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Are syllabification and resyllabification strategies phonotactically directed in French children with dyslexia? A preliminary report

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Abstract

Purpose: In this study, the authors queried whether French-speaking children with dyslexia were sensitive to consonant sonority and position within syllable boundaries to influence a phonological syllable-based segmentation in silent reading.

Method: Participants included 15 French-speaking children with dyslexia, compared with 30 chronological age–matched and reading level–matched controls. Children were tested with an audiovisual recognition task. A target pseudoword (TOLPUDE) was simultaneously presented visually and auditorily and then was compared with a printed test pseudoword that either was identical or differed after the coda deletion (TOPUDE) or the onset deletion (TOLUDE). The intervocalic consonant sequences had either a sonorant coda–sonorant onset (TOR.LADE), sonorant coda–obstruent onset (TOL.PUDE), obstruent coda–sonorant onset (DOT.LIRE), or obstruent coda–obstruent onset (BIC.TADE) sonority profile.

Results: All children processed identity better than they processed deletion, especially with the optimal sonorant coda–obstruent onset sonority profile. However, children preserved syllabification (coda deletion; TO.PUDE) rather than resyllabification (onset deletion; TO.LUDE) with intervocalic consonant sequence reductions, especially when sonorant codas were deleted but the optimal intersyllable contact was respected.

Conclusions: It was surprising to find that although children with dyslexia generally exhibit phonological and acoustic–phonetic impairments (voicing), they showed sensitivity to the optimal sonority profile and a preference for preserved syllabification. The authors proposed a sonority-modulated explanation to account for phonological syllable-based processing. Educational implications are discussed.

Keywords

Syllable; Sonority; Dyslexia; Syllabification; Resyllabification.

Introduction

This report presents data from a preliminary phase on whether, and how, consonant sonority (obstruent vs. sonorant) and consonant deletion (coda vs. onset) within intervocalic consonant sequences influenced phonological syllable-based segmentation in silent reading in French-speaking children with dyslexia compared with chronological age–matched and reading level–matched controls. Of interest was to determine whether the acoustic–phonetic properties of consonants regarding their position within the syllable boundaries are relevant cues that influence and contribute to silent reading, especially to phonological segmentation strategies. Identifying acoustic–phonetic properties in reading and segmentation strategies may contribute to further understanding the importance of the syllable awareness in syllable-timed such as French, Spanish, and Italian. This is also of major importance to further understanding whether impairment in acoustic properties processingmay be an undisclosed source of reading disorders in children with dyslexia. With such knowledge, one might be able to design, for instance, sonority-based remediation training. Accordingly, issues that we raised were twofold: Are children with dyslexia sensitive to sonority despite having impaired phonological abilities? Do consonant sonority and position influence a phonological syllable-based segmentation in silent reading in children?

Simple CV syllables, represented by C and V for consonant and vowel, respectively, are cross-linguistically preferred and are more frequent than complex syllables (i.e., CCV, CVC; e.g., Blevins, 1995). No language that includes complex syllables excludes the CV syllables. The *sonority* within the syllable affects how certain sequences of phonemes are likely to occur (Selkirk, 1984). *Consonant sonority* refers to the sound's "loudness relative to that of other sounds with the same length, stress, and pitch" (Ladefoged, 1975, p. 221). Thus, acoustic-phonetic properties of phonemes are hierarchically-ranked from high-sonority (vowels) to low-sonority phonemes (ranked from liquids and nasals [labeled as *sonorant*] to fricatives and stops [labeled as *obstruent*]). Hence, within such a sonority hierarchy, the *sonority sequencing principle* is a straightforward linguistic explanation that accounts for phoneme associations over others (e.g., Clements, 1990): A syllable preferentially relies on a contour with a prevocalic consonant (onset) maximally growing in sonority towards the vowel and falling minimally to the postvocalic consonant (coda). An optimal syllable describes a CV syllable, but CV syllables with high-sonority onsets (e.g., /la/) are less preferred than those with low-sonority onsets (e.g., /ta/), whereas, in syllables that do contain a coda, high-sonority codas (e.g., /al/) are preferred to low-sonority codas (e.g., /at/). As proposed with the *syllable contact law* (e.g., Murray & Vennemann, 1983), the optimal contact between syllables has to embed a first syllable high-sonority coda and a second syllable low-sonority onset (i.e., the sonorant coda–obstruent onset sonority profile [SP], e.g., /kaʁ.tɔ̃/; the dot represents the syllable boundary).

Interestingly, the linguistic system encourages French to be a syllable-timed language (e.g., Ziegler & Goswami, 2005). First, the syllable boundaries are clear-cut and predictable; that is, intervocalic consonants that could be considered ambisyllabic within the syllable boundaries are not as ambiguous as in English because the final syllable always carries the stress in single words (e.g., Treiman & Danis, 1988). Thus, the optimal CV syllables are overrepresented (e.g., 55% of CV syllables vs. 17% of CVC syllables in French; Delattre, 1965). Further, low-sonority consonants prevail in onsets but are rare in codas but are rare in onsets in CVC syllables, whereas high-sonority consonants prevail in codas but are rare in onsets in CVC syllables (e.g., 70% of sonorant codas vs. 30% of obstruent ones; Wioland, 1985). Finally, French primarily has polysyllabic words (i.e., 76% vs. 24% of monosyllabic words; Content, Mousty, & Radeau, 1990), which benefit from syllable-based segmentation strategies.

However, empirical studies of children with normal and impaired reading skills often have focused on statistical properties of French within syllable boundaries but generally have disregarded intrinsic phoneme properties to explain how segmentation strategies are influenced in silent reading (e.g., Chetail & Mathey, 2009; Doignon & Zagar, 2006; Maïonchi-Pino, Magnan, & Écalle, 2010a, 2010b). Surprisingly, studies dedicated to the role of intrinsic phoneme properties in reading processes have been basically interested in the categorical perception (voicing discrimination between minimal pairs of phonemes) in French-speaking children with dyslexia (e.g., Bedoin, 2003; Magnan, Écalle, Veuillet, & Collet, 2004). Indeed, children with dyslexia experience persistent reading disorders that stem from a cognitive deficit related to underspecified and degraded phonological representations (e.g., Snowling, 2001). More

specifically, an impaired phonological grapheme-to-phoneme correspondence process underlies the reading disorders (e.g., Ramus, 2001; Vellutino, Fletcher, Snowling, & Scanlon, 2004). Serniclaes, Sprenger-Charolles, Carré, and Démonet (2001) and Serniclaes, Van Heghe, Mousty, Carré, and Sprenger-Charolles (2004) also proposed that children with dyslexia are impaired in the grapheme-to-phoneme correspondence learning because they fail in the selection of acoustic–phonetic properties to process phonemes that differ by minimal features (e.g., voiced vs. unvoiced oppositions). Therefore, difficulties discriminating phonemes that differ by a single feature impair the storage and retrieval of acoustic–phonetic properties of phonemes, subsequently affecting children's phonological awareness skills (e.g., Magnan et al., 2004). Unfortunately, no study has thoroughly investigated the role of acoustic–phonetic properties such as sonority within intervocalic consonant sequences in silent reading in French-speaking children with dyslexia. Recently, Fabre and Bedoin (2003) used a modified version of the illusory conjunction paradigm with French-speaking dyslexic and normally reading children to examine how consonant sonority within intervocalic consonant sequences affected CVC.CV disyllabic pseudoword processing. The authors were especially interested in whether an optimal contact between syllables (sonorant coda–obstruent onset SP; e.g., LT) compared with a nonoptimal contact between syllables (obstruent coda–obstruent onset SP; e.g., CT) automatically and early on influenced the identification of syllable boundaries. An *illusory conjunction* is a misperception of a briefly presented target letter within two-colored printed items (e.g., in English speaking children [Prinzmetal, Hoffman, & Vest, 1991]; in French-speaking children [Doignon & Zagar, 2006]). Participants are instructed to report the color of the target letter in the two-colored items. Two illusory conjunctions are distinguished: illusory conjunctions that preserve the syllable boundaries (i.e., report that a target letter V is the same color as il in AN.Vil, in which upper- and lower-case letters represent the two different colors, and the dot represents the syllable boundary) and illusory conjunctions that violate the syllable boundaries (i.e., report that a target letter v is the same color as AN in AN.vil). Hence, if participants really perceive syllable-like units in the printed items, illusory conjunction preservations would be higher than illusory conjunction violations. Fabre and Bedoin (2003) failed to show a syllable-based segmentation in children with either normal or impaired reading skills: illusory conjunction preservations were not significantly more frequent than illusory conjunction violations. However, they evidenced consistent findings with the optimal contact between syllables (i.e., sonorant coda–obstruent onset; Murray & Vennemann, 1983); children with dyslexia correctly reported the color of sonorant codas as target letters in color–syllable compatibility (e.g., VUL.ti), whereas they failed to identify the color of obstruent codas as target letters in color–syllable compatibility (e.g., VUC.ti). No sonority-modulated illusory conjunction preservation has been evidenced in color–syllable incompatibility (e.g., report that the targetletter l was the same color as VU in VUl.ti). Nevertheless, children with dyslexia correctly reported the color of obstruent codas in color–syllable incompatibility (e.g., report that the target letter c is the same color as ti in VUc.ti). Children with dyslexia were so sensitive to the optimal sonority profile within syllable boundaries that their response patterns sometimes violated the maximal onset satisfaction principle. This principle, in French, maximizes the number of consonants at the beginning of a syllable as long as the phonotactic constraints allow a consonant cluster to be a legal cluster in the word-initial position (e.g., Spencer, 1996). For instance, in a $C_1V_1C_2C_3V_4$ word (e.g., PATRON), the syllable boundary is located between C_1V_1 and $C_2C_3V_4$ (i.e., PA.TRON) because a consonant cluster such as TR is considered as legal in the word-initial position. But, for a consonant cluster that is illegal in the word-initial position (e.g., CT), syllabification breaks the intervocalic consonant sequence (e.g., VUC.TI). The authors did not reveal any effect in control children, who were younger and had less reading experience.

For instance, Sprenger-Charolles and Siegel (1997) used a reading aloud task to investigate how French-speaking beginning readers process phonological structure of syllables within printed disyllabic pseudowords with a cluster onset (CCV.CVC) or a complex coda (CVC.CVC). The results demonstrated that children basically reduced a CCV or CVC syllables to a CV syllable. The authors also noticed that consonant sonority may account for cluster reduction within complex syllables. Hereby, they showed that consonant deletion occurred with high-sonority consonants (e.g., /l/ or /ʁ/) rather than with low-sonority consonants (e.g., /p/ or /t/) regardless of the consonant position within the pseudowords. The authors

concluded that children omitted high-sonority consonants because of their phonetic properties (sonority) more so than their location within the syllable.

Based on both the Fabre and Bedoin (2003) and Sprenger-Charolles and Siegel (1997) results, we proposed to further determine whether French-speaking children with dyslexia are sensitive to consonant sonority and position within the syllable boundaries, which may influence and account for a phonological syllablebased segmentation in silent reading.

To answer these issues, we used an original audiovisual task that has previously demonstrated an implicit acoustic–phonetic and phonological syllable-based support for reading strategies in adults (Maïonchi-Pino, de Cara, Magnan, & Écalle, 2008). With regard to the Fabre and Bedoin (2003) paradigm, this audiovisual task is fitted to the natural time course of speech and reading processes because it does not constrain the cognitive processes as it does in the illusory conjunction paradigm. Indeed, a purely visual short-duration display might prevent clear-cut sonority-modulated effects on segmentation strategies in children. Further, this audiovisual task provides support for the phonological codes and, potentially, excludes a pure visual match.

Regarding the Fabre and Bedoin (2003) method, we addressed two additional issues. First, the authors did not thoroughly investigate consonant sonority. Only two SPs were studied (i.e., sonorant coda–obstruent onset and obstruent–obstruent SPs). We therefore designed all possible SPs such as the obstruent coda–sonorant onset SP that may constitute legal word-initial syllables. Because normally reading children typically develop implicit knowledge about spoken syllables (e.g., Goslin & Floccia, 2007) and the acoustic–phonetic properties of phonemes, and because they benefit from explicit knowledge about printed syllables, we hypothesized that the optimal sonorant coda–obstruent onset SPwithin syllable boundaries (e.g., LP in TOLPUDE) would be faster andmore accurately processed than any other SPs in normally reading children. However, because children with dyslexia are known to be impaired in the selection of acoustic–phonetic properties to process phonemes, we hypothesized that SPs would influence them to a lesser extent.

Then, Fabre and Bedoin (2003) justified that reading level–matched controls did not exhibit any sonority-modulated segmentation effect because children "were probably not trained enough at reading to allow much importance to phonotactic rules, to organize the string of letters" (p. 5). In response, with the reading level–matched controls we included chronological age–matched controls who had benefited fromlonger exposure to reading instruction and therefore should have had a higher reading level.

Regarding the Sprenger-Charolles and Siegel (1997) results, we hypothesized that consonant deletion within syllable boundaries, which might rely on both sonority and location, induces distinct processes that favor either phonological syllable-based processing or serial processing. Coda deletion preserves syllabification (e.g., TO.PUDE instead of TOL.PUDE), whereas onset deletion induces resyllabification (the coda is resyllabified and moved into the onset; e.g., TO.LUDE instead of TOL.PUDE; Encrevé, 1988). Thus, if children use a phonological syllable-based segmentation (phonological hypothesis), they will decide more quickly and more accurately whether a printed onset-deleted test pseudoword (e.g., TO.LUDE) or a printed coda-deleted test pseudoword (e.g., TO.PUDE) is identical to the audiovisual target pseudoword (e.g., TOL.PUDE). If children sequentially encode and decode from left to right (serial hypothesis), they will decide more quickly and more accurately whether a printed coda-deleted test pseudoword (e.g., TO.PUDE) is identical to the audiovisual target pseudoword (e.g., TOL.PUDE). With reference to Sprenger-Charolles and Siegel's (1997) conclusion, we expected that sonorant consonant deletion should be detected more quickly and more accurately than obstruent consonant deletion. Finally, if phonological syllable-based processing depends on reading skills, then the phonological hypothesis would be relevant in both normally reading groups, whereas the serial hypothesis should be relevant in children with dyslexia.

Method

Participants

Forty-five children were recruited after parents returned a form giving their consent. All the children were French native speakers, middle class, and right-handed, and were taught reading with a mixture of analytical

grapheme-to-phoneme correspondences and global procedures. They had normal or corrected-to-normal vision and no hearing disorders. Fifteen chronological age–matched controls (CA) and 15 reading level–matched controls (RL) were recruited from an urban elementary school, and they each individually completed a French standardized word reading test (in RL controls, TIMÉ 2; Écalle, 2003, and in CA controls, TIMÉ 3; Écalle, 2006) to be matched to 15 children with dyslexia (DY) based on the scores obtained in the Alouette test (Lefavrais, 1967). TIMÉ 2 and TIMÉ 3 were used to ensure that they did not have reading disorders and could be compared with DY children. Both the TIMÉ tests and the Alouette test assess reading speed and accuracy as well as orthographic and phonological knowledge level. TIMÉ 2 is intended for use with 6- to 8-year-old children, and TIMÉ 3 with 8- to 16-year-olds; the Alouette test is used with 6- to 16-year-olds. Correlations between TIMÉ 2, TIMÉ 3, and the Alouette test are .64 and .74. No detailed analysis was conducted on responses. Scores showed expected reading age–based profiles. The DY children, with no comorbid ADHD, had all received weekly phonological-based interventions from speech and language therapists for less than a year. Phonological-based interventions basically focused on phonemic awareness, minimal pair of phonemes discrimination, and reading-aloud tasks. Reading and IQ tests were conducted prior to the experiment to ensure that the groups were comparable. Student's *t* test confirmed that chronological age differed between DY children and RL controls, $t(28) = 10.05$, $p < .001$; neither reading level nor verbal and performance IQs significantly differed, $p > .1$. Reading level differed between DY children and CA controls, $t(28) = –16.95$, $p < .001$, as did verbal and performance IQs, $t(28) = –2.94$, $p < .007$; $t(28) = –4.01$, $p < .0004$, respectively. Chronological age did not significantly differ, $p > .1$. Overall, verbal and performance IQs neither differed significantly, $p > .1$ nor correlated, $r(45) = .264$, $p < .08$.

This research received approval from the Regional School Management Office and the Édouard Herriot Hospital, Lyon, France, for conducting the experiment. Profiles of the participants are summarized in Table 1.

Table 1. Chronological and reading level ages as well as verbal and nonverbal IQs for children with dyslexia (DY), chronological age–matched controls (CA), and reading level–matched controls (RL).

Group	*N* (boys/girls)	Chronological age	Range	Reading level	PIQ	VIQ
DY children	15 (9/6)	121.7 (13.6)	8;7-12;1	88.0 (4.4)	102.2 (8.0)	100.5 (9.1)
CA controls	15 (10/5)	120.9 (12.8)	8;7-12;4	136.9 (10.3)***	113.4 (7.3)	110.1 (8.8)
RL controls	15 (10/5)	83.8 (6.2)***	6;5-8;2	88.8 (4.7)	106.6 (6.2)	102.6 (8.1)

Note. Performance IQ as measured by Raven's Progressive Matrices for French Children (Raven, 1998); verbal IQas measured by WISC–III for French children (Wechsler, 1996). SDs appear in parentheses. Significant differences with DY children: * $p < .007$. ** $p < .0004$. *** $p < .0001$.

Material and design

Experimental stimuli included 24 seven-letter disyllabic pseudowords (Table 2). Letters within the pseudowords had regular grapheme-to-phoneme correspondences. Disyllabic pseudowords had an initial CVC syllable structure and intervocalic consonant sequence. Syllable boundaries were located within the consonant clusters (e.g., TOR.LADE). The intervocalic consonant sequences were considered as phonotactically illegal in the word-initial position.[1]

Consonant sonority (sonorant vs. obstruent) within the intervocalic consonant sequence was manipulated. A 2 × 2 (Coda Sonority × Onset Sonority) design provided four SPs: sonorant coda–sonorant onset (e.g., TOR.LADE), sonorant coda–obstruent onset (e.g., TOL.PUDE), obstruent coda–sonorant onset (e.g., DOT.LIRE), and obstruent coda–obstruent onset (e.g., BIC.TADE).

[1] We acknowledge that /pt / and /kt / are phonotactically attested consonant clusters, although rare, in oral French word-initial position (Dell, 1995). Also, "PT" is a "phonotactically legal" written consonant sequence in word-initial position. However, its initial bigram and biphone frequencies are 0 (Manulex-Infra; Peereman et al., 2007).

The mean positional bigram frequencies were calculated with a sublexical database (i.e., Surface) computed from the Lexique 2 database (occurrences per million were used; New, Pallier, Brysbaert, & Ferrand, 2004) for the bigrams that precede, straddle, and follow the syllable boundary; these bigrams were 2,536, 273, and 1,947, respectively. After the coda deletion, the bigrams that precede and follow the syllable boundary were 1,709 and 1,932, whereas after the onset deletion, the bigrams that precede and follow the syllable boundary were 1,676 and 2,018. High-frequency intervocalic consonant sequences were found within the obstruent coda–obstruent onset SPs (M = 538; e.g., CT [840]) and the sonorant coda–sonorant onset SPs (M = 477; e.g., RL [954]). Midfrequency ones were found within the sonorant coda–obstruent onset SPs (M = 75; e.g., LD [103]), and low-frequency ones were found within the obstruent coda–sonorant onset SPs (M = 3; e.g., TL [6]). Mean initial frequencies were estimated with the French sublexical Manulex-Infra database (Peereman, Lété, & Sprenger-Charolles, 2007) that provides sublexical frequencies in the initial position in words for French first- to fifth-grade readers. Initial frequencies for bigrams, trigrams, and syllables were 4,408, 48, 446 (CV), and 22 (CVC).

Auditory stimuli (always presented as target pseudowords and simultaneously with their printed counterpart) were recorded prior to the experiment by a French female speech and language therapist and converted into Sound Designer II format, sampled at a 44100-Hz rate in 16 bits stereo. Pseudowords were first presented as target pseudowords and then compared to test pseudowords. The target pseudoword (e.g., TOLPUDE) was related to three possible test pseudowords. One of them was identical to the target pseudoword (i.e., yes response), and the two others differed from the target pseudoword (i.e., no responses) after the cluster reduction, thus in either the coda deletion (i.e., TO.PUDE) or the onset deletion (i.e., TO.LUDE). The target pseudoword was repeated twice in the identical condition and twice in the deletion condition (i.e., once for coda deletion and once for onset deletion).

Table 2. Stimuli used in the Experiment.

Sonorant Coda		Obstruent Coda	
Sonorant Onset	Obstruent Onset	Sonorant Onset	Obstruent Onset
BILRATE	BULPOTE	BUDLOTE	BICTADE
BIRLOTE	PILDORE	DATLORE	BIPTADE
DALRITE	PULDITE	DOTLIRE	DACTULE
PURLIDE	TALPIDE	PIDLARE	DAPTOLE
TOLRUDE	TOLDARE	PITLUDE	DOPTILE
TORLADE	TOLPUDE	TADLITE	PUCTODE

Procedure

Children were individually tested in a single 15-min session. The script was designed and compiled with PsyScope 1.2.5 software (Cohen, McWhinney, Flatt, & Provost, 1993), and was run on a Macintosh PowerBook G4 laptop. Target pseudowords were always displayed on the left visual field and simultaneously pronounced by the computer through Altec Lansing AHS 502i headphones. Test pseudowords were always displayed on the right visual field.

Children sat at 57 cm from the screen. Both target and test pseudowords were black-colored uppercase letters typed in Arial font on a white background. Pseudowords covered approximately from 2.10° to 2.94° of visual angle. Trials progressed as follows: A vertically centered fixation cross (i.e., +) was displayed on the left visual field for 500 ms and immediately replaced by a mask (i.e., XXXXXXX) flashed for 75 ms. Then, the target pseudoword (e.g., TOLPUDE) was presented on the left visual field for 2,500 ms, with the corresponding auditory stimulus (duration of approximately 500 ms), and presented with the

onset of the visual stimulus. After that, a 250-ms blank screen preceded a second 75-ms flashed mask. Then, on the right visual field, a vertically angled 500-ms centered fixation cross appeared and was replaced by a 75-ms flashed mask before the visual test pseudoword (e.g., TOLPUDE, TOPUDE, or TOLUDE) was presented until the child responded. Finally, the test pseudoword was replaced by a 75-ms flashed mask. A 1,000-ms delay separated two consecutive trials. The test pseudoword was always displayed in the opposite visual field of the target pseudoword to prevent children from using visual matching strategies.

Children were first trained with a practice list and corrective feedback. No feedback was provided for the experimental trials. Children had to decide whether the test and target pseudowords were identical. Children were instructed to respond as quickly and accurately as possible. Stimuli were balanced and randomized across the lists. The software automatically recorded response times (RTs) and errors. The experimenter never intervened during the session.

Results

Analyses of variance (ANOVAs) were run by subject (*F*1) and by item (*F*2) on mean RTs and error percentages (17.8% of the data). Only RTs for correct responses were included in the analyses. Correct RTs were trimmed (i.e., for each subject, RTs off by more than two SDs were replaced by the mean RT of each subject [2.6% of the data]). A 3 × 2 × 2 × 2 mixed-designed ANOVAwith Group (DY, CA, and RL) as the between-subjects factor and Coda Sonority (obstruent vs. sonorant), Onset Sonority (obstruent vs. sonorant), and Condition (identical vs. deletion) as repeated measures was carried out on mean RTs and errors. Descriptive data are summarized in Table 3.

Table 3. Descriptive data for Condition (identical vs. deletion), Coda Sonority (sonorant vs. obstruent), Onset Sonority (sonorant vs. obstruent), and Deletion (coda vs. onset)) for children with dyslexia (DY), chronological age–matched controls (CA), and reading level–matched controls (RL).

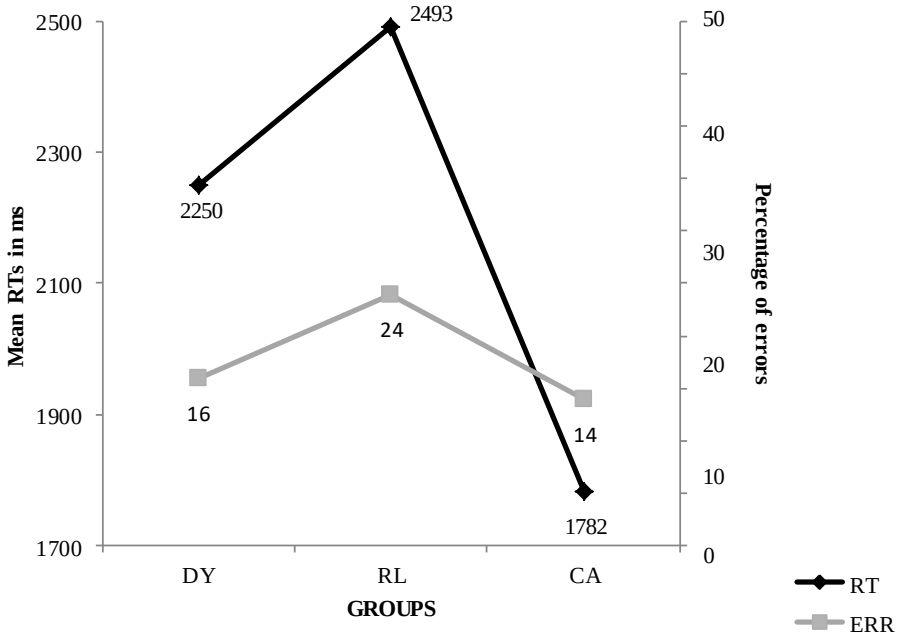
	identical condition				deletion condition							
	sonorant coda		obstruent coda		sonorant coda				obstruent coda			
	sonorant onset	obstruent onset	sonorant onset	obstruent onset	sonorant onset		obstruent onset		sonorant onset		obstruent onset	
					coda deletion	onset deletion	coda deletion	onset deletion	coda deletion	onset deletion	coda deletion	onset deletion
DY children	2193 (374)	1868 (256)	2229 (364)	2333 (388)	2337 (333)	2775 (379)	1993 (458)	2472 (393)	2645 (430)	2076 (305)	1999 (313)	2457 (487)
	4.4% (5.3)	5.6% (7.5)	6.7% (7.2)	3.9% (4.3)	26.7% (20.7)	26.7% (27.3)	33.3% (28.2)	27.8% (22.4)	18.9% (21.7)	23.3% (22.5)	25.6% (20.8)	24.4% (21.7)
CA controls	1671 (157)	1442 (163)	1847 (135)	1896 (191)	1980 (194)	2065 (329)	1424 (323)	1962 (243)	1679 (313)	1916 (205)	1825 (430)	1947 (437)
	7.2% (6.2)	3.9% (6.2)	6.7% (5.6)	5.6% (5.1)	18.9% (16.5)	16.7% (15.4)	22.2% (12.1)	24.4% (10.7)	25.6% (19.8)	26.7% (18.7)	22.2% (17.4)	20.0% (21.1)
RL controls	2424 (353)	2338 (496)	2456 (512)	2323 (394)	2488 (429)	2614 (322)	2678 (579)	2614 (514)	2738 (592)	2449 (438)	2630 (368)	2587 (529)
	16.1% (15.9)	12.8% (9.9)	6.7% (9.0)	18.3% (15.5)	26.7% (23.4)	30.0% (23.7)	46.7% (28.3)	30.0% (30.3)	35.6% (29.5)	33.3% (27.5)	32.2% (27.8)	38.9% (30.0)

*Note. SD*s appear within parentheses.

Error percentages

Performance varied between groups (Figure 1) on errors, $F1(2, 42) = 4.97$, $p = .01$, $\eta^2 = .19$, $F2(2, 176) = 16.51$, $p < .001$, $\eta^2 = .16$. Post hoc tests showed that RL controls (23.8%) made more errors than CA controls (13.9%; Fisher's least significant difference [LSD] = .006) and DY children (16.1%; Fisher's LSD = .02). There were no significant differences between CA controls and DY children. Further, children made more errors in the deletion condition (27.4%) than in the identical condition (8.1%), $F1(1, 42) = 58.66$, $p < .001$, $\eta^2 = .58$, $F2(1, 88) = 25.05$, $p < .001$, $\eta^2 = .20$.

Figure 1. Mean response times (RTs) in ms and percentage of errors (ERR) for all conditions in children with dyslexia (DY), chronological age–matched controls (CA), and reading level–matched controls (RL).



Response times

Performance varied between groups (Figure 1) on RTs, $F1(2, 42) = 5.71$, $p < .006$, $\eta^2 = .21$, $F2(2, 176) = 156.47$, $p < .001$, $\eta^2 = .64$. Post hoc tests revealed that CA controls (1,782 ms) responded more rapidly than RL controls (2,493 ms; Fisher's LSD = .002) and DY children (2,250 ms; Fisher's LSD = .03). There were no significant differences between RL controls and DY children. Thus, the main effect of Condition showed that children responded more rapidly to the identical condition (2,085 ms) than the deletion condition (2,265 ms), $F1(1, 42) = 11.64$, $p = .001$, $\eta^2 = .22$, $F2(1, 88) = 17.73$, $p = .0002$, $\eta^2 = .15$. In the identical condition, we found two main effects of Coda Sonority and Onset Sonority, $F1(1, 42) = 30.13$, $p < .001$, $\eta^2 = .42$, $F2(1, 44) = 30.93$, $p < .001$, $\eta^2 = .41$; $F1(1, 42) = 3.56$, $p = .06$, $\eta^2 = .08$, $F2(1, 44) = 5.38$, $p = .03$, $\eta^2 = .11$ respectively. The children responded faster to sonorant codas (1,989 ms) than obstruent ones (2,181 ms) and faster to obstruent onsets (2,033 ms) than sonorant ones (2,137 ms).

Furthermore, the Coda Sonority × Onset Sonority interaction was significant (Figure 2), $F1(1, 42) = 5.82$, $p = .02$, $\eta^2 = .12$, $F2(1, 44) = 15.01$, $p = .0004$, $\eta^2 = .25$. Post hoc tests confirmed that children responded more quickly to identical target and test pseudowords with a sonorant coda–obstruent onset SP (1,883 ms) than a sonorant coda–sonorant onset SP (2,096 ms; Fisher's LSD = .002), an obstruent coda–obstruent onset SP (2,184 ms; Fisher's LSD < .001), and an obstruent coda-sonorant onset SP (2,177 ms; Fisher's LSD < .001). In the deletion condition, coda deletion (2,201 ms; e.g., TO.PUDE for TOL.PUDE) was detected more quickly than onset deletion (2,328 ms; e.g., TO.LUDE for TOL.PUDE), $F1(1, 42) = 4.90$, $p = .03$, $\eta^2 = .10$, $F2(1, 40) = 9.47$, $p = .004$, $\eta^2 = .19$. Finally, we observed a significant Coda Sonority × Onset Sonority × Deletion (Figure 3), $F1(1, 42) = 4.97$, $p = .01$, $\eta^2 = .19$, $F2(1, 40) = 11.11$, $p = .003$, $\eta^2 = .13$. Post hoc tests are summarized in Table 4.

Figure 2. Mean response times (RTs) in ms for the Coda Sonority × Onset Sonority interaction in the identical condition for all Groups.

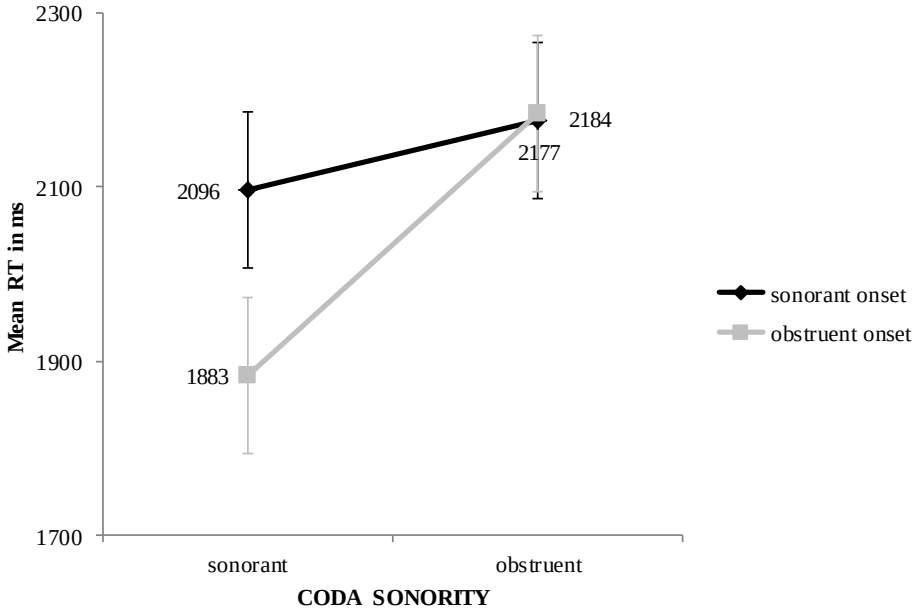
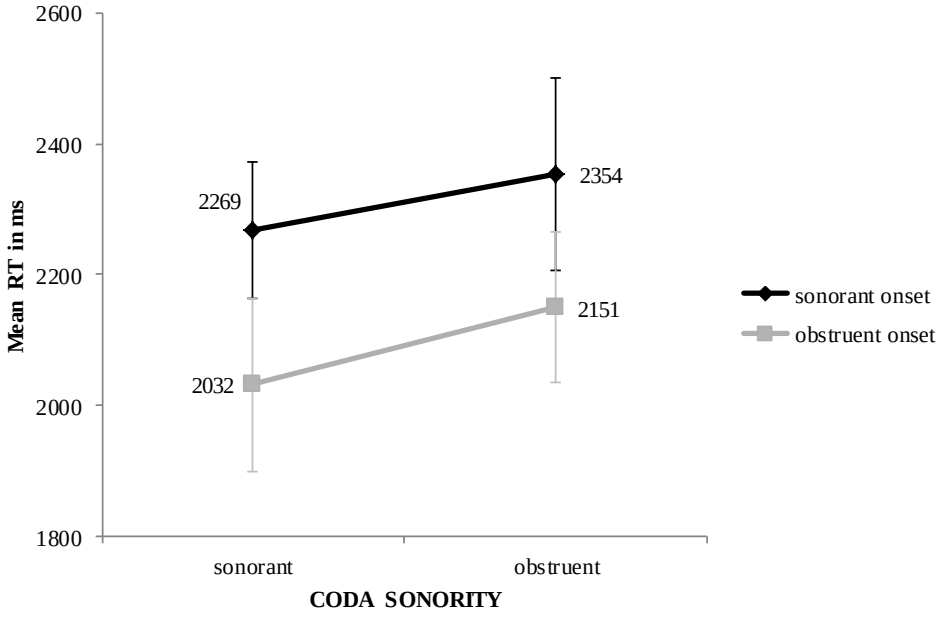


Figure 3. Mean response times (RTs) in ms for the Coda Sonority × Onset Sonority × Deletion interaction in the deletion condition for all Groups (upper panel: coda deletion; lower panel: onset deletion).



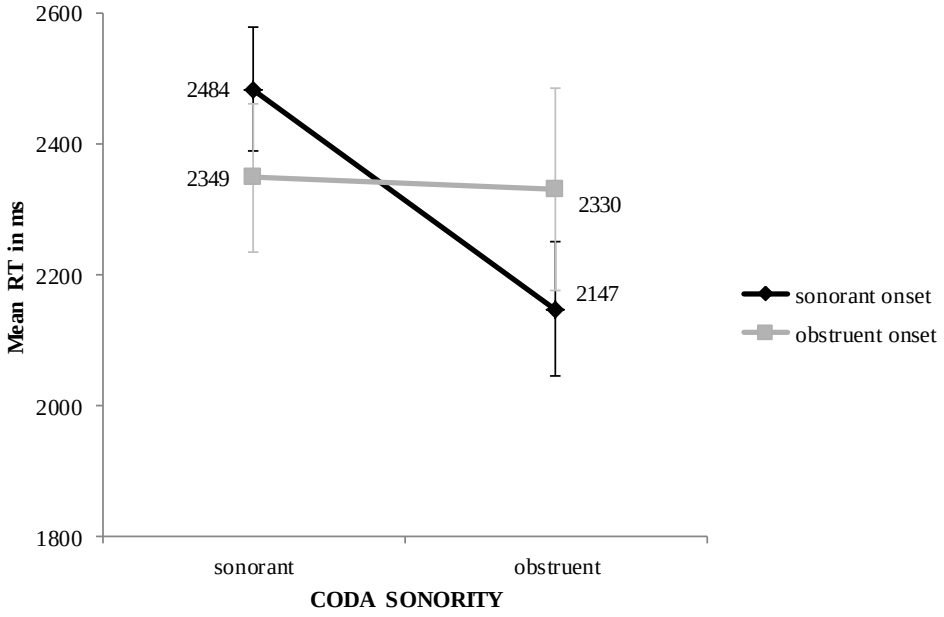


Table 4. Post-hoc Fisher's least significant difference (LSD) tests of the Coda Sonority (sonorant vs. obstruent) × Onset Sonority (sonorant vs. obstruent) × Deletion (coda vs. onset)) interaction for all groups in the deletion condition.

deletion condition						
Profile 1	Example 1	*M* & *SD*	Profile 2	Example 2	*M* & *SD*	Post-hoc Fisher's LSD
sonorant coda sonorant onset coda deletion	e.g., PULIDE instead of PURLIDE	2268 (724)	sonorant coda obstruent onset coda deletion	e.g., TOPUDE instead of TOLPUDE	2032 (1016)	Fisher's LSD = .03
sonorant coda sonorant onset onset deletion	e.g., PURIDE instead of PURLIDE	2484 (668)	obstruent coda sonorant onset onset deletion	e.g., DOTIRE instead of DOTLIRE	2147 (712)	Fisher's LSD = .002
sonorant coda sonorant onset onset deletion	e.g., PURIDE instead of PURLIDE	2484 (668)	obstruent coda obstruent onset coda deletion	e.g., BITADE instead of BICTADE	2151 (831)	Fisher's LSD = .002
sonorant coda sonorant onset onset deletion	e.g., PURIDE instead of PURLIDE	2484 (668)	sonorant coda obstruent onset coda deletion	e.g., TOPUDE instead of TOLPUDE	2032 (1016)	Fisher's LSD = .0001
sonorant coda obstruent onset onset deletion	e.g., TOLUDE instead of TOLPUDE	2349 (794)	sonorant coda obstruent onset coda deletion	e.g., TOPUDE instead of TOLPUDE	2032 (1016)	Fisher's LSD = .003
obstruent coda sonorant onset coda deletion	e.g., DOLIRE instead of DOTLIRE	2354 (1071)	sonorant coda obstruent onset coda deletion	e.g., TOPUDE instead of TOLPUDE	2032 (1016)	Fisher's LSD = .003
obstruent coda sonorant onset coda deletion	e.g., DOLIRE instead of DOTLIRE	2354 (1071)	obstruent coda sonorant onset onset deletion	e.g., DOTIRE instead of DOTLIRE	2147 (712)	Fisher's LSD = .05

Note. M: Mean response times in milliseconds; *SD*: standard deviations within parentheses.

Discussion

Objectives of this preliminary study were twofold. We investigated whether French-speaking children with dyslexia compared with chronological age–matched and reading level–matched controlswere sensitive to consonant sonority (sonorant vs. obstruent) and consonant position (coda vs. onset) within intervocalic consonant sequences to influence a phonological syllable-based segmentation.

As we first hypothesized, children were sensitive to the optimal sonorant coda–obstruent onset SP within syllable boundaries (e.g., LP in TOL.PUDE) compared with any other SPs. This conforms to the Murray and Vennemann (1983) syllable contact law: Schematically, the optimal contact between consecutive syllables that bears an intervocalic consonant sequence embodies a high-sonority coda followed by a low-sonority onset. We dismiss the idea that the positional bigram frequency basically influences the optimal sonorant coda–obstruent onset SP within syllabic boundaries. The bigram trough hypothesis cannot fully account for performances (Seidenberg, 1987): The positional bigram frequency embedded within the intervocalic consonant sequence stresses the syllable boundary because it is less frequent than the positional bigramfrequencies that surround the intervocalic consonant sequence. Although we found a bigram trough within the sonorant coda–obstruent onset SP (e.g., in PIL.DORE, IL [3,262], LD [103], and DO [314]), the obstruent coda–sonorant onset SP (e.g., in DOT.LIRE, OT [2,455], TL [6], and LI [2,512]), and the sonorant coda–sonorant onset SP (e.g., in PUR.LIDE, UR [7,811], RL [954], and LI [2,512]), the obstruent coda–sonorant onset and sonorant coda–sonorant onset SPs were not processed significantly more rapidly than the obstruent coda–obstruent onset SP. Similarly, low-frequency SPs found within the obstruent coda–sonorant onset SPs as well as high-frequency SPs found within the obstruent coda–obstruent onset and sonorant coda–sonorant onset SPs were not processed more quickly than the mid-frequency SPs found within the optimal sonorant coda–obstruent onset SPs.

Correlatively, children also exhibited an asymmetry regarding consonant sonority: Sonorant codas were processed more quickly than obstruent codas, whereas obstruent onsets were detected more quickly than sonorant onsets. Our results can be interpreted by the French language–specific statistics: Low-sonority consonants prevail in onsets but are rare in codas, whereas high-sonority consonants prevail in codas but are rare in onsets in CVC syllables (e.g., 70% of sonorant codas vs. 30% of obstruent ones; Wioland, 1985). For all children, response times were faster for identical test pseudowords with optimal SP; unexpectedly, the DY children exhibited the same position-dependent consonant sonority preference as the CA and RL controls. This result is straightforwardly compatible with previous results of Blomert, Mitterer, and Paffen (2004) or Nittrouer (1999), who demonstrated normal sensitivity to acoustic–phonetic and phonological contexts in speech perception in children with dyslexia. They proposed that children with dyslexia could strongly rely on contextually dependent coarticulation cues rather than locally dependent cues to achieve phonological processing. Blomert et al. (2004) concluded that phonological deficits in developmental dyslexia may be related to deficits in online phonetic–phonological processing rather than deficits in phonetic–phonological representations. Following this conclusion, unsurprisingly, we observed that CA controls systematically outperformed RL controls. However, DY children outperformed RL controls but did not differ from CA controls regarding accuracy, whereas they underperformed CA controls and did not differ fromRL controls regarding speed. This pattern is also compatible with the hypothesis of Ramus and Szenkovits (2008), who proposed that the DY children might not have basically degraded phonological representations; impaired phonological processes, coupled with a well-known inefficient phonological shortterm memory (e.g., Sprenger-Charolles, Colé, Lacert, & Serniclaes, 2000), might slow down the reading.

Children also processed identity more quickly and more accurately than deletion. Furthermore, children detected the coda deletion (e.g., TO.PUDE instead of TOL.PUDE) more quickly than the onset deletion (e.g.,TO.LUDE instead of TOL.PUDE). Referring to our two alternative hypotheses, children detected preserved syllabification faster than resyllabification. Accordingly, we assume that our results are compatible with a left to-right process (serial hypothesis). However, we acknowledge that the preference for preserved syllabification over resyllabificationmight refer to either an orthographic left-to-right process—without any use of phonological processing—or a phonological grapho-phonemic processing (sequential phonological decoding process based on the grapheme-to-phonemecorrespondences). Our

current results do not allow disentangling both interpretations. In addition, we highlight that the deletion depended on the consonant sonority. Although we did not find clearcut evidence that sonorant coda deletion was detected more quickly than obstruent coda deletion as in the Sprenger-Charolles and Siegel (1997) study, an insightful overview of Table 4 shows sonority-modulated deletion performance. The children were quicker to detect the consonant deletion, which systematically provided both an optimal low-sonority onset and an optimal syllable contact (e.g., DO.TIRE is processed more quickly than DO.LIRE or TO.PUDE is processed more quickly than DO.LIRE). Nevertheless, we observe that the sonorant coda deletion within an optimal SP (e.g., L in TOL.PUDE) was systematically processed more rapidly. We propose that the children were quicker to detect the mismatch between the target and test pseudoword because a sonorant coda respects the maximal cohesiveness with the vowel (Clements, 1990). We hypothesize that the acoustic–phonetic properties are properly encoded as syllabically embedded within the CVC syllable when the cohesiveness is optimal. As proposed by Altmann (1997), a syllable-based segmentation in French is influenced by coarticulation and the cohesiveness between the vowel and the coda. For instance, in BA.LANCE (scale), coarticulation from the L on the vowel is low, so the L is assigned to the second syllable, whereas in BAL.CON (balcony), coarticulation from the L on the vowel is high, so the L is assigned to the first syllable. However, we point out that if the cohesiveness is important, the contact between syllables that results from the coda deletion has also to conform to the optimal contact law (i.e., the deletion of L in TOL.PUDE was detected more quickly than L in DAL.RITE or T in DOT.LIRE). Although the vowel-coda sound pattern may respect the sonority sequencing principle (e.g., TOL.PUDE), we claim that the coda deletion provides a prototypical CV syllable that depicts the universally optimal SP, which can account for a phonological syllablebased segmentation. This is basically congruent with Sprenger-Charolles and Siegel (1997), who showed that children tended to primarily match syllable representations to an optimal and overrepresented CV syllable, whereas the consonant deletion relied on their sonority properties.

Overall, our findings are consistent with those of Maïonchi-Pino, de Cara, Écalle, and Magnan (in press, 2012). Using a modified version of the illusory conjunction paradigm, Maïonchi-Pino et al. investigated whether consonant status and consonant sonority within syllable boundaries influenced printed two-colored CVC.CVC disyllabic pseudoword processing in French-speaking children with normal versus impaired reading skills. They extended Fabre and Bedoin's (2003) method, controlling target-letter status (coda vs. onset) and designing four SPswithin the intervocalic consonant sequence (sonorant coda–sonorant onset, sonorant coda–obstruent onset, obstruent coda–obstruent onset, and obstruent coda–sonorant onset). Maïonchi-Pino et al. consistently evidenced that children, even children with reading impairment, mademore illusory conjunction preservations (i.e., they reported that the target letter P in TOL.Pude or L in TOl.pude was the same color as ude or TO, respectively) than illusory conjunction violations (i.e., they reported that the target letter P in TOL.pude or L in TOL.pude was the same color as TOL or pude, respectively). Of interest is that Maïonchi-Pino et al. evidenced that children showed early and long-lasting benefit from a sonority-modulated sensitivity to progressively use a syllable-sized segmentation: Illusory conjunction preservations increased whereas illusory conjunction violations decreased within the sonorant coda–obstruent onset SP, whether in children with dyslexia or in children with no reading impairment. However, the authors concluded that sonority is a relevant acoustic–phonetic cue within the syllable boundaries, whereas the syllablebased segmentation appeared to be developmentally constrained by reading skills and age.

Our results underpin a robust, early, skill-independent sonority-modulated segmentation during reading acquisition, even in children with reading impairments. Indeed, no significant statistical difference on withinsubject factors was revealed by the 2 × 2 ANOVAs (DY vs. CA, and then RL controls, not described in this article). Thus, we propose that children have developed a reliable language-specific sensitivity to sonority-related cues within the syllable boundaries. In this study, all children, including those with dyslexia and their age- and reading level–matched controls, were sensitive to the optimal sonorant coda–obstruent onset SP within intervocalic onsonant sequences and sonority-modulated deletion in silent reading, although children with dyslexia are basically described as having degraded and underspecified phonological representations. Our results indicate that the sonority seems not to be an impaired acoustic–

phonetic component as evidenced with voicing (e.g., Magnan et al., 2004). Children with dyslexia might suffer from selective acoustic–phonetic disorders that do not affect the sensitivity to sonority (see also Fabre & Bedoin, 2003).

For several years, studies have shown that computerassisted interventions can lead to improvements in French children's reading skills by focusing on phonological grapho-syllabic units (for a review, see Écalle, Magnan, & Calmus, 2009). More specifically, we suggest that a syllable- and sonority-based training could be envisaged as essential for syllable awareness development in languages sharing common characteristics with French, such as Spanish, Italian, or Portuguese. A mixed phonological and acoustic–phonetic training might support the improvement of reading skills in DY children and provide further knowledge about language learning. We acknowledge that further investigation is required to assess how phonological sonority-modulated syllablebased segmentation is involved. We are currently pursuing the issues raised by this report.

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