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Reading in French-speaking adults with dyslexia

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Abstract This study investigated the reading and reading-related skills of 15 French-speaking adults with dyslexia, whose performance was compared with that of chronological-age controls (CA) and reading-level controls (RL). Experiment 1 assessed the efficiency of their phonological reading-related skills (phonemic awareness, phonological short-term memory, and rapid automatic naming (RAN)) and experiment 2 assessed the efficiency of their lexical and sublexical (or phonological) reading procedures (reading aloud of pseudowords and irregular words of different lengths). Experiment 1 revealed that adults with dyslexia exhibited lower phonological reading-related skills than CAs only, and were better than RL controls on the RAN. In experiment 2, as compared with RL controls, only a deficit in the sublexical reading procedure was observed. The results of the second experiment replicated observations from English-language studies but not those of the first experiment. Several hypotheses are discussed to account for these results, including one related to the transparency of orthographic systems.

Keywords Adults with dyslexia · Orthographic transparency · Reading procedures

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Introduction

Objectives of the study

Over the past few decades, developmental dyslexia has been studied extensively, and much has been learned about the causes of reading difficulties in children with dyslexia (for a review, see Vellutino, Fletcher, Snowling, & Scanlon, 2004). Although most of the evidence comes from studies on children, research with adults makes it possible to examine the life-long impairments that constitute the core characteristics of this disability. Yet studies with adults with dyslexia are scarce, and those that do exist mostly pertain to English-speaking populations.

In studies with English-speaking participants, adults with dyslexia have been found to exhibit deficits in reading and reading-related skills similar to those typically observed in children with dyslexia (Ben-Dror, Pollatsek, & Scarpati, 1991; Bruck, 1990, 1992; Pennington, van Orden, Smith, Green, & Haith, 1990). However, we know little about the reading deficits of adult with dyslexia in languages with shallower orthographies (Paulesu et al., 2001). This poses an important problem since English orthography is so deep that it can be viewed as an "outlier" (Share, 2008).

Deep orthographies are characterized by multiple grapheme-phoneme correspondences. With about 40 phonemes that can be spelled by 1,120 graphemes (Coulmas, 1996), English is considered to have the deepest orthography among alphabetic scripts. Italian and Spanish, in contrast, are examples of transparent orthographies, with the number of graphemes just above the number of phonemes. French occupies an intermediate position between these extremes, with 30 to 36 phonemes (see Delattre, 1966) for 125 graphemes, including 40 graphemes with both a regular and an ambiguous pronunciation ("ll" pronounced /l/ in "ville" [town] and /j/ in "fille" [girl]), or an exceptional pronunciation ("ch" pronounced /k/ in "chorale" [choral] and /S/ in "cheval" [horse]; see Peereman, Lété, & Sprenger-Charolles, 2007).

Research has shown that the speed of reading acquisition mirrors the transparency of the orthography (for reviews, see Sprenger-Charolles, Colé, & Serniclaes, 2006; Ziegler & Goswami, 2005) with near-ceiling performance of Spanish-speaking children after only 1 year of schooling, intermediate performance for French-speaking children, and clearly lower performance for English-speaking children (Goswami, Gombert, & de Barrera, 1998; Seymour, Aro, & Erskine, 2003). For developmental dyslexia, it is thus necessary to conduct studies in languages with a more transparent orthography than English to determine which aspects depend on general features of languages with an alphabetic orthography and which on language-specific features (Sprenger-Charolles et al., 2006; Sprenger-Charolles, Siegel, Jimenez & Ziegler, accepted; Ziegler & Goswami, 2005).

To address this issue, we designed a study with French-speaking adults with dyslexia, whose language has an orthographic system with much more regular grapheme-phoneme correspondences than in English (Peereman & Content, 1998; Peereman et al., 2007). In experiment 1, we assessed the reading-related skills of French adults with developmental dyslexia, and in experiment 2 their reading skills.

Some initial comments on methodology and terminology

In order to establish the presence of processing impairments, performance of people with dyslexia is usually compared with that of chronological-age (CA) controls. However, as Bradley and Bryant (1985) pointed out, there is an important limitation on the conclusions that can be drawn from this type of comparison, because it does not make it possible to determine whether the particular difficulties experienced are responsible for the disability in learning to read or a consequence of it. For example, reading level has been shown to have an impact on vocabulary size and phonemic awareness (Bryant & Impey, 1986). Therefore, differences in these skills between people with dyslexia and CA controls may be merely a consequence of the lower reading level of the people with dyslexia. A way around this problem is to compare the performance of people with dyslexia to that of normal readers matched for reading level (RL; see Bradley & Bryant, 1985), thus controlling for differences in reading level. This is viewed as a powerful technique for pinpointing the deficits that are implicated in developmental dyslexia. When people with dyslexia do less well than RL controls, the skill being assessed is considered deficient and is assumed to be causally related to the reading impairment observed in dyslexia. However, comparisons of people with dyslexia with RL controls have also been criticized on several occasions and for several reasons, including statistical considerations and issues with the interpretation of the results (Bryant & Goswami, 1986; Foorman, Francis, Fletcher, & Lynn, 1996; Jackson & Butterfield, 1989; Stanovich & Siegel, 1994). In particular, Bryant and Goswami (1986) pointed out that the interpretation of null results in comparisons between people with dyslexia and RL controls is very ambiguous. These authors argued that such results cannot found any conclusion at all, because they are consistent with two contradictory possibilities. On one hand, the lack of difference could emerge from similarity in the skills that were tested. Alternatively, a difference in the skill tested might have been present, but have been masked by the difference in general development between the target group and their RL controls.

This latter problem is amplified in studies with adults with dyslexia, whose reading level generally corresponds to that of children. The RL control group, then, is made up of children. The result is a strong discrepancy between the general cognitive development of the target group and the RL control group. In spite of such discrepancies between the level of development of adults with dyslexia and that of RL controls, a RL control group was included in various studies conducted with English-speaking adults with dyslexia (e.g., Ben-Dror et al., 1991; Bruck, 1990; Chiappe, Stringer, Siegel, & Stanovich, 2002; Pennington et al., 1990) to test for specific deficits in adults with dyslexia.

We have therefore included a RL control group in the present study, in which we examined the reading and reading-related skills of French adults with dyslexia in two experiments. We assumed that the reading tasks used to study dyslexia tap into more or less automatic processes, so that the impact of general cognitive ability is reduced. Moreover, we considered that inferior performance in adults with dyslexia compared with RL controls would offer very significant evidence of a deficit. If no difference was found between adults with dyslexia and their RL controls, on the other hand, it would be hard to draw any conclusion, but it would at least indicate that on the surface adults with dyslexia perform at a level that corresponds to their reading level. In any case, we regard comparison of adults with dyslexia with CA controls as important to evaluate the persistency of impairments across the lifespan.

Experiment 1: reading-related skills in adults with developmental dyslexia

Introduction

In reading, phonological processing refers to a set of processes that involve the phonological structure of words. As such, it refers both to the efficiency of the sublexical (or phonological) reading route, used to convert graphemes into phonemes, and to the capacity of phonological short-term memory (STM), which is needed to retain the assembled phonological code and decode newly encountered words and pseudowords, for example. It also refers to the ability to rapidly access the phonological representations of spoken words (usually assessed on the Rapid Automatic Naming task (RAN) with highly frequent items). Phonological processing also contributes to other reading-related skills such as phonological awareness, which requires manipulating the phonological units (syllables, rimes, and phonemes) of spoken words. Phonological awareness, and especially phonemic awareness, are crucial for reading acquisition because they are required to grasp the principle of the alphabet, which must be understood before grapheme-phoneme correspondences can be used to decode words phonologically (i.e., to access a phonological representation of the sequence to be decoded). In addition, the sublexical reading procedure is seen as the bootstrapping mechanism on the basis of which the lexical (or orthographic) procedure can develop (Share, 1995, 1999; Sprenger-Charolles, Siegel, Béchennec, & Serniclaes, 2003; Sprenger-Charolles, Siegel, & Bonnet, 1998).

The most widely accepted explanation of developmental dyslexia is the phonological-deficit hypothesis, which holds that the disability is rooted in a specific cognitive deficit that is phonological in nature. In particular, phonological deficits are thought to hinder the proper acquisition of the sublexical reading procedure because this procedure requires the ability to connect sublexical writing units (graphemes) to their corresponding sublexical speaking units (phonemes) and then to assemble the units' output through the phonemic decoding process. The first operation requires fully established phonemic categories; the second, adequate phonological short-term memory. A child who is unable to correctly handle phonemes and who also suffers from a deficit in phonological short-term memory (as assessed by pseudoword repetition) will have little or no ability to use the sublexical reading procedure. The development of the lexical procedure will in turn be affected.

It is well established that children with dyslexia suffer from a phonological deficit, especially in phonemic awareness (for a review, see Snowling, 2001), but also in phonological short-term memory (e.g., McDougall, Hulme, Ellis, & Monk, 1994; Sprenger-Charolles, Colé, Lacert, & Serniclaes, 2000) and in speed of access to the spoken lexicon (Wolf & Bowers, 1999; Wolf, Bowers, & Biddle, 2000; Wolf et al., 2002). Group studies with children with dyslexia suggest that deficits in phonemic awareness are more consistently present than deficits in phonological short-term memory or in rapid naming (Bowers, 1995; Johnston, Rugg, & Scott, 1987; Pennington, Cardoso-Martins, Green, & Lefly, 2001; Wimmer, 1993). Several longitudinal studies further suggest that the impact of phonological short-term memory on reading acquisition is not as great as that of phonemic awareness skills (Lecocq, 1991; Parrila, Kirby, & McQuarrie, 2004; Wagner, Torgesen, & Rashotte, 1994; Wagner et al., 1997). Furthermore, some studies have found no difference in short-term memory between average readers and children with reading disabilities (Bowers, 1995; Wimmer, 1993).

Phonological processing by adults with developmental dyslexia

Phonemic awareness Studies with adults with dyslexia show that the impairment of phonemic awareness observed in children with dyslexia is long-lasting. In many studies, English adults with dyslexia have been found to perform worse than CA controls on tasks requiring the identification and/or manipulation of phonemes (Bruck, 1992, 1993; Downey, Snyder, & Hill, 2000; Griffiths & Frith, 2002; Hatcher, Snowling, & Griffiths, 2002; Pennington et al., 1990; Ramus et al., 2003; Snowling, Nation, Moxham, Gallagher, & Frith, 1997). This pattern has also been observed for languages with a shallower orthography than English (French: Dufor, Serniclaes, Sprenger-Charolles, & Démonet, 2007; Szenkovits & Ramus, 2005; Danish: Elbro, Nielsen, & Petersen, 1994; Polish: Reid, Szczerbinsky, Iskierka-Kasperek, & Hansen, 2007). Paulesu et al. (2001) directly compared the phonemic awareness of adults with dyslexia reading in English, French, and Italian. According to latency measures, Italian speakers with dyslexia performed less well than their CA controls on phonemic awareness, and differed from their CA controls as much as the English and French speakers with dyslexia.

Phonemic awareness deficits have also been attested in English-speaking adults with dyslexia, who have been found to perform less well than RL controls on phonemic awareness tasks (Bruck, 1992, 1993; Chiappe et al., 2002; Pennington et al., 1990).[1] Bruck's (1992) study further attested phonemic awareness deficits in English-speaking children and adults with dyslexia, regardless of reading level. According to Bruck, unlike normal readers, readers with dyslexia develop very little phonemic awareness—it does not improve with either chronological age or reading level (Bruck, 1992, 1993). To our knowledge, there are no studies that take both accuracy and latency into account in comparing the phonemic awareness of adults with dyslexia to RL controls in a shallower orthography than English.

Phonological short-term memory English-speaking adults with dyslexia are known to perform less well than CA controls in phonological short-term memory tasks involving the immediate repetition of words (Brunswick, McCrory, Price, Frith, & Frith, 1999) and pseudowords (Ramus et al., 2003; Snowling et al., 1997). They are also outperformed by CA controls on the digit span task (Brosnan et al., 2002; Hanley, 1997; Hatcher et al., 2002; Stoodley, Harrison, & Stein, 2006). The poor scores of people with dyslexia on the digit span task are usually interpreted to reflect a phonological impairment, since this task requires retaining and manipulating phonological forms in short-term memory. In orthographies shallower than English, adults with dyslexia have been shown to be impaired relative to CA controls on a phonological short-term memory task involving words (In French: Dufor et al., 2007; Paulesu et al., 2001) and on the digit span task (In French: Szenkovits & Ramus, 2005; In Finnish: Helenius, Utela, & Hari, 1999).

Overall, adults with dyslexia seem to exhibit impaired phonological short-term memory as compared with CA control groups across languages of variable transparency. Phonological STM appears to be deficient in English-speaking adults with dyslexia, who are outperformed by RL controls on phonological short-term memory tasks (for words and pseudowords: Pennington et al., 1990). It remains to be determined whether this holds true for adults with dyslexia reading in a shallower orthography than English.

Access to phonological forms in the mental lexicon On the RAN task, which according to Wolf and Bowers (1999) assesses access to the phonological forms of words in the mental lexicon, English-speaking adults with dyslexia have been found to be slower than CA controls (Hatcher et al., 2002; Pennington et al., 1990; Ramus et al., 2003; Snowling et al., 1997; Zabell & Everatt, 2002). This pattern has also been observed for French (Paulesu et al., 2001; Szenkovits & Ramus, 2005). Ramus et al. (2003) suggested that this pattern reflects phonological difficulties beyond individual differences in overall speed. However, English-speaking adults with dyslexia have been found to perform similarly to RL controls on the RAN

[1] However, in one study (Ransby & Swanson, 2003) no differences in accuracy were found between English-speaking adults with dyslexia and RL controls on a phoneme deletion task.

task (Chiappe et al., 2002; Ransby & Swanson, 2003). Thus, in English-speaking adults with dyslexia, access to phonological forms does not appear deficient in comparison to RL controls.

Summary and presentation of the first experiment

As reviewed above, in English-speaking populations, adults with dyslexia exhibit deficits in phonemic awareness and in phonological short-term memory in comparison to RL controls, while their access to phonological forms in the mental lexicon corresponds to their reading level. This means that phonological impairments persist across the lifespan in readers with dyslexia, at least for ones reading in a language with a deep orthography. Moreover, existing findings suggest the presence of phonological impairments in adults with dyslexia reading in a more transparent orthography like French. However, because no RL control group was included, they do not indicate whether these impairments are deficits. This is the purpose of the first experiment.

More precisely, experiment 1 was aimed at testing the phonological reading-related skills of adults with dyslexia reading in French, a language with a shallower orthography than English. Phonemic awareness, phonological short-term memory, and rapid naming were assessed in 15 French adults with dyslexia who were compared to both CA and RL controls, using a group-study design. Both accuracy and latency were measured.

Hypotheses

We expected the phonological skills of French adults with dyslexia to be impaired, and thus that they would perform less well than CA controls. The question of whether their impairments constitute a deficit will be addressed through comparisons with RL controls. Two hypotheses can be set forth. The first and simplest possibility is that phonological processing deficits are central to developmental dyslexia and are likely to be present across orthographies, regardless of their transparency. Alternatively, orthographic transparency could have an impact on the development of phonological skills in dyslexia, at least on phonemic awareness (as found for normally developing children: Goswami, 2002) because of the difference it makes to the ease of developing and using a sublexical procedure. Transparent orthographies are more likely to allow readers with dyslexia to use a sublexical procedure. On this hypothesis, the performance of French adults with dyslexia should match their reading level and therefore be equal to that of RL controls.

Method

Participants

Adults with dyslexia were recruited from the Health Services of the University of Savoie in Chambéry (France) and of three universities in Grenoble (France). All reported histories of reading difficulty, and were given extra time on the tests to compensate for their reading disability. Extra time was granted on the basis of either a recent diagnosis of developmental dyslexia from a speech therapist or a neuropsychological profile established at a health service. The profiles contained measures of regular word reading, irregular word reading, pseudoword decoding, and nonverbal IQ. The group with dyslexia was composed of 15 participants, seven women and eight men, who were native speakers of French. They were between 18 and 27 years of age (mean chronological age=21.78, SD=2.56).

To ascertain that participants with dyslexia met the research criteria for developmental dyslexia, we ensured that (a) they were native, monolingual speakers of French, (b) none had any known neurological/psychiatric disorder or hearing impairment, (c) all had a nonverbal IQ within the normal range (see Table 1, Raven's Matrices, Raven & Court, 1995) and d) all presented a reading score two standard deviations below the control mean (no standardized reading test exists in French above the age of 16 years: see Szenkovitz & Ramus, 2005, for a study on French students with dyslexia for using a similar criterion). Reading scores were obtained using the Alouette test (Lefavrais, 1967),[2] a standardized French reading test employed in the study of developmental dyslexia (i.e., Bogliotti, Serniclaes, Messaoud-Galusi, & Sprenger-Charolles, 2008; Casalis, Colé, & Sopo, 2004; Sprenger-Charolles, Colé, Kipffer-Piquard, Pinton, & Billard, 2009; Ziegler et al., 2008; Ziegler, Pech-Georgel, George, & Lorenzi, 2009). This test requires subjects to read a meaningless text aloud. Performance on the test is converted into a reading age. Given that the Alouette test was standardized for the reading performance of children aged 5 to 14 years, the highest possible reading age is 14 years (which was reached by the CA controls). Thus, to avoid ceiling effects, we calculated a composite score (called “reading score”), which takes both accuracy and speed into account. The reading score is calculated by adding the time taken to read (in seconds) to the number of errors. If the participant did not finish reading the text within the 3-min time limit, the score was the sum of 180, the number of words not read, and the number of errors.

Participants with dyslexia were matched to two control groups, one of the same chronological age and the other of the same reading level. Participants with dyslexia were matched pairwise to controls, including by gender. In both groups, control subjects were native monolingual speakers of French with normal literacy skills and no history of learning disability. Their nonverbal IQ also fell within the normal range (assessed, for reading-level controls, using Raven's Coloured Progressive Matrices: Raven, 1956).

The CA controls were 15 students, seven women and eight men, recruited from the student body of the University of Savoie. They were 18–27 years old (mean chronological age=21.64, SD=2.36) and their mean reading score was 98.60 (range: 83-113; SD= 8.57). The mean reading score of the participants with dyslexia was 157.80 (range: 120-272; SD=34.81), which differed significantly from the CA controls' score ($t(28)=6.40$, $p<.001$; $W_S=120$, $p<.001$; Wilcoxon rank-sum test, nonparametric test), whereas the chronological age of the two groups did not ($t(28)<1$, *ns*; $W_S=230$, $p>.20$).

The RL controls were 15 children, seven girls and eight boys, who were recruited from elementary schools and middle schools in the city of Chambéry. They were 8 to 12 years old (mean chronological age=10.49 years, SD=1.07). Their mean reading score was 149.53 (range, 116–249; SD=30.37), which did not differ significantly from that of the participants with dyslexia ($t(28)<1$, *ns*; $W_S=201.5$, $p>0.20$), whereas the chronological age of the two groups did ($t(28)=15.77$, $p<0.001$; $W_S=120$, $p<0.001$).

Experimental tasks

Several tasks were used to assess the subjects' verbal short-term memory and phonological skills. Apart from the digit span task, all were taken from EVALEC, a computerized battery of tests of reading and reading-related skills for French elementary school children (Sprenger-Charolles, Colé, Béchennec, & Kipffer-Piquard, 2005).

[2] The Alouette-R (Lefavrais, 2005) has been standardized on pupils up to the age of 16 years. However, the groups used for this standardization were fairly small (on average 36 readers per level), so we preferred to rely on the original version.

Table 1 Means (and standard deviations) of adults with dyslexia, CA controls, and RL controls for chronological age, reading level, and raw scores on Raven's Matrices

	Chronological-age controls		Adults with dyslexia		Reading-level controls
Chronological age	21.64 (2.36)		21.78 (2.56)	***	10.49 (1.07)
Reading score	98.60 (8.57)	***	157.80 (34.80)		149.53 (30.37)
Raven's Matrices (raw scores)	52.86 (max=60) (2.85)		48.15 (max=60) (6.72)		30.20 (max=36) (2.91)

***$p<.001$

Phonemic awareness The two tests used to assess phonemic awareness involved the deletion of the first phoneme of a pseudoword composed of three phonemes. Both tests consisted of 12 three-phoneme pseudowords, with a consonant-vowel-consonant structure (CVC: e.g. *puf*) for the first test and a consonant-consonant-vowel structure (CCV: e.g. *klo*) for the second. The subjects heard the items one by one through headphones, and had to repeat each item as accurately as possible, with no time limit. The time taken to complete each task (response time) and accuracy were measured.

Phonological short-term memory This task consisted of repeating pseudowords aloud (e.g. *moukola*). Twenty-four pseudowords from three to six syllables long (six per length, three with CV syllables only and three with CVC syllables) were presented in increasing order of syllable length. The subjects heard the items one by one through headphones, and had to repeat each item as accurately as possible, with no time limit. The time taken to perform the whole task (response time) and accuracy were measured.

Verbal short-term memory The digit span subtests from the WAIS-R (Wechsler, 1981) were used to assess verbal short-term memory. Both the forward digit span subtest (the subject repeats the digits in the order they were read to him/her) and backward digit span subtest (the subject repeats the digits in the opposite order) were administered, following the standard procedure.

Lexical access To assess lexical access to spoken forms in the mental lexicon, we used a rapid automatic naming task (RAN) that involved color naming. Six colors were presented eight times in color-patch format on a single sheet of paper. A different order was used each time. Subjects were instructed to name the colors as accurately and rapidly as possible. The time taken to perform the task was measured.

Results

The mean scores of the adults with dyslexia and control groups are given in Table 2. On the CVC subtest, all groups performed at ceiling in terms of accuracy, and analyses were conducted on response times only.

Apart from the forward digit span task ($W=.97$, $p>.20$), the data were not normally distributed (CVC: response times: $W=.93$, $p<.01$; CCV: accuracy: $W=.74$, $p<.001$, response times: $W=.95$, $p<.05$; Phonological short-term memory: accuracy: $W=.94$, $p<.05$, response times: $W=.89$, $p<.001$; backward digit span: W=, p.91, $p<.01$; RAN: $W=.91$, $p<.01$).

Table 2 Mean scores (and standard deviations) of adults with dyslexia, CA controls, and RL controls on tests of verbal short-term memory, phonological short-term memory, phonemic awareness, and the RAN

			Chronological-age controls		Adults with dyslexia		Reading-level controls
Phonemic awareness	CVC	Accuracy (%)	99.44 (2.15)		100 (0)		98.89 (2.93)
		Response time (s)	16.28 (2.18)	***	24.00 (5.82)		21.83 (3.51)
	CCV	Accuracy (%)	94.44 (7.50)	*	85 (17.59)		72.28 (29.16)
		Response time (s)	19.06 (3.15)	***	30.94 (7.80)		29.61 (5.92)
Phonological STM		Accuracy (%)	79.44 (11.19)	**	68.05 (11.54)		62.5 (16.74)
		Response time (s)	77.53 (8.28)	***	97.00 (17.37)		91.79 (14.27)
Forward digit span			10.2 (1.78)	*	8.53 (2.10)		8.53 (1.68)
Backward digit span			7.33 (2.47)	*	5.87 (2.20)		4.93 (1.44)
RAN		Response time (s)	23.47 (2.75)	***	27.8 (3.86)	***	35.73[a] (7.06)

*$p<0.05$; **$p<0.01$, ***$p<0.001$

[a] RL controls had lower scores than adults with dyslexia

Moreover, the variance observed for the participants with dyslexia and for normal readers was very different, as can be seen in Table 2. In consequence, we used the Wilcoxon rank-sum test (W_S), a nonparametric test, to verify the parametric test results. Supplementing parametric analyses with nonparametric analyses to ensure validity has been done in previous study on dyslexia (Heiervang, Stevenson, & Hugdahl, 2002).

We were interested in the comparison of the performance of the adults with dyslexia to that of their CA controls, on one hand, and to that of their RL controls, on the other. Since these comparisons are not orthogonal, we lowered the significance level to $p<.025$, following Bonferroni correction.

Phonemic awareness

On the CVC subtest, all groups performed at ceiling in terms of accuracy, and analyses were conducted on response times only. The response times of adults with dyslexia were slower than those of CA controls ($t(28)=4.81$, $p<.001$; $W_S=134$, $p<.001$) but did not differ from those of RL controls ($t(28)=1.23$, $p>.10$; $W_S=217.5$, $p>.20$).

On the CCV subtest, adults with dyslexia were less accurate than their CA controls (marginally at least: $t(28)=1.91$, $p=.03$; $W_S=190.5$, $p<.05$), and significantly slower ($t(28)=5.48$, $p<.001$; $W_S=129.5$, $p<.001$). Their performance did not differ from RL controls either for accuracy or for response times (accuracy: $t(28)=1.45$, $p<.10$; $W_S=205.5$, $p>.20$; response times: $t(28)<1$, *ns*; $W_S=205.5$, $p>.20$).

Phonological short-term memory and verbal short-term memory

Adults with dyslexia performed significantly slower and less accurately than CA controls on the phonological short-term memory task (accuracy: $t(28)=2.74$, $p<.01$; $W_S=173.5$, $p<.01$; response time: $t(28)=3.92$, $p<.001$; $W_S=141.5$, $p<.001$). They were as accurate and as fast as RL controls (accuracy: $t(28)<1$, *ns*; $W_S=212.5$, $p>.20$; response time: $t(28)<1$, *ns*; $W_S=196$, $p<.10$).

Adults with dyslexia exhibited lower performance than CA controls on both the forward and backward digit span tasks (forward span: $t(28)=2.34$, $p<.025$; $W_S=179.5$, $p<.025$; backward span: $t(28)=1.72$, $p<.05$; $W_S=191.5$, $p<.05$). There was no difference between RL controls and adults with dyslexia on either the forward span task ($t(28)<1$, *ns*; $W_S=231.5$, $p>.20$) or the backward span task ($t(28)=1.38$, $p<.10$; $W_S=207$, $p>.20$).

Lexical access

On the RAN task, adults with dyslexia were significantly slower than CA controls ($t(28)=3.54$, $p<.001$; $W_S=157$; $p<.001$), but faster than RL controls ($t(28)=3.82$, $p<.001$; $W_S=155$, $p<.001$).

Discussion

Comparisons of adults with dyslexia with CA controls evidenced the expected impairments of reading-related phonological processing. Indeed, on the subtests of phonemic awareness, both groups performed at the ceiling level on the CVC subtest, but not on the CCV subtest, where adults with dyslexia were less accurate than their CA controls. On both subtests adults with dyslexia were slower than their CA controls. Participants with dyslexia were also outperformed by CA controls on phonological short-term memory tasks, in terms of both accuracy and processing time. They also performed below the CA controls on the forward and backward digit span tasks, further indicators of impaired short-term memory. Finally, the adults with dyslexia were slower than their CA controls on the RAN task. The present results replicate previously observed impairments among French adults with dyslexia in phonemic awareness (Dufor et al., 2007; Paulesu et al., 2001), phonological short-term memory (Dufor et al., 2007; Paulesu et al., 2001; Szenkovits & Ramus, 2005), and rapid access to spoken forms in the mental lexicon (Paulesu et al., 2001; Szenkovits & Ramus, 2005). These impairments are generally observed in English-speaking populations (see for example Snowling et al., 1997).

The phonological deficits attested in comparisons to CA controls in this first experiment are not found in comparisons with RL controls. Indeed adults with dyslexia and RL controls performed similarly on the two phonemic-awareness subtests in terms of both accuracy and processing time. This was also true of phonological short-term memory, since the two groups had similar processing times and accuracy on pseudoword repetition as well as similar digit span scores. Finally, adults with dyslexia in the present study were faster than their reading-level controls on the RAN.

These results provide, for the first time, comparisons of the performance of French-speaking adults with dyslexia on phonological tasks with that of both CA and RL controls. Together, the results show strong impairments of phonological skills in French adults with dyslexia as compared with their CA controls—impairments that did not appear in comparisons to their RL controls. The findings with RL comparisons differ somewhat from what is usually observed in English-speaking populations (Bruck, 1992; Chiappe et al., 2002), where adults with dyslexia exhibit deficient phonemic awareness and phonological short-term memory skills in comparison to RL controls. Moreover, in English adults with dyslexia have been found to perform similarly to RL controls on the RAN task (Chiappe et al., 2002; Ransby & Swanson, 2003), whereas in our study the French speaking adults with dyslexia were faster than their RL controls on the RAN task. This result suggests that in our target population, access to phonological forms in the spoken lexicon is better than what would be expected based on their reading level. Based on these results, it may be contended that access to phonological forms in the mental lexicon, as assessed by the RAN task, is not a key component of the reading failure observed in dyslexia. The question of the kind of phonological processes that are involved in this task is currently under discussion in research on normal reading acquisition (Manis, Seidenberg, & Doi, 1999) and on expert reading (Misra, Katzir, Wolf, & Poldrack, 2004).

As a whole, these results suggest that the phonological impairments of French-speaking adults with dyslexia persist across the lifespan, but might not be as deep as those observed in English-speaking populations. Of the two hypotheses we initially set forth, the most likely one is that orthographic transparency has an impact on the development of phonological skills in people with dyslexia. This phenomenon can be interpreted as an effect of orthographic transparency on the development of phonological skills. Orthographic transparency is known to have an effect on the development rate of phonemic awareness in normally developing children who are learning to read (Goswami, 2002). It is therefore quite conceivable that orthographic transparency also influences the development of phonological skills in people with dyslexia. This phenomenon might be mediated by partial reliance on the sublexical procedure, which appears to be more difficult in opaque orthographies. This hypothesis is developed further below in the general discussion.

Experiment 2: written-word processing in adults with developmental dyslexia

Introduction

Most studies on developmental dyslexia are based on the dual-route model (Baron & Strawson, 1976; Coltheart, 1978; Coltheart, Curtis, Atkins, & Haller, 1993; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001), which holds that written words can be read either by a lexical or a sublexical procedure. The lexical procedure yields direct access to the subject's internal lexicon based on the orthographic word form. Reliance on the sublexical procedure in alphabetic scripts consists of translating the sublexical written units (graphemes) into the sublexical units of the spoken language (phonemes), which are then "assembled." This procedure acts as a bootstrapping mechanism upon which the lexical procedure can develop. The two procedures are assumed to be used in parallel to process printed material, with processing tradeoffs that depend on the overall level of word recognition attained (e.g., see for English-speaking children: Backman, Bruck, Hebert, & Seidenberg, 1984; Waters, Seidenberg, & Bruck, 1984; for French-speaking children: Sprenger-Charolles et al., 2003; Sprenger-Charolles et al., 1998).

In the dual-route model, the efficiency of the sublexical procedure is usually assessed through performance on reading pseudowords aloud. The lexicality effect (superiority of words over pseudowords) is taken as an indicator of the subjects' use of the lexical procedure to read words. The presence of a regularity effect (superiority of regular words over irregular words) indicates reliance on the sublexical procedure for word reading. Since familiar words are assumed to be read via the lexical procedure, performance on such words should not depend on sublexical factors such as regularity. The length of the items used in reading aloud tasks, whether words or pseudowords, is another sublexical factor that reflects the use and efficiency of the sublexical procedure. Finally, both accuracy and processing time must be taken into account, due to speed-accuracy tradeoffs as well as the fact that processing time offers a finer-grained measure of performance (see for example Sprenger-Charolles et al., 2003).

Efficiency of the sublexical reading procedure in children and adults with dyslexia

Children with dyslexia are poorer at reading pseudowords than their CA and RL controls in terms of both processing time and accuracy, which means that they are deficient in using the sublexical procedure. This pseudoword deficit is well documented in English-speaking children with dyslexia, at least for accuracy scores (for a qualitative analysis, see Rack, Snowling, & Olson, 1992; for a quantitative meta-analysis, see van Ijzendoorn & Bus, 1994). It has also been reported for languages with a shallow orthography, but mostly on the basis of processing time[3] (in Spanish: Gonzalez & Valle, 2000; in German: Wimmer, 1993; Wimmer, 1996; in French: Casalis, 1995; Grainger, Bouttevin, Truc, Bastien, & Ziegler, 2003; Sprenger-Charolles et al., 2000; Ziegler, Perry, Ma-Wyatt, Ladner, & Schulte-Korne, 2003).

English-speaking adults with dyslexia are slower and less accurate at reading pseudowords aloud than CA controls. This pattern of results has also been observed in Danish (Elbro, Nielsen, & Petersen, 1994) and French (Dufor et al., 2007). Paulesu et al. (2001) found that Italian adults with dyslexia selected for their slow pseudoword reading made fewer pseudoword-reading errors than both English and French adults with dyslexia. However, all groups differed from CA controls to the same extent. All groups with dyslexia were also slower than their respective CA control groups, but because of slight differences in hardware and administration procedures used in different countries, response latencies are not directly comparable. Note, however, that latency patterns apparently correspond to what has been observed for accuracy. Impairments in pseudoword reading thus seem to be characteristic of adults with dyslexia reading in both deep and shallow orthographies.

Compared to RL controls, English-speaking adults with dyslexia have been found to be slower (Ben-Dror, et al., 1991; Bruck, 1990) and less accurate on pseudoword reading.[4] A pseudoword deficit thus characterizes English-speaking adults with dyslexia and appears to be long-lasting in English-speaking populations. To our knowledge, this comparison has never been made for adults in a language with a shallower orthography than English.

Efficiency of the lexical reading procedure in children and adults with dyslexia

The regularity effect, which indicates reliance on the sublexical procedure, is known to be limited to low-frequency words in expert readers (Seidenberg, Waters, Barnes, & Tanenhaus, 1984). For high-frequency words, whole-word representations are accessed from the mental lexicon before information from the phonological assembly route becomes available.

In the case of dyslexia, because of an impaired sublexical procedure, it may be expected that all words will be read by the lexical route, so that the predicted advantage with regular words should be eliminated or reduced. Despite the apparent validity of this prediction, a regularity effect on accuracy of equal magnitude for English-speaking children with dyslexia and RL controls has been observed in most studies (e.g. Bruck, 1988; Olson, Kliegel, Davidson, & Foltz, 1985; Snowling, Goulandris, & Defty, 1996; for a review, see Metsala, Stanovich, & Brown, 1998). What is more, this regularity effect is obtained for

[3] Note that a dyslexic pseudoword deficit can be observed on accuracy scores in a transparent orthography, at least for very poor young readers (e.g. Sprenger-Charolles et al., 2009).

[4] However, see Ransby and Swanson (2003), who found English-speaking adults with dyslexia and reading-level controls to perform similarly on pseudoword reading accuracy.

both low-frequency and high-frequency words, among both children with dyslexia and RL controls (Metsala et al., 1998).

Only two studies have looked at the regularity effect in adults with developmental dyslexia; both found that English-speaking adults with dyslexia exhibited a regularity effect on high-frequency words (Ben-Dror et al., 1991; Bruck, 1990). More specifically, this effect was observed for accuracy only in Ben Dror's study, and was a bit smaller for adults with dyslexia than for their RL controls. Bruck (1990) found a regularity effect on high-frequency words with latencies (due to ceiling effects, she conducted statistical analyses on reaction times only, but the pattern for followed the one observed for reaction times), which was exhibited only by adults with dyslexia. The results of these two studies are thus contradictory in some respects. Nonetheless, for English-speaking adults with dyslexia, both studies indicate that for high-frequency words, the lexical procedure is not fast enough to override the information given by the sublexical procedure.

Summary and presentation of the second experiment

As reviewed above, English-speaking adults with dyslexia exhibit the well-known pseudoword deficit observed in children with dyslexia; they also exhibit a regularity effect, even on high-frequency words, which indicates that the lexical procedure is not fast enough to dominate the reading of such words. The efficiency of the lexical and sublexical procedures of adults with dyslexia has never been examined in a language with a shallower orthography than English. Experiment 2 was aimed at addressing these issues.

Experiment 2 was set up to examine both the lexical and sublexical reading procedures of French adults with dyslexia. In line with Sprenger-Charolles et al. (2005), we administered a naming task using the items assumed to be the best “signature” of one of the two reading procedures: pseudowords for the sublexical procedure and irregular words for the lexical procedure. Each time we varied length, a sublexical factor, thereby presenting short as opposed to long items.

The effect of length on naming latency can be accounted for by the sequential operation of the sublexical reading procedure. Pseudowords can only be processed by the sublexical procedure and need to be decoded in a serial mode to be named. As a consequence, length effects are characteristic of pseudoword naming, independently of the overall level of word recognition attained (Weekes, 1997; Sprenger-Charolles, et al., 2005; Sprenger-Charolles, et al., 2009). Written words, in contrast, can be processed by both the sublexical and the lexical procedures, and length effects for word naming are usually found to depend on the overall level of word recognition attained. Expert readers do not exhibit a length effect on word naming (e.g., Weekes, 1997) whereas such effects are found in typically developing children (e.g., Sprenger-Charolles et al., 2005) and children with dyslexia (e.g., Sprenger-Charolles et al., 2009). More precisely, typically developing French-speaking children in grades 3 and 4 exhibit length effects on the latency of the vocal response for both irregular word and pseudoword naming, the effect of length being greater on the latter than on the former. These authors suggested that increases in irregular word naming latencies with increasing word length reflect part of the pre-programming of articulatory codes, thereby revealing sequential programming. In addition, the fact that the length effect was less noticeable on irregular words than on pseudowords suggests that irregular word naming benefits from some direct parallel orthographic processing. In other words, the sublexical reading procedure appeared to compete with the lexical one for irregular word reading. In the same experiment, a length effect was also found with accuracy scores, but with strong differences between irregular words and pseudowords. Indeed, while the length effect was negative on pseudowords (long pseudowords were named less accurately than short pseudowords), as would be expected, surprisingly it was positive on irregular words (long irregular words were named more accurately than short irregular words). The authors argued that the positive effect of length on irregular words can be understood in light of the facts that, first, irregular words are never totally irregular, and second, the amount of regularity is greater for long words (e.g., *sculpture*/skyltyr/) than for short ones (e.g., *sept*/sɛt/). If the sublexical procedure is used to process irregular words then it can lead to more problems with short words, whose amount of irregularity is relatively greater.

Manipulating the length of irregular words in a naming task will thus allow us to test the efficiency of the lexical procedure in adults with dyslexia. It should be noted that length was preferred over regularity (comparing irregular words to regular words) as a sublexical factor, because the impact of regularity on word naming depends on word frequency. Written word frequency is difficult to control for in populations like adults with dyslexia and their controls, because exposure to written words can vary greatly.

Hypotheses

Given that the pseudoword deficit is a hallmark of developmental dyslexia which is present across varying degrees of orthographic transparency, French adults with dyslexia are likely to exhibit deficient use of the sublexical procedure. As with children with dyslexia, we expected this deficit to be observed at least for processing time. In short, we expected French adults with dyslexia to perform worse than both CA and RL controls on pseudoword reading, and therefore we predicted that the lexicality effect would be greatest for participants with dyslexia as compared to both CA and RL readers.

The two published studies on the efficiency of the lexical procedure conducted with English adults with dyslexia obtained contradictory results. Whereas Ben-Dror's et al. (1991) study suggests an impairment, Bruck (1990) reported deficient use of the lexical procedure. Because of these discrepant results, and the fact that there is no data on the efficiency of the lexical procedure among French adults with dyslexia, it is rather difficult to make a clear-cut prediction. Two plausible hypotheses can be set forth. The first hypothesis involves a deficient lexical procedure. In this case, we expect adults with dyslexia to rely more heavily on sequential processing (sublexical procedure) to process irregular words than their RL controls. In consequence, this first hypothesis predicts a greater length effect on irregular words for French adults with dyslexia than for their RL controls. This hypothesis is reinforced by the observation that this effect has been found to decrease with age among normal-developing 8- to 10-years-old French readers (Sprenger-Charolles et al., 2005). The second hypothesis holds that the use of the lexical procedure of French adults with dyslexia corresponds to their reading level. In this case, the pattern exhibited by adults with dyslexia should be comparable to that of RL controls: we would expect to observe a length effect in both groups. Under both hypotheses, we also expect not to obtain a length effect on irregular words among CA controls.

Method

Participants

The participants were the same as in Experiment 1.

Task and materials

The task used to assess the relative efficiency of the lexical and sublexical procedures is called LEXLENGTH (EVALEC: Sprenger-Charolles et al., 2005). LEXLENGTH uses 20 irregular words and 20 pseudowords, ten short and ten long (mean irregular word lengths: 4.30 and 8.00 letters; mean pseudoword lengths: 4.40 and 7.80 letters). The words and pseudowords are matched for length (number of letters, phonemes, and syllables), orthographic frequency (bigram frequency: Content & Radeau, 1988), and initial grapheme. According to MANULEX (Lété, Sprenger-Charolles, & Colé, 2004), a lexical database that tracks children's exposure to vocabulary, the irregular words in this task have an average lexical frequency of 14.55 (SD=17.29). However, since there are few irregular words in French, matching the short and long irregular words for lexical frequency is impossible: the long irregular words are less frequent (10.20, SD=22.17) than the short irregular words (18.90, SD=22.29).

Procedure and apparatus

Subjects were instructed to read the item displayed in the center of the screen as accurately and as quickly as possible. They were told to be sure they had the right word in their mind before answering. The procedure on each trial was as follows. A fixation cross was displayed in the center of the screen and remained there for 500 ms; it was immediately followed by the test item in lower case. The item remained on the screen until the subject had finished reading it aloud, at which point the experimenter triggered the presentation of the next item. Practice items were used to make sure the subject understood the instructions.

The tasks were displayed at a resolution of 1,024×768 pixels on the 14-inch screen of a laptop computer. Response latency and accuracy were measured. A sound card was used to record the responses. The software calculated latency by detecting the onset of the response in the speech signal. The software allowed for manual readjustment if necessary and the elimination of latencies on incorrect responses. This enabled the experimenter to ensure that no latencies were invalid and to calculate the percentage of errors.

Results

All latencies under 300 ms were eliminated (which never represented more than 0.25% of the data). The latencies were then smoothed in the following manner: for each subject and each category of items (irregular word vs. pseudoword), latencies exceeding 1.5 times the interquartile range above the third quartile or below the first quartile were discarded. This eliminated less than 5% of the latencies.

The results are reported in Table 3. Because chronological age controls performed at ceiling in all but the long pseudoword condition, we analyzed only latencies, and not error rates for this group.

Data analysis

Here again, we were interested in comparing the performance of adults with dyslexia to that of the two control groups separately, as well as the performance of subjects within each group. More precisely, for each group we were interested in lexicality and length effects and

Table 3 Mean scores (and standard deviations) of adults with dyslexia, CA controls, and RL controls on experiment 2

	Response latencies (ms)			Errors (%)		
	Short	Long	Total	Short	Long	Total
CA controls						
Pseudowords	607 (122)	704 (188)	655 (152)	5.33 (7.43)	10.67 (7.99)	8.00 (6.49)
Irregular words	514 (68)	506 (64)	510 (65)	4.00 (8.28)	2.67 (5.93)	3.33 (6.73)
Total	560 (91)	605 (121)	583 (105)	4.67 (6.94)	6.67 (5.56)	5.67 (5.78)
Adults with dyslexia						
Pseudowords	1049 (464)	1491 (1005)	1270 (719)	10.00 (7.56)	28.67 (16.84)	19.33 (10.15)
Irregular words	772 (318)	845 (434)	809 (375)	8.00 (9.41)	3.33 (4.88)	5.67 (5.63)
Total	910 (382)	1168 (699)	1039 (535)	9.00 (7.12)	16.00 (9.30)	12.50 (6.20)
RL controls						
Pseudowords	813 (167)	1041 (289)	927 (218)	13.33 (9.00)	24.67 (11.25)	19.00 (6.87)
Irregular words	699 (172)	721 (215)	710 (190)	18.00 (15.8)	10.67 (12.80)	14.33 (12.23)
Total	756 (162)	881 (228)	818 (190)	15.67 (7.29)	17.67 (9.23)	16.67 (6.99)

in possible interactions between them. A two-way repeated measures analysis of variance (ANOVA) with lexicality (words vs. pseudowords) and item length (short vs. long) as within-subject factors was carried out for each group. Planned comparisons were used to test for simple effects of length on the reading of words and pseudowords. The variance between words and pseudowords differed across groups, but also within the group with dyslexia, so planned comparisons based on the mean square error specific to the group and to the type of item (word vs. pseudoword) were performed.

For the group comparisons, we compared performance and the impact of length and lexicality across groups. We carried out 2×2×2 ANOVAs to compare the adults with dyslexia to their CA controls on the one hand (on latencies only, as CA controls performed at ceiling in terms of accuracy), and to their RL controls on the other hand, so group was a between-subjects factor. The within-subjects factors were lexicality and length.

Again, the application conditions for ANOVAs were not met, as the data were not normally distributed (accuracy: $W=.61$, $p<0.001$; latencies: $W=.89$, $p<0.001$), and variance differed greatly across conditions, as can be seen in Table 3. In consequence we supplemented the parametric analyses with nonparametric analyses. Wilcoxon's signed-rank test (W) was used within each group to test the effects of lexicality and length, as well as the effect of length on word and pseudoword reading. Wilcoxon's rank-sum test (W_S) was used to compare the groups' performance. Supplementing parametric analyses with nonparametric analyses has already been used to ensure validity in studies on developmental dyslexia (Heiervang et al., 2002).

Latencies

Analyses by group

Adults with dyslexia Both lexicality and length had main effects (lexicality: $F(1,14)=18.83$, $p<0.001$, partial $\eta^2=.57$; $W(15)=1$, $p<0.01$; length: $F(1,14)=7.96$, $p<0.05$, partial $\eta^2=.36$; $W(15)=1$, $p<0.01$) and interacted significantly ($F(1,14)=6.71$, $p<0.05$, partial $\eta^2=.32$). Adults with dyslexia responded faster to irregular words than to pseudowords. They responded faster to short than to long items, for both irregular words ($t(14)=2.22$, $p<0.05$; $W(15)=15$, $p<0.001$) and pseudowords ($t(14)=2.76$, $p<0.01$; $W(15)=7$, $p<0.001$).The interaction can be explained by the greater effect of length on pseudowords (42.12% increase) than on words (9.55% increase).

CA controls Both lexicality and length had significant effects (lexicality: $F(1,14)=29.09$, $p<0.001$, partial $\eta^2=.68$; $W(15)=0$, $p<0.01$; length: $F(1,14)=15.24$, $p<0.01$, partial $\eta^2=.52$; $W(15)=6$, $p<0.01$) and interacted significantly ($F(1,14)=20.58$, $p<0.001$, partial $\eta^2=.60$). CA controls responded more slowly to pseudowords than to irregular words. There was a significant negative effect of length on pseudowords only ($t(14)=4.43$, $p<0.001$; $W(15)=2$, $p<0.001$).

RL controls Both lexicality and length had significant effects (lexicality: $F(1,14)=29.86$, $p<0.001$, partial $\eta^2=.68$; $W(15)=1$, $p<0.01$; length: $F(1,14)=18.81$, $p<0.001$, partial $\eta^2=.57$; $W(15)=5$, $p<0.01$) and interacted significantly ($F(1,14)=22.16$, $p<0.001$, partial $\eta^2=.61$). RL controls had significantly shorter response latencies to words than to pseudowords. An analysis for simple effects revealed a length effect for pseudowords only (words: $t(14)=1.03$, $p>0.15$; $W(15)=40$, $p>0.20$; pseudowords: $t(14)=4.92$, $p<0.001$; $W(15)=0$, $p<.005$).

Group comparisons

Adults with dyslexia vs. CA controls The group effect was significant ($F(1,28)=10.51$, $p<0.01$, partial $\eta^2=.27$; $W_S(15)=127$, $p<0.001$), with higher latencies overall among adults with dyslexia than among CA controls. A simple effects analysis revealed that, compared to CA controls, adults with dyslexia were slower to respond to all types of items (short irregular words: $t(28)=3.06$, $p<0.01$; $W_S(15)=130$, $p<0.001$; long irregular words: $t(28)=2.99$, $p<0.01$; $W_S(15)=130$, $p<0.001$; short pseudowords: $t(28)=3.57$, $p<0.001$; $W_S(15)=131$, $p<0.001$; long pseudowords: $t(28)=2.98$, $p<0.01$; $W_S(15)=132$, $p<0.001$). The two-way interactions were significant (Lexicality×Group: $F(1,28)=8.31$, $p<0.01$, partial $\eta^2=.23$; length×group: $F(1,28)=5.35$, $p<0.05$, partial $\eta^2=.16$) and can be explained by the greater effects of lexicality and length among adults with dyslexia (lexicality: 57.05% increase; length: 28.31% increase) than among CA controls (lexicality: 28.45%; length: 8.00%). The three-way interaction lexicality×length×group did not reach the conventional significance level ($F(1,28)=3.32$, $p=0.08$, partial $\eta^2=.11$).

Adults with dyslexia vs. RL controls The main effect of group did not reach the conventional significance level ($F(1,28)=2.27$, $p>.10$, partial $\eta^2=.07$; $W_S(15)=192$, $p=.05$) but the lexicality×group interaction was significant ($F(1,28)=4.63$, $p<0.05$, partial $\eta^2=.14$). The effect of lexicality was greater in adults with dyslexia than in RL controls. A simple effects analysis revealed that adults with dyslexia were not slower to respond to irregular words than RL controls (short and long irregular words: $t(28)<1$, *ns*; $W_S(15)=210$, $p>.10$). In contrast, they were slower on pseudowords (short and long pseudowords: $t(28)=1.77$, $p<.05$; $W_S(15)=192$, $p=.05$). The other interactions were not significant (length×group: $F(1,28)=1.92$, $p>.15$, partial $\eta^2=.06$; lexicality×length×group: $F(1,28)=1.20$, $p>.20$, partial $\eta^2=.04$).

Error percent

Because CA controls performed at ceiling in terms of accuracy, analyses were not conducted on error percentages for this group, nor was the comparison with adults with dyslexia.

Analyses by group

Adults with dyslexia There was a main effect of lexicality ($F(1,14)=24.16$, $p<0.001$, partial $\eta^2=.63$; $W(15)=1.5$, $p<0.001$) and length ($F(1,14)=6.09$, $p<0.05$, partial $\eta^2=.30$; $W(15)=16.5$, $p<0.01$), and these two factors interacted significantly ($F(1,14)=32.36$, $p<0.001$, partial $\eta^2=.32$). Adults with dyslexia responded more accurately to words than to pseudowords. Length had a negative impact on pseudoword reading ($t(14)=4.40$, $p<0.001$; $W(15)=1$, $p<0.001$) but a positive impact on irregular-word reading ($t(14)=1.82$, $p<0.05$; $W(15)=9$, $p<0.001$).

RL controls The main effects of lexicality and length were non-significant (lexicality: $F(1,14)=1.65$, $p>0.20$, partial $\eta^2=.11$; $W(15)=24.5$, $p<0.05$; length: $F(1,14)<1$, *ns*, partial $\eta^2=.05$; $W(15)=34$, $p>0.10$) but these factors interacted significantly ($F(1,14)=9.18$, $p<.01$, partial $\eta^2=.40$). There was a negative effect of length (percentage of errors increasing with length) on pseudowords only ($t(14)=2.92$, $p<0.01$; $W(15)=9.5$, $p<0.01$).

Group comparison

Adults with dyslexia vs. RL controls Overall, the difference between the mean error percentages of RL controls and adults with dyslexia was not significant ($F(1,28)=2.99$, $p<0.10$, partial $\eta^2=.10$; $W_S(15)=188.5$, $p<0.10$). None of the interactions reached the conventional significance level (lexicality×group: $F(1,22)=3.87$, $p=0.0591$, partial $\eta^2=.12$; length×group: $F(1,28)=1.86$, $p>0.15$, partial $\eta^2=.06$; lexicality×length×group: $F(1,22)<1$, *ns*, partial $\eta^2=.01$). A simple effects analysis revealed that the difference in the pseudoword error percentages of the adults with dyslexia and the RL controls was non-significant (short and long pseudowords: $t(28)<1$, *ns*; $W_S(15)=232$, $p>0.20$). On irregular words RL controls made more errors than adults with dyslexia (both short and long: $t(28)=2.49$, $p<0.01$; $W_S(15)=166.5$, $p<0.005$).

Discussion

On pseudoword naming, adults with dyslexia were slower than their CA controls. Ceiling performance for accuracy by the CA controls prevented us from statistically comparing their performance to that of adults with dyslexia. It should be noted, however, that the pattern observed with error percentages follows that observed with latencies in CA controls. In comparison to RL controls, adults with dyslexia were not less accurate, but they were slower to name pseudowords. Thus, the present results reveal a pseudoword deficit in French-speaking adults with dyslexia.

The pseudoword deficit was revealed by the fact that the lexicality effect in adults with dyslexia was larger than that of either control group, a phenomenon that showed up in processing times relative to both control groups. Thus, as expected, a pseudoword deficit is not limited to English-speaking populations, and can be considered characteristic of the reading of adults with dyslexia regardless of orthographic transparency. Moreover, these results correspond to what is usually observed in children with dyslexia. Indeed, while English studies indicate the presence of a pseudoword deficit in children with dyslexia mostly in terms of accuracy (see Rack et al., 1992; van Ijzendoorn & Bus, 1994), processing time is usually the indicator of a pseudoword deficit in the reading of children with dyslexia in shallower orthographies (e.g., Casalis, 1995; Sprenger-Charolles et al., 2000; Sprenger-Charolles et al., accepted; Wimmer, 1993).

For irregular words, adults with dyslexia were also slower than CA controls. Again, the ceiling performance of the CA controls prevented us from comparing their accuracy to that of adults with dyslexia. In comparison to RL controls, adults with dyslexia were as fast as RL controls, and more accurate. Because there are few high-frequency irregular words in French orthography, it could be that the adults with dyslexia had come across the irregular words more frequently than the reading-level controls.

Finally, we observed differences in length effect between the two measures, the two types of items, and the three groups. In speed terms, this factor had a negative impact on pseudoword naming for the three groups, and on irregular words for adults with dyslexia only. However, the effect of length was less marked on irregular words than on pseudowords. In accuracy terms, this factor had a negative impact on the reading of pseudowords for both adults with dyslexia and RL controls, and a positive impact on the reading of irregular words, again for adults with dyslexia only. These results replicate what has already been observed in typically developing readers of French in grades 3 and 4. As discussed in the introduction, such length effects on irregular word naming reveals reliance on the sublexical procedure to process these words. Despite the apparently similar, or even better, performance of the adults with dyslexia as compared to their RL controls, these findings thus show that the two groups do not process irregular words in the same manner. In adults with dyslexia, the lexical procedure seems to compete with the sublexical procedure, even for irregular word reading. These results thus suggest that the lexical procedure is deficient in French adults with dyslexia, which is comparable to findings obtained with English-speaking populations (Bruck, 1990).

General discussion

The present study investigated both the reading and reading-related skills of French adults with dyslexia studying at a university. We were interested in the potential impact of orthographic transparency on the reading and reading-related skills of people with dyslexia, since data from languages with a transparent orthography is lacking. In this context, it is particularly interesting to study adults with dyslexia because they can provide evidence of the life-long deficits that constitute the core characteristics of dyslexia.

Reading-related skills of french-speaking adults with dyslexia

We compared the reading-related skills of adults with dyslexia in French, a shallower orthography than English, to those of both CA and RL controls, by testing their phonemic awareness, phonological short-term memory, and rapid access to spoken forms in the mental lexicon.

Compared to CA controls, for both phonemic awareness (except on the CVC subtest of phonemic awareness, where both groups performed at ceiling) and phonological short-term memory, adults with dyslexia were less accurate. They were also slower than CA controls on the RAN task. These results replicate previously observed impairments among French adults with dyslexia in phonemic awareness (Dufor et al., 2007; Paulesu et al., 2001), phonological short-term memory (Dufor et al., 2007; Paulesu et al., 2001; Szenkovits & Ramus, 2005), and rapid access to spoken forms in the mental lexicon (Paulesu et al., 2001; Szenkovits & Ramus, 2005). Thus impairments in phonological reading related skills are long-lasting in French adults with dyslexia and are not limited to English-speaking populations.

Compared to RL controls, the adults with dyslexia never exhibited poorer performance, either in terms of accuracy or processing times, regardless of the task, and they were faster than RL controls on the RAN task. Thus, contrary to our predictions, the adults with dyslexia participating in the present study did not exhibit a deficient phonemic awareness or phonological short-term memory in comparison to their RL controls. They even achieved faster access to spoken word forms in the mental lexicon than RL controls. This contrasts with English-language studies where adults with dyslexia were found to exhibit accuracy deficits in phonemic awareness (Bruck, 1992) and in phonological short-term memory (Pennington et al., 1990), and to perform RAN tasks at a speed similar to RL controls (Chiappe et al., 2002; Ransby & Swanson, 2003).

One possible explanation for our results could be the fact that phoneme deletion at the beginning of pseudowords was too easy for adults, as suggested by the high percentage of correct answers, a fact that could have prevented the phonemic deficit from emerging. However, processing time measures are supposed to act as a control for such methodological problems. Processing times were analyzed in the present study, yielding no significant difference between adults with dyslexia and RL controls. It is also worth noting that phoneme deletion has the advantage of tapping phonological short-term memory to a lesser extent than spoonerisms or pig Latin-type tasks. Indeed, when selecting a phonemic awareness task, task requirements must be given careful consideration, since the deficit can emerge because of a heavy load on phonological short-term memory (Ramus & Szenkovitz, 2008).

Three alternative, nonexclusive hypotheses can be advanced to explain our results. The first pertains to the impact of orthographic transparency on phonological skills; the second is related to the population tested in the present study; the third deals with the kind of processes involved in phonemic awareness tasks.

The present results suggest that orthographic transparency may affect the development of phonological skills in dyslexia. It remains to be explained how the transparency of a given written language might influence phonemic awareness. As Morais, Cary, Alegria, and Bertelson (1979) and Morais, Bertelson, Cary, and Alegria (1986) demonstrated, phonemic awareness does not arise spontaneously in the course of general cognitive growth. Rather, it is the very process of learning to read that alerts the beginning reader to the presence of phonemes in speech. Morais et al. (1979) proposed a reciprocal relationship between learning to read and developmental changes in phonemic awareness, since awareness appears to depend on instruction, which in turn depends on phonemic awareness. As explained earlier, phonemic awareness is central to reading acquisition because it paves the way to understanding how the alphabet works. When trying to understand the principle of the alphabet, children are likely to be puzzled by the presence of inconsistent grapheme-phoneme relationships. On the other hand, consistent correspondences between graphemes and phonemes may help children understand that the linearity of the written language mirrors the sequentiality of speech. This would facilitate the development of phonemic awareness and could be particularly helpful for people with dyslexia. A good example is the German language, considered to have a transparent orthography. A series of studies by Wimmer (1993; 1996) with German children with dyslexia showed that only in first grade did the children have trouble with phonemic parsing. The problems were no longer found at the end of the fourth grade.

It may be wondered whether orthographic transparency also has an additional positive impact on performance in tasks that tap phonological short-term memory or require rapid access to spoken forms in the mental lexicon. It appears from studies with children with dyslexia that among the various phonological skills, deficits in phonological awareness, especially phonemic awareness, are the greatest. In light of the lack of difference in performance on phonemic awareness tasks in adults with dyslexia relative to RL controls in the present experiment, it was not surprising to observe no difference in phonological short-term memory or rapid access to spoken forms in the mental lexicon as well. It could be that the three phonological skills studied here, especially phonemic awareness and phonological short-term memory, are in constant interaction during the process of learning to read. It can be imagined that a deficit in one of these abilities might be costly and overload the cognitive system, preventing the correct functioning of the others. An absence of deficit in phonemic awareness might enhance the development of phonological short-term memory at least. Thus the impact of orthographic transparency, if any, on phonological awareness and access to the spoken forms in the mental lexicon would be mediated by the absence of deficit in phonemic awareness. Note, in addition, that the task used to measure access to phonological forms in the mental lexicon, the RAN, has been criticized. The questions concern the nature of the mechanisms involved in the task. Some suggest that beyond phonological processes, the RAN measures processing speed and requires integrating low-level visual processes and high-level linguistic and cognitive mechanisms (Manis et al., 1999). Seen from this angle, the present RAN task results could also stem from differences in the general cognitive levels of adults with dyslexia and their reading-level controls, rather than from differences in phonological processes.

The second hypothesis has to do with the population under study. Clearly, for adults with dyslexia, the developmental factor has to be taken into account because of the large age gap between adults with dyslexia and their RL controls. Even though adults with dyslexia and RL controls are matched on reading level, the two groups differ in their exposure to printed and verbal material, especially in the present study where the adults with dyslexia were university students. Their greater exposure to printed and verbal material might have helped them improve their phonological skills. This consideration is especially important given our first hypothesis, that relatively transparent orthographies such as French may help readers with dyslexia to improve their phonological skills. People with dyslexia are capable of such progress, as indicated by experiments where they are trained in phonological skills (see for example Hatcher, Hulme, & Ellis, 1994; Wise, Ring, & Olson, 1999). Unfortunately, we do not have data on the type of remediation that the adults with dyslexia involved in the present study benefited from. In consequence it is hard to state whether remediation programs could also have had a positive impact on the development of the phonological skills of the present sample.

The third hypothesis is that the adults with dyslexia executed the phonemic awareness tasks using their orthographic knowledge. The stimuli were pseudowords composed of three-sound sequences comprised of very simple grapheme-phoneme correspondences, many of which were part of the orthographic representations of words. Some examples are the target *"grou"* in *groupe* and *grouper*, the target *"pra"* in *praline*, *pratique*, and *pratiquer*, and the target *"blo"* in *bloquer*, *blocage*, and so on. According to Siegel, Share, and Geva (1995), people with dyslexia have better orthographic skills than normal achievers in reading. Their study assessed the development of both the phonological and orthographic skills of 257 children with dyslexia and 342 control readers matched on reading age (from first to eighth grade). A pseudoword reading task was used to measure phonological skills and an orthographic awareness task was used to measure awareness of the properties of English words and the probable sequences and positions of letters within words. The children with dyslexia got significantly higher scores than the normally achieving readers on the orthographic awareness task, but significantly lower scores on the phonological task. The authors suggested that because of their poor phonological skills, people with dyslexia learn to pay more attention to the visual-orthographic form of words rather than to their sounds.

Reading skills in french-speaking adults with dyslexia

The present study was the first to test for the presence of a pseudoword deficit and to investigate the efficiency of the lexical procedure in adults with dyslexia, as compared to RL controls in a language with a shallower orthography than English. As predicted, French adults with dyslexia displayed a pseudoword deficit. Based on their processing times, the adults with dyslexia were slower than RL controls on pseudoword reading only, and showed larger lexicality effects. The pseudoword deficit did not show up on accuracy scores, thereby reflecting what is usually observed in children with dyslexia in shallower orthographies than English (e.g., Casalis, 1995; Sprenger-Charolles et al., 2000; Wimmer, 1993).

When reading irregular words, adults with dyslexia were slower than their CA controls (accuracy was not examined, because of ceiling effects in the control group), and they were as fast as and more accurate than their RL controls. However, the adults with dyslexia were the only ones to be sensitive to the effect of length when reading irregular words, not only for speed (the effect of length being only less marked than on pseudowords) but also for accuracy: they read long irregular words more accurately than short irregular words. Thus, words that do not have completely regular patterns still appear to be problematic for adults with dyslexia. As we suggested, a length effect on irregular word naming suggests reliance on the sublexical procedure. The positive impact of length on accuracy suggests that when French adults with dyslexia are reading long irregular words, they may use orthographic knowledge to prime and pre-activate the right candidate. Thus, this pattern of results suggests that in adults with dyslexia, the lexical procedure competes with the sublexical procedure, even in irregular word reading, when the use of the lexical procedure alone would be facilitatory. So, although the lexical procedure seems to be more functional than the sublexical one in French adults with dyslexia, it does not work in the normal way. The sublexical procedure apparently continues to be used quite systematically by readers with dyslexia to process printed material. This is consistent with the notion that the sublexical procedure is the bootstrapping procedure upon which the lexical procedure develops. When the sublexical procedure cannot develop normally (as in dyslexia), the development of the lexical procedure is altered. These results further suggest that long-lasting impairments in the use of the lexical procedure are not restricted to English-speaking populations, but also characterize readers with dyslexia in shallower orthographies than English.

Concluding remarks

The present study highlights very important and new findings on reading and reading-related skills in adults with dyslexia who have learned to read in a language with an orthography less deep than that of English—namely, French.

The present study suffers, however, from some limitations that should be addressed in the future. First, the number of participants within each group was not large, and so the present results need to be replicated with a larger number of participants. Moreover, to ensure that the present results are linked to the transparency of the French orthography as compared to the English one, these results should be replicated in other orthographies with transparencies similar to or greater than French.

A second limitation of the present study lies in the lack of information about the kind of remediation that the adults with dyslexia benefited from. Indeed, if our participants benefited from remediations that involve heavy training for phonological processing, it is likely that this training had a positive impact on the phonological processes investigated in the present study. Future studies should take into account information about phonological training.

A third limitation is linked to the lack of standardized tests of reading and phonological processing in French-speaking adults. Such tests would be helpful in several ways, such as identifying deficits without the need to rely on comparisons with reading-level controls. Furthermore, in the absence of such tests the screening of adults with dyslexia is very difficult. Future research should thus focus on the construction of such tests for French-speaking populations.

Moreover, the use of naming tasks (experiment 2) with people with dyslexia can be called into question. Influential models describing normal and impaired single-word reading (Coltheart et al., 2001; Harm & Seidenberg, 1999; and more recently Perry, Ziegler, & Zorzi, 2007) mainly focus on the processes implemented in the reading aloud of single words. They generally account for data collected via the naming task. However, because reading words aloud requires full access to phonological forms and their subsequent articulation (Jared, 1997), it does not represent the usual reading situation for adults. The nature of this task, which calls heavily upon phonological processing, is likely to impair the performance of adults with dyslexia. Recent work by Ramus and Szenkovits (2008) with French-speaking adults with dyslexia suggests that the phonological deficit lies in access to phonological forms and the incurred memory load, rather than in degraded phonological representations. Silent reading tasks such as lexical decision tasks are likely to be easier for adults with dyslexia because they do not necessarily require phonological processing. This opens up an important route for research, and we are currently investigating this issue using a lexical decision task on pseudohomophones. This method should provide some indications about reliance on the sublexical procedure.

Finally, one of the main results of this study was that French university students with dyslexia continue to experience the substantial reading problems they had during childhood. As Kirby, Silvestri, Allingham, Parrila, and La Fave (2008) pointed out, about 1.61% of undergraduate students in the United States suffer from specific learning disabilities. One of these learning disabilities is dyslexia. It thus seems worthwhile to conduct studies not only to further identify the cognitive limitations of students with dyslexia, but also to understand the compensatory strategies they devise in order to attain academic success. Very little research has been performed in the latter domain, although Kirby et al. (2008) identified two main methods for grasping how university students cope with their reading deficit in the face of their academic work, i.e., self-report questionnaires and observational methods in which strategies are observed or inferred from performance. These two methods are complementary in that self-report questionnaires reveal students' beliefs and understandings of their academic tasks.

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