

**Characterizing Different Types of Developmental Dyslexias
in French: The Malabi Screener**

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Abstract

Reading is a complex process involving multiple stages whose impairment may cause distinct types of reading deficits. We describe the Malabi, a screener to identify deficits in various orthographic, lexical, and sublexical components in French. Malabi uses stimuli sensitive to different dyslexias, including attentional dyslexia, an impairment in letter-to-word binding leading to letter migrations between words (“bar cat” may be misread as “bat car”), and letter-position dyslexia, leading to letter transposition errors (“destiny” may be misread as “density”). After collecting reading error norms from 138 French middle-school students, we analyzed error types of 16 dyslexic students. We identified three selective cases of attentional dyslexia and one case of letter-position dyslexia. Further tests replicated our interpretation and explored factors modulating letter migration between- and within- words. Our results support prior evidence of multiple developmental dyslexias, including deficits rooted in impaired orthographic rather than phonological processing.

Introduction

Reading is a complex activity involving many processes and pathways linking visual and language systems of the brain, as demonstrated by brain-imaging studies comparing illiterates and literates (Dehaene et al., 2010, 2015a; Price, 2012) and identifying multiple changes in the brain over the course of learning to read (Brem et al., 2010; Dehaene-Lambertz et al., 2018; Monzalvo & Dehaene-Lambertz, 2013; Wandell & Yeatman, 2013). This multi-module complexity is also illustrated by the variety of case studies of acquired dyslexia following brain damage in adults (Caramazza et al., 1985; Coltheart, 1981; Coslett, 2000; Coslett & Turkeltaub, 2016; Ellis, 1984; Lambon & Ellis, 1997; Lambon Ralph & Patterson, 2005; Marshall & Newcombe, 1973; Newcombe & Marshall, 1981; K. E. Patterson, 1981; K. Patterson & Lambon Ralph, 1999; Shallice & Warrington, 1977; Temple & Marshall, 1983) and the diversity of reading difficulties presented in cases of developmental dyslexia (Castles & Coltheart, 1993; Coltheart & Kohnen, 2012; Ellis & Young, 2015; Friedmann & Coltheart, 2018; Friedmann & Haddad-Hanna, 2014a; Jackson & Coltheart, 2001; Marshall, 1984a, 1984b). However, current screening and remediation tools are rarely optimized to cover the possibility of multiple different deficits.

Much of research has been focused on trying to explain dyslexia as a single underlying cognitive deficit, without converging on what this deficit might be. For example, from the perspective of the visual system, multiple theories of dyslexia have surfaced, spanning from retinal anomalies (Le Floch & Ropars, 2017) to a dysfunctional magnocellular pathway (e.g., Stein & Walsh, 1997) or deficient visuo-spatial attention (Bosse et al., 2007; Valdois et al., 2004; Vidyasagar & Pammer, 2010b) (e.g., Bosse et al., 2007; Valdois et al., 2004; Vidyasagar & Pammer, 2010). The dominant hypothesis, however, is that dyslexia relates to an underlying phonological deficit (Landerl et al., 1997; Ramus, 2003; Vellutino et al., 2004), characterized by difficulties in perceiving and manipulating phonemes, the smallest sound units of spoken words that distinguish one word from another (Goswami & Bryant, 1990).

The fragility of core deficit hypotheses is that the verdict of dyslexia has been filtered through the unitary theory itself, and in many cases, the person's difficulties in reading itself were not thoroughly analyzed. For example, researchers and clinicians assessing for phonology-related core deficits typically make a diagnosis of dyslexia using oral phoneme awareness tasks such as phoneme deletion, phoneme fusion, and pseudoword repetition (Elbro & Jensen, 2005; Landerl et al., 1997; Peterson & Pennington, 2012; Ramus et al., 2003; Saksida et al., 2016; Wagner & Torgesen, 1987). The argument is that a deficit in the person's phoneme awareness, exemplified in language difficulties pre-existing reading, causes dyslexia. We do not disagree that poor phoneme processing may lead to later reading difficulties, but we do argue that this methodology is at risk of filtering for certain types of dyslexia while excluding others, generating both false positives and negatives (Scarborough, 1998; Torgesen, 2002). In the particular case of using phoneme awareness tasks to identify dyslexia, false positives could stem from lack of appropriate reading experience, as literacy is known to facilitate phoneme processing (Dehaene et al., 2015a; Morais et al., 1979); and false negatives could arise from failing to carefully test reading itself in the absence of a phonological deficit. Indeed, various studies have reported individuals with dyslexia who showed no difficulties on nonword repetition tasks, phonological span tasks, or phonological awareness tasks (Castles, 1996; Castles & Friedmann, 2014; Friedmann & Rahamim, 2007; Güven & Friedmann, 2022; Khentov-Kraus & Friedmann, 2018b).

The multiple deficit theory of dyslexia, and its screening

Several authors, even those who favor the phonological hypothesis, have recognized that multiple deficits may exist in developmental dyslexia (e.g. Ramus et al., 2003; Siok et al., 2009). Thus, another methodology has been to develop tests that seek to understand dyslexias (in the plural) as arising from multiple possible deficits, depending on the locus of impairment within the complex architecture for reading (Castles et al., 2009; Castles & Coltheart, 1993; Ellis et al., 1996; Temple & Marshall, 1983). This line of research draws upon models of multiple reading pathways in expert

readers, such as the Dual-Route model (Coltheart, 2005; Friedmann & Coltheart, 2018) and its computational variants (Coltheart et al., 2001; Plaut et al., 1996; Ziegler et al., 2008; Zorzi et al., 1998); see Figure 1. According to this model, reading begins with orthographic visual analysis. This peripheral reading stage is responsible for letter identification, invariantly for case, size and other visual factors; encoding of letter-position within words; and letter-to-word binding (Ellis & Young, 1996; Friedmann & Coltheart, 2018). Words are then held in a short-term orthographic buffer and, and from there, processed along two distinct parallel routes: a lexical and a sublexical route. Reading via the lexical route involves the fast and fluent immediate access of known written words in the orthographic input lexicon to the inventory of the phonological form of words, the phonological output lexicon. The lexical route also includes a branch that connects the orthographic input lexicon to the semantic system, from where information about the meaning of known words is retrieved. Reading via the sublexical route refers to the grapheme-phoneme decoding procedure, which is involved in reading unknown words and pseudowords, and is dominant during learning to read in beginner readers. The outputs of the two routes are held in another buffer, a phonological output buffer, until the word or the pseudoword is produced. A computational implementation of the Dual Route model, the Dual Route Cascaded Model (Coltheart et al., 2001) successfully explains various aspects of normal reading behavior of morphologically simple words, including faster reading times for regular words (lexical reading) than for pseudowords (sublexical reading) (Rastle & Coltheart, 1999).

Figure 1. A version of the Dual Route Model (taken from Friedmann & Coltheart, 2018).

The Dual Route model and the study of dyslexia have had a mutually beneficial relationship. On the one hand, the model provides a tentative map of the different types of dyslexia that may exist. This has benefitted educational research and therapists alike in the common goal of improving screeners and remedial training. On the other hand, detailed reports of individuals with selective

deficits, either acquired dyslexia or developmental dyslexia, have been integral to refining the model (Friedmann & Coltheart, 2018). Screeners that adhere to this model test the reading of isolated word and pseudoword. Sentence or text reading is more problematic as a means to identify reading disorders, both because it requires additional abilities such as syntax, so a reader with syntactic deficits and no dyslexia may show difficulties with such stimuli (Szterman & Friedmann, 2020), and because a dyslexic reader may use the semantic and syntactic context to reduce the number of errors (Friedmann & Rahamim, 2007; Shaywitz, 2003).

The predominance of the Dual Route model to describe expert reading and various types of acquired dyslexias has also influenced how developmental dyslexia is screened. Several screeners require the reader to read aloud separate lists of regular words, irregular word, and pseudowords, for readers in English (Castles et al., 2009; Parkin, 2018), French (Jacquier-Roux et al., 2002), or Italian (Zoccolotti et al., 2005). Such an approach can already identify developmental deficits that differentially affect the lexical or the sublexical route. The logic is that if the locus of impairment is in the lexical path, demonstrating surface dyslexia, the reader will struggle to read irregular words, but will be able to read regular words and pseudowords correctly. Conversely, in case of impairment to the sublexical route, causing phonological dyslexia, reading of pseudowords will be impacted. Still, such screeners are limited in the range of dyslexia types they can identify, as they are based primarily on the number of reading errors made, but not on the type of errors. Moreover, the dimensions of regularity and lexicality that they explore are relevant for surface and phonological dyslexia, but not for developmental dyslexias affecting the orthographic visual analysis stage, such as letter identity dyslexia (R. Brunson et al., 2006), letter-position dyslexia (Friedmann & Gvion, 2001; Friedmann & Haddad-Hanna, 2012; Friedmann & Rahamim, 2007; Güven & Friedmann, 2019; Kohnen et al., 2012), attentional dyslexia (Davis & Coltheart, 2002; Friedmann, Kerbel, et al., 2010b; Hall et al., 2001; Rayner et al., 1989; Shallice & Warrington, 1977), or neglect dyslexia (for examples in Hebrew, see Friedmann & Nachman-Katz, 2004; Nachman-Katz & Friedmann, 2007, 2010). They may also not be sensitive enough for selective deficits in the sublexical route such as vowel dyslexia (Güven &

Friedmann, 2021; Khentov-Kraus & Friedmann, 2018a) and voicing dyslexia (Gvion & Friedmann, 2010). For these, as further explained below, other types of stimuli should be presented. Screeners that do not take into the account the rich evidence from case studies in dyslexia research risk misdetecting dyslexia, and in turn, biasing teachers and therapists to provide remediation techniques, such as phoneme awareness training, that do not in fact address the real locus of the deficit for many students with dyslexia.

The Malabi project, a French screener for multiple deficits

The present approach, motivated by the various components of the Dual Route model and by previous evidence for selective dyslexia detection, aims to search for selective reading deficits in French readers using appropriate stimuli and the analysis of reading errors. This method derives from the Tiltan reading battery in Hebrew (Friedmann & Gvion, 2003). Instead of measuring overall accuracy and speed, our French screener (christened “Malabi” after the delicious eponymous dessert that the last two authors were eating during the design of this project) measures the number of errors of each type made by a given reader. When the reader shows an abnormal number of errors in one of the predefined categories (thought to be characteristic of a certain type of dyslexia), and in the absence of errors outside of the normal range in other categories, we may speak of a selective deficit. To this end, each word in the screener is strategically selected to increase the likelihood of detecting errors characteristic of different types of dyslexia. In particular, the words are chosen so that the relevant type of error yields another existing word, reducing the likelihood of self-correction or of lexical filtering of pseudoword errors. Below, we briefly describe the types of dyslexia that are targeted by the Malabi screener and their properties, which guided our selection of stimuli.

Attentional dyslexia

Attentional dyslexia is a deficit in binding letters to the words they appear in, resulting in migrations between words (for example, reading 'win fed' as 'fin fed', Shallice & Warrington, 1977). During reading, multiple words are simultaneously processed (Snell & Grainger, 2019). This is

demonstrated by eye-tracking experiments showing that eye fixation of expert readers collects letter information from about ten letters after the fixation point (McConkie & Rayner, 1975). Word information is first gathered at the peripheral level, followed by a saccadic eye movement to bring the word into the fovea. This joint attentional effort of peripheral gleaming followed by focused orthographic processing, ensuring that each letter is bound to its proper word, was the inspiration for naming an acquired deficit characterized by letter migrations between words as “attentional dyslexia” (even though later studies revealed that dyslexia and attention can be fully dissociated: attentional dyslexia can appear without visuo-spatial attention deficits, and vice versa, (Lukov et al., 2015). Developmental attentional dyslexia was broadly described in a case of an English reader (Rayner et al., 1989) and its properties were examined in detail in multiple cases in Hebrew (Friedmann, Kerbel, et al., 2010b; Lukov et al., 2015) and in Arabic (Friedmann & Haddad-Hanna, 2014a). These studies found that the majority of letter migrations between words maintain their original relative position within the new word. This is important because it underscores a difference between coding for letter position within words (which is preserved) and between words (which is impaired). Letters can migrate from words above, below, to the left and to the right of the target word. Importantly for the identification of this dyslexia, Friedmann et al. (2010) found that the likelihood for letter migration is higher when the migration creates an existing word. Therefore, in the Malabi, to test for attentional dyslexia we included words that can be read as another existing word through the migration of a letter to the same position in a neighboring item. An error is encoded as a migration when an erroneous letter may have come from the same relative position in a word (or nonword) that is horizontally located to the right or left of the target word, or vertically, one or two words above or below the target. We included a dedicated subtest of word pairs where all items allow for a possible migration between any two letters at the same within-word position (e.g., ‘bise vase’ can also be read as ‘bise base’, ‘bise vise’, ‘vise vase’ or ‘base vase’, ‘vise base’, all of which are French words).

Letter-position dyslexia

Our ability to distinguish anagrams such as ‘density’ and ‘destiny’ underlines the importance of encoding the relative position of letters within words. Letter-position dyslexia refers to readers who make errors that respect the identity of the letters, but alter their locations within the same word, often resulting in the transposition of adjacent middle letters (e.g., reading ‘form’ as ‘from’). Cases of selective developmental letter-position dyslexia have been described in readers of Hebrew (Friedmann, Dotan, et al., 2010; Friedmann et al., 2015; Friedmann & Rahamim, 2007, 2014); English (Kezilas et al., 2014; Kohnen et al., 2012); Arabic (Friedmann & Haddad-Hanna, 2012, 2014b), and Turkish (Güven & Friedmann, 2019), and Italian (Traficante et al., 2021). The deficit has been characterized as a problem of under-specification of middle letter-positions, thus yielding an elevated rate of errors in both words and pseudowords when they are anagrams of another word (Friedmann & Gvion, 2001; Friedmann & Rahamim, 2007). Even in normal readers, there is evidence for a partial underspecification of letter-position within a word (Davis, 2010), a conclusion supported by masked priming experiments during lexical decision tasks (Davis & Bowers, 2006; Schubert et al., 2018). Trials in which the prime is a letter-transposition version of the target (e.g., caniso-CASINO) produce more priming than an orthographic substitution control (e.g., casiro-CASINO; Perea & Lupker, 2004).

Importantly, in letter position dyslexia, errors occur mainly when the transposition creates an existing word. As a consequence, “transposable” words, i.e., words in which transpositions of letters create other existing words, are the most sensitive stimuli to detect this dyslexia. Therefore, in the Malabi, to identify letter-position impairments, we included words and pseudowords in which a transposition of two letters yields another French word. Note that the letters could both be inside the letter string (e.g., reading ‘signe’ as ‘singe’) or could include an exterior letter (e.g., reading ‘vélo’ as ‘volé’). Because the deficit is thought to happen before either lexical or sublexical processing, we also use pseudowords that can become words if two letters are transposed (e.g., reading ‘pocile’ as ‘police’).

Also observed in letter position dyslexia are errors of letter doubling (i.e., reading 'bible' as 'bible') or omission of one instance of a letter that appears twice in a word (i.e., the opposite, reading 'bible' as 'bile') (Friedmann & Rahamim, 2007). These authors hypothesized that when letter position encoding is impaired, distinguishing two instances of the same letter that only differ in their position becomes difficult. As a result, repeated letters may be dropped. Therefore, in the Malabi, we included words in which the omission of one instance of a doubled letter creates other existing words (e.g. reading 'montage' as 'montage').

Finally, because letter position errors have been found both in consonants and in vowels (and because vowel dyslexia, described below, only causes transpositions that involve vowels), we included in the Malabi both target words in which a transposition of two consonants create a word (e.g., reading 'signe' as 'singe'), and words in which a transposition of a vowel and a consonant creates a word (e.g., reading 'prie' as 'pire').

Letter identification dyslexia

Located in the visual orthographic stage, this refers to the readers ability to access abstract letter identity. A deficit at this stage may lead to an inability to identify or the substituting of letters. Substitutions have generally been reported as being between orthographically similar letters (e.g., 'p', 'q' or 'l', 'i') (R. Brunson et al., 2006). Errors are also produced at the prelexical stage of single letter identification manifesting as difficulty in letter name or sound production. Both developmental and acquired cases report that subjects can match letters of varying shape, but not letters presented in different case as it is the abstract letter identity that is impaired (R. Brunson et al., 2006; Perri et al., 1996; Schubert & McCloskey, 2013). The Malabi assesses letter identification dyslexia by coding for substitution and specifically substitutions of similar orthographic form (i.e., reading 'pire' as 'dire').

Neglect dyslexia

In word-level neglect dyslexia (or "neglexia"), the reader may omit and substitute letters in reading, but errors predominantly affect one side of the word (i.e., reading 'yellow' as 'pillow', an

example from Ellis et al., 1987). This impairment may affect reading exclusively, without neglect of other visual stimuli. Neglexia has been relatively well-documented in adult cognitive neuropsychology (for a review, see Vallar et al., 2010), but few developmental cases with children have been reported (for examples in Hebrew, see Friedmann & Nachman-Katz, 2004; Nachman-Katz & Friedmann, 2007, 2010). To probe neglexia, the Malabi includes words and pseudowords in which letter omission/substitution on one side creates existing words. We include both words that allow for the assessment of left neglect dyslexia (e.g., a target ‘frime’ that may be read as ‘prime’ or ‘flache’ as ‘lache’) and words that allow for the assessment of right neglect dyslexia (e.g., a target ‘rasé’ which may be read as ‘ras’ or ‘rien’ as the word ‘rie’).

Visual dyslexia (orthographic-visual analyzer dyslexia)

Visual dyslexia refers to a deficit that causes various kinds of errors in which the erroneous response shares some of the letters with the target word (e.g., reading ‘unicorn’ as ‘united’, or ‘coronary’, or ‘acorn’). Errors may involve letter substitutions, omissions, additions, and transpositions. These errors cannot be accounted for by the three separate deficits of letter-position, letter-to-word binding, and letter identification (for example, unlike letter identification dyslexia, single letter identification is intact), nor can they be explained by neglect dyslexia. It seems that this dyslexia results from a deficit in the output of the orthographic-visual analyzer, or in the orthographic input buffer (Friedmann et al., 2012; Friedmann & Coltheart, 2018). Case studies of acquired visual dyslexia have been reported, but the evidence is rare in developmental cases (Friedmann & Haddad-Hanna, 2014b; Valdois et al., 1995) and in some cases confounded with general visual deficits such as a more general developmental deficit in perceiving the location and orientation of visual stimuli (McCloskey & Rapp, 2000). Stimuli that are sensitive to this type of dyslexia are a mixed bag of the previously described items used to test for letter-position dyslexia, attentional dyslexia, and letter identity and neglect dyslexia. To identify visual dyslexia, the Malabi includes words and pseudowords which allow for new word through consonant omissions (i.e., ‘grave’ which could be read as ‘gave’)

or substitutions (i.e., reading ‘frime’ as ‘frite’) that cannot be explained by the aforementioned deficits.

Surface dyslexia

Surface dyslexia refers to an impairment in the lexical route that pushes the reader to overly depend on sublexical reading. The resulting outcome is difficulty in reading irregular words and a frequent over-regularizing of infrequent grapheme-phoneme combinations (e.g., reading ‘now’ as ‘know’). Pseudoword and regular word reading is unaffected in cases of pure surface dyslexia. In highly transparent languages, such as Italian, surface dyslexia is identified as slow reading (Zoccolotti et al., 1999), even though some regularization errors may be identified in these languages too, for example with respect to stress position (Traficante et al., 2011, 2021, for Italian), and vowel length and properties of consonants (Güven & Friedmann, 2019 for Turkish). Surface dyslexia may result from impairments in different components and connections of the lexical route (Friedmann & Lukov, 2008, 2011), but in reading aloud all these variants show similar patterns. There is ample work and reports on developmental surface dyslexia across many languages with transparent orthographic codes, such as Italian (Zoccolotti et al., 1999), Spanish (Jiménez et al., 2009), Filipino (Dulay & Hanley, 2015), Greek (Sotiropoulos & Hanley, 2017) and more recently Turkish (Güven & Friedmann, 2022) and irregular orthographies, such as English (Castles, 1996; Castles & Coltheart, 1993), French (Valdois et al., 2003), Hebrew (Friedmann & Lukov, 2008; Gvion & Friedmann, 2016), and Arabic (Friedmann & Haddad-Hanna, 2014a). French is an intermediate language in terms of transparency, being rather regular in reading, but quite irregular in spelling (i.e. there are many possible spellings for a given sound, but relatively few pronunciations for a given sequence of letters). Nevertheless, many highly frequent but irregular words exist in French and were used to test for surface dyslexia in the Malabi (e.g. “femme” pronounced /fam/, not /fem/).

Because French also includes many multi-letter grapheme-phoneme conversion rules, over-regularizations akin to surface dyslexia may also occur in pseudoword reading. For instance, the letter G is generally pronounced as a hard /g/, but before some vowels it becomes /ʒ/ (e.g. “âge”,

“agir”). Thus, pronouncing the French pseudoword “trage” as “trag” would be an over-regularization, consistent with an over-reliance on an (insufficiently sophisticated) surface route. Similarly, “ti” is generally pronounced /ti/ (as in “partie”, “bêtise”) but can be pronounced /siõ/ (as in “partiel”, “patio”, “nation”). Thus, pronouncing the pseudoword “martiel” with a hard sound /t/ (/martiel/) could be classified as a surface error (indeed this is how such an error would be classified in response to the real word “partiel”). Note that such errors, however, may be the outcome of insufficient teaching or reading experience, rather than dyslexia per se. Thus, our main criterion for surface dyslexia is an excessive number of regularization errors on irregular words, not pseudowords.

Phonological dyslexia

Phonological dyslexia is reported as a deficit in reading tasks that depend upon grapheme-phoneme decoding such as reading novel words and pseudowords. Because phonics instruction is often the first step to literacy, phonological dyslexia generally makes learning to read slow, and words must be memorized by their orthographic form (Castles & Coltheart, 1993). Phonological dyslexia was first discussed in the case of a patient with dyslexia who was able to read familiar words fluently, but unable to read pseudowords despite of an intact ability to orally repeat and write spoken items (Beauvois & Derouesne, 1979). Phonological dyslexia can result from a deficit in grapheme-to-phoneme conversion or from a deficit in output stages of reading (the phonological output buffer (Guggenheim & Friedmann, 2014). In the case of a deficit in conversion, the reader can fluently read words stored in the orthographic lexicon but has difficulty reading novel or pseudowords due to an impairment in grapheme-phoneme conversion (see the developmental case study of Campbell & Butterworth, 1985). In this case, even the conversion of single syllables would be impaired. In the case of a deficit in the phonological output buffer, the deficit lies in the short-term memory buffer that holds phonological units until their production and assembles phonemes into a word. Individuals with aphasia following brain damage who have impairment in the phonological output buffer demonstrate difficulty in reading aloud long and morphologically complex pseudowords or words. Because the phonological output buffer is involved not only in reading aloud

but also in speech production, individuals with a deficit in this stage also show similar difficulties in oral production tasks such as repetition of the same types of complex stimuli, and they also substitute numbers and function words with other words from the same category (Dotan & Friedmann, 2015). The same has been reported for developmental cases in Hebrew (Guggenheim & Friedmann, 2014). To detect phonological dyslexia in the grapheme-to-phoneme conversion route, Malabi includes pseudowords. It also includes morphologically complex words and long words to allow for the identification of the phonological output buffer deficit variant.

Vowel Dyslexia

More recently documented (Güven & Friedmann, 2021; Khentov-Kraus & Friedmann, 2018a), vowel dyslexia is characterized by errors in reading aloud vowels, without parallel errors in reading consonant letters. Vowel dyslexia affects the sublexical route, so when a reader has pure vowel dyslexia, vowel errors occur only in pseudowords. Individuals who also have surface dyslexia, in addition to vowel dyslexia, are forced to read existing words through the sub-lexical route, so they may make vowel letter errors in existing words as well. Vowel errors include vowel letter omission, migration, substitution, and addition. Vowel dyslexia is diagnosed when a participant makes significantly more vowel errors in comparison to the controls, but not more consonant errors than the controls, and when this vowel-consonant difference is significant. Individuals with vowel dyslexia do not demonstrate difficulty in vowel phoneme manipulation in oral language tasks (Khentov-Kraus & Friedmann, 2018; Güven & Friedmann, 2021). Stimuli that are most sensitive to detect vowel dyslexia, then, and which were included in the Malabi, are pseudowords in which a vowel error creates an existing word (e.g., reading 'flache' as 'flèche'), and in case the participant also has surface dyslexia (which is quite common), also in words in which vowel errors create other existing words (e.g., reading 'fille' as 'folle').

Deep dyslexia

Deep dyslexia results from a complex deficit in both the lexical route (in the path linking the orthographic and phonological lexicons) and the sublexical route. As a result, readers with deep

dyslexia can only read via the semantic lexicon: they read a word, understand it, imagine it, and then name what they had understood or imagined. This cumbersome procedure results in semantic errors, which are the hallmark of this dyslexia (e.g., reading 'sand' as 'beach'), as well as by morphological and visual errors. Because reading proceeds via meaning, individuals with developmental deep dyslexia show increased difficulty in reading abstract words, morphologically complex words and function words, and have a severe impairment in reading pseudowords. Developmental deep dyslexia, which is relatively rare, has been reported in English (in children with Williams Syndrome, Temple, 2003, 2006), in Japanese (Yamada, 1995), and in Arabic (Friedmann & Haddad-Hanna, 2014b). The items most susceptible to this dyslexia, and hence which were included in the Malabi, are abstract words, morphologically complex words, and function words, as well as pseudowords.

Experimental study

The goal of the current project was to assess if the Malabi screener could detect selective types of reading deficits. To this aim, we established norms for the test and used them to detect the first cases, to our knowledge, of developmental attentional dyslexia and letter-position dyslexia in French. We provide an in-depth analysis of the factors that modulate the deficit for these readers, and confirm a double dissociation between the two dyslexias. This research was carried out in two phases:

- **Experimental screening.** We first established norms for the different error categories made by 141 normal readers in middle-school 6th and 7th graders (age ranges 11;3-13;8 and 12;11-14;10). In France, middle-school begins in the American equivalent of 6th grade. We chose middle-school to ensure a population that should have had enough years of schooling to have mastered the alphabetic code of French and have a large orthographic lexicon, therefore limiting the number of errors due to lack of reading experience. Relative to those norms, we then screened sixteen 6th and 7th graders from a specialized learning disabilities school. We present the results of this

dyslexic population and focus on the students that appear to have a selective type of dyslexia.

Traditional tests for dyslexia screening in France were also used to assess a phonological deficit.

- **Experimental investigation.** Having identified putative cases of selective attentional or letter-position dyslexia according to the Malabi, we revisited these students with a second battery of tests designed to replicate the original diagnosis, clarify the locus of the deficit, and understand the factors that modulate reading in these dyslexia types in French.

Experimental screening

Method

Dyslexic participants

Our dyslexic participants all came from CERENE (www.cerene-education.fr), a specialized school for children with normal IQ who have developmental learning disorders (dyslexia, dyspraxia, dyscalculia, etc.), located in Paris, and providing 2nd to 8th grade education. Our reason for working with this school was to exclude dyslexic readers with other cognitive or environmental confounds that could influence our measures. Admission to CERENE requires a stringent neuropsychological assessment to ensure normal IQ and specific understanding of the student's profile. Dyslexia can often exist in comorbidity with other deficits, such as attention disorders and dyspraxia (Pauc, 2005). The school provides high-quality education through trained teachers for learning disorders, small classes, and adaptive tools to help students compensate for their deficit (i.e., electronic readers that use larger font with spacing and highlighting, audio instructions, explicit step-by-step instructions, etc.). Testing students at CERENE thereby provided us with a sample of readers whose difficulty could not be due to low intelligence or insufficient reading instruction and practice. Sixteen students were sent to us by the school, seven in 6th grade and nine in 7th grade. All these students were native speakers of French and in a normal age range for their grade.

Control group for establishing screener norms

For the control sample, 141 students gave consent to participate, none of whom were receiving special help in language or reading skills, as reported by the school director. These students came from six classes in two middle-schools and included 77 6th graders (age range 11;3-13;0) and 64 7th graders (age range 12;3-15;2). Both schools were situated in lower to middle socio-economic areas, in towns about an hour outside of Paris. Three students in 6th grade and three students in 7th grade were removed because their age was greater than 2 standard deviations from the mean. 51% of 6th graders and 34% of 7th graders reported speaking another language at home than French, but school administrators confirmed that all students had been in the French school system for over four years (our minimum criterion for inclusion).

Procedure

All parents of the participating students were sent a letter explaining the study and given the possibility of opting out if they did not want their child to participate. Each participant was tested individually in a quiet room in the school. Each of the three sub-tests was printed on paper in 14pt Calibri font, with vertical double spacing between words. No time limit was imposed during testing, but children were timed and told to try and read quickly but accurately. They were also instructed to not use their finger to guide their reading. If a student did this instinctively, they were immediately asked to remove their finger. A short break was taken between the tests. The three tests were presented in a fixed order (single word, pseudoword, word-pair reading). No response-contingent feedback was given during reading, only general encouragement. The testing was carried out over a 3-month period at the end of the French school year. Reading errors were phonetically noted. For each type of reading error, an error type was attributed by agreement between three researchers in the project (the allowed error types are listed in table 2). This method allowed us to eventually automate the error-coding process. In some cases, an error could be attributed to more than one error type, for example, reading the word pair “puis sois” as “suis pois” could be labeled as an attentional migration of or letter-doubling. In such cases, the error type was categorized using both

labels. Our logic was that if a reader has a selective deficit, they will make many more mistakes of a particular type, so those ambiguities will be lifted by compiling data from multiple errors. For example, if the reader also makes significantly more attentional migrations than the controls, and does not make other letter-transposition type errors (switching letter position or doubling errors), we may conclude that the deficit is attentional dyslexia rather than letter-position dyslexia.

The Malabi screener

The Malabi screener is an oral reading test that includes three subtests: 161 single words (2–8 letters long, $M = 5.12$, $SD = 1.29$), 40 pseudowords (4–5 letters long, $M = 4.88$, $SD = 0.92$), and 44 word-pairs (including 2–9 letters long words, $M = 5.16$, $SD = 1.62$). Table 1 describes the stimuli used in the Malabi screener.

Dyslexia type	Typical errors	Malabi stimuli sensitive to that dyslexia type	Sensitive stimuli example -> possible error
Attentional	Migration of letters between neighboring words. The migrating letter retains its within-word position. Omission of a letter that appears in the same position in two neighboring words	Migratable word pairs: word pairs in which a migration of a letter between neighboring words (horizontal or vertical distance < 2 items) that retains its within-word position creates another existing word. Items in the vertical single word list also organized accordingly. 44 horizontally presented word-pairs	morte varie -> <i>marie</i> balle selle -> <i>salle belle</i>
Letter Position	Letter transpositions within words and pseudowords. Omission of an instance of a doubled letter, or doubling of a letter.	Transposable words/nonwords: Items in which a within-word transposition can form a new word. 44 words 22 pseudowords	magner -> <i>manger</i> fotre -> <i>forte</i>
Neglect	Omission, substitution, and addition of letters consistently on one side of the word/nonword	Items in which an omission or substitution of a letter on the neglected side creates an existing word. 80 left-neglect words 60 right-neglect words 13 left-neglect pseudowords	ruse -> <i>use</i> or <i>muse</i> cela -> <i>la</i> truche -> <i>ruche</i> or <i>cruche</i>
Letter identity	Omission/ substitution of letters (which cannot be explained by letter position dyslexia or attentional dyslexia, and are not consistent to one side of the word)	Examined through all words in the test	prie -> <i>plié</i>
Visual (orthographic-visual analyzer)	Omissions, substitutions, and additions of letters, letter-position, and attentional errors	Examined through all words in the test. Omission, substitution, addition of consonants, that cannot be explained by attentional or letter position dyslexias.	(A mixed bag of the visual-analyzer errors.) bras -> <i>bas</i> vole -> <i>voté</i>
Phonological Grapheme-to-phoneme conversion	Difficulty reading new words and pseudowords. Reading from the mental lexicon is intact	Easily pronounceable pseudowords 40 pseudowords	flache -> <i>flaque</i>
Phonological Output Buffer	Difficulty with long or morphologically complex words and pseudowords, function words, number words	Long and, morphologically complex words and pseudowords; function words, number words single words including: 40 morphologically complex 8 number words 13 function words	marcherions -> <i>marchons</i> trois -> <i>treize</i> mais -> <i>car</i>
Vowel	Vowel omissions, migrations, substitutions, and additions in pseudowords (and words, when read via the sublexical route, such as in cases it is combined with surface dyslexia). More vowel errors than the control group, not more consonant errors.	Items in which a vowel error forms another word. 73 words allowing for omission, substitution, or addition 20 pseudowords	lueur -> <i>leur</i> mais -> <i>mois</i> qui -> <i>quoi</i> porte -> <i>pourte</i> truche -> <i>triche</i> nouveau -> <i>nouveau</i>
Surface	Regularization of letters, digraph, and diphthongs in irregular words.	Irregular, but frequent, words. 97 single words	vise /viz/ -> <i>visse</i> /vis/ fille /fij/ -> <i>fil</i> /fil/ parfum /paʁfœ/ -> <i>parfume</i> /paʁfym/
Deep	Semantic errors and associations (reading another word of a related meaning); morphological errors, visual errors. Severe difficulty with nonwords, abstract words, function words and number words.	40 unambiguously imaginable single words Abstract, morphologically complex, function words, and nonwords 40 morphologically complex 8 number words 13 function words	boulangerie -> <i>croissant</i> marcherions -> <i>marchons</i> trois -> <i>treize</i> mais -> <i>car</i>

Table 1. The different types of dyslexia screened by the Malabi: Errors characteristic of each type of dyslexia, the types of stimuli in the Malabi used to detect this dyslexia, and examples of sensitive words in French. Words in *italic* demonstrate the possible reading response that identifies the dyslexic category's error.

Establishing norms

For the control group, we calculated the mean number of errors and standard deviation for each of the error types in our coding scheme. Participants who made a number of errors that was more than 3 standard deviations away from the mean in any particular error-type or in their total number or reading errors, were removed from further calculation of the control group norms. According to this criterion, 13 outliers were excluded from the control group. To ensure that the retained controls from both of our participating schools were comparable in their populations, we conducted a mixed analysis of variance with 2-levels of the within factor subtest (single words, pseudo words, word pairs) and the between factors of grade (6th, 7th), sex (male, female) and school (school 1, school 2). We report only significant effects at $\alpha=0.05$. There was a significant main effect of grade, $F(1, 114) = 6.16, p = .014$, highlighting a slightly less error for the upper grade (average percent error in 6th grade = 3.5% (2%); 7th grade = 4% (2%)). We had an interaction school x sex, $F(1, 114)=11.75, p<0.001$. Critically, a grade x school x sex x subtest interaction, $F(2, 228)=4.35, p=0.01$, indicated that the previous school x sex interaction was due to girls in school 2 making more errors than boys in 6th on the single word test, $F(1, 31)=8.17, p<0.01$ (average percent error for girls = 6% (3%); boys = 3% (2%)), and more errors on the word pair test in 7th grade, $F(1,28)=7.87, p<0.01$ (average percent error for girls = 6% (4%); boys = 2% (3%)). In school 1, girls only made significantly fewer errors than boys in 6th grade on the single word test, $F(1, 33)=5.87, p= 0.02$ (average percent error for girls = 2% (3%); boys = 4% (2%)). Given that all error rates were with 1SD of the other, we did not correct groups.

For the comparison of the rates of different error types between grade 6 and grade 7, and in order to reduce the false discovery rate, we used the following approach: we summarized the total number of errors across subtests for each participant, and conducted a comparison between grades for an dyslexia type only when the average total number of errors across the three subtests was 2 or above, or when the mean number of errors in one subtest exceeded 1. We used false discovery rate (FDR) analysis (Benjamini & Hochberg, 1995) at $\alpha = 0.05$. This analysis showed that between

grades, error rates neared being significantly different for surface errors on the single word test ($p = .016 > \text{critical value} = 0.006$). For the other error types we found no significant difference, suggesting that whereas the lexicon is still being built in sixth grade, other decoding skills have plateaued after many years of school and reading experience.

After removal of outlier subjects, a new mean and standard deviation were calculated, providing our normed data. For each dyslexia type, we then computed the threshold number of errors a reader would have to make to be significantly below the control group ($p < .05$) (i.e., to make significantly more errors of this type compared to the control group). This comparison was done using a t-test for the comparison of an individual to a control group (Crawford & Howell, 1998).

Sample demographics for the retained controls are in Table 2.

Errors: Mean (SD), Threshold	6th grade (N=68, 31 female, age 11;3-12;8)			7th grade (N=54, 18 female, age 12;3-13;4)		
	Single Words N=161	Pseudowords N=40	Word pairs N=88	Single Words N=161	Pseudowords N=40	Word pairs N=88
Total Mean (SD)	11.6 (7.93)	4.03 (3.50)	3.87 (2.83)	8.30 (6.58)	3.57 (3.26)	2.72 (2.54)
Attentional	0.65 (1.18) 3	0.21 (0.54) 2	2.52 (1.98) 6	0.67 (0.95) 3	0.33 (0.73) 2	1.83 (1.55) 5
Letter-position	2.00 (2.19) 6	1.93 (2.18) 6	0.12 (0.33) 2	1.22 (1.89) 5	1.74 (2.03) 6	0.07 (0.38) 2
Left Neglect	0.04 (0.21) 2	0.02 (0.12) 2	0 (0) 2	0.02 (0.14) 2	0.0 (0.0) 2	0.0 (0.0) 2
Right Neglect	0.38 (0.65) 2	0.09 (0.29) 2	0.09 (0.29) 2	0.43 (0.77) 2	0.04 (0.19) 2	0.04 (0.19) 2
Visual	0.43 (0.65) 2	0.75 (1.20) 3	0.28 (0.49) 2	0.35 (0.59) 2	0.43 (0.66) 2	0.17 (0.38) 2
Multi-letter phonological		0.87 (1.01) 3			0.74 (0.94) 3	
Phonological Buffer (morphological errors)	0.88 (1.11) 3		0.10 (0.31) 2	0.59 (0.98) 3		0.11 (0.32) 2
Vowel	1.01 (1.14) 3	0.16 (0.37) 2	0.10 (0.31) 2	0.54 (0.95) 3	0.30 (0.60) 2	0.06 (0.23) 2
Surface	6.12 (4.03) 13		0.62 (0.98) 3	4.43 (3.61) 11		0.44 (0.90) 2
Deep (semantic)	0.04 (0.21) 2		0.02 (0.12) 2	0.06 (0.23) 2		0.0 (0.0) 2

Table 2. Retained control sample demographics and mean (SD) number of errors for each error type in each test, and in bold/italic the threshold for impairment (i.e., the number of errors of the specific type that is already significantly higher from the control group at Crawford and Howell's one-way t-test for single-case vs. control comparisons, $p < .05$). We decided not to consider a single error as marking a significant deficit, so in case the statistical analysis yielded 1 as the threshold for determining impairment, we set it to 2 instead.

Screening for selective deficits with the Malabi screener, and principles to determine dyslexia type

We defined a selective dyslexia when a student made significantly more errors in one of the eight error types established by the normed data, in the absence of a greater number of errors than the control of another error-type. Only one exception was made to this rule: the frequent case of a large amount of surface dyslexia errors in concert with another type of error. Surface errors are due to inability to read words via the lexical route, which results in over-reliance on decoding, which leads to regularizing letter sounds. Inefficient lexical route reading could either result from dyslexia, a deficit in the direct lexical route, or from lexicons that are not fully-established, which could be a result of insufficient exposure to effective reading, which typically builds up the mental lexicons. Given that most children with dyslexia develop strategies to avoid reading, surface errors may also results as a lack of adequate reading experience secondary to another type of dyslexia, as opposed to being a genuine case of surface dyslexia.

Here we explain how we planned to identify each dyslexia (although not all types were found in our data). In each case, the diagnosis was based on a reader making a significantly larger number of errors than age-matched controls. A participant was diagnosed with **Attentional dyslexia** if they made on the word pair test (and possibly the single word and pseudoword tests) a significant number of between-word consonant migrations or omissions or additions that could be explained by a neighboring word (two words vertically or horizontally from the target). **Letter Position dyslexia** was diagnosed when the reader made within-word transpositions that involved two consonants on the single word and the pseudoword test (the word pair test was not designed to include words with possible within-word letter transpositions.) Also included in letter position dyslexia were errors of consonant doubling or removing of a one instance of a double consonant. Double letters that make a single phoneme were not included in this category. **Letter-Identity Dyslexia** was diagnosed when the reader showed more errors than controls on all three reading lists, and omissions, additions, and substitutions that could not be attributed to a transposition or migration, especially when substitutions were made between orthographically similar letters (i.e., b, d, p, q). If this happened,

we would also test the readers single letter knowledge (we did not have any of these cases in our sample). **Neglexia**, left or right, was diagnosed when a reader produced errors on a single side of words that could not be explained by within or between word migrations or a misreading due to the regularization of letter sounds, and had a within-normal rate of errors on the middle and on the other side of the word. **Visual dyslexia** (orthographic-visual analyzer deficit) or orthographic input buffer dyslexia was identified when a subject made a mixed bag of within-word and between-word consonant migrations, but importantly, also consonant omissions, additions, and substitutions that could not be attributed to a migration. The distinction between an orthographic-visual analyzer deficit and an orthographic input buffer deficit was made on the basis of morphological errors and length effect. **Vowel dyslexia** was detected when a subject made significantly more vowel letter errors than the controls (omission, substitution, addition, vowel transpositions, and vowel migrations), which could not be attributed to letter position dyslexia or attentional dyslexia. **Surface dyslexia** was detected by a greater number of errors than matched controls in reading irregular words (only single word test), slow syllable-by-syllable reading of words. Phonological dyslexia (in sublexical conversion or the phonological output buffer) was diagnosed primarily when the reader made a greater number of errors than matched controls in reading pseudowords, more than in reading words. **Phonological dyslexia in sublexical conversion** errors could include omission, substitution, addition and migration of letters in the pseudoword, as well as slow syllable-by-syllable reading of pseudowords, regularizing of rule-based letter sounds or the reading of digrams as their individual letters (the latter indicating impaired multi-letter conversion). **Phonological dyslexia in the phonological output buffer** was identified when the reader made a greater number of morphological errors on words with long complex morphology and function-word substitutions. **Deep dyslexia** was diagnosed when the reader made a larger number of semantic errors than age matched controls. For deep dyslexia, if the participant made semantic errors, we continued and assessed whether they also made morphological errors, substitutions of function words, and visual errors, also characteristic of

deep dyslexia. There were also a few responses that could not be categorized by our scheme. These instances, however, were minimal.

Alouette

Our testing sessions also included the administration of the “Alouette” reading test (Lefavrais, 2005), which is often used in France to screen for dyslexia. This test requires reading of syntactically well-formed sentences that include many rare words that create a near non-sense text (e.g., “And when the evening descends, when the amethyst of the sunset plays, the sky blushes its waters.”). It forces the reader to read each word carefully since they cannot rely on meaning to extract word identity. Readers are asked to read the text as quickly and accurately as possible in no more than 3 minutes. A combined score of number of words read correctly and time is collected, which can be compared to standardized scores for grade level.

Oral language and phonological awareness

To assess oral language, phonological working memory, and phonological awareness skills, we presented students with a pseudoword repetition task, and two phoneme manipulation tasks taken from the frequently used Odédys dyslexia test battery (Jacquier-Roux et al., 2002). In the pseudoword repetition task, 20 items were orally presented. The students had to repeat each one. Pseudowords were between 2 to 5 syllables. In the first phoneme manipulation task, the listener was orally presented a word and had to remove the first phoneme and say aloud the new word (for the word ‘brame’, respond ‘rame’). In the second task, two words were orally presented, and the listener had to say aloud the syllable created by the combination of the first phoneme from each of the two words (for the words ‘photo – artistique’, respond ‘fa’). Ten items for each of the phoneme manipulation tasks were presented. For all three tasks, the number of correct responses was recorded. Two non-scored trials with feedback were given before starting.

Readers with selective kinds of dyslexia: Results

The Malabi identified readers with attentional dyslexia, letter position dyslexia and surface dyslexia

Of the 16 students from the learning disability school we tested, 12 had dyslexia of some kind, whereas the reading of four participants was within the normal range for all errors. Of the 12 children with dyslexia, 7 showed selective patterns of three types of dyslexia that have not been reported for French yet : LP, TR, and LD showed attentional dyslexia; JB and PO showed letter-position dyslexia (JB also had vowel dyslexia in addition to his letter position dyslexia); HW had phonological dyslexia, and JC had surface dyslexia. Five other participants had dyslexias that were non-selective, showing above normal range of errors in many different types of dyslexias. These cases were outside of the scope of analysis in the article focussing on the detection of selective dyslexia. We will now describe in more detail the patterns of performance of the 7 participants with selective deficits. The number of errors for each of these participants is reported in Table 3.

	Dyslexias						
	Attentional	Letter Position	Vowel	Surface	Visual	Deep	Phonological Buffer
Types of errors	Migrations	Transposition	Vowel - omission, addition, substitution	Regularizations	Consonant - omission, addition, substitution	Semantic & Function errors	Morphological errors
Tests of interest	Word pairs	Single words, Pseudowords	Single words Pseudowords	Single words Word pairs	Single words Pseudowords	Single words Word pairs	Single words Word pairs
Control Mean (SD)	.65(1.18)	2.00(2.19)	1.01(1.14); 0.16(0.37)	6.12(4.03)	0.43(0.65); 0.75(1.20)	0.04(0.21); 0.02 (0.12);	0.88 (1.11); 0.10 (0.31)
Subj: sex, grade, age in months							
LP:m, 6, 152	6*	3	0, 0	13*	0, 2	0, 0	0, 0
TR:m, 7, 139	12*	3	0, 0	6, 2	0, 1	0, 0	1, 0
LD: f, 7, 145	10*	0	0, 0	7, 1	0, 2*	0, 0	2, 0
JB:m, 6, 151	3	13*	3*, 1	9, 0	1, 0	0, 0	1, 0
PO:m, 7, 142	3	14*	1, 1	11*, 0	0, 1	0, 0	1, 0
HW:m, 7, 144	4	1	1, 0	9, 1	0, 0	0, 0	1, 0
JC:m, 6, 147	4	4	2, 0	18*, 1	0, 2	0, 0	2, 1

Table 3. The error types and number of errors made by each of the 7 participants with selective dyslexia made in the Malabi screener.

* Significantly more than the control group

~ Included in the omission/addition/substitution errors and morphological errors are only errors that could not be accounted for as migrations between or transpositions within words.

Student LP, 6th grade. LP's between-word migrations in word-pair reading were the only error type to reach threshold, for a score that was 1.76 SD above the control's mean, 100% of these errors were of a consonant migration. Between-word migrations included exemplarily attentional pairs such as reading 'fend rond' as 'rend rond' and 'cape page' as 'cage page'. Migrations were made from the right to the left word as well as vice versa. In the single word subtest, attentional (1.99 SD above control mean) and surface errors (1.71 SD above the control mean) reached significance, demonstrating the importance of word pair reading when identifying attentional dyslexia.

Student TR, 7th grade. TR made many between-words migration errors on the word pair test, equivalent to 6.76 SD above the matched control group. 75% of these errors were of a consonant, and 25% included a vowel. He made errors migrating letters from both right to left (reading 'aime armé' as 'arme aime') and left to right (reading 'litre vivre as 'litre vitre') word. On the single word test, too, TR made significantly more between-word migrations than the controls (2.45 above the control mean), while all other error types were otherwise in the normal range. Furthermore, upon closer examination of errors scored as surface errors (i.e., reading 'base' /baz/ as 'basse' /bas/), it was noticed that many could have been caused by a migration of a letter from a neighboring word rather than from an overregularization of the letter sound. For instance in the base->basse case, the additional letter 's' could have originated from the word 'rose' written two lines above the target word. This mistake in reading did not appear to stem from not knowing the rule converting a single s to a /z/phoneme, as he correctly made the /z/ sound in other words with 's' when there was no neighboring word with an 's' in the same position.

The pseudoword test was not actually designed for between-word migrations. Nevertheless, TR misread 14 items (35% of the pseudowords he read), and 8 of these errors could be a result of between-word migrations. (5 were pure attentional errors, surpassing the Crawford threshold for a score of 6.42 SD from the mean, another 3 errors could be classified either as migrations between words or as migrations within words. For example, TR read the pseudoword matreau as 'martreau', thus doubling the r (which does not produce an existing word in French). The origin of the error could

have been from doubling the letter r due to poor position encoding, or from migrating the letter r from the item just below 'corque'. When removing these ambiguous errors, TR's dyslexia, even in pseudoword reading, was clearly attentional dyslexia.

Student LD, 7th grade. LD's reading appeared fluent and easy, but her reading errors in the word-pair reading task revealed that she had attentional dyslexia: her migration errors surpassed threshold for a score at 5.27 SD from the mean. 70% of these errors were of a consonant migration, 30% included a vowel. Horizontal migrations in word pairs reflected errors from letters moving from the right word to the left (e.g., 'fous tour' was read as 'tour four') and vice versa ('masse cesse' was read as 'masse casse'). Vertical migrations in the single word reading task just reached threshold for a score that was 3.50 SD from the mean. Errors included reading 'varie' as 'marie', where the 'm' migration plausibly came from the word 'morte' two lines above and reading 'rasé' as 'rusé', the 'u' from the word 'ruse' written one line above. Again, despite the pseudoword list not being specifically designed for attentional migrations, LD also made above-threshold between-item migrations with pseudowords, at a rate that was 3.67 SD above the mean. LD's visual errors in the pseudoword test also reached significance, but they only represented 2 of the 9 total errors made. No other error types were significant.

Participants with letter position dyslexia

Student JB, 6th grade. JB had a selective letter-position deficit, making a significant number of transposition errors in reading single words (e.g., magner -> manger; patrie -> partie, cirer -> crier) (5.50 SD above the control mean). 45% of transpositions concerned two consonants, and 55% concerned a transposition with at least one vowel letter. In pseudoword reading, too, JB made significantly more transpositions than the controls (4.16 SD above the mean). 62% of these errors were of consonant transpositions and 38% contained at least one vowel. To a lesser extent, some multi-letter grapheme-phoneme conversion errors (2.12 SD). Vowel errors also reached threshold in single words, but letter position errors could not be explained by vowel dyslexia (rather than letter position dyslexia), as two out of three vowel errors could also be attributed to letter doubling both,

which occurred in both consonants and in vowel letters (transpositions and doubling/omission that involved a vowel letter were only 47% of letter transpositions in the single words test, and 58% in the pseudoword test). The word-pair list was not designed to detect letter position errors, as it included migratable word pairs (in which between word migrations create existing words) but no transposable words (where a transposition inside the word creates another word). Indeed this subtest was not sensitive to JB's letter position dyslexia, and his reading of the word-pair list was fluent and absent of an identified dyslexia.

Student PO, 7th grade. PO also made a very significant number of letter transpositions on the single-word test (6.76 SD above the control mean). 43% of transpositions were with two consonants (e.g., reading *linge* as *ligne*) while transpositions including a vowel were of 57% of errors (e.g., reading *calque* as *claque*). He also made many transpositions on the pseudoword list (4.07 SD above the mean). Vowel transpositions formed 40% of transpositions. On the word-pair list, in which there are no transposable words, PO did not produce a significant number of errors in any of the categories. Eleven surface errors were also made on this test, which is at Crawford's significance for this error type (1.82 SD above the control mean).

Letter position errors resulting from a sublexical route impairment

Student HW. HW's word reading was relatively fluent. When he read existing words, none of the error types reached significance. In contrast, his reading of pseudowords was markedly strained, with a significant number of letter transposition errors (3.58 SD above the control mean) and of incorrect multi-letter conversion (2.42 SD above the control mean), in which he converted letters to their regular phoneme, without taking into account multi-letter conversion rules. Letter position errors only in nonwords, alongside additional difficulties in nonwords, cannot be a result of letter position dyslexia. These results indicate a difficulty in the sublexical route, either at the level of the phonological output buffer or the grapheme-to-phoneme conversion route. Given HW's success on the nonword repetition and the phonological manipulation tasks, (see upcoming section, **Dyslexia**,

but no phonological impairment) it seems that his deficit results a deficit in grapheme-to-phoneme conversion.

Surface dyslexia

Student JC. JC made many surface errors, namely, reading errors that indicate that he was reading via the sublexical, instead of the lexical, route. On the single word reading test, JC's rate of surface errors was 2.95 SD above the control mean. JC's surface dyslexia is in the absence of a phonological impairment as his pseudoword reading was intact. On the word pair list he did not make significantly more surface errors than the controls, but the word-pair list was not created to detect surface dyslexia, and it mostly includes short regular words.

Could the patients' dyslexia be detected by traditional French screeners?

An important result is that none of the seven patients described above would be considered at risk for dyslexia by the Alouette reading test (see Table 4, a deficit is considered at $< -2SD$ from the mean). All their scores in the Alouette, except for JB, were between the 25th and 50th percentile on the Alouette, and JB's performance was even above the mean. This may seem surprising, but it should be considered that all these students were relatively fluent in reading, even in the Malabi screener. Their errors were few, but selective, and the Alouette does not contain the relevant stimuli to identify migrations within or between words.

Dyslexia, but no phonological impairment

All seven students with dyslexia described above performed within the normal range on the tasks testing oral language and phonological awareness, as summarized in Table 4.

	Alouette percentile	Pseudoword repetition ** N=20 M= 19, SD=1	Phoneme fusion* N=10 M=7.5, SD=2.4	Phoneme suppression* N=10 M=8.3, SD=2.0
LP	[25, 50)	20	9	9
TR	[25, 50)	20	7	8
LD	[25, 50)	20	10	10
JB	(50, 75)	19	9	8
PO	[25, 50)	20	7	8
HW	[25, 50)	20	8	8
JC	[25, 50)	20	8	8

Table 4. Dyslexic participants' scores on tests used to assess dyslexia in France through reading fluency and oral phoneme awareness tasks. Scores for all participants were within their grade norms.

+ Standardized scores are not provided after 5th grade, when children are at ceiling. This was clearly the case for all participants.

* Standardized scores are provided for the 7th grade (the screener has not been normed for the 6th grade).

Experimental investigation of attentional and letter-position dyslexia profiles

Method

Participants

Having found seven tentative cases of specific dyslexia types using the Malabi screener, we recontacted these students to evaluate if our inferences could be replicated, and to shed light on the factors that modulate reading errors. Four of these students were available for further testing: three of the students who made between-word migrations on the initial Malabi screener and were therefore identified as having attentional dyslexia (LP, TR, LD) and one of the students with within-word transposition errors (JB) in the Malabi, who was therefore identified with letter position dyslexia. They were tested 22 months after they had been tested with the Malabi. Six control students from Paris schools, matched to the earliest grade-year (8th grade) of our dyslexic participants, were also tested for comparison.

Materials

Attentional dyslexia was further tested by a new list of 528 word-pairs. These included 468 migratable pairs in which a between-word letter migration would create another existing word, (1152 possible lexical migrations), and 60 pairs in which no between-word letter migration would create an existing word (see Table 5 for details). The two words in each pair had the same number of letters, between 4 and 6 letters. All pairs allowed for migration in either direction, with both all

migratable possibilities presented (e.g., lent vois; vois lent; vent lois; lois vent), but never on the same page. The words ranged in frequency between 0 and 8,296 per million, $M=158$ (frequencies taken from the Lexique French database;(New et al., 2004). There was no difference in frequency between the words in the migratable and non-migratable categories, $p = .38$.

Number of letters	Number of different letters between words	Position of migration	Number of pairs	Number of possible lexical migrations N=1152	Target pair	Possible migration
Migratable word pairs N=468						
4	All	First	20	40	bête fois	fête bois
		Middle	20	40	sale fois	sole fais
		Last	20	40	aime volé	aimé vole
	One	First	20	40	loin soin	soin loin
		Middle	20	40	fuit fait	fait fuit
		Last	20	40	fous four	four fous
	Two	first_last	12	48	fini mine	mini fine, fine mini
		first_middle	12	48	poux deux	doux peux, peux doux
		middle_last	12	48	dura dire	dira dure, dure dira
5	All	First	20	40	flans paire	plans faire
		Middle	20	40	repue laver	revue laper
		Last	20	40	monté gagna	monta gagné
	One	First	20	40	banal canal	canal banal
		Middle	20	40	douce douze	douze douce
		Last	20	40	marié marie	marie marié
	Two	first_last	12	48	serai feras	ferai seras, seras ferai
		first_middle	12	48	belle salle	selle balle, balle selle
		middle_last	12	48	bougé boude	boudé bouge, bouge boudé
6	All	First	20	40	réparé soutes	séparé routes
		Middle	20	40	bottés lampes	bottes lampés
		Last	20	40	acheté pleura	acheta pleuré
	One	First	20	40	otages étages	éttages otages
		Middle	20	40	places plages	plages places
		Last	20	40	devine deviné	deviné devine
	Two, different letters and two opportunities for migration.	first_last	12	48	drainé graine	grainé draine, draine grainé
		first_middle	12	48	centre vendre	ventre cendre, cendre ventre
		middle_last	12	48	marges manger	manges marger, marger manges
non-migratable word-pairs N=60						
4			20	0	joli gros	
5			20	0	balai taper	
6			20	0	reflet occupé	

Table 5. Types of word-pairs in the list targeting attentional dyslexia – letter migrations between words. For all pairs, the migration could move from the left to right word or the right to left word. Consonants were always migratable for consonants (650 possible lexical migrations) and vowels for vowels (502 possible lexical migrations).

Letter-position dyslexia was further tested using a single word reading-aloud test comprising 406

new words: 304 words that had a possible letter transposition that would make a new word and 102

words did not have such an anagram (see Table 6 for details). Each word and its anagram were

present in the list. The words ranged in frequency between 0 and 14,662 per million, $M=151$

(frequencies taken from the Lexique French database; (New et al., 2004). For each word and its

anagram, the frequency of the most frequent word was $M=68$ per million ($SD=157$) and $M=10$ ($SD=26$) for the least frequent. There was no difference in frequency between transposable and non-transposable words, $p = .59$.

	Number of items	Example target -> <i>transposition error</i>
Transposable words (N=304)		
Middle transposition		
Adjacent consonant-consonant (CC) migration	26	congé -> <i>cogné</i>
Adjacent including a vowel (VV or CV) migration	110	loin -> <i>lion</i>
Non-adjacent consonant-consonant migration (C-C)	6	préside -> <i>prédise</i>
Non-adjacent including vowel migration (C-V, V-V)*	14	clouer -> <i>couler</i>
Exterior transposition		
Adjacent consonant-vowel (CV) migration	68	lier -> <i>lire</i>
Non-adjacent consonant-consonant migration (C-C)	66	coude -> <i>douce</i>
Non-adjacent including vowel migration (C-V, V-V)	14	pela -> <i>pale</i>
Non-transposable words	102	Maison

Table 6. Types of words included in the 406 words list targeting letter position dyslexia

* Unlike non-adjacent pairs in the other categories, whereby the two letters could make a same position switch, these were all words that allowed for the rearranging of middle letters that were orthographically not adjacent to make a new word. This difference in the category was due to the absence of stimuli in French orthography characterizing an exact position transposition.

Statistical Analysis

Within-participant comparisons between two conditions were conducted using chi-squared tests. Crawford and Howell's significance t-test was used to compare the performance of each participant with the control group (Crawford & Garthwaite, 2002; Crawford & Howell, 1998).

Results

Double dissociation between letter transpositions within words and letter migrations between words

We first sought to confirm the existence of a double dissociation, suggested by the initial Malabi screener, between attentional dyslexia (causing letter migrations between words, as observed in participants LP, TR, and LP) and letter-position dyslexia (causing letter transpositions within words, as observed in participant JB). To test this, we had all four students read both the

word-pair test with 468 migratable pairs and the single word test with 304 transposable words. It should be noted that migration errors were only counted when a letter migrated from one word to the other if it maintained its position. For first and last letters this was the exact position, while middle letters could be anywhere in between.

Participants with Attentional dyslexia

The performance of the four participants and controls is summarized in Table 7. The findings are clear-cut: a double dissociation was found between letter position encoding within and between words. All three participants with attentional dyslexia make significantly more migration errors on the word-pair test than transposition errors on the transposable word test.¹ Those participants also make significantly more between-words migrations than the control group and than the participant with letter-position dyslexia. For the three children with attentional dyslexia, migrations between words on the word-pair test far outnumbered any other type of errors. LP made 80 errors, 66 of them (83%) explainable as migrations between words. Similarly, 78 of TR's 84 errors were migrations between words (93%) and 51 of LD's 52 errors (98%) could be categorized as attentional migrations. The opposite picture emerged for patient JB: he made a significantly greater number of within-word transpositions than of between-word migrations and he differed from controls only in his abnormal percentage of transpositions, with 35 transposition (71%) out of 49 total errors. Together, these results confirm the inferences arising from the Malabi screener and indicate a double dissociation between attentional dyslexia and letter-position dyslexia, namely, between letter-position encoding between- and within-words.

¹ In the case of the between-words migration errors in the attentional dyslexia test, migrations between words are always possible in both directions between the two words. We counted each migration made, so that a double migration (e.g., bête fois -> fête bois) was counted as two migrations, and a single-direction error (e.g., bête fois -> fête fois) was counted as one. There were 1152 possible sites of migration in the list. Double migrations represented 5% of LP's migration errors, 14% of TR's migration errors, and 2% of LD's migration errors.

	LP attentional dyslexia	TR attentional dyslexia	LD attentional dyslexia	JB letter-position dyslexia	Controls N=6
Word-pairs migration test					
between-words letter migration	5.7%	6.8%	4.4%	1.2%	0.9% (0.7)
Single word letter-position test					
Within-word letter transpositions	2.6%	0.7%	1.0%	11.5%	1.7% (1.6)
Between-word migrations vs. within word transpositions	$\chi^2 = 4.78$ $p = .029^*$	$\chi^2 = 17.31$ $p < .001^{***}$	$\chi^2 = 7.97$ $p = .005^{**}$	$\chi^2 = 78.43$ $p < .001^{***}$	$\chi^2 = 1.61$ $p = .20$
Between-word migrations compared to control	$t(5) = 6.73$, $p < .001^{***}$	$t(5) = 8.18$, $p < .001^{***}$	$t(5) = 4.93$, $p = .002^{***}$	$t(5) = 0.48$, $p = .33$	
Within-word transpositions compared to control	$t(5) = 0.55$, $p = .30$	$t(5) = -0.61$, $p = .28$	$t(5) = -0.42$, $p = .35$	$t(5) = 5.76$, $p = .001^{**}$	

Table 7. Test percentage error made by dyslexic and control participants for an error type

Attentional dyslexia: Detailed analysis of migrations between words

Our data afforded a detailed analysis of the nature and causes of migration errors. We first note that the deficit was highly selective. To understand what factors may modulate attentional dyslexia, we next examined which stimuli were most likely to induce migration errors. Our attentional word pair test was specifically designed for direct horizontal migrations between the word pairs. However, in scoring the errors, we noticed that some could be assigned to vertical migrations, i.e., correctly reading a word-pair ‘vendre centre’, then on the next row, incorrectly reading the pair ‘gisait lavage’ as ‘visait lavage’. In this case the migration plausibly stemmed from the first letter in the word vertically above the target. We scored for horizontal migrations when the migration could have come from the word adjacent and vertical migrations when the migration could plausibly come two words directly above or below. For both horizontal and vertical migrations (vertically arranged letters did not necessarily have the same number of letters), we used the strict criterion that position be preserved for first a last letters and relative position for middles letters. Horizontal migrations counted for 89% of LP’s errors, 91% of TR’s errors and 91% of LD’s. We restrained further analysis to only include horizontal errors, per previous analysis of attentional errors (Friedmann et al., 2010b)

Lexicality

The majority of migration errors resulted in a real word (percentage of real word responses: LP = 97%, TR = 99%, LD = 98%). This finding indicates an impact of the orthographic input lexicon on migrations: an error resulting from failed letter-to-word binding may pass the orthographic input lexicon if it is a real word, but may be blocked if it is not. Further analysis only counts migration errors that were lexical.

Frequency

Since most errors resulted in real words, we next tested if frequency mattered: did students make more letter migrations leading to a word more frequent than the target word? To assess this, we compared the frequency of the target to the frequency of the student's erroneous response. LP's responses were equally likely to lead to a more or less frequent word (50%, $\chi^2 = 0$, $p = 1$). LD and TR both made on average fewer migrations leading to a more frequent word (LD = 44%, TR = 37%), but this distinction only reached significance for TR (LD, $\chi^2 = 1.44$, $p = .23$; TR, $\chi^2 = 9.89$, $p = .002$). Another analysis yielded a similar result. We used the fact that both a pair and its inverse were presented, which allowed us to examine whether migrations occurred more frequently when the more frequent word presented. This was not the case (LD: 47%, LP: 45%, TR: 46%, all individual χ^2 s = 1.09, $p > .30$).

Word length

Previous research on attentional dyslexia in Hebrew has shown an effect of longer words leading to more between-word migrations (Friedmann et al., 2010), a possible explanation being that more letters in the visual field may lead to more possibility for error. Our design only included word pairs with two words of the same length, with 156 word pairs (384 possible migrations) for each of the lengths four, five, and six letters (Table 5). For each length, we calculated the number of between-word migrations (see Table 8). Unlike previous results reported in Hebrew comparing stimuli of 3, 4, and 5 letter words, we did not observe a length effect. Children are just as likely to produce a migration error if the words comprise 4, 5 or 6 letters.

	4- letters	5- letters	6- letters	4 vs. 5 letters	5 vs. 6 letters	4 vs. 6 letters
LP	7%	3%	5%	$\chi^2 = 6.74$ $p < .01^{**}$	$\chi^2 = 4.06$ $p = .04^*$	$\chi^2 = 0.37$ $p = .54$
TR	7%	5%	7%	$\chi^2 = 1.54$ $p = .21$	$\chi^2 = 1.54$ $p = .21$	$\chi^2 = 0.0$ $p = 1$
LD	4%	3%	5%	$\chi^2 = 1.03$ $p = .30$	$\chi^2 = 4.06$ $p < .05^*$	$\chi^2 = 1.05$ $p = .31$
average	6%	3%	6%	$\chi^2 = 2.42$ $p = .12$	$\chi^2 = 2.42$ $p = .12$	$\chi^2 = 0.0$ $p = 1$

Table 8. Percentage of between-word migrations in words of different lengths. Percentages are based on our design including only word pairs with two words of the same length, with 384 possible migrations (in 156 words) for each of the lengths four, five, and six letters.

Consonant versus vowel migrations

Our word pair list contained 650 possible consonant migrations and 502 vowel migrations. We looked to see if out three subjects were more likely to make consonant or vowel errors (none of these participants had shown vowel dyslexia during the Malabi screener) to ensure that none of the subjects tended towards vowel dyslexia. Our word list was built to allow for only lexical consonant to consonant and vowel to vowel migrations. A selective attentional dyslexia was again confirmed as all participants were equally likely to make consonant and vowel migrations : LP made errors on 4% of possible consonant migrations and 6% of possible vowel migrations, $\chi^2s = 1.6$, $p = .20$, TR made errors on 6% of possible consonant migrations and 7% of possible vowel migrations, $\chi^2s = 0.78$, $p = .38$, LD made errors on 3% of possible consonant migrations and 4% of possible vowel migrations, $\chi^2s = 0.79$, $p = .36$. Furthermore, the combined average did not produce a difference, $\chi^2s = 1.02$, $p = 0.31$.

Sensitivity to the position of the potential lexical migration

It was previously observed that Hebrew readers, who read from right to left, make more between-word migrations on the final (leftmost) letter of the word (Friedmann et al., 2010a). It has been suggested that this is possibly due to enhanced coding for the first letters (Humphreys et al., 1990; Shalev et al., 2008). Furthermore, there is evidence that other orthographic visual-analyzer dyslexia types are position-sensitive. For example, neglect dyslexia is generally categorized as omissions or substitution systematically on one side of words, typically on the left side (Ellis et al., 1987; Reznick & Friedmann, 2015). Letter-position errors in letter position dyslexia occur more frequently in middle

positions (Friedmann & Rahamim, 2007; Güven & Friedmann, 2019; Kohnen et al., 2012). In this context, we were interested in seeing if the error rate in French children with attentional dyslexia would also vary with letter position. The 468-word-pairs include 192 pairs (384 migrations) with a lexical potential for each letter position : first, middle, last. 120 pairs only permitted a lexical migration in one position, and 72 had multiple migration positions. Our results (Table 9) show that the final letter (the rightmost letter), like in Hebrew, was more likely to be affected by a migration despite the opposite directionality of reading. All three participants made significantly more errors on the last letter compared to the first letter and middle letter: combined average first vs last χ^2 s = 17.39, $p < 0.001$ and middle vs last, χ^2 s = 10.76, $p = 0.001$. No difference was found between first and middle, χ^2 s = 1.05, $p = 0.31$. Last letter lexical migrations were 80% vowels (i.e., reading ‘abrite blessé’ as ‘abrité blesse’) and 20% consonants (i.e., reading ‘fous tour’ as ‘four tous’). That this last letter was predominantly a vowel, however, did not have an effect on errors as all three children were just as likely to make lexical migrations on the last letter if it was a consonant or a vowel: LP made errors on 13% on items with consonant migrations and 11% with vowel migrations, χ^2 s = 0.27, $p = 0.60$; TR made errors on 17% on items with consonant migrations and 12% with vowel migrations, χ^2 s = 0.92, $p = 0.34$; and LD made errors on 8% on items with consonant migrations and 9% with vowel migrations, χ^2 s = 0.06, $p = 0.81$.

	First	Middle	Last	first vs middle	middle vs last	first vs last
LP	2%	3%	10%	$\chi^2 = 0.49$ $p = .49$	$\chi^2 = 15.02$ $p < .001^{***}$	$\chi^2 = 19.85$ $p < .001^{***}$
TR	3%	4%	11%	$\chi^2 = 0.04$ $p = .84$	$\chi^2 = 15.10$ $p < .001^{***}$	$\chi^2 = 16.47$ $p < .001^{***}$
LD	2%	3%	7%	$\chi^2 = 2.64$ $p = .10$	$\chi^2 = 4.57$ $p = .03^*$	$\chi^2 = 13.04$ $p < .001^{***}$
average	2%	3%	9%	$\chi^2 = 0.64$ $p = .42$	$\chi^2 = 11.16$ $p = .001^{***}$	$\chi^2 = 16.29$ $p < .001^{***}$

Table 9. Percentage of between-word migrations of first, middle, and final letters. The word pair list had 384 possible lexical migrations for each position. While first and last letters were discrete, middle letters could be any position between.

Direction of migrations

We examined if the migration was more likely to result from a carry-over from the first word onto the next (1->2, sometimes called “perseveration”), or in the converse direction (2->1). In a previous

report in Hebrew (Friedmann et al., 2010b), a letter was more likely to migrate from the first word in a pair to the second word (1->2; e.g., ‘cat hub’ was more commonly misread as ‘cat hut’ than as ‘cab hub’). To address this question, we scored the direction of movement for each horizontal migration error. The results showed that LD and TR made significantly more migrations from the forthcoming word (2->1; LD: 69%, $\chi^2 = 6.55$, $p = .01$; TR: 70%, $\chi^2 = 10.89$, $p < .001$). For example, ‘ceux pela’ was read ‘cela pela’, ‘réparé soutes’ as ‘séparé soutes’, and ‘dons cric’ as ‘donc cric’. The two directions neared significance in favor of the 2nd word to 1st word migration for LP (63%, $\chi^2 = 3.59$, $p = .06$). The observation of anticipations (2->1) is surprising, particularly since previous work in Hebrew found that participants with migration errors made twice as many forward errors than backward errors (Friedmann, Kerbel, et al., 2010b). Note, however, that the next word appears to the left of the page in Hebrew; thus, both findings might be putatively reconciled as an effect, onto the currently fixated word, of the word that lies on the right side of the page (Cohen & Dehaene, 2000; Molko et al., 2002). It has been reported that normal readers in English make more first to second word migrations in horizontal pairs (Humphreys et al., 1990). We would argue in that subjects with attentional dyslexia do not read like normal readers and that normal readers are more likely to make carry-over errors of the phoneme due to its storage in an articulatory buffer despite correct visual representation. Whether or not this interpretation is correct, the present findings in French patients are important in that they allow to reject the hypothesis that migrations merely stem from perseveration in a memory buffer that carries information from one word to the next (Cohen & Dehaene, 1998). Rather, the deficit appears to affect a visual stage since it is influenced by visuospatial rather than temporal factors.

Number of shared letters and opportunities for errors

Our list of word-pairs also systematically manipulated letter similarity between two words: it comprised pairs of words differing in only one letter, two letters, or all letters. 180 word-pairs existed for the categories of ‘one’ and ‘all’ different letters, with both categories allowing each for 360 possible migrations. There were 108 word-pairs with ‘two’ different letters, allowing for 432 possible

migrations (see Table 5 for examples). This variable could impact reading in several different ways. On the one hand, shared letters increase the similarity between words and may therefore increase the chances that they are confused. This hypothesis finds support in experiments that flash two words simultaneously in the visual field of the normal readers (a paradigm initiated by (Allport, 1977), and later further investigated by McClelland & Mozer, 1986; Mozer, 1983; Shallice & McGill, 1978; Shetreet & Friedmann, 2011; Treisman & Souther, 1986, but see (Davis & Bowers, 2006), for an argument that the deficit in attentional dyslexia crucially differs from migrations that normal readers experience in such short exposure situations). In these cases, an illusory perception arising from a combination of the two words is more likely when the word pair is more similar (Davis & Bowers, 2006; Mozer, 1983). On the other hand, when two words share more letters in the same position, migrations between them may go undetected, thus reducing the apparent number of errors. In the final analysis, what may count is simply the number of opportunities for errors that respect the lexicality filter. In our stimuli, word pairs differing by 1 letter (e.g., 'douce douze') offered, by definition, a single opportunity for migration for each word (two for the pair), but so did the majority of word-pairs differing by all letters (e.g., flans paire → plans faire; for all other letter swaps would not result in a word). The word-pairs differing by 2 letters, however, offered two opportunities for errors (e.g., in 'belle salle', swapping the initial consonants 'b' and 's' results in 'selle balle', and swapping the vowels 'e' and 'a' results in 'balle selle'). Thus, if this was the dominant factor, then word-pairs differing by two letters should yield more migration errors. Since we did not find a length effect earlier, we collapsed the data across word lengths to look at differences created by the number of different letters. Our results did not provide evidence in favor of the "opportunities for error" account (see Table 10). For all participants, when taking into account the number of opportunities for a lexical migration, were not effected by word-pairs that differed by 1, 2 or all letters.

	1 different letter (canal banal)	2 different letters (belle salle)	all different letters (passe tendu)	1 vs. others	2 vs. others	All-different vs. others
LD	8%	15%	9%	$\chi^2 = 0.70$ $p = .40$	$\chi^2 = 2.4$ $p = .12$	$\chi^2 = 0.70$ $p = .40$
LP	15%	21%	8%	$\chi^2 = 0$ $p = 1$	$\chi^2 = 3.03$ $p = .08$	$\chi^2 = 5.13$ $p < .02^*$
TR	12%	25%	14%	$\chi^2 = 4.79$ $p = .03^*$	$\chi^2 = 6.38$ $p = .01^*$	$\chi^2 = 0.36$ $p = .55$
Average	12%	20%	10%	$\chi^2 = 8.6$ $p = .35$	$\chi^2 = 4.08$ $p = .04^*$	$\chi^2 = 1.59$ $p = .21$

Table 10. Percentage of between-word migrations for word-pairs with 1, 2, or all different letters.

Letter-position dyslexia: Detailed analysis of within-word transposition errors

We also took a deeper look into the factors that impacted the likelihood of a transposition error in participant JB. JB was a clear and selective case of letter position dyslexia: He was more likely to make letter transposition errors on this test than the controls and than the participants with attentional dyslexia (as reported above), and the large majority of his errors (69%) could be uniquely attributed to a letter transposition within words. A new list of stimuli was designed to replicate this observation and probe several factors: frequency (is the reader more likely to transpose letters when the transposition yields a word that is more frequent than the target word?), within-word position of transposed letters (do transpositions occur more frequently in the middle of the word than with exterior letters?), adjacency (are transpositions more likely to occur between adjacent letters?), and consonant-vowel status.

Transpositions made in words with a lexical transposition versus words without a lexical transposition.

For the following analysis, we focus on the transposition errors that were made on designated sensitive words, thus excluding two of JB's non-lexical transpositions that occurred on words that were not specifically put in the test as transposition-sensitive. Words with 3-letters (N=14) were removed from the analysis because they do not allow for middle letter migrations, which have been reported to be the main type of migrations in other languages — indeed, no errors were made on these short words.

Word frequency

It has been found in Hebrew (Friedmann & Rahamim, 2007), Turkish (Güven & Friedmann, 2019), and in English (Kohnen et al., 2012) that letter transpositions errors are more likely to occur when the original target word is less frequent than the word that results from the transposition. The hypothesis is that if the positions of letters are underspecified, and such partial information is combined with a Bayesian prior based on word frequency (e.g., Norris, 2006), then the best-matching lexical entry is likely to be the more frequent word. Since our list included all words and their transposition (N=145 each), we could easily test this theory by examining how often a less-frequent word was transposed to yield the more frequent one, and how often the opposite happened. Our results indicate that JB was more likely to convert a low-frequency word to its higher frequency anagram (13%) than vice-versa (6%), $\chi^2 = 4.94$, $p = .04$. This finding replicates prior observations and further emphasizes the importance of choosing appropriate stimuli, in this case transposable words that are less frequent than their migration counterparts, in a screener for different types of dyslexia.

Middle versus exterior letters

It has been observed that transpositions are more likely to involve middle letters than exterior ones (Friedmann & Gvion, 2001; Friedmann & Haddad-Hanna, 2012; Friedmann & Rahamim, 2007; Güven & Friedmann, 2019; Kohnen et al., 2012). The theory is that the position of these letters may be less precisely coded, causing greater potential for transposition than the exterior letters. Here, we compared the rates of letter transposition for stimuli affording a transposition of middle letters (N=156 stimuli) versus those affording a transposition including at least one exterior letter (N=134). Our results show that, like previous cases, JB made significantly more migrations of middle letters (16%) than of exterior letters (2%), $\chi^2 = 18.03$, $p < .001$.

Adjacent versus non-adjacent letters

Another factor that was previously shown to modulate letter transpositions is whether the transposed letters are adjacent (e.g., plier-piler) or not (e.g., étape-épate): adjacent letters are more frequently transposed (Friedmann & Gvion, 2001; Güven & Friedmann, 2019). We compared the

rates of letter transposition for stimuli with a lexical potential for adjacent transposition (N=196 stimuli) versus potential transpositions between non-adjacent letters (N=94 stimuli). JB was more likely to make transpositions from adjacent (28%) than nonadjacent letters (1%), $\chi^2 = 15.71$, $p < .001$. This result has its limitations as we already noted that JB, like previously reported cases of this type of dyslexia, is more likely to make errors on middle letters. In our own list, out of 94 words with a potential lexical transposition between non-adjacent letters, only 20 involved middle letters, (74 words allowed for non-adjacent migrations that involved an exterior letter), whereas out of the 196 words with a potential for adjacent migrations, 136 involved middle letters.

Consonants versus vowels

Transpositions can involve two consonant letters (e.g., linge->ligne), two vowels (e.g., lion->loin), or a consonant and a vowel (e.g., porche->proche). Distinguishing these errors is required to distinguishing letter-position dyslexia from vowel dyslexia. In previous cases of pure selective letter-position dyslexia, readers make equal to significantly more consonant-consonant transpositions compared to transpositions including at least one vowel (Friedmann & Rahamim, 2007 for Hebrew; Güven & Friedmann, 2019 for Turkish; Kohnen et al., 2012 for English). In contrast, readers with vowel dyslexia, identified as a vowel-specific processing deficit in the sublexical route prompting vowel errors, including vowel position errors, make significantly more transpositions that involve vowel letters compared to consonant transpositions (Güven & Friedmann, 2021 for Turkish; Khentov-Kraus & Friedmann, 2018, for Hebrew). Therefore, comparing consonant to vowel errors is important to ruling out the possibility of having overlooked a vowel deficit, and possibly to ascribing letter position dyslexia to a person whose letter position errors were only due to vowel dyslexia. In our list, 98 words allowed for a consonant-consonant transposition, 178 words allowed for CV transposition, and 28 words allowed for VV transpositions. Similar to previous results on letter-position dyslexia in other languages, when taking into account the number of lexical opportunities, JB showed similar rates of transpositions involving two consonants (8%, cc vs others, $\chi^2 = 1.59$, $p = .21$), a consonant

and vowel migration (12%, cv migrations vs others, $\chi^2 = .31$, $p = .58$), and two vowels (18%, vv migrations vs others, $\chi^2 = 1.22$, $p = .27$).

Silent reading, lexicality

If the transposition of letters occurs during the orthographic-visual analysis stage, which is a pre-lexical stage, then even if the reader knows that they are reading pseudowords, the competition created from the presence of nearby words stored in the lexicon should give rise to a bias towards words, i.e., a significantly greater number of transpositions in transposable words and nonwords than in non-transposable ones. To examine this hypothesis, we presented a list of 72 written items to the participant for lexical decision. Half of the items in the list were existing words, the other half were pseudowords matched for length. Of the 36 pseudowords, 18 pseudowords were transposable, i.e., they offered a possible middle transposition that yielded a real word, while the other 18 pseudowords did not. The participants were given the list (presented in 14pt Calibri font) and asked to silently read the stimuli and circle all “real words”. The participants read the list silently by themselves and completed the task at their own pace.

The control participants made very few errors on this test: four out of six controls answered correctly to all items. One control participant failed to circle one existing word and another control incorrectly circled one transposable pseudoword. JB’s results provide a stark contrast to the control’s performance (Table 11). JB circled six of the 18 transposable pseudowords (33%; e.g., *pocile*, anagram of *police*), thus perceiving them as words. This error rate was significantly worse than the control group, $t(5)=13.23$ $p < .001$. Like the control group, he responded correctly to the non-transposable pseudowords. JB also missed two real words (6% of the words). These results, whereby significantly more transpositions occur on transposable than on non-transposable pseudowords, are in line with the findings reported in Friedmann and Gvion (2001). The difficulty that JB demonstrated even when he did not need to read aloud the words also indicates that his deficit is in the orthographic-visual analyzer stage, rather than the phonological output stage.

	JB	Controls	JB vs. controls
Transposable pseudowords, N=18	33.3%	0.93% (2.3%)	$t(5) = 13.23, p < .001^{***}$
Non-transposable pseudowords, N=18	0	0	=
Words, N=36	5.6%	0.93% (1.4%)	$t(5) = 2.99, p = .02^*$

Table 11. Percentage of errors in a silent lexical decision task (N=72 words)

Discussion

We developed a novel reading screener, the Malabi, capable of exposing different types of reading errors in French, and were able to identify with it types of developmental dyslexia that have not been reported before in French. We documented in great detail 3 cases of attentional dyslexia and one case of letter-position dyslexia; and the Malabi also identified 3 other potential cases of letter-position dyslexia (1 other student), phonological dyslexia (1 student), and surface dyslexia (1 student). These students would not have been identified as having dyslexia using the currently available tests in French.

As a second step, we used further tests to examine the properties of two kinds of dyslexia: attentional dyslexia, a deficit in letter-to-word binding that manifests itself in between-word migrations; and letter position dyslexia, a deficit in letter position encoding within words, manifesting in within-word transpositions. We found a double dissociation between the two functions, with 3 students who had migrations between- but not within words, and 1 student who had transpositions within-words. This finding supports the existence of dissociable cognitive processes of letter position encoding within and between words, in line with previous studies (Friedmann et al., 2010a; Friedmann & Rahamim, 2007). Other studies not purely interested in double dissociation have also reported differences in subjects within- and between word migrations. For instance, a study interested in the possible relations between various dyslexia types and attention deficits reported 32 participants with letter-position dyslexia in the absence of attentional dyslexia, and 5 participants with the opposite profile (Lukov et al., 2015). Another treatment to test the effect of mindfulness training on reading errors in dyslexia reported 6 participants with letter-position dyslexia in absence of attentional dyslexia (Tarrasch et al., 2016). Such double dissociations indicate that although both

the encoding of letter position within words and the encoding of letter position between words occur at the early stage of orthographic-visual analysis, they involve different processes that can be independently altered.

As further discussed below, letter position errors within words could arise from a deficit in the spatial resolution of visual analysis, e.g. visual letter detectors in or prior to infero-temporal cortex (Davis, 2010; Davis & Bowers, 2006; Rajalingham et al., 2020), whereas migration errors between words could arise from an improper attentional selection and/or amplification of one out of several words, all of which are processed in parallel at an early visual level (McConkie & Rayner, 1975; Rayner, 1975; Snell & Grainger, 2019).

Not many studies examined the properties of attentional and letter-position dyslexias, i.e. which stimuli are most sensitive to detect them, and what are the characteristics of the errors. In line with a previous study of 10 Hebrew-readers with attentional dyslexia (Friedmann et al., 2010a) we discovered that more migrations occur when the migration creates an existing word and more migrations affect the final letter in comparison to the middle and first letters. On the other hand, neither frequency, number of opportunities, consonant versus vowel status, nor length seem to have a strong influence.

As concerns letter-position dyslexia, in line with previous studies (Friedmann & Gvion, 2001; Friedmann & Haddad-Hanna, 2012, 2014a; Friedmann & Rahamim, 2007; Güven & Friedmann, 2019; Kohnen et al., 2012), the main characteristics we found were: more transpositions occur when the transposition creates another existing word; more transpositions transform a lower-frequency target word into a more frequent word; more transpositions occur with middle letters than with an exterior letter (and accordingly, there are no errors with 3-letter words); more errors occur in adjacent compared to non-adjacent letters; and transpositions are equally likely to involve consonants and vowels. The occurrence of letter position errors in silent reading indicated that transpositions do not depend on overt oral reading, thus pointing to a deficit in the orthographic-visual analyzer rather than at phonological output.

Our findings regarding the types of stimuli that give rise to most migrations between words (in attentional dyslexia) or within words (in letter position dyslexia) help specify the conditions that are most likely to yield errors for these two types of dyslexia, and hence, the stimuli that would be most sensitive to these dyslexias in a reading test. For attentional dyslexia, this is the presence of a neighboring word whose final letters may be switched with those of the target word to create another existing word. For letter-position dyslexia, it is the existence, within the target word, of adjacent middle letters that, if transposed, yield another word of higher frequency.

In both types of dyslexia, the presence of a lexical bias (almost all errors make plausible words) suggests that dyslexias at the orthographic-visual stage may be partially compensated by using the orthographic input lexicon, which retrieves the most plausible existing words in the face of partial letter information. In the case of letter-position dyslexia, both lexicality and frequency influence reading, exactly as would be expected from a “Bayesian reader” that optimally combines incoming perceptual evidence with lexical priors (Norris, 2006) (sentence-level contextual priors may also influence reading, see Smith & Levy, 2013). This finding, as well as the double dissociation between migrations within and between words, exemplify the fact that developmental deficits can selectively affect a particular stage of the orthographic identification process while leaving subsequent lexical stages intact. Another important aspect brought to light by the present study is the longitudinal stability of the selective dyslexia profiles. Over a year elapsed from the first time that the students were identified with the Malabi test to their retesting with longer tests, yet these selective cases continued to show identical, double-dissociated error types.

Many previous studies have found that dyslexic readers can be impaired only in specific types of stimuli (Sotiropoulos & Hanley, 2017), for instance in selective developmental deficits of surface dyslexia (Castles, 1996; Friedmann & Lukov, 2008; Zoccolotti et al., 1999) or phonological dyslexia (Campbell & Butterworth, 1985). However, whereas studies of selective deficits have historically focused on central reading processes as described by the Dual Route Model, the present research provides additional evidence supporting a locus of some deficits within the orthographic visual

analyzer. This finding highlights the need to better characterize the key processes that govern orthographic analysis. In the case of attentional dyslexia, this means considering the orthographic-attentional window that selectively amplifies information from a target word and filters out the letter information arising from other words. In this respect, our results concur with considerable prior research suggesting the existence of a non-conscious processing of parafoveal words (McConkie & Rayner, 1975; Rayner, 1975; Snell & Grainger, 2019) and the importance of selective attention during reading (Facoetti et al., 2006, 2008; Franceschini et al., 2012; Peyrin et al., 2011; Vidyasagar & Pammer, 2010a). In the case of between-word migration errors, it may be that the attentional window that attributes specific letters to the target word and inhibits letters from surrounding words is less powerful than in normal readers, thus causing letters to hold their within-word position but jump between words.

Considering letter-position dyslexia, the results could arise from an abnormal uncertainty about letter-position, resulting in an ambiguous coding of the incoming letter string, particularly for letters inside the word. Even in normal readers, priming experiments indicate that information about letter position is fragile, such that visual word recognition can be primed by the prior presentation of the same word with transposed letters, particularly under conditions of impoverished inputs (e.g., with flashed or masked words), and more so for middle letters (Perea & Lupker, 2003). These results are compatible with spatial coding models of reading and especially models of the orthographic stage, that differentiate the encoding of letter identity and relative position, as supported by a cumulative benefit in masked primes that share a letter and position, share a letter in a position once removed, and share neither letter or position (Davis & Bowers, 2006). Recent evidence from both behavioral, brain-imaging, and computational modeling studies suggest that the information flow may proceed directly from letter-position coding to lexical access (Agrawal et al., 2019, 2020; Hannagan et al., 2021; Woolnough et al., 2020). Most interestingly, the dominant effect of reading acquisition seems to be to refine the positional accuracy with which nearby letters are encoded

(Agrawal et al., 2019). Letter-position dyslexia would occur at precisely that stage where each letter must be bound to a specific ordinal position, in order to avoid confusing anagrams.

The Dual Route Model was originally designed as a model of expert reading, and nicely accounts for acquired dyslexias. The present research lends behavioral support for its usefulness in also understanding at least some selective cases of developmental dyslexia (Perry et al., 2019). However, developmental reading deficits may entail an additional complexity beyond acquired ones, since an early deficit in one of the processes may lead to a lack of acquisition of the others. In the future, therefore, proper modeling of the present cases may require an explicit simulation of the learning process (Perry et al., 2019), possibly using recent detailed convolutional models of invariant word recognition (Hannagan et al., 2021).

Dyslexia (in the singular) has often been argued as stemming from a systematic phonological deficit in language processing, as supported by reports of poor phoneme processing in the majority of dyslexic cases (Landerl et al., 2013; Ramus, 2003; Saksida et al., 2016; Sprenger-Charolles et al., 2000; Ziegler et al., 2008b). This argument is often supported by the importance of oral phoneme manipulation as a predictor of early literacy skills (Melby-Lervåg et al., 2012; Piquard-Kipffer & Sprenger-Charolles, 2013; Torgesen et al., 1997). While a precise representation of phonemes is clearly necessary to reading, the argument that poor phoneme processing is the exclusive core deficit of dyslexia has been contested (Castles & Coltheart, 2004). Causes and consequences are hard to disentangle since phonological awareness appears to be a poor in illiterate adults (Schaadt et al., 2013) and gets refined during the acquisition of literacy (Dehaene et al., 2010, 2015b; Froyen et al., 2008; Monzalvo & Dehaene-Lambertz, 2013; Morais et al., 1986). Interventions to improve phoneme awareness only improve reading acquisition when learning phonemes is combined with learning of their corresponding grapheme, (National Reading Panel, 2000; Zarić et al., 2021). Dyslexic children may develop strategies to avoid reading, therefore leading to poorer phoneme processing skills compared to normal readers.

Another argument against the phonological core deficit is the evidence of recruitment biases. It is possible that, in dyslexia diagnosis, an over-reliance on tests that tap into phoneme awareness created a bias towards students with a phonemic deficit. In France, the tools used by speech therapists, teachers, and researchers to identify dyslexia often use oral phoneme awareness or pseudoword reading tasks. This may have caused practitioners to specifically diagnose dyslexia, and therefore to refer patients to researchers, only in the presence of a phonemic deficit, thereby increasing their representation in the literature. Other types of dyslexia may have been discarded as poor readers. In this work, we assessed all seven cases with selective dyslexias (letter position dyslexia, attentional dyslexia, phonological output buffer deficit, surface dyslexia) on tasks commonly used to test phonemic deficits, and found that all showed normal ability. All performed within the normal range on the Alouette test, pseudoword repetition, phoneme fusion, and phoneme suppression. Their dyslexias could not, therefore, be explained by an underlying phoneme processing deficit. Unfortunately, we do not know in these cases if it is because these children all received intensive language and reading support from their specialized school, or if they never had a phoneme deficit in the first place. At the very least, however, these cases indicate that phonological abilities can be normal in students with clear and reproducible dyslexia.

Limitations

Converging research points to the importance of early and individualized interventions for at-risk students in order to improve the effectiveness of remediation (Morris et al., 2010; Ozernov-Palchik et al., 2017; Shaywitz et al., 2008; Torgesen, 2002). The Malabi test, however, requires overt reading and can therefore only be used once a certain reading fluency has been attained. Future research should attempt to expand the screening to students in lower grades, using simpler perceptual tests. A second limitation of the current work is that, while we report single-case studies of selective dyslexias, we cannot determine their frequency. Future research should seek to evaluate the prevalence of different types of selective deficits. A third limitation to the Malabi is its usability.

Currently, testers must be trained to transcribe the errors in phonetic notation, and to attribute them to an appropriate level of the reading process. For example, if the reader read the word *signe* \sin\ as *singe* \sɛ̃ʒ\, the tester must recognize that this phonological output could have arisen from a single letter transposition. Such detailed error coding is far more time consuming than classical recordings of reading speed and accuracy, particularly for severe dyslexics who make many errors. We are working towards automating the error-coding process by compiling a large database of the most frequent errors and their codes. Manual phonetic transcription could also be avoided once accurate speech recognition becomes available for children.

Future directions

In considering the importance of early diagnosis and test usability, we argue for a multi-step process to mitigate the effects of dyslexia. This process would begin with pre-reading language and visual testing of all children on known predictors of reading, using tests that can be easily administered by teachers and may spot students that need individual attention early in reading instruction (Ozernov-Palchik et al., 2017). To reduce confounding dyslexia with a possible poor learning environment, learning to read in school should then follow an evidence-based explicit phonics curriculum known to best help all students, including those who are most at risk for dyslexia (Castles et al., 2018; Conseil scientifique de l'éducation nationale, 2019; Ehri et al., 2001; National Reading Panel, 2000). Finally, children who still show poor reading outcomes despite optimal circumstances could be assessed with a screener such as the Malabi, administered by a trained tester. Based on its outcomes, a detailed model of the child's reading deficit, be it selective or mixed, would then guide individualized remediation (Perry et al., 2019). The Malabi provides a more detailed account of the possible sources of errors than other screeners, and its potential to pinpoint the sources of their dyslexia therefore seems better than a general diagnosis of slow or inaccurate reading.

The possibility that multiple specific deficits underlie the umbrella term "dyslexia" also has consequences for brain imaging and genetics. The existence of distinct types of dyslexia, with doubly-

dissociated performances on specific tests, is not surprising, neither from the perspective of classical adult cognitive neuropsychology where such dissociations have been attested (Beauvois & Derouesne, 1979; Campbell & Butterworth, 1985), nor from the perspective of multiple-route models of reading (Coltheart et al., 2001; Coltheart, 2005), which clearly point to the possibility that many different impairments may result in a reading deficit. However, it is ripe of consequences for large-scale studies of the genetic or neurological basis of those deficits, which often treat “dyslexia” as a single entity. By doing so, they run the risk of identifying very broad genetic risk factors, for instance related to intelligence or education (Gialluisi et al., 2020) or, in the case of brain imaging, the generic consequences of non-proficient reading rather than the specific causes of the reading deficit (Dehaene et al., 2015a; Feng et al., 2020; Maisog et al., 2008; Martin et al., 2015; Rueckl et al., 2015). The present results suggest that a careful analysis of behavior, based on the existence of distinct types of errors, should precede, guide, and facilitate the mechanistic understanding of the various causes of reading impairments, as well as improve the efficiency of their rehabilitation. One place to start would be testing for the similarity of selective deficits in cases where dyslexia runs in families, as there is strong evidence for familial transmission (Cardon et al., 1994; Defries et al., 1978; Gialluisi et al., 2020; Pennington et al., 1991; Plomin et al., 1997).

Finally, the ultimate goal of improved assessment is to provide targeted remediation. Specific interventions for selective dyslexia should reduce the impact of dyslexia in daily life. In the majority of cases, dyslexia does not make reading impossible, only difficult. Previous research, although scant, has shown that remedial training, or tactics that alleviate the deficit, may help the learner re-engage in reading. For example, training of grapheme-to-phoneme conversion rules has been shown to improve cases of phonological dyslexia that stem from deficits in the grapheme-to-phoneme conversion route (R. K. Brunsdon et al., 2002; Kendall et al., 1998; Kiran, 2005). For errors of letter migration between words, the use of a cut-out window slid from word to word while reading was shown to reduce migrations from neighboring words, thus improving fluency (Friedmann et al., 2010; Rayner et al., 1989; Shvimer et al., 2009). It has also been suggested that crowding of nearby letters

is a frequent source of errors in beginner readers and struggling readers (Martelli et al., 2009; Pelli et al., 2007), who may benefit from the spacing of letters (Zorzi et al., 2012). This simple adjustment to text also seems to be a factor in alleviating letter transpositions for individuals with letter position dyslexia (Friedmann & Rahamim, 2014).

Conclusion

By showing a double dissociation between attentional and letter-position dyslexias on the Malabi screener and on follow-up tests, the present study supports the existence of selective deficits stemming from distinct steps of the orthographic visual analysis stage of reading. Importantly, this work in French adds to the growing body of languages in which there is for specific dyslexia types resulting from deficits in the orthographic analysis stage (see, for instance, in Hebrew: Friedmann et al., 2010; Friedmann & Gvion, 2001; Friedmann & Rahamim, 2007; Arabic : Friedmann & Haddad-Hanna, 2014; English: (R. Brunston et al., 2006; Ellis et al., 1987; Kohnen et al., 2012); Turkish: Güven & Friedmann, 2019; Italian: Lavelli et al., 2019; Traficante, Luzzatti, & Friedmann, 2021). This work also highlights the importance of developing dyslexia screeners that include specific stimuli to detect selective deficits, according to the types of words and nonwords most sensitive to each type of deficit, and to analyze specific types of errors, which are characteristic of different types of dyslexia, as opposed to just screening for the number of correct responses and reading speed, as is generally done in most screeners of dyslexia. This approach may identify dyslexic children that would otherwise be missed – remember that none of the participants in our sample of highly trained dyslexic students were considered dyslexic on the traditional French test for dyslexia. Understanding dyslexia through error types to selected words will in turn help researchers and practitioners to provide improved remediation tactics, tailored to each child's specific deficit.

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