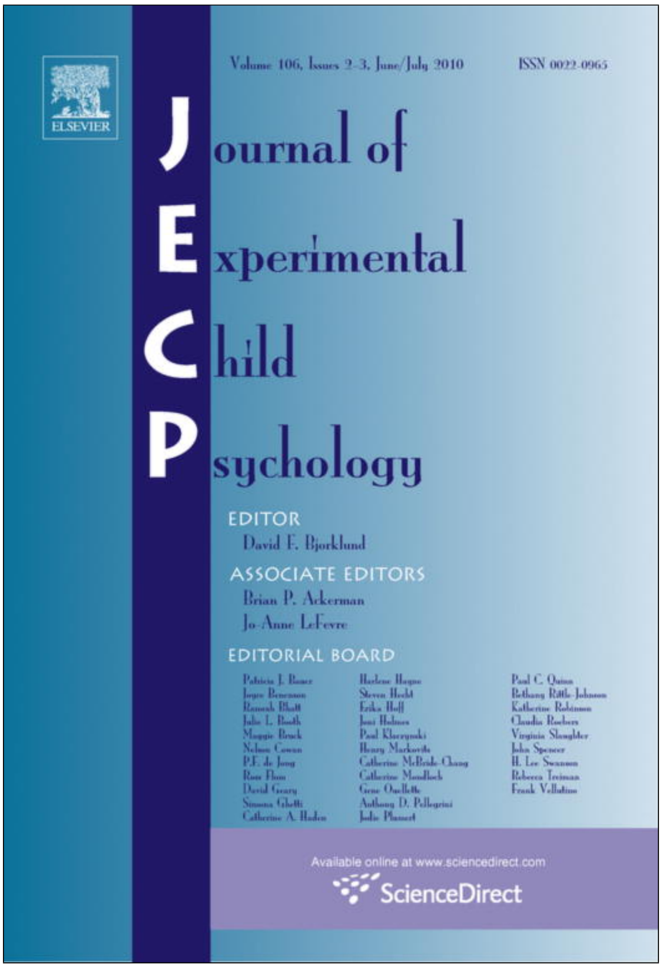
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Brief Report

The development of lexical representations: Evidence from the position of the diverging letter effect

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A R T I C L E I N F O

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A B S T R A C T

In this article, the position of the diverging letter effect has been used to investigate the interactions between lexical and sublexical information during reading acquisition. The position of the diverging letter effect refers to the fact that nonwords derived from words by changing a letter are read more quickly when the diverging letter is toward the end of the string than when it is at the beginning. The position of the diverging letter effect has been explained as a result of the interaction between sublexical procedures, which operate serially, and lexical procedures, which operate in parallel, on the letter string. We demonstrated that the literacy level of the reader determines whether facilitation or interference effects for late diverging nonwords are observed. The oldest children showed the same effect as that shown by the adults. The youngest children showed a reversed pattern; late diverging nonwords were read more slowly and less accurately than early diverging nonwords. We propose that this pattern is due to the combination of (a) the readiness with which lexical information (which increases as literacy increases) is activated and (b) the refining of the mechanism that balances the contributions of the lexical and sublexical procedures.

Introduction

Many models of literacy acquisition converge on the idea that reading develops throughout a sequence of stages in which phonological recoding strategies based on grapheme-to-phoneme

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correspondences become more and more practiced and allow the creation of direct links to the orthographic and phonological representations of words in lexical memory. The shift from a previous reading strategy based mainly on alphabetic cues to one based on a mature orthographic strategy is the "core" stage of reading acquisition. How do sublexical and lexical information interact to develop an efficient reading system? To what extent does letter–sound mapping support lexical access and, conversely, to what extent does lexical information processing support letter–sound mapping? This article deals with these questions by studying nonword reading in children of three different ages. In particular, we investigated the developmental trend of a recently reported effect according to which nonword reading proficiency depends on the point at which a given nonword diverges from a known word.

The position of the diverging letter effect

Mulatti, Peressotti, and Job (2007) showed that the time needed to read a nonword derived from a word by changing a letter is a function of the position of the diverging letter. In their experiment, participants read aloud easily pronounceable nonwords derived from Italian words by changing either the first or fourth letter (i.e., *B*UNTO/bunto/derived from *P*UNTO (point)/punto/ or MON*S*O/monso/ derived from MON*D*O (world) /mondo/). The results showed that first letter diverging nonwords were read aloud more slowly than fourth letter diverging nonwords.

Mulatti and colleagues (2007) explained their finding within the dual-route cascaded model of reading aloud (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). According to the model, two routes are available to translate print into sound: the lexical route, which recovers the stored orthographic and phonological information of known words, and the nonlexical route, which translates letters into phonemes via a set of grapheme-to-phoneme correspondence rules. Both routes deliver their output to the phonemic buffer in which activation of the individual phonemes accumulates over time according to some criterion. Overt pronunciation starts when all phonemes have reached the criterion. According to this architecture, even if the correct pronunciation of a nonword can be fully specified only through computations of the nonlexical procedure, information activated by the two routes interacts at the level of the phonological buffer to produce the final output for both words and nonwords.

Mulatti and colleagues (2007) simulated the position of the diverging letter effect (PDL effect) using the Italian version of the dual-route cascaded model (Mulatti & Job, 2003). The simulation revealed two important facts. First, the activation of the lexical representation of the baseword (i.e., the word from which the nonword is derived) in the lexical route contributes positively to the assembling of the nonword phonology. Second, late diverging nonwords activate the baseword's lexical representation more strongly than early diverging nonwords. This is because the nonlexical route operates serially on the stimulus, one letter at time and from left to the right, activating the corresponding phonemes in the phonemic buffer. The activated phonemes are then engaged in interactive activation with the phonological output lexicon. When the model processes a late diverging nonword (i.e., MON*S*O) for a certain amount of time (i.e., the time required to process the first letters of the nonword, MON-) the output of the nonlexical procedure is consistent with the baseword phonological representation activated in the phonological lexicon (i.e., /mondo/), increasing its rate of activation. If the nonword diverges early (i.e., *B*UNTO from *P*UNTO), the nonlexical procedure delivers inconsistent information from the very beginning (when the first letter is processed), thereby slowing the activation rate of the baseword lexical unit. Therefore, given that lexical activation facilitates nonword phonology assembling, late diverging items are read faster than early diverging items.

The developmental study of the PDL effect

According to Ehri's (1995, 2005) theory, reading develops through four phases: prealphabetic, partial alphabetic, full alphabetic, and consolidated alphabetic, with the former and latter stages nearly corresponding to the logographic and orthographic stages of Frith's (1985) stage model. During the first phase, children do not have any knowledge of the relations between letters and sounds; they only read words they have seen many times on the basis of their visual features. During the second phase, children learn to read words by forming connections between *some* of the letters and the corresponding sounds. Stuart and Coltheart (1988) suggested that some "more relevant" letters (the initial and final ones in English) could be used to construct in memory scaffolds of words that are more easily retained and that facilitate the learning of letter–sound consistencies that recur across words (Savage, Stuart, & Hill, 2001). During the full alphabetic phase, a complete system of connections between graphemes and phonemes becomes available and children can read new words and nonwords. According to Share (1995), this stage is critical for the consolidation of word spellings in memory and the acquisition of a readily accessible orthographic lexicon; as a reader encounters a given word, direct connections between the corresponding orthographic and phonological representations are established in memory, allowing the child to name the word as a single unified whole. As the number of words sharing letter patterns with the same pronunciation increases, a consolidated unit is formed, allowing the reader to directly associate larger orthographic units, such as morphemes and syllables, with their corresponding pronunciations.

According to such a view, children from the very beginning use both their knowledge about the phonology of the words and their decoding skills to translate letters into sounds; hence, they are faced with the task of balancing the contributions of these two mechanisms: the phonological/lexical mechanism and the sublexical mechanism. This is especially true if they need to read a nonword that is phonologically similar to a word because, in such a case, the outputs of the two mechanisms are similar but not identical; the system can benefit from the support of the lexical mechanism only if its contribution can be modulated and controlled by the sublexical procedure (the only procedure able to correctly assemble the output string). Instead, if the lexical procedure dominates, either the baseword is produced instead of the nonword or the correct assembly is delayed.

We hypothesize that the positive contribution of lexical activation to nonword assembly is the marker of a mature reading strategy that can be acquired only after some years of literacy; during the first stages of reading, the contributions of the lexical and sublexical procedures are not efficiently balanced, meaning that lexical activation is detrimental to nonword assembly. Therefore, we predict that the PDL effect should reverse in younger readers. An example should clarify the rationale. Suppose that the stimulus is a late diverging nonword such as MON*S*O. The sublexical procedure serially activates the phonemes /m/, /o/, and /n/ in the phonemic buffer. Those phonemes send activation to the phonological output lexicon, and the phonological representation /mondo/ is activated. Once activated, /mondo/ attempts to activate the phoneme /d/ in the fourth position. When the sublexical route reaches the fourth letter of the nonword and attempts to activate the phoneme /s/ in that position, the two phonemes (/s/ and /d/) compete against each other. If in younger readers the phonological/lexical procedure tends to dominate, the phoneme /d/ will strongly interfere with the phoneme /s/, resulting in slow response times (RTs) if /s/ wins or in an error if /d/ wins. Suppose now that the stimulus is an early diverging nonword such as *B*UNTO. The sublexical procedure activates the diverging phoneme /b/ from the very beginning. So, although the phonemic sequence /_unto/ sends activation to the lexical unit /punto/, the phonological representation is inhibited from the very beginning by the activation of the phoneme /b/. Thus, the activation of /punto/ is much lower than the activation of /mondo/. Being less activated, /punto/ does not strongly activate /p/ in the first position, which does not compete with /b/. As a consequence, RTs will be short(er) and the probability of error will be diminished.

The pattern should change radically for more proficient readers. As Mulatti and colleagues (2007) showed, in a mature reading system, a highly activated phonological representation (e.g., /mondo/) contributes to the selection of the phonemes it shares with the nonword /monso/ (i.e., /mon_o/) rather than interfering with the selection of the phoneme it does not share with the nonword (/s/); this is because the phoneme activated by the sublexical procedure promptly inhibits the competing phoneme activated by the lexical procedure. Given that late diverging nonwords activate the corresponding basewords more strongly than early diverging nonwords, it follows that the former stimuli are assembled faster and more accurately than the latter stimuli.

The current experiment

We asked children of three ages to read nonwords aloud. Nonwords were derived by changing either the first or fourth letter in five- or six-letter words. The basewords were middle- to high-frequency words taken from the child frequency count database of Marconi, Ott, Pesenti, Ratti, and

Tavella (1993). The baseword was the highest frequency neighbor of the nonword (i.e., the highest frequency word that could be derived from the nonword by changing one letter at time).

Methods

Participants

We tested 24 children at the beginning of the second grade (14 girls and 10 boys, mean age = 7 years 2 months), 41 children at the end of the second grade (18 girls and 23 boys, mean age = 8 years 0 months), and 25 children at the beginning of the fourth grade (10 girls and 15 boys, mean age = 9 years 2 months). The children came from average socioeconomic backgrounds, and none had neurological problems or showed any form of learning disability. All were native Italian speakers.

Materials

We selected 116 words (39 adjectives, 60 nouns, and 17 adverbs) of five letters (93 stimuli) and six letters (23 stimuli) from the children frequency count of Marconi and colleagues (1993). This database reports the normalized frequency values for the 6000 highest frequency words (based on 500,000 occurrences) extracted from a representative sample of Italian textbooks, reading books, and comic strips for children.

From half of the words we derived the nonwords by changing the first letter, and for the remaining half we changed the fourth letter. The two groups of words were matched in terms of length (5.22 and 5.17 letters, respectively), initial phoneme, grammatical class, and baseword frequency. For each nonword, number and frequency of neighbors (Coltheart, Davelaar, Jonasson, & Besner, 1977) were calculated in the child and adult frequency counts (Istituto di Linguistica Computazionale–CNR Pisa., 1988 [1,000,000 occurrences]). Including the baseword, early and late diverging nonwords had 1.78 and 1.98 neighbors, respectively, in the child database and had 3.6 and 3.8 neighbors, respectively, in the adult database, $ts < 1$. In addition, the mean frequency of the neighbors (excluding the baseword frequency) was not different for the two types of nonwords (child database: 18.05 and 32.06, respectively; adult database: 5.70 and 9.58, respectively), $ts < 1$, and it was very low with respect to the mean frequency of the basewords (child database: 142.06 and 142.45, respectively; adult database: 175.42 and 180.52, respectively).

Two lists of 58 nonwords (29 early diverging and 29 late diverging) and 58 words were constructed. Words and nonwords within the two lists were counterbalanced so that if a nonword was presented in one list, the corresponding baseword was presented in the other list.

Procedure

Data were collected at the Borgonuovo Primary School in Prato (Tuscany, Italy) on two occasions. In May we tested the children at the end of the second grade, and in October we tested the children at the beginning of the second and fourth grades. Each participant was instructed to read aloud, one after the other, the stimuli presented on the computer screen while trying to avoid stumbling or other disfluencies. The experiment was developed in E-Prime, and each trial started with a smiling face at the center of the screen that remained in view until the child pressed the space bar to start the trial. After 1 s, a fixation point (+) appeared at the center of the screen for 800 ms and was then replaced by the stimulus that remained in view until the vocal response. The stimulus was a lowercase string of white letters in 24-point Courier font on a black background. RTs were recorded through a voice key connected to a microphone, and accuracy was checked by the experimenter. Hesitations or disfluencies were treated as errors. Sometimes the child pronounced the stimulus correctly but the voice key failed to record the RT. In these cases, the response was scored as correct but the RT was not analyzed. Order of item presentation was randomized for each participant. To familiarize the child with the procedure, a practice session (32 stimuli) preceded the experimental session.

Results

Mean RTs and error percentages according to conditions are reported in Table 1. On the RTs, we performed analyses of variance (ANOVAs) by participants (F_1) and by items (F_2) with position (early and late diverging) as a within-participant and between-item factor and age as a between-participant and within-item factor. Outliers (2.25%) were identified using the Van Selst and Jolicoeur (1994) recursive procedure and were excluded from the RT analyses. The results showed a significant effect of age, $F_1(2, 87) = 22.11$, $\eta_p^2 = .34$, $p < .001$, $F_2(2, 228) = 521.08$, $\eta_p^2 = .82$, $p < .001$; a significant effect of position, $F_1(2, 87) = 9.60$, $\eta_p^2 = .01$, $p = 003$, $F_2(1, 114) = 21.90$, $\eta_p^2 = .16$, $p < .001$; and (critically) a significant interaction between age and position, $F_1(2, 87) = 25.80$, $\eta_p^2 = .37$, $p < .001$, $F_2(2, 228) = 70.50$, $\eta_p^2 = .38$, $p < .001$. The same analyses were conducted on error means and showed an analogous pattern: age, $F_1(2, 87) = 26.70$, $\eta_p^2 = .38$, $p < .001$, $F_2(2, 228) = 40.49$, $\eta_p^2 = .26$, $p < .001$; position, $F_1(2, 87) = 25.70$, $\eta_p^2 = .23$, $p < .001$, $F_2(1, 114) = 10.01$, $\eta_p^2 = .081$, $p = .002$; interaction between age and position, $F_1(2, 87) = 83.40$, $\eta_p^2 = .66$, $p < .001$, $F_2(2, 228) = 93.68$, $\eta_p^2 = .45$, $p < .001$. The PDL effect changed according to age. Children at the beginning of the second grade read late diverging nonwords more slowly and less accurately than early diverging nonwords: RTs, $F_1(1, 23) = 16.29$, $\eta_p^2 = .42$, $p = .001$; errors, $F_1(1, 23) = 67.48$, $\eta_p^2 = .75$, $p < .001$. At the end of the second grade, no PDL effect was obtained: RTs, $F < 1$; errors, $F_1 = 1.40$. Finally, children at the beginning of the fourth grade read late diverging nonwords faster and more accurately than early diverging nonwords, just as adults do: RTs, $F_1(1, 24) = 21.95$, $\eta_p^2 = .48$, $p < .001$; errors, $F_1(1, 24) = 60.44$, $\eta_p^2 = .72$, $p < .001$.

To better understand the contribution of lexical knowledge at the different levels of literacy, we examined the errors more closely and classified them into three categories (Table 2): nonword error (NWE, when the child mispronounced the stimulus and produced another nonword), baseword lexicalization (BWL, when the child produced the baseword), and other lexicalization (OL, when another word was produced). In all conditions, the most frequent errors consisted in lexicalizations (BWL + OL). Moreover, the lexicalization distribution reflected the RT pattern; whereas the youngest children (beginning of the second grade) made more lexicalizations to late diverging nonwords, the oldest children (beginning of the fourth grade) showed the reverse pattern.

Let us now consider children of the intermediate age. As reported above, RTs and errors did not differ across conditions. However, of the 41 children, 32 showed a PDL effect larger than 40 ms; some of them (15) read early diverging nonwords faster, whereas others read late diverging nonwords faster. Thus, the null effect could be due to the presence of two groups of children: one group that read as the youngest children do and one group that read as the oldest children do. This intuition is supported by a significant correlation between the size of the PDL effect and the performance of each participant (i.e., overall mean RTs). The correlation (from which we excluded the data of a child who showed an extremely large effect, i.e., more than three standard deviations) was significant, $R^2 = .254$, $F(1, 38) = 12.93$, $p = .001$. The slow readers read late diverging nonwords more slowly than early diverging nonwords, whereas the fast readers read late diverging nonwords faster than early diverging nonwords.

A further analysis was performed on the RTs to word stimuli. If the children at the beginning of the fourth grade readily activate lexical information through direct connections from orthographic to phonological representations, we should find a frequency effect. Indeed, frequency effects in reading aloud are often considered to reflect the readiness with which orthographic and phonological word

Table 1
RTs and error percentages on the total trials to words and nonwords for the three age levels.

Age level	Words	Nonwords		
		Early diverging	Late diverging	Difference
7 years 2 months: Beginning second grade	2543 (1.7)	2929 (7.8)	4165 (34.05)	−1236* (−26.15)*
8 years 0 months: End second grade	1330 (0.5)	1671 (9.58)	1680 (10.59)	−9 (−1.01)
9 years 1 month: Beginning fourth grade	839 (0.1)	1314 (15.44)	915 (4.69)	+399* (10.75)*

Note. Error percentages on the total trials are in parentheses. Early diverging nonwords were derived from words by changing the first letter, and late diverging nonwords were derived by changing the fourth letter, of five- or six-letter words. Asterisks (*) indicate significant effects.

Table 2
Errors classified as nonword error, baseword lexicalization, or other lexicalization.

Age level	Early diverging		Late diverging	
7 years 2 months: Beginning second grade	NWE	2.1	NWE	4.6
	BWL	1.4	BWL	15.7
	OL	4.2	OL	13.8
8 years 0 months: End second grade	NWE	4.4	NWE	2.5
	BWL	2.3	BWL	4.6
	OL	2.9	OL	3.4
9 years 1 month: Beginning fourth grade	NWE	0.8	NWE	0.5
	BWL	6.7	BWL	2.6
	OL	7.8	OL	1.5

Note. Errors were classified as nonword errors (NWE), when the child misspelled the stimulus producing another nonword or produced a correct but not fluent response; baseword lexicalization (BWL), when the child pronounced the base word from which the nonword was derived; or other lexicalization (OL), when the child produced another word. The table reports the percentage of each type of error with respect to the total number of trials.

representations become active (cf. Marcolini, Burani, & Colombo, 2009). When lexical information is indirectly activated through decoding strategies, however, frequency effects should be less pronounced or not evident at all. We performed a by-item correlation between the log10 of the word frequency and the RTs separately for each age group. The frequency effect accounted for a significant amount of variance in the performance of the older groups (end of the second grade and beginning of the fourth grade) but not of the youngest group, $R^2 = 0.10$, $F(1, 114) = 12.70$, $p = .001$; $R^2 = 0.124$, $F(1, 114) = 16.20$, $p < .001$; and $R^2 = 0.01$, *ns*, respectively.

Discussion

The results show that the PDL effect is sensitive to the literacy level. During the first stages of literacy, late diverging nonwords were more difficult to process compared with early diverging nonwords. As schooling progressed, this difference first disappeared and then reversed so that for the older children late diverging nonwords became the fastest stimuli. As revealed by a deeper inspection of the results, the null effect obtained with children at the intermediate age was due to the fact that some children behaved mostly like the youngest children, whereas others behaved like the oldest children, consistently (as indexed by the overall mean RTs) with the level of literacy reached.

We started from the assumption that the PDL effect obtained with adults emerges from the differential amount of lexical activation brought about by early and late diverging nonwords; basewords corresponding to late diverging nonwords are activated more strongly than basewords corresponding to early diverging nonwords.

The results of this article showed that the impact of lexical activation on sublexical processing modulates this effect. Within the dual-route cascaded model, lexical and sublexical processes interact through the connections between the phonemic output buffer (where the phonemes are assembled) and the phonological output lexicon (where the sound of known words is stored). During the first reading acquisition stages (i.e., partial/full alphabetic stages), the child relies mainly on sublexical (decoding) procedures that operate on single letters (or graphemes) and activate phonemes in the phonemic buffer. Once the phonemes are activated, they then activate the phonological representation in which they appear. This process is costly and slow. However, once a unit in the phonological output lexicon is activated (and the word is somehow recognized), the corresponding phonemic sequence is readily computed given that the system, which already supports speaking, relies on strong connections between the phonological output lexicon and the phonemic buffer. In other words, lexical information is activated quite late through decoding processes, but afterward it tends to dominate phonology computation. This unbalanced contribution of lexical activation explains the result observed with the younger children, that is, that late diverging nonwords are read more slowly than early diverging nonwords. Indeed, as the activation of the phonological/lexical representation of the baseword increases (and late diverging basewords become more active than early diverging basewords), the time needed to assemble the correct sequence of phoneme increases and/or the likelihood of a lexicalization error increases.

By the fourth grade, the child has had many chances to experience reading. Therefore, it is likely that by this age lexical information is more readily activated via both the development of the connections from the phonemic buffer to the phonological lexicon and the development of an orthographic system directly connected to lexical phonology. This latter claim is consistent with the results of many studies that demonstrate that older children gradually acquire lexical competence and create an orthographic lexicon that is directly accessible through visual input (e.g., Coltheart & Leahy, 1992). Job (1994), for example, presented Italian children attending either the second or fifth grade with stimuli written either in homogeneous or mixed case and showed that case alternation was more disruptive for older children than for younger children. As suggested by Mayall and Humphreys (1996), the disrupting effect of case mixing lessens when a sublexical procedure is used because it operates on subword units; instead, given that lexical reading is based on the coding of the word as a whole, it is more susceptible to disruption by case mixing. Thus, this result is consistent with the idea that older children develop a reading strategy based on the activation of whole-word representations and, hence, are more strongly affected by word shape alterations such as case alternation.

In the fourth grade, therefore, reading is characterized by fast lexical activation within a sophisticated interactive activation system where the phonological output lexicon and the phonemic buffer interact through well-established excitatory and inhibitory bidirectional connections that control and balance the contribution of the lexical and sublexical procedures.

In conclusion, we have shown that the PDL effect is sensitive to reading proficiency; whereas at the partial/full alphabetic level of reading acquisition lexical activation (mostly) interferes with nonword reading, at the consolidated alphabetic or orthographic stage lexical activation (mostly) contributes to nonword reading. In addition to being relevant to the theorizing on the acquisition of literacy, the results reported in this article are relevant for research aimed at developing finely tuned tests to identify the reading level reached by individuals and to highlight specific developmental or acquired reading disabilities.

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