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Abstract

The present study describes two French teenagers with developmental reading and writing impairments whose performance was compared to that of chronological age and reading-age matched non-dyslexic participants. Laurent conforms to the pattern of phonological dyslexia: he exhibits a poor performance in pseudo-word reading and spelling, produces phonologically inaccurate misspellings but reads most exception words accurately. Nicolas, in contrast, is poor in reading and spelling of exception words but is quite good at pseudo-word spelling, suggesting that he suffers from surface dyslexia and dysgraphia. The two participants were submitted to an extensive battery of metaphonological tasks and to two visual attentional tasks. Laurent demonstrated poor phonemic awareness skills but good visual processing abilities while Nicolas showed the reverse pattern with severe difficulties in the visual attentional tasks but good phonemic awareness. The present results suggest that a visual attentional disorder might be found to be associated with the pattern of developmental surface dyslexia. The present findings further show that phonological and visual processing deficits can dissociate in developmental dyslexia.

key words

reading, developmental dyslexia, phonological skills, visual processing.

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INTRODUCTION

An impressive number of group studies have shown that individuals with developmental dyslexia exhibit impairments in tasks that involve phonological processing. Dyslexic participants are poor at non-word repetition (Snowling, 1981) and pseudo-word reading (Rack, Snowling & Olson, 1992). They have difficulties in object naming (Snowling, Wagtendonk & Stafford, 1988) and phonemic fluency (Frith, Landerl & Frith,1995). They have poor short-term memory (e.g., Nelson & Warrington, 1980), poor phonemic awareness (e.g., Bradley & Bryant, 1978; Morais, Cluytens & Alegria, 1984) and difficulty using phonological cues in verbal memory tasks (Rack, 1985). Finally, the persistence of phonological difficulties in well-compensated adult dyslexics has been pointed out (Bruck, 1992; Fawcett & Nicolson, 1995) suggesting that the phonological deficit is the core problem in developmental dyslexia and might be at the origin of this learning disorder.

Many data showing a strong link between phonological processing ability and learning to read are compatible with such a causal relationship. Children's knowledge of the phonological structure of language is a good predictor of early reading ability (e.g., Bradley & Bryant, 1983; Lundberg, Olofsson & Wall, 1980). Phonological awareness is strongly related to reading progress (e.g., Morais, Cary, Alegria & Bertelson, 1979; Wimmer, Landerl, Linortner & Hummer, 1991; for a review see Goswami & Bryant, 1990). Phonemic awareness instruction improves reading development (e.g., Davidson & Jenkins, 1994; Defior & Tudela, 1994; Ehri, Nunes, Willows, Schuster, Yaghoub-Zadeh & Shanahan, 2001; Farmer, Nixon & White, 1976; Hatcher, Hulme & Ellis, 1994; Lundberg, Frost & Petersen, 1988; Schneider, Kuspert, Roth, Vise & Marx, 1997). All these findings have led to the formulation of the phonological deficit hypothesis (Frith, 1997;

Snowling, 1987; Wilding, 1989, 1990) according to which developmental dyslexia results from an underlying phonological impairment.

Nevertheless, visual processing deficits have also been reported in developmental dyslexia. In particular, a disturbance of the magnocellular pathway is well documented on the basis of data showing longer-lasting visible persistence (Dilollo, Hanson & McIntyre, 1983; Martin & Lovegrove, 1984; Slaghuis & Lovegrove, 1984; Slaghuis, Lovegrove & Davidson, 1993; Stein, 1991), less sensitivity to low contrast (Livingstone, Rosen, Drislane & Galaburda, 1991; Lovegrove, Martin & Slaghuis, 1986; Stein, Talcott & Walsh, 2000) and abnormal processing of visual motion (Cornelissen, Richardson, Mason, Fowler & Stein, 1995; Eden, VanMeter, Rumsey, Maisog, Woods & Zeffiro, 1996; Demb, Boynton & Heeger, 1998) in developmental dyslexia. The magnocellular deficit occurs in most dyslexic participants (Lovegrove et al., 1986) together with the phonological disorder (Slaghuis et al., 1993). As a consequence, this visual deficit is rather viewed as a marker symptom, not directly involved in the origin of dyslexia (Frith, 1997; Kruk & Willows, 2001).

Other visual processing dysfunctions have been pointed out in developmental dyslexia (Willows, Kruk & Corcos, 1993). Differences between dyslexics and good readers have been reported in tasks of search for a target among distractors (Marendaz, Valdois & Walch, 1996) and in localisation tasks (Graves, Frerichs & Cook, 1999; Facoetti, Paganoni, Turatto, Marzola & Mascetti, 2000) suggesting a visual attentional disorder (see also Brannan & Williams, 1987). Also compatible with the visual attentional deficit hypothesis, some studies pointed out that dyslexic participants have difficulty inhibiting information from the periphery of the visual field (Geiger, Lettvin & Zegarra-Moran, 1992; Geiger, Lettvin & Fahle, 1994; Rayner, Murphy, Henderson & Pollatsek, 1989).

Evidence from single case studies and from studies taking into account the heterogeneity of the dyslexic population suggests however that phonological and visual processing disorders are not found in all subtypes of developmental dyslexia. Developmental phonological dyslexia is characterised by poor pseudoword reading but preserved ability to read consistent and inconsistent words (Temple & Marshall, 1983; Campbell & Butterworth, 1985; Snowling, Stackhouse & Rack, 1986; Funnel & Davison, 1989; Snowling & Hulme, 1989; Broom & Doctor, 1995a; Howard & Best, 1996; Temple, 1997). Children primarily rely on a global reading procedure based on activation of specific word knowledge so that lexicalisation errors typically occur on pseudowords. A similar pattern characterises written productions with selective difficulties in pseudoword spelling and errors that violate phonological plausibility. Poor phoneme awareness has been systematically reported in this subtype of dyslexia together with a verbal short-term memory deficit. Phonological dyslexia is therefore interpreted as resulting from a phonological disorder. The few studies that investigated visual processing abilities according to dyslexia subtypes also concluded there was an associated low level perceptual deficit (magnocellular impairment) in these children (Borsting, Ridder, Dudeck, Kelley, Matsui & Motoyama 1996; Cestnik & Coltheart, 1999).

Children with surface dyslexia exhibit a quite different pattern (Job, Sartori, Masterson & Coltheart,1984; Temple, 1984; Goulandris & Snowling, 1991; Hanley, Hastie & Kay, 1992; Romani & Stringer, 1994; Broom & Doctor, 1995b; Hanley & Gard, 1995; Castles & Coltheart, 1996; Romani, Ward & Olson, 1999; Samuelsson, 2000). They are impaired in inconsistent word reading but not in pseudo-word reading. Their reading depends heavily on the use of an analytic reading procedure based on activation of general knowledge about spelling-sound correspondences. So, most reading errors are regularisations. With respect to spelling, they exhibit selective difficulties on inconsistent words and make a high proportion of phonologically plausible errors. In contrast to phonological dyslexics, surface dyslexics show no evidence of impairment in tasks involving phonological awareness or phonological short term memory. They seem also unimpaired in tasks of low level visual processing (Borsting et al., 1996; Spinelli, Angelelli, De Luca, Di Pace, Judica & Zoccolotti, 1997; Cestnik & Coltheart, 1999). A problem with visual memory was reported in one young adult with developmental surface dyslexia (JAS, Goulandris & Snowling, 1991). However, all other reported cases showed evidence of good performance in visual memory tasks. The absence of evidence for an associated disorder in developmental surface dyslexia and the fact that their reading pattern -- inconsistent words read with less accuracy than pseudo-words -- is similar to that of younger normal readers has led some to interpret this disorder as just reflecting a delay in the acquisition of reading skills (Manis, Seidenberg, Doi, McBride-Chang & Petersen, 1996; Stanovitch, Siegel & Gottardo, 1997; Harm & Seidenberg, 1999). However, Romani et al. (1999) identified a selective deficit of order encoding in AW, a young adult with developmental surface dysgraphia. They hypothesised that this problem would lead to underspecified orthographic representations and reinforce a reading strategy based on partial word features. Valdois (1996) reported a case of developmental surface dyslexia, Clement, who also picked up partial information from words to be read and exhibited an associated visual processing disorder in a task of search for a target among distractors. The analysis of eye-movement patterns in reading revealed alteration of eye movements in surface dyslexia suggesting that words were parsed into sub-units while reading (De Luca, Di Pace, Judica, Spinelli& Zoccolotti, 1999). Their atypical pattern of eye-movements was interpreted as secondary to a defect in visual processing. The aim of the present paper was to assess whether a phonological deficit was associated to developmental phonological dyslexia in the absence of (high level) visual processing impairment. It was hypothesised that the reverse pattern might be found in surface dyslexia, good phonological but poor visual processing abilities.

For this purpose, the performance of two French teenagers with contrasted patterns of developmental reading and spelling impairments was studied. The two participants were closely matched in terms of reading age and were given the same set of tests under similar conditions. They had received only minimal or no help for their reading difficulties during childhood and, in particular, they had been given no specific reading instruction emphasising a phonic approach. The two dyslexic participants were submitted to a battery of metaphonological tasks and to two visual processing tasks. It will be shown that the surface dyslexic participant exhibits a visual processing disorder that is not found in the other participant with phonological dyslexia. In contrast, the phonological dyslexic participant demonstrates a phoneme awareness disorder whereas the surface dyslexic does not. Overall, the present study suggests that different kinds of cognitive deficits are associated with phonological and surface developmental dyslexia.

CASE REPORTS

The two dyslexic teenagers who took part in this study were right-handed male native French speakers of average intelligence. Characteristics of the two participants are summarised in Table 1.

Table 1: Characteristics of the Two Participants.

	Laurent	Nicolas
Chronological age (months)	176	157
Reading age (months)	102	98

Full IQ	110	104
Grade level	7th	6th
Word repetition	92/92	92/92
Pseudo-word repetition	89/92	89/92
Peabody score	113	94
Verbal fluency		
Semantic criterion	21	19
Formal criterion	7	12
Verbal Short Term Memory		
Digit span forward	6	7
Digit span backward	2	5
Short word span	4	5
Long word span	2	5
Corsi span	5	5

As shown in Table 1, Laurent was 14 years 8 months old at the time of testing, Nicolas was 13 years 1 month old. None of them reported any history of neurological disorder or severe problems in speech and language development. Hearing was found to be normal as well as visual acuity in both of them. There was no family history of learning disabilities or psychiatric illness. They both received conventional reading instruction when attending primary school. Although Laurent repeated Grade 1 twice because of his difficulties in learning to read, he was not diagnosed as dyslexic and received no special help during primary school. He was in 7th grade at the time of testing and was given remedial reading instruction for one year. Nicolas reported difficulties in reading and spelling from the first Grade. He repeated Grade 5 but never received special help for his reading and spelling difficulties. He was in 6th Grade at the time of testing. Both Laurent and Nicolas acknowledged they did not like to read and avoid reading as often as possible. On the

« Alouette Reading Test »[1] (Lefavrais, 1965), Laurent and Nicolas achieved a reading age of 8 years 6 months and 8 years 1 month respectively, demonstrating the persistence of severe reading difficulties. An investigation of their oral language skills showed average performance on tasks of repetition and vocabulary. Although they performed similarly on a verbal fluency test using a semantic criterion, Laurent scored poorly when asked to name words beginning with /p/. On this latter task, Nicolas named 12 words without any error (a score within the normal range of 7th grade children; mean=11.6, SD=3.7). With respect to verbal short term memory, Laurent's performance was inferior to that of Nicolas on the digit span (forward and backward) and on the word span for both short and long words. Nicolas had a normal span for both digits (forward and backward) and (short and long) words. Overall, their performance essentially differs on tasks of formal verbal fluency and verbal short-term memory in which Laurent alone is impaired.

Test of reading ability

Laurent and Nicolas were asked to read aloud a mixed list of 40 highly consistent words (20 high frequency (HF) and 20 low frequency (LF) words) and 40 highly inconsistent words matched on frequency, word length and grammatical class. The 80 words were written (lower case, Times 14) in columns on a white sheet and presented without time limitation. The two participants were further submitted to a test of pseudo-word reading. The 90 pseudo-words were 4-to-8 letters long and made up of 1-to-3 syllables. They were constructed from a list of 90 consistent words by substituting the vowels (for example, the pseudo-word « fégore » was constructed from the word

[1] The Alouette Reading Test requires children to read a 265-word text as quickly and accurately as possible. The text includes unfamiliar words and avoids guessing based on world knowledge. It measures the number of words read in 3

« figure » *face*). The list of source words was also given in reading to enable comparison between strictly matched lists of words and pseudo-words. Words and pseudo-words written in columns (lower case, Times 14), were presented on separate sheets. The participants were instructed of the nature of the items and asked to read them aloud as quickly and accurately as possible. Their performance was compared to that of a reading-age matched (RA=3rd Grade) control group (N=50; mean CA= 103.6, SD=3.7; mean RA=98.4, SD=3.1, range: 96-110). Performance of a school-level (SL) control group is also provided for comparison (N=24; mean CA=152, SD=3.7; mean RA=147.9, SD=11, range: 131-171). Children from the control groups were submitted to the same lists of consistent and inconsistent words but to a reduced list of only 40 pseudo-words having the same characteristics as the extended list proposed to Laurent and Nicolas. Processing time on the lists of pseudowords and matched words was taken into account. It corresponded to the time taken to read each list of 20 items. Since control subjects were submitted to shorter lists, time needed to read the entire list was divided by the number of items to have an estimation of reading speed per word and pseudo-word.

Results

As can be seen in Table 2, Laurent and Nicolas have identical reading scores on consistent words (37/40) but differ significantly in their ability to read inconsistent words (35/40 vs. 23/40; $\chi^2 = 7.59$, $p<.01$). Laurent demonstrates no dissociation between consistent and inconsistent words (37/40 vs. 35/40) suggesting that both types of words are read using the global procedure. In contrast, a strong dissociation (consistent words=37/40; inconsistent words=23/40; $\chi^2 = 11.27$,

minutes with one point deducted for each word read with errors. The reading level is therefore established from both p<.001) characterises Nicolas' performance. When compared to SL controls, Laurent's scores on both consistent and inconsistent words are within the normal range. Nicolas' performance on inconsistent words is lower than the mean performance of SL control children and is even outside the normal range when compared to the SL sample. However, his overall reading pattern on words resembles that of younger controls.

Table 2

Performance of Laurent and Nicolas on Reading, Writing and metaphonological Tasks as compared with Means, Standard Deviations, Ranges and Reaction Rime from two Samples of Reading Age and School Level controls.

	Laurent		Nicolas		SL controls			RA controls		
Word reading	Score	Time	Score	Time	Score	Range	Time	Score	Range	Time
Consistent HF	19/20		20/20		19.9 (0.3)	19-20		19.5 (0.8)	17-20	
Consistent LF	18/20		17/20		19.3 (0.8)	18-20		18.1 (1.4)	14-20	
Inconsistent HF	19/20		15/20		19.9 (0.3)	19-20		16.8 (2.0)	12-20	
Inconsistent LF	16/20		8/20		17.7 (1.3)	15-20		9.7 (3.6)	1-17	

reading accuracy and reading speed.

Pseudo-word reading	87.8%	2.9 sec/w	84.4%	2.2 sec/w	85.5% (6.5)	75-100	0.9	82.4% (10.3)	57-100	1.9
Matched words	94.4%	1.3 sec/w	86.7%	1.5 sec/w	98% (1.7)	93-100	0.6	94% (5.6)	77-100	1.5
Lexicalisations	54%		7%		2.1%					
Visual errors (PW)	36%		93%		30%					
Words writing										
Consistent	16/22		13/22		20.7 (1.7)	16 - 22		19.15 (1.91)		
Inconsistent	13/22		13/22		19.9 (1.8)	15 - 22		16.19 (3.68)		
Higly inconsistent	8/22		6/22		17.9 (2.9)	10 - 22		12.27 (4.61)		
%PPEs	68.9% (20/29)		91.2% (31/34)		80.5%			72.6%		
PseudoWord writing	26/40		35/40		36.5 (2.2)	31 - 40		26.36 (4.72)		
Metaphonology										
Rhyme judgement	78/80		78/80		78 (4.7)	76 - 80		-----		
Sound categorisation	10/20		17/20		16.4 (2.6)	11 - 20		13.2 (2.4)	9 - 19	
Phoneme deletion	10/20		20/20		18.7 (1.9)	13 - 20		16.6 (2.5)	12 - 20	
Phon. segmentation	12/20		19/20		16.4 (2.6)	11 - 20		14.0 (2.3)	7 - 18	
Spoonerisms	0/12		12/12		10.0 (2.0)	2 - 12		------		
Syllable deletion	6/20		18/20		18.1 (2.0)	11 - 20		------		

An analysis of the nature of errors on inconsistent words revealed that almost all misreadings corresponded to regularisation errors in Nicolas (N=16/17; errors are listed in Appendix A). From the five errors collected in Laurent, three were regularisations and two corresponded to the production of another real word (dolmen /dolmèn/ *dolmen* -> domaine /domèn/ *property*; paon /pâ/ *peacock* -> pont /pô/ *bridge*).

Laurent's performance in pseudo-word reading did not differ significantly from that of Nicolas (79/90 vs. 76/90; χ^2 =0.19, NS) and was comparable in accuracy to that of SL controls. With respect to reading speed, both Laurent and Nicolas read pseudo-words more slowly than real words but the speed difference was far stronger in Laurent who took more than twice as much time to read pseudo-words as to read words (1.3 sec/word vs. 2.9 sec/pseudo-word). Both participants read words and pseudo-words more slowly than SL controls. The time taken by Nicolas was comparable to the time needed for RA matched controls (with a performance at the 30th and 45th percentile for pseudo-words and words respectively). Although Laurent's word reading time was faster than the mean performance of RA children (=70th percentile), he took a quite longer time to read pseudo-words (=5th percentile). Overall, Laurent exhibited a poor performance on pseudo-words but showed a normal word advantage effect in reading (better accuracy and higher speed). In contrast, Nicolas read words and pseudowords the same way, a pattern that is not found even in RA control children. A qualitative analysis of their errors on pseudowords revealed that 54% (6/11) of Laurent's errors were lexicalisations against only 7% (1/14) in Nicolas[2]. Visual errors were the main error type in Nicolas (13/14; 93%) and more rarely occurred in Laurent (4/11; 36%) whose rate of visual paralexias was comparable to that of SL controls. Nicolas also tended to produce a visually similar word instead of the target in consistent word reading (9/12; 75% of the errors). His errors were not more prone to occur on longer items whether words or pseudo-words.

Nicolas' reading performance is characterised by a strong dissociation between consistent and inconsistent words suggesting a dysfunction of the global procedure of reading. No such dissociation was found in Laurent. The performance of both Laurent and Nicolas in pseudo-word reading is within the normal range with respect to accuracy. However, Laurent is very poor in pseudo-word reading speed. This finding suggests that the analytic procedure of reading is more impaired in Laurent. The fact that he read words more quickly than pseudo-words and that most of his errors were lexicalisations suggests that he primarily relies on the global procedure of reading. In Nicolas, difficulties in inconsistent word reading and the production of many regularisations support the hypothesis of an impairment of the global procedure. The absence of any word

[2] Nicolas produced « dire » (to say) instead of the pseudo-word « dirc ». This error here considered as a lexicalisation could as well derive from a visual confusion between « e » and « c », an interpretation more compatible with his overall pattern of performance.

advantage effect in Nicolas further suggests that both words and pseudowords are processed through the analytic procedure of reading. His slow pseudo-word reading further suggests that his analytic procedure is not totally efficient.

Test of spelling ability

Laurent and Nicolas were further asked to spell a list of 66 words (Martinet & Valdois, 1999). The list included 22 highly consistent words that could be spelled correctly by application of the most frequent phoneme-grapheme conversion rules (e.g., /fRit/ -> frite, /moto/ -> moto); 22 words with an inconsistent phoneme associated to a relatively infrequent grapheme (e.g., /dâtist/ -> dentiste, /fokô/ -> faucon) and 22 highly inconsistent words (e.g., /klun/ -> clown, /fam/ -> femme) including a grapheme very rarely associated to its corresponding phoneme. Words from each category were matched in length and frequency. They were read out loud, one at a time and in a random order. Performance of the two dyslexics was compared to that of 26 children of the same reading level on one hand and to the same 24 SL controls as in the previous experiment, on the other hand. A list of 40 pseudowords was also dictated. It comprised 4 to 6 phonemes long pseudowords most of which included contextual phonemes (i.e., « c », « s », « g »).

Results

As shown in Table 2, Laurent and Nicolas scored similarly in the word dictation task whatever word consistency (16/22 vs. 13/22; χ^2 =0.4, NS). Laurent's spelling performance was similar to that of younger children of the same reading age for inconsistent words (for all *Z*-scores, p>.05) but his score was slightly inferior on consistent words (*Z-score* = 1,65; p<.05) and far below that which would be expected in similar school level readers/spellers. Nicolas' pattern of performance was quite similar except that his score on consistent words was significantly lower than the scores of RA controls (*Z-score* =-3.22; p<.001).

The quantitative analysis of performance in the spelling to dictation task suggests the presence of a severe spelling impairment affecting both words which require activation of specific word knowledge and those which might be spelt on the basis of more general knowledge about the correspondences between sounds and letters. Such findings might be interpreted as reflecting an impairment of the two spelling procedures, the lexical and the analytic one. A qualitative analysis of errors was performed to test the validity of this hypothesis. The rate of phonologically plausible errors was considered as being particularly relevant with regard to this question since such errors reflect good phonological processing (Goodman & Caramazza, 1986). Laurent produced 20/29 (68.9%) phonologically plausible errors (PPEs) while Nicolas made 31/34 (91.2%) misspellings of this type[3] (spelling errors are listed in Appendix B). Laurent's rate of PPEs was inferior to the mean rate of RA matched control children (mean=72.6%) whereas Nicolas produced a rate of PPEs greater than that of SL controls (mean=80.5%). Results from the qualitative analysis therefore revealed that Nicolas spelt words in a way consistent with their phonological form suggesting that he could use the analytic spelling procedure as efficiently as expected at his age. In contrast, the occurrence of non phonologically plausible errors (e.g., cuvette /kyvEt/-> guvette /gyvEt/; culbute /kylbyt/-> coulbute /kulbyt/; freiner /fRene/-> frémé /freme/) in Laurent suggests that his analytic spelling procedure was not very efficient.

On a subsequent test of pseudo-word spelling, Laurent spelt 26/40 pseudo-words correctly whereas Nicolas gave an appropriate spelling for 35/40 of these pseudo-words. Laurent's performance was outside the normal range as compared to SL controls but similar to the mean performance of RA children. Nicolas performed at a normal level in this task. Laurent's errors (e.g., /goRdon/ gordone -> corrdone /koRdon/; /flêdR/ flindre -> flendre /flâdR/; /Raswê/ rassoin -> rassin /Rasê/; /géRap/ guérape -> géraple /zeRapl/) were farther from the expected phonological form than those of Nicolas who produced 4/5 mispellings which could be judged as phonologically correct if the graphemic context was not taken into account (e.g., janifle -> janifl; guérape -> guérap; verbette -> verberte; guipour -> gipour).

Results from spelling assessment suggest that orthographic word knowledge is only poorly developed in the two dyslexic participants. However, the analytic procedure of spelling appears to be quite efficient in Nicolas who usually spelt words in a way consistent with their phonological form and correctly translated most pseudo-words. In contrast, Laurent's spelling errors were less likely to be phonologically accurate and his ability to spell pseudo-words was impaired suggesting difficulties using the analytic spelling procedure.

Tests of phonological awareness

Laurent and Nicolas were further submitted to a battery of phonological awareness tests including:

- *An auditory rhyme judgement task*: eighty pairs of words were presented auditorily for rhyme judgement. Following Rack (1985), the list contained 20 pairs that rhymed and were spelt similarly (e.g., /tER - gER/ terre - guerre), 20 pairs that rhymed but were orthographically dissimilar (e.g., /volkâ - aRzâ/ volcan-argent), 20 pairs that did not rhyme but were spelt

[3] Note that all errors made by Nicolas on consistent words were phonologically plausible; 8/9 errors resulted from the

similarly (e.g., /amak-taba/ hamac-tabac) and 20 pairs that were phonologically and orthographically dissimilar (e.g., /valiz - gato / valise-gâteau).

- *A sound categorisation task* in which an odd word had to be retrieved among four words presented orally (e.g., vent /vâ/ - banc /bâ/ - *thon /tô /* - rang /Râ/).

- *A phoneme deletion task:* the participants were asked to delete the first sound of a word and produce the resulting pseudoword (e.g., "outil" /uti/ -> /ti/; "placard" /plakaR/ -> /lakaR/). Twenty words were proposed: 7 began with a vocalic phoneme corresponding to a multiple letter grapheme so that the omission of the first letter (instead of the first phoneme) yielded incorrect responses; 9 began with a consonantal cluster, 4 with a singleton.

- *A phoneme segmentation test:* A set of 20 words were presented auditorily to the participants who had to successively pronounce each of the word constitutive phonemes (e.g., "fontaine" -> /f/-/ ô/-/t/-/ E/-/n/).

- *A spoonerising test:* the task required exchanging the first phonemes from two heard words (e.g., banane ficelle -> fanane bicelle). Responses were always pseudo-words.

- *A syllable deletion task*: a 4-syllable word was orally produced followed by a number (2 or 3) that indicated the syllable to delete. The participants had to pronounce the pseudo-word resulting from this omission (e.g., mathématiques /matematiK/, 3 -> /matetiK/).

Results

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absence of application of an orthographic rule requiring to add a mute « e » at the end of the words.

Scores of the two dyslexic participants are given in Table 2 together with the mean scores (and SD) of SL and RA controls. When compared to SL controls, Laurent performed outside the normal range on all tasks of phonological awareness except the rhyme judgement task. He was almost unable to do spoonerisms and was very poor in syllable deletion, two tasks which are particularly demanding in working memory resources. In contrast, Nicolas obtained an above average score on all metaphonological tasks. His performance was also significantly higher than that of Laurent on all tasks except rhyme judgement (sound categorisation: $\chi^2 = 4.1$, $p<.05$; phoneme deletion: $\chi^2 = 10.8$, $p<.001$; phoneme segmentation: $\chi^2 = 5.16$, $p<.05$; spoonerisms: $\chi^2 = 16.2$, $p<.0002$; syllable deletion: $\chi^2 = 12.6$, $p<.0005$).

The comparison of Laurent and Nicolas performance in tasks of phonological awareness shows that these two dyslexic teenagers differ significantly in their ability to manipulate the sounds of words. Laurent's poor scores on most tasks point to an associated phonological awareness impairment whereas Nicolas demonstrates good phonological skills.

Tests of visual processing

The two dyslexic participants were further submitted to two tasks that assessed visual processing abilities using literal material. Consequently, their ability to identify single letters was previously investigated.

Letter identification test

The two participants were first submitted to a letter identification test to be sure that they exhibited no difficulty in recognising and naming the letters of the alphabet displayed for a limited presentation time. Letters (2x26) were presented on the computer screen in a random order written in lower and upper case (Geneva 24-point font). Each trial began with the presentation of a fixation point that was displayed for 1000 ms in the centre of the screen followed by a blank interval of 500 ms. The letter was then displayed for 100 ms immediately followed by a mask (a series of XXX). The participants were asked to name each letter successively.

Both Laurent and Nicolas performed very well on this task scoring 52/52 and 51/52 respectively. Nicolas error consisted in naming « b » as « d ».

Bar probe task

Following Averbach & Sperling (1968), the bar probe task was presented under the two conditions of whole report and partial report. In the whole report condition, participants were required to report all letters in a briefly presented visual array whereas under the partial report condition, a cue (e.g., a bar) following the display indicated the one letter to be reported.

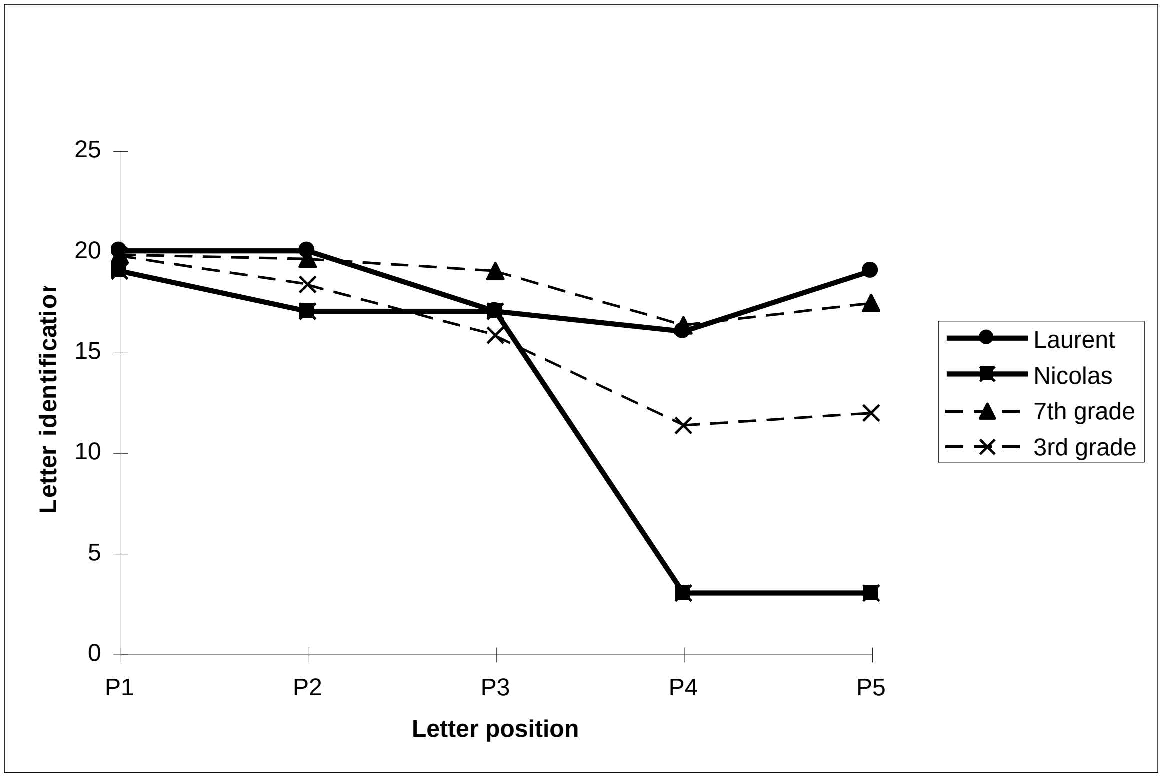
- *Whole report condition*

Stimuli: Stimuli were 20 random 5-letter strings (e.g., R H S D M) built up from the 10 consonants B, P, T, F, L, M, D, S, R, H. Each letter was used 10 times and appeared twice in a given position. They were presented in upper case (Geneva 24-point font) in black on a white background. Each letter was separated from the one nearest to it by a distance of 1 cm to avoid lateral masking. The array subtended an angle of approximately 5.4°

Procedure: At the start of each trial, a central fixation point was presented for 1000 ms followed by a blank screen for 500 ms. A 5-letter string, with no repeated items, was then presented at the centre of the display monitor for 200 ms. The participants' task was to report verbally all letters immediately after they disappeared. The participants pressed a button after their response to start the next trial. For each participant, the experiment began with 5 training trials for which they received feedback. No feedback was given during the experimental task. Laurent's and Nicolas' performance was compared to that of 20 2nd-grade and 24 7th grade control children.

Results: Overall, Laurent successfully identified all five letters of the string in 13 cases out of the 20 given trials. His score was similar to the mean performance of SL controls (mean=13.7; SD=3.3; range: 5-19). Nicolas reported none of the 5-letter sequence as a whole, a score outside the range of RA controls (mean=5.24; SD=3.95; range: 1-14). Data were further analysed taking into account letter position in the sequence. Results are presented on Figure 1.

Figure 1: Bar probe task, Whole report condition



Laurent's scores did not differ significantly from those of 7th Grade children whatever the position of the letter in the string. Nicolas performed like 7th Grade children on letters in the first and third positions but his score was outside the normal range on the second (SL range: 19-20; mean=19.6; SD=0.5), fourth and fifth (mean=16.3; SD2.1; range: 10-19 and mean=17.4; SD=2; range:13-20) positions. His ability to report the last two letters of the string was particularly impaired and his performance was even worse than that of 2nd-Grade children on these two positions (Position 4: mean=11.3; SD=3.4; range=4-19; Position 5: mean=11.95; SD=3.5; range=5-18). It is noteworthy that most of Nicolas' responses (18/20) consisted in the report of only three letters without any attempt to name the last two letters. On request, he said he was aware of the presence of other letters but unable to identify them. On subsequent occasions, Nicolas demonstrated quite similar patterns of performance on this task (he scored 20, 18, 18, 1 and 2 for each position respectively on a second occasion; he scored 19, 16, 18, 9 and 6 on a third occasion) thus showing stability of his response pattern.

- Partial report condition

Stimuli: Stimuli were 50 random 5-letter strings (e.g., T H F R D) built up from the same 10 consonants used in the whole report condition. The occurrence of each letter was 25 and each appeared five times in each position. As previously, letters were presented in upper case (Geneva 24-point font) spaced by one centimetre. The cue indicating the letter to be reported was a vertical bar presented for a duration of 50 ms, 1 cm below the target letter. Each letter was used as target once in each position.

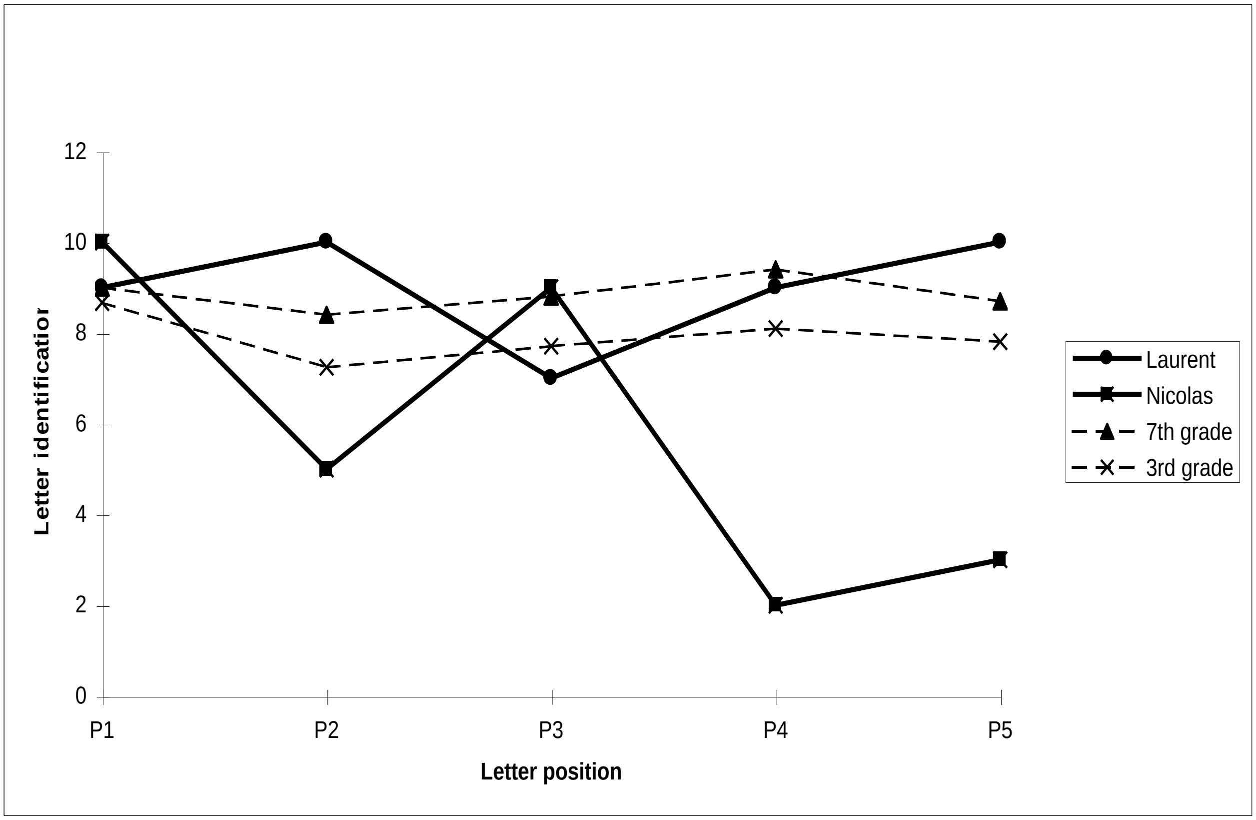
Procedure: At the start of each trial, a central fixation point was presented for 1000 ms followed by a blank screen for 500 ms. A 5-letter string, with no repeated letters, was then presented at the centre of the display monitor for 200 ms. Onset of the bar probe was simultaneous with the offset of the stimulus array. Participants were asked to report only the target indicated by the probe. They were instructed to be as accurate as possible and no time pressure was applied. For each participant, the experiment began with 5 training trials for which they received feedback. No feedback was given during the experimental task. The performance of the two dyslexic participants was compared to that of 21 2nd-grade and 24 7th grade control children.

Results: Results are presented on Figure 2.

Laurent's performance was within the range of normal performance of 7th Grade children on all positions. Nicolas performed at the level of 7th Grade children on the first and third positions but was much lower than either the 2nd or 7th grade controls for letters located in position 2 (Nicolas' score=5; SL mean=8.4; SD=1.1; range:7-10; RA mean=7.2; SD=1.5; range=5-10), position 4

(Nicolas' score=2; SL mean=9.4; SD=0.8; range:8-10; RA mean=8.1; SD=1.6; range=4-10) and position 5 (Nicolas' score=3; SL mean=8.7; SD=1.5; range:5-10; RA mean=7.8; SD=2.2; range=2-10). His erroneous responses were of various types: There were 4 no response and 5 responses corresponding to an adjacent letter. In four cases, the named letter was not in the string and was visually dissimilar to the target letter (M-> H; D -> S; R -> E; F -> S). One naming might have resulted from a visual confusion (E -> F). In the seven remaining cases, « I » was produced instead of the target letter, a response which might reflect an attempt to name the vertical cue indicating the target letter. Overall, Nicolas demonstrated a far lower performance for letters located on the right than for those located on the left of the array in both the whole report and partial report tasks.

Figure 2 : Bar probe task, Partial report condition



The investigation of visual processing abilities revealed that although both Laurent and Nicolas performed similarly when asked to name single letters presented for 100 ms, they differed in their ability to process letter strings. Laurent's number of correct responses was within the range of normal performance in both the full and partial report conditions suggesting the absence of any obvious visual processing impairment. In sharp contrast, Nicolas demonstrated severe difficulties on both tasks with a similar trend towards a left bias.

Reading briefly presented words

The two dyslexic participants were further asked to read consistent words that were displayed for a short time at the centre of the computer screen. This task was designed in order to assess whether the visual processing deficit exhibited by Nicolas similarly affected word reading performance. A similar trend to report the leftmost letters of the word string more accurately than the rightmost letters was expected in Nicolas but not in Laurent who should demonstrate good identification of letters whatever their location in the word.

Stimuli: A list of 60 consistent words was designed including 20 4-letter words, 20 6-letter words and 20 9-letter words. Words were matched for frequency. Each length category was made up of 10 high frequency and 10 low frequency words.

Procedure: The experiment started with a central fixation point presented for 1000 ms and followed by a blank screen for 500 ms. The word (Geneva 24-point font) was presented at the centre of the display monitor for a limited time immediately followed by a mask (a series of XXX). Words of each length and frequency were randomly displayed. Time of presentation was determined for each participant on the basis of their ability to read more than 80% of another list of 4-letter words. Time was fixed at 150 ms for Laurent and 250 ms for Nicolas. The participants were instructed to name the words immediately after their presentation or to orally name the letters they had identified when they were unable to name the whole sequence.

Results: Laurent and Nicolas exhibited quite different patterns of performance on this task. Laurent read correctly 18/20 short words and 15/20 6- and 9-letter words, thus showing the absence of any strong length effect. In contrast, Nicolas named only a few long words, scoring 5/20 and 3/20 for 6-letter and 9-letter words but was able to read most short words accurately (score = 16/20). The absence of any length effect in Laurent suggests that words were recognised as familiar items and processed globally, a result compatible with his good performance in inconsistent word reading. As for Nicolas, he showed a strong length effect and was almost unable to process words made up of more than 4 letters when presented for only 250 ms. A qualitative analysis of Laurent's and Nicolas' reading performance was conducted in order to assess whether their pattern of letter identification was similar to that highlighted in the bar probe task. For that purpose, the number of correct letter identification was calculated in each position for words made up of 6 and 9 letters. Laurent demonstrated no position effect on both 6-letter words (score by position /20: 19-20-19-19-18-17) and 9-letter words (score: 18-16-18-17-18-20-19-19-20). Nicolas' ability to identify letters accurately was influenced by their position in the string. He scored 20-16-18-17-**11-8** on 6-letter words and 18-11-**8-9**-14-10-**8-5-5** on 9-letter words, therefore demonstrating a poorer performance on the rightmost letters. His pattern of performance when reading briefly presented words seems therefore very close to that pointed out in the bar probe task.

Discussion

In this study, two developmental dyslexic participants with similar reading levels were submitted to a variety of cognitive tasks showing strong qualitative differences in their performance. The way they conform to the profiles of phonological or surface dyslexia will first be examined. Table 3 summarises the appropriateness of Laurent's and Nicolas' performance to these profiles.

Table 3 : Matching of Laurent and Nicolas Pattern of Performance to Phonological and Surface Dyslexia Profiles.

Features of phonological dyslexia	Laurent	Nicolas
Good inconsistent word reading	+	-
Few regularisations	+	-
Poor pseudo-word reading		
accuracy	-	-
speed	+	+
A lot of lexicalisation errors	+	-
Good inconsistent word spelling	-	-
Few phonologically plausible errors	+	-
Poor pseudo-word spelling	+	-
Language disorder	+	-
Verbal short term memory deficit	+	-
Poor phonemic awareness	+	-

++ = presence of the feature as expected in phonological dyslexia

- - = absence of the feature as expected in surface dyslexia

As can be seen in Table 3, Laurent exhibits all the defining features of developmental phonological dyslexia except two: he shows rather good reading accuracy on pseudo-words and poor inconsistent word spelling. His score on pseudo-word reading is in fact comparable to that of the SL controls so that he does not exhibit the cardinal feature of phonological dyslexia: poor pseudo-word reading. However, Laurent's performance on pseudo-words can not be considered as normal. He shows dramatic difficulties with respect to reading speed since he needs more than twice the time taken by SL controls to read pseudo-words and takes even more time than RA controls. His performance is therefore better characterised as demonstrating a speed-accuracy trade-off for pseudowords. Although poor accuracy in pseudo-word reading is typically reported in English phonological dyslexics, accuracy on grade level has already been described in German and French dyslexic children with a history of phonological processing problems. Indeed, a similar pattern of high reading accuracy and pervasive speed deficit has been reported by Wimmer (1993) with respect to German children with a phonological processing impairment. In a cross-linguistic study, Landerl, Wimmer & Frith (1997) also reported that German dyslexic children showed very few reading errors on pseudo-words as compared to English dyslexic children. As in Laurent's case, the German dyslexics showed very similar reading times for words compared to RA controls but took more time reading pseudo-words. In their study on French dyslexics, Sprenger-Charolles, Colé, Lacert & Serniclaes (2000) also reported that the phonological impairment of the French phonological dyslexics only showed up as slow pseudo-word reading. It appears therefore that poor reading speed rather than poor reading accuracy is the cardinal feature of phonological dyslexia in languages with more transparent orthographies than English.

The second point not *a priori* expected within phonological dyslexia is Laurent's poor performance in inconsistent word spelling. Phonological dyslexia is typically associated with difficulties with phonological spelling skills leading to a selective impairment of pseudo-words. As reported in all previous cases, Laurent indeed exhibits poor pseudo-word spelling, a pattern consistent with the phonological deficit hypothesis. However, Laurent also shows a significant effect of consistency in spelling with a performance on inconsistent words which is comparable to that of Nicolas and RA controls. Such a disorder suggests poor development of lexical knowledge and is more typically found within the context of developmental surface dyslexia. It is noteworthy however that poor word spelling and a consistency effect in spelling have been repeatedly reported in previous cases of phonological dyslexia (Temple & Marshall, 1983; Temple, 1986; Funnell & Davison, 1989; Manis, Custodio & Szeszulski, 1993). In their comparative study of two cases, Hanley & Gard (1995) also found that Gregory, a phonological dyslexic, had poor irregular word spelling and performed at a level comparable to that of Mandy who exhibited a surface dyslexia. Also, French phonological dyslexics have been described as systematically lagging behind the average readers on inconsistent word spelling (Sprenger-Charolles et al., 2000). However, all studies pointed out that the word spelling errors of phonological dyslexics were less likely to be accurate phonologically than were those of the control children. This was also found in Laurent and contrasts with data from surface dysgraphia where misspellings are mainly phonologically appropriate. The presence of a consistency effect in spelling therefore appears as a feature typically found in phonological dyslexia and is in fact not so hard to reconcile with the phonological deficit hypothesis. Indeed, it is now well documented that children with good phonological recoding skills are endowed with a self-teaching mechanism enabling them to acquire specific knowledge about the orthographic form of words (Jorm & Share, 1983; Stuart & Masterson, 1992; Share, 1995, 1999). The self-teaching hypothesis therefore predicts that children with poor phonological recoding skills should have difficulty to acquire word specific knowledge. Data from developmental phonological dyslexia support this hypothesis together with Laurent's data. It therefore appears that all features of Laurent's cognitive profile are compatible with the phonological deficit hypothesis and conform to the pattern of phonological dyslexia.

As can be seen in Table 3, Nicolas shows all the defining features of surface dyslexia except one: he is slow in pseudo-word reading. Nicolas' excellent phonological skills, his good reading accuracy and spelling of pseudo-words, his phonologically accurate reading and spelling errors and his marked difficulty in inconsistent word reading make him a particularly striking case of developmental surface dyslexia. However, Nicolas is slow in pseudo-word reading. This feature must be carefully considered for two reasons: first, poor reading speed on pseudo-words is the cardinal feature of phonological dyslexia in languages like French and is typically interpreted as evidence for an underlying phonological deficit. Second, a phonological deficit might prevent the establishment of specific lexical knowledge (self-teaching hypothesis) thus resulting in poor reading and spelling of inconsistent words. It follows that the two cardinal features of developmental surface dyslexia (poor inconsistent word reading and spelling) found in Nicolas might be explained as deriving from a phonological disorder if his slow pseudo-word reading resulted from an underlying phonological impairment. However, Nicolas' good accuracy for pseudo-word reading, good performance in pseudo-word spelling and the production of a majority of phonologically based errors in both reading and spelling suggest that he has good phonological recoding skills. Furthermore, a phonological deficit is expected to affect all tasks involving the phonological component. Accordingly, poor phoneme awareness, poor verbal short term memory, poor oral language skills, poor pseudo-word reading and spelling have been typically reported in phonological dyslexia as evidence for an underlying phonological dysfunction. In contrast, Nicolas exhibits very good performance on all tasks of phonological awareness and pseudo-word spelling.

He has normal verbal STM skills and no oral language impairment. In sum, he has good performance on all tasks involving the phonological component except one, pseudo-word reading, which is also the sole of these phonological tasks involving a visual input.

The presence of difficulty with pseudo-words in Nicolas might be viewed as hard to reconcile with the idea that he is a surface dyslexic who has no phonological weakness. However, within the dual-route framework (Coltheart, 1978; Castles & Coltheart, 1996; Coltheart, Curtis, Atkins, & Haller, 1993; Coltheart, Rastle, Perry, Langdon & Ziegler, 2001), an evaluation of pseudoword reading performance is viewed as a straightforward way to assess intactness of the analytic reading procedure but gives no insight on the nature of the cognitive component that is responsible for this poor reading performance. Indeed, many processing components are involved in this task and dysfunction of any one of these components will result in pseudo-word reading difficulties (Derouesné & Beauvois, 1985; Howard & Best, 1996). Since most of the involved components (grapheme-phoneme conversion system, blending, phonemic buffer) are phonological, a pseudo-word reading impairment most of the time results from a phonological disorder. However, visual analysis also is part of the analytic reading procedure and the theory predicts that a deficit at this level should also result in pseudo-word reading difficulties.

It has been widely advocated that there is no direct relation between the nature of the behavioural dysfunction and the nature of the damaged underlying component (Caramazza, 1986; 1992). It follows that the interpretation of a patient's performance in terms of disruption to a particular cognitive component must be constrained by converging evidence from a variety of different tasks (Caramazza & Hillis, 1990; Rapp & Caramazza, 1991; Olson & Caramazza, 1990). Although Laurent and Nicolas both demonstrate difficulty in pseudo-word reading, their differing performance on other cognitive tasks implies that this difficulty arises from dysfunction to different components of the analytic reading procedure. Laurent shows poor pseudo-word reading but also exhibits a poor performance in all tasks involving the phonological component. This pattern of performance points to a dysfunction of a phonological component of the analytic reading procedure. At the same time, Laurent shows a normal word advantage effect in reading and no regularity effect suggesting good functioning of the lexical procedure of reading. The intactness of the lexical reading procedure constitutes evidence that the dysfunction arises at a component level of the analytic reading procedure not shared by the lexical procedure. This discards the visual analysis system as being potentially responsible for Laurent's reading disorder. Then, his pattern of performance may be taken to reflect a phonological impairment. The fact that Nicolas was poor at reading pseudo-words without demonstrating poor performance in any other phonological tasks must be interpreted to reflect that poor pseudo-word reading results from the impairment of a component of the analytic reading procedure not involved in phonological processing. His poor performance on the only task involving a visual input suggests that his difficulty in reading pseudo-words could be due to a dysfunction at the level of the visual analysis system. Since this system is common to the two reading procedures, a problem at this level is expected to affect word reading performance as well. In accordance with this prediction, Nicolas exhibits poor consistent and inconsistent word reading. Finally, his atypical pattern of performance on tasks of global and partial report constitutes further evidence for a visual processing dysfunction. Nicolas' overall pattern of performance thus leads to the hypothesis that cognitive dysfunction is at a component level involved in visual processing.

It has already been rightly argued that a difficulty in pseudo-word reading might derive either from a central phonological difficulty or from a visual disturbance (Seymour & Evans, 1993). Furthermore, pseudoword reading difficulties have been reported in the classic case CD described by Coltheart, Masterson, Byng, Prior & Riddoch (1983) as a surface dyslexic[4]. The fact that CD exhibited a low score in pseudo-word reading while her phonological processes were meant to be intact was heavily criticised by Bryant and Impey (1986). Their doubt about the non-phonological origin of CD's reading impairment was entirely justified in the absence of external evidence constraining the interpretation of CD's reading performance. In contrast, Laurent's and Nicolas' different patterns of performance across the phonological and visual processing tasks strongly support different types of dysfunctions. Converging data constitute evidence that Nicolas' poor pseudoword reading arises from a visual processing dysfunction rather than a phonological impairment. Investigation of Nicolas' performance shows that he has difficulty processing the right part of briefly presented literal sequences. He also shows a positional effect when reading briefly presented consistent words with a similar tendency to misname the rightmost letters of 6- and 9-letter words. These findings suggest that Nicolas has a visual processing impairment that prevents him from processing letters in parallel during reading. Furthermore, his parallel processing deficit cannot be viewed as resulting from his poor lexical knowledge since it also characterises performance on the bar probe task where non-lexical unpronounceable letter strings have to be processed.

A large body of research considers that developmental surface dyslexia does not result from a specific cognitive impairment but should rather be viewed as reflecting a general delay in the acquisition of reading skills. In line with this hypothesis, it has been demonstrated that the performance of the surface dyslexic participants resembled that of younger normal readers of the same reading level (Manis et al., 1996; Stanovitch et al., 1997; Genard, Mousty, Content, Alegria, Leybaert & Morais, 1998; Sprenger-Charolles et al., 2000). This pattern contrasts with that of

[4] . It seems that MI (Castles & Coltheart, 1996) also exhibited slow and effortfull pseudoword reading (see Harm &

phonological dyslexic participants whose performance in pseudo-word reading remains weaker when compared to that of reading age matched controls. These data are consistent with the view that the phonological dyslexic profile results from a specific cognitive disorder whereas the surface dyslexics may be considered as delayed readers. In line with the delay hypothesis, it has been demonstrated that a general resource limitation within a connectionist network simulated the pattern of surface dyslexia (Manis et al., 1996; Plaut, McClelland, Seidenberg & Patterson, 1996). Harm & Seidenberg (1999) set out four ways to create the delay pattern characteristic of surface dyslexia within their attractor network. These four ways will be now discussed with regard to Nicolas' data. The first way proposed by Harm and Seidenberg (1999) is simply to provide less training for the normal model. They argued that reading ability is related to reading experience, so that children who have normal capacities but read less often or receive less feedback about their reading will progress less rapidly. They demonstrated accordingly, that earlier in training, the network exhibited poorer performance on inconsistent words than pseudowords. This interpretation is at first glance compatible with Nicolas' case since he admits avoiding reading as often as possible and received no specific help providing feedback. Also compatible with the delay hypothesis, his word reading and spelling accuracy is similar to that of reading-age controls together with the time he needs to decode words and pseudo-words. However, Laurent and Nicolas were closely matched on their reading age and both have impoverished reading experience. As a consequence, a « delay pattern » should characterise both Laurent and Nicolas performance if resulting from just less training. The existence of a consistency effect in Nicolas alone gives no support to the less-training hypothesis.

Seidenberg, 1999, Note 5 page 507).

A second way to create a delay pattern in the network is to use a non-optimal learning rate. Indeed, the network's inconsistent word performance was more affected than pseudo-word performance when the learning rate parameter of the model was reduced. However, as acknowledged by Harm and Seidenberg themselves, children whose delayed reading is related to a learning problem would exhibit this type of deficit on other tasks. In disagreement with this last point, Nicolas demonstrated a very good performance in pseudo-word spelling and was excellent in tasks of phoneme awareness, performing at a level comparable to that of SL children. His normal performance on these tasks rules out the hypothesis of a general learning problem.

The delay pattern can also result from a degradation of the orthographic input. Seidenberg (1992) described the results of a simulation in which the input orthographic representation was degraded by ensuring that each letter string activated more orthographic units than in the « normal » simulation. The consequence was an acute decrement of the network level of performance on inconsistent words together with poor generalisation to pseudo-words. In this simulation, Seidenberg located the dysfunction responsible for the pattern of surface dyslexia at the level of visual processing. This is in total agreement with our interpretation of Nicolas' performance. However, the simulation conducted by Seidenberg mimics a visual processing impairment that does not yield clear information about letters identity, making them more confusable with each other. Nicolas' performance gives no evidence for such a disorder. Like Laurent, Nicolas was able to name isolated letters presented for 100 ms. His performance on the two last letters in global report typically consisted in no responses rather than substitutions between visually similar letters. In the partial report task, only one erroneous response (1/21) might be interpreted as resulting from letter confusion. Furthermore, the left-to-right gradient that characterises Nicolas' performance in the bar probe tasks cannot be predicted from a letter identification problem.

Harm & Seidenberg (1999) also simulated a delayed pattern in a fourth way: reducing the network's capacity to encode information regarding the mapping from orthography to phonology. They reported simulated results showing that reducing the number of hidden units between the orthographic and phonological layers affected inconsistent word reading more than pseudo-word reading (see also Plaut et al., 1996). They argued that such a reduction affected the capacity of the network to encode dependencies that span more letters. Inconsistent word reading was impaired because reading these words generally requires using information from the entire word sequence. In contrast, information from smaller portions of the word is sufficient to process consistent words and pseudo-words, so that the damage had less impact for these items. This hypothesis might appear to fit Nicolas' results at first glance since he demonstrated an inability to process all word letters in parallel during reading. However the same pattern characterises his performance on both words and literal but unpronounceable sequences, suggesting that the disorder does not arise at the level of mapping between orthography and phonology. It appears therefore that none of the four hypotheses put forward by Harm & Seidenberg (1999) to account for surface dyslexia offers a satisfactory explanation of Nicolas' reading pattern.

Ans, Carbonnel & Valdois (1998) have proposed a connectionist model of polysyllabic word reading that attributes an important role to visual processing in reading. The model assumes that two types of reading procedures, a global and an analytic one, are required for processing all kinds of letter strings. The two procedures work using essentially similar computational principles but differ in the kind of visual processing they involve. In the global reading mode, the focal attentional window extends over the whole sequence of the input letter-string but it is restricted to parts of the input when reading in the analytic mode. In this latter case, the orthographic input is sequentially processed, segment by segment (typically syllable by syllable) from left to right. Consequently, the size of the attentional visual window determines the reading mode. The model further assumes that all letters within the attentional window are activated maximally and in parallel during processing whereas letters outside the window are only minimally activated or not at all. It was hypothesised within this theoretical framework that a reduction of the attentional window through which information from the orthographic input is extracted should result in an inability to create word traces, thus leading to the pattern of surface dyslexia and dysgraphia. Such an interpretation seems to fit rather well with Nicolas' pattern of performance. The model also predicts that a reduction of the attentional window should disturb word processing more than pseudo-word processing. Reading inconsistent words requires the attentional window to embrace the whole sequence of the word so that any reduction of the window would affect inconsistent word reading. In contrast, the attentional window is normally reduced to portions of the literal sequence when reading pseudo-words. Pseudo-word and consistent word reading accuracy will therefore depend on the severity of the attentional window reduction. A reduced window may have no impact on pseudo-word reading and just slow down consistent word reading if a sufficient number of letters can be processed in parallel. A more severe reduction will however begin to affect consistent word and pseudo-word reading accuracy as well. Ans et al., (1998) conducted two simulations with a reduced visual-attentional window. They showed that a moderately reduced window affected inconsistent word processing while consistent word and pseudo-word reading remained largely preserved. With a more severely reduced window, performance decreased on all type of items with a bigger impact on inconsistent words. The two simulations revealed that regularisations were the dominant error type as expected in surface dyslexia. The model's predictions are consistent with the present findings showing that Nicolas exhibited severe impairment of inconsistent word reading but weaker deficit on pseudo-words.

Conclusion

The two case studies here reported show that phonological and visual processing impairment can dissociate in developmental dyslexia. Converging evidence points to a phonological impairment responsible for the pattern of phonological dyslexia exhibited by Laurent who otherwise shows intact visual processing skills. In the absence of any phonological disorder, Nicolas exhibits a pattern of surface dyslexia associated to a visual processing disorder that prevents him from processing letter strings in parallel. Future research is needed to establish whether such a visual processing disorder is systematically found in developmental surface dyslexia. Neuropsychological studies typically demonstrated that a similar pattern of performance could derive from quite different cognitive disorders so that a visual processing impairment might be expected to arise in only some children with surface dyslexia. A second important issue is to determine the exact nature of the visual processing disorder responsible for poor inconsistent word reading. The non automatisation of letter identification skills would yield to the pattern of performance exhibited by Nicolas but a visual attentional disorder seems more probably to be at the origin of his reading impairment. This hypothesis is also more in line with previous reports of a visual attentional disorder in developmental dyslexia. Finally, the present findings suggest that a specific cognitive disorder might be at the origin of the pattern of surface dyslexia, in at least some cases. The term reading delay is irrelevant in such cases even when the reading pattern exhibited by these children is close to that found in younger normal readers.

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Appendix A

Listing of Nicolas' errors in inconsistent word reading. (* Word not regularised)

word	expected pronunciation	Nicolas response
écho	eko	eSo
août	ut	aut
sept	sèt	sèpt
orchestre	ORkèstR	ORSèstR
examen*	egzamê	eksamê
toast	tOst	toast
poêle	pwal^	pOèl
galop	galo	galOp
aquarelle	akwaRèl	akarèl
aquarium	akwaRjOm	akaRijym
chorale	koRal^	SoRal
cake	kèk	kak
escroc	èskRo	èskROk
orchidée	ORkide	ORSidé
bourg	buR	buRz
paon	pâ	paô
stand	stâd	stâ

Appendix B

List of Laurent’s and Nicolas’ errors in word and pseudoword spelling

Consistent words	Laurent	Nicolas	Pseudowords	Laurent	Nicolas
soucoupe	soucoipe *	soucoup	gordone	corrdone	
individu	individue		guipour	gipour	gipour
miroir	miroire	miroire	réguise	régise	
carpe	carp	carp	verbette	verrbete	verberte
culbute	coulbute *	culbut	barugue	baruge	
soda	sodat		flindre	flendre	
frite		frit	griboise		gribouse
bouture		boutur	janifle	ganifle	janifl
globule		globul	mageon	magon	
confiture		confitur	guérape	géraple	gérap, guérap
ourson		oursson	rassoin	rassin	
			aveste	avesste	
			sovigne	souvigne	
			déguipe	dégipe	
			quilane	cilanne	
Inconsistent words			Highly inconsistent words		
ruban	rubent		b**ei**gne**t**	bégnier	bégnié
bain	bien *		cageo**t**	cago *	cageau

gitan	gittent		clo**w**n	cloune	cloun
boucher	bouchet	bouchai	fa**o**n	fant	fan
faucon	focon		pi**sc**ine	pi**c**ine	pissine
cuisson	cousson *	cusson *	**g**enti**l**	**g**entie	janti
cuvette	guvette *		exam**en**	examin	examin
freiner	frémé *	fréné	a**qua**ri**u**m	ag**ua**ri**u**m *	acoiriom
pharmacie	farmaci	farmaci	ba**p**tême	battème	batème
mimosa		mimausa	gru**y**ère	guillère *	gruière
relation		rolation *	**h**abi**t**	abi**t**	abi
figue		fig	**h**arico**t**	arrico	aricau
témoin		témoi *	po**ê**le	poille	poil
cuisinier		cuisignier	ra**y**ure	reillure	
			taba**c**		taba
			ag**en**da		aginda
			te**ch**nique		tecnique

* Non phonemically plausible errors In bold: highly inconsistent graphemes

Table 1: Characteristics of the Two Participants.

	Laurent	Nicolas
Chronological age (months)	176	157
Reading age (months)	102	98
Full IQ	110	104
Grade level	7th	6th
Word repetition	92/92	92/92
Pseudo-word repetition	89/92	89/92
Peabody score	113	94
Verbal fluency		
Semantic criterion	21	19
Formal criterion	7	12
Verbal Short Term Memory		
Digit span forward	6	7
Digit span backward	2	5
Short word span	4	5
Long word span	2	5
Corsi span	5	5

Table 2

Performance of Laurent and Nicolas on Reading, Writing and metaphonological Tasks as compared with Means, Standard Deviations, Ranges and Reaction Rime from two Samples of Reading Age and School Level controls.

	Laurent		Nicolas		SL controls			RA controls		
Word reading	Score	Time	Score	Time	Score	Range	Time	Score	Range	Time
Consistent HF	19/20		20/20		19.9 (0.3)	19-20		19.5 (0.8)	17-20	
Consistent LF	18/20		17/20		19.3 (0.8)	18-20		18.1 (1.4)	14-20	
Inconsistent HF	19/20		15/20		19.9 (0.3)	19-20		16.8 (2.0)	12-20	
Inconsistent LF	16/20		8/20		17.7 (1.3)	15-20		9.7 (3.6)	1-17	
Pseudo-word reading	87.8%	2.9 sec/w	84.4%	2.2 sec/w	85.5% (6.5)	75-100	0.9	82.4% (10.3)	57-100	1.9
Matched words	94.4%	1.3 sec/w	86.7%	1.5 sec/w	98% (1.7)	93-100	0.6	94% (5.6)	77-100	1.5
Lexicalisations	54%		7%		2.1%					
Visual errors (PW)	36%		93%		30%					
Words writing										
Consistent	16/22		13/22		20.7 (1.7)	16 - 22		19.15 (1.91)		
Inconsistent	13/22		13/22		19.9 (1.8)	15 - 22		16.19 (3.68)		
Higly inconsistent	8/22		6/22		17.9 (2.9)	10 - 22		12.27 (4.61)		
%PPEs	68.9% (20/29)		91.2% (31/34)		80.5%			72.6%		
PseudoWord writing	26/40		35/40		36.5 (2.2)	31 - 40		26.36 (4.72)		
Metaphonology										
Rhyme judgement	78/80		78/80		78 (4.7)	76 - 80		-----		
Sound categorisation	10/20		17/20		16.4 (2.6)	11 - 20		13.2 (2.4)	9 - 19	
Phoneme deletion	10/20		20/20		18.7 (1.9)	13 - 20		16.6 (2.5)	12 - 20	
Phon. segmentation	12/20		19/20		16.4 (2.6)	11 - 20		14.0 (2.3)	7 - 18	
Spoonerisms	0/12		12/12		10.0 (2.0)	2 - 12		------		
Syllable deletion	6/20		18/20		18.1 (2.0)	11 - 20		------		

Table 3 : Matching of Laurent and Nicolas Pattern of Performance to Phonological and Surface Dyslexia Profiles.

Features of phonological dyslexia	Laurent	Nicolas
Good inconsistent word reading	+	-
Few regularisations	+	-
Poor pseudo-word reading		
accuracy	-	-
speed	+	+
A lot of lexicalisation errors	+	-
Good inconsistent word spelling	-	-
Few phonologically plausible errors	+	-
Poor pseudo-word spelling	+	-
Language disorder	+	-
Verbal short term memory deficit	+	-
Poor phonemic awareness	+	-

++ = presence of the feature as expected in phonological dyslexia

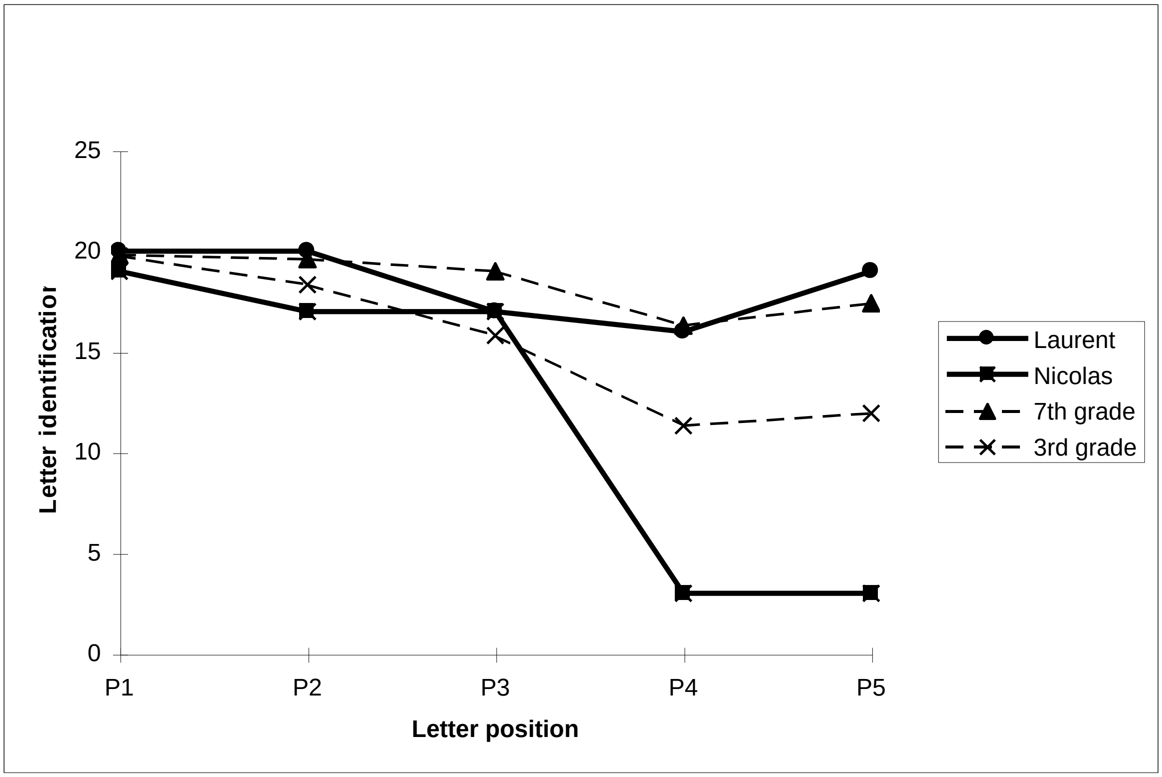
- - = absence of the feature as expected in surface dyslexia

Figure legends

Figure 1: Bar probe task, Whole report condition

Figure 2: Bar probe task, Partial report condition

Figure 1: Bar probe task, Whole report condition



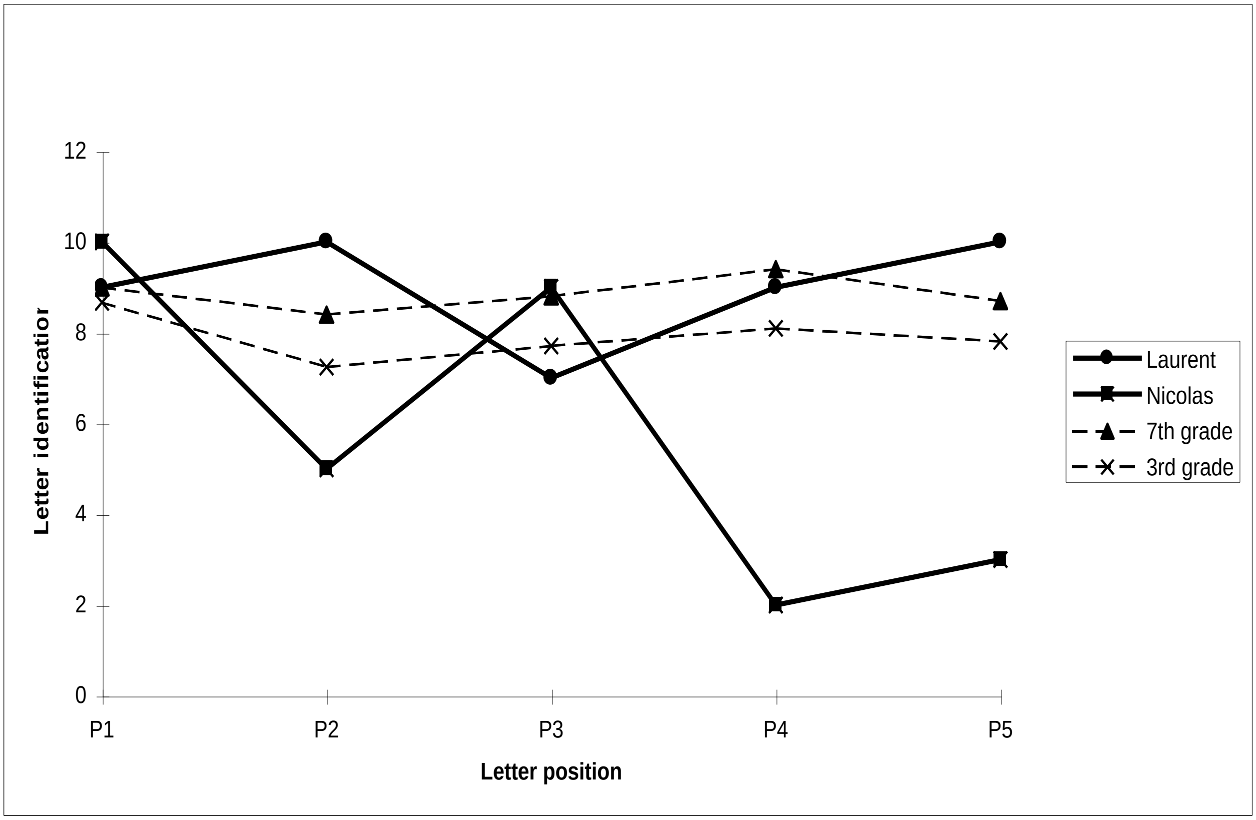


Figure 2 : Bar probe task, Partial report condition