What's Morphology Got to Do With It: Oral Reading Fluency in Adolescents With Dyslexia

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Abstract

Individuals with dyslexia often present phonological difficulties, ultimately impacting their reading and writing. Nevertheless, an individual with dyslexia may circumvent these difficulties through a reliance on linguistic units with more consistent spellings, such as morphemes. The increased use of morphological information by individuals with dyslexia has been argued to be a form of compensation. However, the contribution of morphological skills to reading fluency is still unclear. In this study, French adolescents with and without dyslexia were assessed on their morphological awareness and processing skills, along with reading fluency. Morphological awareness was assessed with a suffixation decision task, while a primed lexical decision task was used to assess morphological processing. Primes shared four possible relationships with the targets: morphological, semantic, orthographic, or unrelated. Group differences were not found for morphological awareness. In contrast, the group of adolescents with dyslexia showed a greater benefit of morphological priming. A continuous approach where reading fluency is seen as a broad spectrum was then used for future analyses. Benefits from morphological and orthographic priming were found to be inversely related to reading fluency. Morphological processing was found to be relatively high for individuals with low reading fluency proficiency, which suggests its use as a compensatory strategy in this population.

Keywords: dyslexia, morphological knowledge, compensation, reading fluency, high school students

Developmental dyslexia (hereafter, dyslexia) is a lifelong reading impairment that negatively affects accuracy and fluency in word decoding and identification, as well as orthographic skills. These difficulties cannot be attributed to extraneous circumstances such as poor-quality teaching, sociocultural deprivation, or intellectual impairment (American Psychiatric Association, 2013; Lyon et al., 1995). The most prominent causal hypothesis about dyslexia is a deficit within the phonological domain (Ramus et al., 2003; Share, 2021). Although phonological deficits have repeatedly been found to explain reading scores of individuals with dyslexia, a large proportion of the variance of these scores remains unexplained. To account for this unexplained proportion of variance, a multifactorial model involving contributions of multiple risk and protective factors has been proposed (Haft et al., 2016; Pennington, 2006). It is thought that the interaction between various risk and protective factors acts to increase or decrease the probability of the expression of literacy difficulties commonly attributed to dyslexia (Pennington, 2006). This multideficit model of dyslexia offers alternative strategies to compensate for underlying phonological difficulties, specifically through a reliance on other linguistic abilities, ultimately supporting reading achievement. For instance, previous studies have reported increased use of oral language skills during reading by individuals with dyslexia (Cavalli et al., 2016; Snowling, 2000; Stanovich, 1980).

Phonological skill deficits are considered as a risk factor for dyslexia (e.g., Hulme and Snowling, 2016 ; Snowling, 2000). In parallel, the relatively preserved morphological skills (the explicit or implicit reliance on morphemes during language processing) in individuals with dyslexia have been suggested to act as a compensatory skill set that can minimize the expression of, or the risk associated with, a phonological deficit (Cavalli, Duncan, et al., 2017 ; Elbro & Arnbak, 1996; Law et al., 2015; Law, Veispak, et al., 2018; Law & Ghesquière, 2021; Quémart & Casalis, 2015). As a result of their impaired ability to map graphemes and phonemes (Law, De Vos, et al., 2018), individuals with dyslexia may vary from typical readers in the use of cognitive processes while reading (Leikin & Hagit, 2006). It has been proposed that, from a young age, they may rely on the morphological structure of words during their recognition, thus circumventing any phonological difficulties (Nagy et al., 2006; Singson et al., 2000).

Although few studies have provided evidence of a weakness in the morphological skills of individuals with dyslexia (Leikin & Hagit, 2006; Schiff & Raveh, 2007), a growing body of literature has reported rather intact morphological skills in this population (Cavalli et al., 2016; Elbro & Arnbak, 1996; Law et al., 2015; Law, Veispak, et al., 2018; Law & Ghesquière, 2021; Quémart & Casalis, 2015). For instance, Elbro and Arnbak (1996) demonstrated that, when compared with typical readers, adolescents with dyslexia were more fluent in reading semantically transparent morphologically complex words, where the meaning of the derived word and its morphological components are closely related (e.g., the base "happy" is closely related to the meaning of "happiness," while "corn" would not be considered semantically linked to "corner"; Bell & Schäfer, 2016). In a study of university students with dyslexia, Leikin and Hagit (2006) observed that adult dyslexics benefited more from morphological priming than age-matched controls. As a result, Leikin and Hagit concluded that, during lexical access, adults with dyslexia might rely more on the morphological decomposition route (e.g., "happi-ness") than on orthographic or phonological codes to increase the speed of whole-word recognition. Furthermore, recent neurological support for the role of morphological skills in reading compensation has been provided by Bitan and colleagues (2020). Through a behavioral and functional MRI study design, Bitan and colleagues tested whether morphological decomposition could compensate for the phonological decoding deficits in readers with dyslexia. Behavioral and neurological results indicated that individuals with dyslexia can rely on morphological skills to compensate for their deficits in phonological decoding. Taken together, these results, along with others, have highlighted the importance of morphological skills in the development of reading skills of individuals with dyslexia (Arnbak & Elbro, 2000; Casalis et al., 2004; Cavalli, Colé, et al., 2017; Cavalli, Duncan, et al., 2017; Kalindi & Chung, 2018; Law et al., 2015; Law, Veispak, et al., 2018; Law & Ghesquière, 2021; Quémart & Casalis, 2015, 2017; Schiff & Raveh, 2007; Suárez-Coalla & Cuetos, 2013).

Building on the growing body of literature supporting the contribution of morphological skills to reading compensation in individuals with dyslexia, the current study aimed to explore whether and how morphological skills are involved as a key component in becoming a good reader: reading fluency. This reported study is novel as it is one of the first to examine the contribution of morphological skills in reading fluency and, moreover, in an adolescent sample of French students. The interest in studying compensatory strategies in high school students with dyslexia is twofold: (a) High school students offer a more representative sample of the primary population of interest compared to university student samples that are often studied instead, which limits the inclusion of the full spectrum of cognitive, linguistic, and reading profiles. In France, schooling is mandatory up to the age of 16 in any general, technical, or professional high school program. Adolescents with severe learning difficulties are often encouraged to pursue shorter technical or professional education routes; therefore, many do not pursue postsecondary educational opportunities (De La Haye et al., 2008). (b) The most recent Programme for International Student Assessment (i.e., Organization for Economic Cooperation and Development, 2019) indicated that 21% of 15 year-olds lack sufficient literacy skills (e.g., in France), highlighting the importance and need for specific literacy interventions for adolescents. The study and identification of potential protective factors among adolescents may support the development of novel and effective interventions.

Defining Morphological Skills

Morphological skills pertain to the explicit and implicit use of individual linguistic units called morphemes, which are the smallest unit of meaning. Morphological spelling is more regular and consistent compared to the spelling of phonological units. The consistency of spelling of morphemes enables the recognition of meaningful units that lead to inferring word meaning as well as its syntactic role in the sentence. For example, when reading the word "worker" (i.e., the word "worker" is composed of the root "work" and the suffix "-er"), the recognition of each morpheme will aid in lexical access and contribute to the understanding of the target word's meaning and its grammatical class—in this case, a noun as denoted by the "-er" suffix. Hence, morphemes can be used to support literacy skills based on the orthographic, syntactic, and semantic information they contain (Kirby & Bowers, 2017; Rey-Debove, 1984).

The term "morphological skill" is often used as a generalized umbrella term within the literature to describe two subskills: morphological awareness and morphological processing (see Li et al., 2012). Morphological awareness is often defined as the ability to consciously manipulate and reflect on the morphological structure of a target word (Carlisle, 1995, p. 194). By contrast, morphological processing refers to the implicit, unconscious use of the morphological structure of target words during language processing (for a review, see Amenta & Crepaldi, 2012). Due to the influence that the stimulus presentation modality has on morphological skills (Beyersmann et al., 2020), Law and Cavalli (2020) argued for the need to state the modality of item presentation (i.e., written or oral) when possible. Disclosing the presentation modality in morphological assessment adds information to the description of experimental tasks and, by consequence, offers a more nuanced understanding of the contribution of morphological skills to various reading skills.

Oral Reading Fluency

Reading fluency goes beyond the ability to read single words as it is the product of automaticity and accuracy of single word recognitions and oral reading rate of connected text, culminating in text comprehension (Kim et al., 2011; Klauda & Guthrie, 2008; Kuhn et al., 2010; Wolf & Katzir-Cohen, 2001). Multiple factors related to oral language contribute to reading fluency (Barth et al., 2009; Katzir et al., 2006; Wolf & Katzir-Cohen, 2001). For instance, Barth and colleagues (2009) showed that the reading fluency of English-speaking adolescents in Grade 8 was explained mainly by a latent variable of naming speed, decoding, and oral language comprehension. In contrast, Rose and Rouhani (2012) reported word identification, verbal working memory, and expressive vocabulary as significant contributors to reading fluency in adolescents with dyslexia. Although differing in their account of reading fluency, both studies noted oral language abilities (i.e., language comprehension and expressive vocabulary) as a vital component of oral reading fluency beyond and above phonological skills. As past work has demonstrated intact oral language abilities in individuals with dyslexia (Cavalli et al., 2016; Cavalli, Duncan, et al., 2017), specifically morphological awareness and morphological processing, it could be argued that any observation of oral reading fluency compensation may be a function of the relative strengths of these abilities.

Morphological Awareness and Oral Reading Fluency

Some studies have demonstrated that morphological awareness explains a part of the variance of visual word recognition independently of orthographic processing, phonological awareness, rapid automatized naming, and vocabulary (Colé et al., 2018; Deacon & Kirby, 2004; Deacon et al., 2013; Pan et al., 2016; Roman et al., 2009). In a longitudinal study, Casalis and Louis-Alexandre (2000) found a positive link between phonemic awareness and morphological awareness scores before reading acquisition. In addition, the prereading morphological awareness level was significantly linked to reading skills in Grade 2. It is thought that morphological awareness aids reading fluency through supporting rapid and accurate decoding or word recognition of text. The semantic and syntactic information provided by the morphemes may be used by a reader to predict subsequent words or meaning within the body of text. For example, in English, the morpheme "-er" permits a derivation of the root verb toward someone or something that performs an action (farm [farm] – farm þ -er [farmer]). Consequently, these studies are compatible with the hypothesis that morphological awareness could facilitate lexical access and support fluency and comprehension, especially in individuals with impaired phonological skills (Nagy et al., 2014).

Among individuals with dyslexia, investigations of the ability to perform in morphological awareness tasks have yielded inconsistent results. Compared to aged-matched typical readers, morphological awareness of individuals with dyslexia has been found to be underdeveloped in children (Casalis et al., 2003, 2004; oral modality: Law et al., 2017), in adolescents (visual and oral modalities: Kalindi & Chung, 2018; visual modality: Tsesmeli & Seymour, 2006), and in adults (visual modality: Law et al., 2015; Law, Veispak, et al., 2018; Metsala et al., 2019). Although rarely found in age-matched subjects, Casalis et al. (2004) did report findings of the relative strength of morphological awareness among children with dyslexia when compared with their reading age counterparts as children with dyslexia were found to outperformed reading-age controls in morphological production tasks while performing equally well in a morphological sentence completion task. In addition, intact morphological awareness of individuals with dyslexia has been reported when compared with typical adult readers (oral modality: Cavalli, Duncan, et al., 2017) and adolescents (oral modality: Quémart & Casalis, 2015, 2017).

Evidence of the influence of morphological awareness on reading outcomes of adults and adolescents with dyslexia has been previously reported in several studies. For instance, Cavalli, Duncan, et al. (2017) confirmed the persistence of intact morphological awareness of university students with dyslexia despite the presence of a phonological deficit, thereby revealing a dissociation in the development of these two skills at both the individual and group levels. Cavalli and colleagues noted that the magnitude of the dissociation correlated with the reading level of individuals with dyslexia. Similarly, the study of Law et al. (2015) showed that morphological awareness of adults with dyslexia explained a significant proportion of word reading after controlling for vocabulary and phonological awareness, which was not the case among typical readers. Similar results have been found by Metsala et al. (2019) after controlling for nonverbal IQ, phonological awareness, and orthographic skills and by Kalindi and Chung (2018) in native-Chinese-speaking adolescents with and without dyslexia. Taken together, these findings on both adults and adolescents with dyslexia support the claim that morphological awareness skills are a significant contributor to word reading in these individuals.

Morphological Processing Skills and Oral Reading Fluency

Morphological processing may contribute to the compensation of oral reading fluency. For instance, the morphological structure of words has been found to have a positive impact on reading speed with children (Carlisle & Stone, 2005) and with a greater benefit for dyslexic children (Burani et al., 2008; Marcolini et al., 2011; Suárez-Coalla & Cuetos, 2013). In the study of Suárez-Coalla and Cuetos (2013), children with dyslexia (from 7 to 10 years old) read morphologically complex words and pseudowords faster than simple ones, while typical readers did not show any difference (for similar results, see Burani et al., 2008).

Lexical decision tasks within a masked priming paradigm are often used as a method of assessing morphological processing, typically designed to distinguish between the early influence of morpho-orthographic and morpho-semantic effects (Diependaele et al., 2005; Meunier & Longtin, 2007; Rastle et al., 2004). Morpho-orthographic segmentation refers to word decomposition into constituent parts based on contained morphological boundaries ("heal-er"; Grainger & Beyersmann, 2017). In contrast, morphosemantic processing refers to the retrieval of semantic information contained in the morphological structure (Diependaele et al., 2005). In an example of such a study, Quémart and Casalis (2015) showed that 13-year-old, French-speaking adolescents with dyslexia benefited only from morphologically complex primes when processing targets (e.g., "tablette" – "TABLE" ["little table" – "TABLE"]), whereas chronologicalor lexical-age typical readers also benefited from morpho-orthographic priming (i.e., they also benefitted from a pseudoderived prime, e.g., "baguette" – "BAGUE" ["French stick" – "RING"]). The absence of morphoorthographic priming in individuals with dyslexia was interpreted as demonstrating the reliance on the semantic properties of morphemes during early visual word recognition. In support of this hypothesis, Law, Veispak, et al. (2018) and Law and Ghesquière (2021) reported larger priming effects in the morphological condition than in the pseudoderivation condition among Dutch-speaking university students and fifth-grade children with dyslexia, suggesting that the semantic properties of morphemes are processed during morphological processing. Furthermore, in the longitudinal study of Law and Ghesquière (2021), morphological processing in fifth-grade children with dyslexia was found to be negatively correlated with second-grade phonological skills, while no relation was observed among age-matched controls. Law and Ghesquière interpreted these results as a potential indication of a shift in the cognitive processes involved during reading to compensate for the earlier observed phonological deficits of children with dyslexia. Taken together, these studies offer support for the early reliance on morphological information during visual word recognition by individuals with dyslexia with a greater reliance on morpho- semantic information than their peers.

These findings have also been corroborated by studies involving neural measures. For example, in an unmasked magnetoencephalography (MEG) priming study with university students with dyslexia, Cavalli, Colé, et al. (2017) showed that the morphological and the morpho-semantic priming effects (i.e., calculated by subtracting orthographic effects from morphological priming effects) were stronger in dyslexic individuals than in typical control readers. In contrast, semantic and morpho-orthographic effects (i.e., calculated by subtracting semantic priming effects from morphological priming effects), although present in both groups, did not differ between typical readers and dyslexic individuals. The MEG results showed a functional reorganization of the cortex in dyslexic individuals with early and late morpho-semantic effects in the frontal areas. These effects were negatively linked with reading fluency, demonstrating a stronger reliance on morphological processing from individuals with dyslexia.

Based on this evidence, Cavalli and colleagues hypothesized that the processing of morphological units during visual word recognition would facilitate reading fluency and would thus act as a compensatory mechanism among individuals with dyslexia. However, to date, this relation between reading fluency and morphological processing has mainly been observed in adult populations. In addition, the role of morphological processing's contribution to reading fluency level has never been investigated. If identified as a significant explanatory variable, this would allow one to argue toward a link between morphological processing and a possible compensatory mechanism, especially in individuals with dyslexia.

The Present Study

The aim of the present study was to understand the potential contributions of morphological skills (i.e., morphological awareness and morphological processing) in oral reading fluency in adolescents with and without dyslexia. So far, current literature is scarce about the individual contributions of morphological awareness and morphological processing to reading fluency in individuals with dyslexia. As shown in previous studies, morphological skills could act as an avenue to circumvent phonological difficulties and achieve a form of reading compensation (morphological processing skills: Cavalli, Colé, et al., 2017; Law, Veispak, et al., 2018; Law & Ghesquière, 2021; Quémart & Casalis, 2015; Suárez-Coalla & Cuetos, 2013; morphological awareness: Cavalli, Duncan, et al., 2017; Kalindi & Chung, 2018; Law et al., 2015; Metsala et al., 2019; Quémart & Casalis, 2015, 2017). To achieve our aim, Frenchspeaking high school students were asked to perform morphological awareness and morphological processing tasks along with reading fluency, phonological skills, vocabulary, and nonverbal reasoning tasks.

First, we aimed to explore morphological skills in high school students with dyslexia compared to adolescents without dyslexia. In line with previous studies, we expected individuals with dysexia to perform as well as individuals without dyslexia in the orally presented morphological awareness task (Cavalli, Duncan, et al., 2017; Martin et al., 2014). Concerning morphological processing, we expected that individuals with dyslexia would benefit more from morphological priming with a larger morpho-semantic

effect than their peers, as observed in the previous study with adult participants of Cavalli, Colé, et al. (2017). Based on the work of Beyersmann and colleagues (2016), but also in line with the current idea that applying a strict categorical approach to decide whether an individual is seen as dyslexic or a skilled reader is contradictory to the normal distribution of reading skills and therefore inevitably arbitrary (see, e.g., Peterson et al., 2021; Peterson & Pennington, 2012; Van der Auwera et al., 2021), we used a continuous approach where reading ability is seen as a broad spectrum. Here, we hypothesized that reading level would modulate morphological priming such that individuals demonstrating low reading fluency would benefit more from the morphological priming compared to highly proficient readers.

Second, we investigated the link between these two morphological skills and reading fluency. We expected a significant contribution of both morphological skills in explaining reading fluency levels. This assumption arises from the literature on morphological awareness (Kalindi & Chung, 2018; Law et al., 2015; Metsala et al., 2019) and could be hypothesized for morphological processing from the studies of Elbro and Arnbak (1996) and SuárezCoalla and Cuetos (2013).

Method

Participants

Fifty-two high school students with dyslexia (DYS; 31 girls) and 33 typical readers (TR; 25 girls) were recruited thanks to their respective high schools. Two participants with dyslexia were excluded from this study due to missing data, as well as one participant with an abnormal error percentage (31% of the answers). The participants of both groups were enrolled in Grades 9 to 11. The adolescents with dyslexia had been diagnosed during primary school by an established physician in a reference center for learning disabilities, with an average age of diagnosis at 8.35 years (SD = 2.67), and had received learning support from a speech therapist for an average of 5.6 years (SD = 3.37). Note that in France, dyslexia remediation and therapy approaches are handled by speech therapists, even if the child presents no other language deficits. It is also very typical for children with dyslexia to have long-term care, even after initial remediation, due to the comprehensive reimbursement programs offered by the French health care system. All participants in this study were French native speakers with no reported history of neurological or psychological disorders and presented normal or corrected-to-normal hearing and vision. Written and informed parental consent was obtained for each participant before their participation in the study.

Participants were enrolled in various high school training programs: the standard curriculum (DYS: 27; TR: 18), which in France leads to higher education opportunities such as university study, and the professional-track study (DYS: 15; TR: 5) and technical-track study (DYS: 10; TR: 10) training programs, which lead to higher education professional/business schools or direct private sector employments. No significant difference was found between groups based on socioeconomic level,[1] as assessed by the Hollingshead index (Hollingshead, 1975).

Group characteristics, such as verbal and nonverbal IQ, are presented in Table 1. The groups were matched based on chronological age, as well as on nonverbal IQ (Matrix Reasoning subtest of the Wechsler Intelligence Scale for Children, 5th ed. [WISC-V]; Wechsler, 2016), verbal IQ (Vocabulary subtest of the WISC-V; Wechsler, 2016), and verbal comprehension (Similarities subtest of the WISC-V; Wechsler, 2016; this test assess both verbal concept formation and verbal abstract reasoning). All participants performed above the fifth percentile on both the Vocabulary and Similarities WISC-V subtests, thereby confirming that none of the participants presented a deficit in semantic oral language skills. Moreover, potential participants with a formal diagnosis of specific language impairment or other impairment that could impact language ability (e.g., autism spectrum disorder) were excluded.

In addition, the presence of a phonological deficit in adolescents with dyslexia was confirmed using a set of tasks including a phonological (phonemic) awareness task and a phonological short-term memory (STM) task. As expected, students with dyslexia displayed significant lower phonological STM efficiency (accuracy [ACC]/ reaction time [RT]; EVALEC; Sprenger-Charolles et al., 2005) as well as lower phonological awareness efficiency (ACC/RT; phonemic segmentation, consonant-consonant-vowel) compared to typical readers.

Materials and Procedures

Phonological Awareness

In this computerized test, participants were instructed to pronounce, as fast and accurately as possible, the pseudowords they heard by deleting the first phoneme (e.g., they heard /blO/ and had to produce orally /lO/). Thirty monosyllabic pseudowords with a consonant-consonant-vowel syllabic structure were selected. Pseudowords were used in order to avoid the activation of lexical knowledge when performing the task. Reliability (Cronbach’s alpha) of the task completed by the participants was .92. The final scores were efficiency scores taking into account both accuracy and response times: (ACC/RT) 3 100.

Phonological Short-Term Memory

This task from the software EVALEC (Sprenger-Charolles et al., 2005) consisted of repeating 24 pseudowords that were three to six syllables long (e.g., “moukola”). Pseudowords were presented in order of increasing syllable length, with six items for

Table 1：Group Characteristics With Mean Comparisons and Effect Size each length. The time taken to perform the whole task (RT) and accuracy were measured.

Variables	DYS(n = 52)M (SD)	TR(n = 33)M (SD)	t(83)	p	Cohen's d
Chronological age,year; month (month)	15; 11 (10.36)	15; 11 (12.91)	<1	.89	0.03
Socioeconomic status (Hollingshead index)	67.35 (21.10)	66.52 (27.66)	<1	.88	0.04
Nonverbal IQ (WISC-V matrix)	9.44 (2.65)	10.18 (2.35)	−1.34	.18	0.29
Verbal IQ (standard score, WISC-V)	10.25 (2.54)	11.09 (2.99)	−1.34	.19	0.31
Similarities (standard score, WISC-V)	11.09 (3.06)	11.84 (3.83)	−0.95	.35	0.22
Phonological STM efficiency (ACC/RT)	1.91 (0.41)	2.12 (0.49)	−2.07	.04*	0.48
Phonological awareness efficiency (ACC/RT)	11.75 (4.37)	15.86 (3.87)	−4.54	2.09×10^{-5}***	0.98

Note. DYS = dyslexic; TR = typical readers; WISC-V = Wechsler Intelligence Scale for Children, 5th ed; STM = short-term memory; ACC = accuracy; RT = reaction time.
* $p < .05$. *** $p < .001$.

Vocabulary

The Vocabulary subtest from the WISC-V (Wechsler, 2016) was used to assess the verbal IQ. This definition task assesses the accuracy and precision of word knowledge. The 29 items were orally produced one by one by an examiner, and the participants had to define them as accurately as possible. The examiner rated the answer as incorrect (0), partially correct (1), or perfectly correct (2). After three consecutive incorrect answers, the examiner stopped the test.

The Similarities WISC-V (Wechsler, 2016) subtest was used to evaluate verbal reasoning and conceptualization. The participant had to tell the similarities between the 23 pairs of items. The examiner rated the answers as incorrect (0), partially correct (1), or perfectly correct (2). After three consecutive incorrect responses, the test was stopped by the experimenter.

Reading Fluency

Reading fluency was evaluated with the leximetric test "l'Alouette" (Lefavrais, 1967, 2005), which is considered in France to be the "gold standard" instrument for assessing both children (Bertrand et al., 2010; Sprenger-Charolles, 2019) and adults (Cavalli et al., 2018). The Alouette test is systematically used by French practitioners and researchers to screen for dyslexia, as well as to assess reading level in general, from childhood to adulthood. The psychometric qualities of this test have been demonstrated in a number of previous studies in both children (Bertrand et al., 2010; Sprenger-Charolles, 2019) and adults (e.g., Cavalli et al., 2018) and, moreover, has been notably found to have high convergence validity (see Bertrand et al., 2010; Cavalli et al., 2018). In this test, the participant is allotted 3 min to read a 265-word text passage aloud as quickly and accurately as possible. The text consists of real words in meaningless but grammatically and syntactically correct sentences in order to limit the dyslexic reader's access to contextual information (Nation & Snowling, 1998; Rack et al., 1992). The test yields measures of accuracy (A, number of words correctly read; self-corrections included), reading time (RT, time taken to read the text; maximum = 180 s), and reading efficiency (called CTL, computed by the following formula: CTL = [A/ RT] 3 180; see Bruyer and Brysbaert, 2011, and Cavalli et al., 2018, for a detailed presentation of efficiency scores).

Morphological Awareness

Knowledge of morphological derivation was assessed through a suffixation decision task, which was previously used in the studies of Cavalli, Duncan, et al. (2017) and Martin et al. (2014). The stimuli consisted of 24 bisyllabic and 24 trisyllabic words, half being genuinely suffixed (e.g., "pendulette" ["little clock"]), in which half contained a suffix-like ending but no root word (e.g., "renard" ["fox"]). Words were prerecorded. Participants made a speeded manual choice about word suffixation. A fixation cross appeared for 250 ms in the middle of the screen, followed by the oral presentation of each target word in isolation. The instruction given to the participant was to decide whether the presented word was suffixed or not by pressing a dedicated key on the computer keyboard. The experimenter made sure that the notion of suffixation was well understood and gave five examples of a truly suffixed word (e.g., "jardinière" ["planter"] is a truly suffixed word in French) and a pseudosuffixed word (e.g., "couleur" ["color"] seems to be suffixed but is not). The intertrial interval was 1,100 ms. The score is expressed as the number of correct responses.

Morphological Processing

The stimuli consisted of 48 quadruplets of prime-target word pairs (leading to a total of 192 pairs of words) divided into four different conditions. Table 2 presents the characteristics of the primes in the four experimental conditions. The same target words were used across the four conditions and were paired with four different primes: Twelve prime-target word pairs were morphologically related (“collage” – “COLLE” [“collage” – “GLUE”]), 12 pairs were orthographically related (“college” – “COLLE” [“middle school” – “GLUE”]), 12 pairs were semantically related (“affiche” – “COLLE” [“poster” – “GLUE”]), and 12 pairs were unrelated (“tromper” – “COLLE” [“cheat” – “GLUE”]). In the morphological condition, each prime and target belonged to the same morphological family and shared the same stem. In order to control for the semantic similarity between primes and targets across the morphological and semantic conditions, we calculated the strength of the cosine similarity between primes and targets using latent semantic analysis (http://lsa.colorado.edu/). There was no difference (p . .63) in semantic association strength between the morphological (M = .28, SD = .18) and semantic conditions (M = .24, SD = .17). In order to control for the orthographic overlap between the morphological and orthographic conditions, targets and primes shared on average the first 3.7 letters (SD = 1.07) in the morphological condition, and they shared on average the first 3.5 letters (SD = .85) in the orthographic condition (p . .34)

Table 2
Characteristics of Target and Primes

Measures	Target	Type of priming: Morphological	Orthographic	Semantic	Unrelated
Frequency (per million)	58.6 (102.39)	9.52 (15.51)	10.09 (12.38)	12.33 (11.81)	9.53 (7.43)
Number of letters	5.10 (1.07)	6.84 (1.12)	6.85 (1.07)	6.60 (1.74)	6.61 (0.92)
Number of syllables	1.60 (0.76)	2.16 (0.37)	2.06 (0.52)	2.17 (0.74)	2.12 (0.33)
Latent semantic association between prime and target	—	0.27 (0.18)	—	0.25 (0.18)	—

All target words were mono-morphemic and had a mean frequency of 58.6 (SD = 102.39) per million according to LEXIQUE (New et al., 2001), a mean number of letters of 5.10 (SD = 1.07), and a mean number of syllables of 1.60 (SD = .76). Across the four conditions, the primes were matched in terms of frequency (all ps . .30), number of letters (all ps . .30), and number of syllables (all ps . .30).

For the purpose of the lexical decision task, 48 pseudoword targets were included. They were formed by changing two letters from real words. Each pseudoword was associated with four prime words, which were matched to the primes of the word condition in terms of frequency (M = 9.8, SD = 2.89), number of letters (M = 6.9, SD = .29), and number of syllables (M = 2, SD = 0). This led to a total of 192 word-pseudoword pairs.

The 384 experimental pairs (192 word-word and 192 wordpseudoword) stimuli were divided into four lists such that each target word and pseudoword would appear only once in each list. Each list contained 48 words targets (12 per condition) and 48 pseudoword targets.

Stimuli were presented in a pseudorandom order, and the maximum repetition of the same priming condition in a row was set at two. The order of presentation of the four lists was counterbalanced across subjects using a Latin square design. The experiment was preceded by a practice session consisting of 10 trials. E-Prime software was used to display the stimuli. Prime words were presented in lowercase, whereas target words were presented in uppercase. Each trial consisted of a fixation cross appearing in the center of the screen for 500 ms, a blank for 50 ms, and a prime for 200 ms. This prime duration was used because it has previously been shown that semantic influences on morphological priming are more prominent when the prime is partially or fully visible (Beyersmann et al., 2014). Target words were presented 50 ms after the offset of the prime (stimulus onset asynchrony = 250 ms) until the subject's response. Participants were instructed to press the “L” key of the keyboard when the target was a word and the “S” key when the target was not a word; it was specified that the answer had to be as quick and as accurate as possible. The intertrial interval was 1,900 ms.

Results

Reading Fluency

Individuals with dyslexia read less accurately compared to typical readers, as seen in the total number of correct words read during the Alouette (DYS: M = 240.85, SD = 22.27; TR: M = 254.96, SD = 6.01, t(83) = 4.33, p , .001, d = .79). The same significant difference was found in reading time, showing a longer reading time for individuals with dyslexia compared to typical readers (DYS: M = 140.35, SD = 26.64; TR: M = 107.73, SD = 19.90, t(83) = 6.44, p , .001, d = 1.34). Reading fluency, or efficiency, as measured by the Alouette test was significantly impaired in the group of individuals with dyslexia (DYS: M = 323.04, SD = 78.16; TR: M = 439.37, SD = 76.82, t(83) = 6.76, p , .001, d = 1.49), thus reflecting a reading fluency impairment in the former group.

Morphological Awareness

The analysis of RTs and accuracy was conducted with correct responses on both suffixed and pseudosuffixed conditions. Trials with an RT inferior to 300 ms were removed from the analysis as they were considered as false alarms. The comparison between groups on accuracy (raw scores) for suffixation decision showed no group effect (DYS: M = 34.31, SD = 4.53; TR: M = 35.24, SD = 4.45, t(83) = .94, p = .35). It should be noted that no ceiling effect was detected in the accuracy scores in both groups. In regard to RTs, however, participants from the dyslexic group were significantly slower compared to typical readers (DYS: M = 1633, SD = 731; TR: M = 1340, SD = 453, t(83) = 2.28, p , .05).

Morphological Processing as a Function of Group

Response errors and RTs were recorded during the priming task. In order to formally evaluate which variables may predict an error response or a slow or fast RT, the errors were modeled with a generalized linear model (Bates et al., 2007) specified with a binomial distribution. Likewise, the RTs were also analyzed with a linear model, canonically specified with a normal distribution. With respect to the RT model, RTs faster than 300 ms (0.11%) and longer than 4,000 ms (1.08%) were removed as they were considered very extreme values (1.2% of the total of observations).

Table 3 provides the mean error percentages and standard deviations for each group. This trial-by-trial accuracy performance was analyzed with a generalized linear model approach in which priming conditions and group were modeled as fixed effects and the by-subject and by-target intercepts were modeled as random effects. The model correctly predicted 76.92% of responses (62% of the errors and 77% of the correct responses). The main effect of conditions was significant (performed with chi-square Type II Wald; v^2 = 33.19, p , .001), compared to the unrelated condition that served as a baseline reference; morphological priming led to a significant reduction of errors (b = .84, SE = .20, z = 2.99, p , .001), while orthographic condition was close to significance (b = .30, SE = .17, z = 1.717, p = .08) and semantic condition was not (p . .55). Group also showed a significant effect (b = .97, SE = .21, v^2 = 31.99, p , .001), revealing that dyslexic individuals made more errors than typical readers. The interaction between groups and conditions was not significant (v^2 = 4.61, p = .20).

Table 3：Mean and Standard Deviation by Groups and Prime Conditions of Reaction Times and Errors

Type of priming	DYS (*n* = 52) RT *M* (*SD*) Error *M* (*SD*)	TR (*n* = 33) RT *M* (*SD*) Error *M* (*SD*)
Morphological	930 (471) 1.92 (1.51)	801 (340) 0.63 (0.89)
Semantic	953 (485) 2.51 (2.09)	805 (341) 1.24 (1.66)
Orthographic	972 (481) 2.32 (1.61)	828 (349) 1.06 (1.80)
Unrelated	1,015 (499) 3.01 (2.69)	849 (348) 1.33 (1.42)

Note. DYS = dyslexic; TR = typical readers; RT = reaction time.

The following analysis on RTs was conducted only on correct word trials; error trials were removed (3.4%). In preparation for modeling the RTs, we deleted observations with an RT below 300 ms and above 4,000 ms. A finer-grained outlier detection approach was performed on a by-participant level based on median absolute deviations (MAD; Leys et al., 2013) from their RT average. The numbers of MAD to detect the outliers were chosen after cautious graph inspection of the distribution of observations and to ensure a maximum retention of observations. As a result, RTs below 2.5 3 MADs and above 7 3 MADs were removed, leading to 7% of trials removed in total. In order to satisfy error-normality conditions, RTs were transformed with the Box-Cox method (k = .8; Gurka et al., 2006).

RTs were analyzed with a linear mixed model as implemented in the lme4 R package (Baayen et al., 2008; Bates et al., 2007). The t and p values of the beta coefficients were computed with the Satterthwaite method (lmerTest; Kuznetsova et al., 2017). Priming condition (morphological, orthographic, semantic, and unrelated) and group (dyslexics, typical readers) were modeled as fixed effects. Subjects and targets were modeled as random effects and were only kept in the model if their contribution was significant. Gender of subjects and block order were nonsignificant as fixed factors; hence, they were not included in the model.

Table 3 provides the mean RTs and standard deviations by condition and by group. The final model on RTs included subjects and targets as random effects (intercepts) and priming condition (morphological, orthographic, semantic, unrelated) and group (dyslexic, typical reader) as fixed effects; model outputs are presented in the Table 4. Main effect of group (F(1, 84) = 6.81, p , .05), T4 and main effect of condition were significant, (F(3, 14408) = 51.20, p , .001). Paired contrasts showed that morphological (t = 6.08, p , .001), semantic (t = 4.73, p , .001), and orthographic (t = 2.02, p , .05) priming conditions elicited shorter

RTs compared to the unrelated condition. The interaction between groups (DYS, TR) and conditions (morphological, orthographic, semantic, and unrelated) showed a trend toward significance, (F(3, 14416) = 2.28, p = .07). The paired interaction between the morphological priming condition and group was significant (t = 2.49, p , .05), revealing a larger morphological priming effect in dyslexic individuals compared to typical readers (unrelated condition minus morphological condition: DYS = 85 ms, TR = 48 ms, both ps , .001). The interaction between orthographic priming and group neared significance (t = 1.78, p = .07), while the interaction between semantic priming and group was not significant (p . .30).

In order to investigate morpho-orthographic effects (i.e., the difference between semantic and morphological priming), a linear mixed model with the corresponding subset of the data was fit, Group (dyslexic, typical reader) 3 Condition (morphological, semantic), with subjects and targets as random effects (intercepts). As expected, the main effect of groups was significant (F(1, 83.9) = 6.12, p , .05), and the main effect of condition was significant (F(1, 7084.7) = 12.17, p , .001), whereas the Condition 3 Group interaction was not (F(1, 7083.4) = 2.11, p = .15).

Table 4：Results of the Linear Mixed Model Contrasting Priming Conditions and Group

Fixed effect	F	β	SE	t	p
Intercept		0.00	0.00	6,371.94	2×10^{-16}***
Priming conditions	51.20				2×10^{-16}***
Morphological – unrelated prime		−0.07	0.01	−6.08	1.25×10^{-9}***
Orthographic – unrelated prime		−0.02	0.01	−2.02	.04*
Semantic – unrelated prime		−0.06	0.01	−4.73	2.23×10^{-6}***
Group	6.81				.01*
Priming Condition × Group	2.28				.07
Morphological Prime × DYS		−0.03	0.01	−2.49	.01*
Orthographic Prime × DYS		−0.02	0.01	−1.78	.07
Semantic Prime × DYS		−0.01	0.01	−1.00	.32

Note. Model equation: Reaction Time $ Priming Condition 3 Group þ (1jSubject) þ (1jTarget). Model AIC = 153,232; null model AIC = 153,060; v^2 = 186.26, p , .001. F and p values for fixed effects calculated thanks to a Type III ANOVA table with Satterthwaite's method. bs were calculated with the StdCoef function from the Hmisc R package. DYS = dyslexic.
*p,.05. ***p,.001.

Similarly, the morpho-semantic effect (i.e., the difference between orthographic and morphological priming) was investigated through a linear mixed model, Group (dyslexic, typical reader) 3 Condition (morphological, orthographic), with the intercept by subjects as random effect. Once again, the main effect of groups was significant (F(1, 83.9) = 5.70, p , .05). The main effect of priming condition was also significant (F(1, 7053.2) = 47.66, p , .001). The interaction was not significant (p = .46), revealing a morpho-semantic effect without group difference.

Morphological Processing as a Function of Reading Level

In this analysis, the RTs were again modeled with a linear mixed model but in which the group factor (dyslexic, typical reader) was replaced by a continuous measure of reading fluency, the individual’s score in the Alouette test. As recently noted by Van Der Auwera et al. (2021), the choice for a categorical or a continuous approach of studying reading skills can influence the interpretability and comparability of the wide array of studies conducted in individuals with and without dyslexia. Indeed, Peterson and Pennington (2012) have argued that applying a strict categorical approach (i.e., using a cutoff) to decide whether an individual is seen as dyslexic or skilled reader is contradictory to the normal distribution of reading skills and therefore inevitably arbitrary. It thus seems interesting to look at the results by using a continuous approach where reading ability is seen as a broad spectrum.

Table 5 : Results of the Linear Mixed Model Contrasting Priming Conditions and Reading Fluency Level

Fixed effect	*F*	β	*SE*	*t*	*p*
Intercept		0.00	0.00	2,819.70	2×10^{-16}***
Priming conditions	11.67				***
Morphological prime		−0.17	0.03	−5.83	5.64×10^{-9}***
Orthographic prime		−0.10	0.03	−3.37	7.49×10^{-4}***
Semantic prime		−0.11	0.03	−3.72	1.97×10^{-4}***
Reading fluency level		−0.33	0.07	−4.98	3.01×10^{-6}***
Morphological Prime × Reading Fluency		0.08	0.03	2.69	.007**
Orthographic Prime × Reading Fluency		0.06	0.03	2.07	.04*
Semantic Prime × Reading Fluency		0.05	0.03	1.56	.12

Note. Model equation: Reaction Time ∼ Priming Condition × Reading Fluency Level + (1|Subject) + (1|Target). Model AIC = −153,246; null model AIC = −153,030; χ^2 = 200.3, $p < .001$. *F* and *p* values for fixed effects calculated thanks to a Type III ANOVA table with Satterthwaite's method. βs were calculated with the StdCoef function from the Hmisc R package.
* $p < .05$. ** $p < .01$. *** $p < .001$.

The reading fluency scores of all participants were scattered in a continuous way. At a descriptive level, if we were to use the diagnostic cut-off from Cavalli et al. (2018) on the Alouette test in adults (i.e., reading efficiency score = 402), we would observe 55 adolescents below the cut-off score (44 DYS and 11 TR) and 30 adolescents with a score superior to the cutoff (8 DYS and 22 TR), thus showing some overlap between groups. The final model was composed of priming condition (morphological, orthographic, semantic, and unrelated) and reading fluency level as a continuous fixed factor and, once again, subjects and targets as random effects. Model output is presented in the Table 5. The main effect of condition was significant (F(3, 14421) = 11.67, p , .001). Paired contrasts showed that morphological (t = 5.83, p , .001), semantic (t = 3.72, p , .001), and orthographic (t = 3.37, p , .001) conditions led to significant faster RTs compared to the unrelated condition. Reading fluency level showed a significant effect on RTs (F(1, 84) = 21.48, p , .001). Individuals with low reading fluency level had slower RTs compared to individuals with high reading fluency. The interaction between reading fluency level and condition was significant (F(3, 14416) = 2.67, p , .05). The paired interaction between morphological condition and reading fluency level was significant (t = 2.69, p , .01). Individuals with low reading fluency level showed a larger facilitation effect from morphological priming. A significant interaction was also found between the orthographic priming condition and reading fluency level (t = 2.07, p , .05). Low proficient readers showed a larger orthographic priming effect compared to highly proficient readers. The respective interactions between morphological and orthographic priming with reading fluency score can be observed in Figure 1. In contrast, the semantic priming conditions did not show any interaction with reading fluency level (t = 1.56, p = .12).

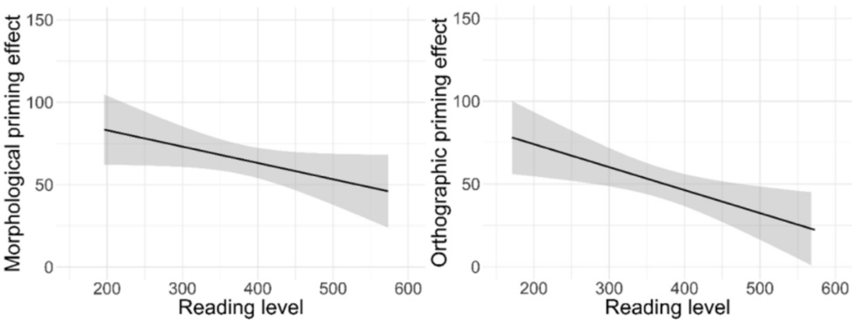
Morpho-orthographic and morpho-semantic effects showed the same pattern of results as in the group analysis; no interaction between reading fluency level and conditions was found (both ps . .20).

Factors Contributing to Variability in Reading Fluency

We then examined the extent to which the different variables measured above contribute to the reading fluency score. The correlations between the different variables are presented in Table 6. Group membership was linked to reading fluency (r = .59, p , .001), morphological priming effect (r = .23, p , .05), phonological awareness (r = .44, p , .01), and phonological STM (r = .23, p , .05), meaning that dyslexic individuals had lower reading fluency level, phonological STM, and phonological awareness in comparison with typical readers. On the other hand, they showed a stronger morphological priming benefit. Reading fluency level was correlated with morphological awareness efficiency (r = .22, p , .05), morphological priming benefit (r = .30, p , 01), verbal IQ (r = .29, p , .01), and phonological awareness (r = .42, p , .001). Morphological awareness efficiency was linked to morphological priming benefits (r = .30, p , .01) and orthographic priming facilitation (r = .35, p , .001). Priming effects were correlated with each other, morphological with orthographic (r = .47, p , .001), morphological with semantic (r = .66, p , .001), and semantic with orthographic (r = .48, p , .001).
Finally, a hierarchical regression was implemented in order to evaluate the respective contribution of each factor in its explanation of reading fluency variance. In this approach, each factor was entered separately and incrementally in

the model in a stepwise fashion, and each of these models were evaluated based on their sum of squares or the improvement in the model's R^2 value (DR^2) and its significance. The final model is presented in Table 7. Posterior model checks were used to verify appropriate satisfaction of regression assumptions such as error normality, homoscedasticity, and no or little multicollinearity and autocorrelation. The final model selected resulted in an adjusted R^2 = .42, df = 79, root mean square error of approximation = 70.09, and p , .001.

Figure 1 Morphological Priming Effect (in Milliseconds) at Left and Orthographic Priming Effect (in Milliseconds) at Right, as a Function of the Reading Fluency Level



The group variable explained a large part of the reading fluency variance (35.32%). Verbal IQ (WISC-V, Vocabulary subtest) was also a significant predictor of reading fluency and explained 4.13% of its variance. In Step 3, phonological awareness and phonological STM were entered in the model and did not significantly add variance explanation, but phonological awareness was still a significant predictor in the final model. Morphological awareness efficiency was entered at Step 4 of the model but did not add any additional R^2. Finally, adding morphological processing, in the form of morphological priming benefit, did allow the model to account for significantly more variance with a significant increase in R^2 (3.19%).

As the orthographic priming interacted with reading fluency, we conducted an alternative hierarchical regression where orthographic priming benefit was entered in place of morphological priming benefit. Orthographic priming benefit did not show any additional contribution to the model.

Table 6 : Correlations and Their Significance Level on All Participants

Variables	1	2	3	4	5	6	7	8	9
1. Group [a]									
2. Nonverbal IQ	−0.14								
3. Reading fluency	−0.59***	0.13							
4. Morphological awareness efficiency	−0.21°	0.14	0.22*						
5. Morphological priming benefit	0.23*	0.16	−0.30**	−0.30**					
6. Orthographic priming benefit	0.21°	0.12	−0.15	−0.35***	0.47***				
7. Semantic priming benefit	0.12	0.14	−0.11	−0.14	0.66***	0.48***			
8. Verbal IQ	−0.14	0.20°	0.29**	0.27	−0.05	−0.02	0.07		
9. PA efficiency	−0.44***	0.20°	0.42***	0.26	−0.01	−0.12	0.11	0.20°	
10. PSTM efficiency	−0.23*	0.04	0.11	0.22	−0.07	0.05	0.08	0.19°	0.33**

Note. PA = phonological awareness; PSTM = phonological short-term memory. [a] Group was coded as a dummy variable.
op,.10. *p,.05. **p,.01. ***p,.001.

Discussion

The present study was conducted to address two research questions about the potential compensational role that morphological awareness and morphological processing skills may play in adolescents with dyslexia. First, it was designed to compare the profile of dyslexic adolescents to that of nondyslexic adolescents in morphological awareness and morphological processing tasks. In this regard, we expected dyslexic individuals to perform as well as typical readers in morphological awareness. In contrast, we expected morphological processing (measured by a primed lexical decision task) to be stronger in individuals with dyslexia compared to typical readers. As a natural consequence of this hypothesis, we also expected to see stronger morphological and morpho-semantic effects in individuals with dyslexia than in individuals without dyslexia. Second, this study was also designed to better understand the contribution of both morphological skills in the explanation of reading fluency in all participants. Based on indirect findings in previous studies, we expected these skills to positively contribute to reading fluency.

Morphological Awareness in Dyslexia

In line with our hypotheses, the adolescents with dyslexia performed as well as those without dyslexia on response accuracy in the morphological awareness tasks. However, they displayed longer RTs than their peers in this task. Therefore, despite their persistent phonological difficulties, adolescents with dyslexia are able to process morphological units orally at comparable accuracy levels as age-matched controls (normal readers) yet require more processing time in order to do so. This result is corroborated by previous studies that employed a reading-age-matched design where children with dyslexia were shown to perform similarly to younger reading skill-matched controls (Casalis et al., 2004; Elbro, 1989; Fowler & Liberman, 1995; Tsesmeli & Seymour, 2006). This suggests that morphological awareness deficits are not causal in the reading struggles of individuals with dyslexia. This observation is coherent and extends to previous studies conducted in adults with dyslexia (Cavalli et al., 2017; Martin et al., 2014), which confirmed the persistence of intact morphological skills despite the presence of a phonological deficit. Taken together, these findings support the claim that the morphological awareness of students with dyslexia is well developed (although less accessible).

The recent literature concerning morphological awareness in individuals with dyslexia has become increasingly inconsistent, with studies demonstrating intact morphological awareness in individuals with dyslexia (Cavalli, Duncan, et al., 2017; Quémart & Casalis, 2015, 2017) and others showing deficits (Kalindi & Chung, 2018; Leikin & Hagit, 2006; Schiff & Raveh, 2007; Tsesmeli & Seymour, 2006). An explanation of these different findings may be offered by the modality to which these skills are assessed. For example, the present study utilized an oral modality of presentation to assess morphological awareness. It could therefore be argued that the oral presentation of items favors the performance of individuals with dyslexia compared to a visual presentation, where they may be penalized by their reading or spelling level. This situation may have impacted the results of previous studies using written items (like in Kalindi & Chung, 2018; Tsesmeli & Seymour, 2006). Nevertheless, this explanation alone cannot solely account for the differences found between the dyslexic and normal reader groups as other studies nonetheless found group differences despite orally presented items (in children: Law et al., 2017). Some concrete initial approaches to developing a new understanding of the difference between individuals with dyslexia and typical readers could consist of addressing the presentation and response modalities of the experimental task and appropriately considering the relevant psycholinguistic variables, such as oral and printed frequency. In respect to the aforementioned inconsistency in the current literature, the findings of the present study tend to suggest that morphological awareness skills of adolescents with dyslexia are well developed. In light of this hypothesis, it would be crucial to ascertain whether these individuals are able to effectively use these skills to their benefit during real-time reading (i.e., morphological processing skills) or not.

Table 7 : R^2 Change Calculated on Total Multiple R^2 and b Coefficients for the Hierarchical Regression on Reading Fluency

Step	ΔR^2	β	*SE*
1. Group	0.353***	−0.45***	18.79
2. Verbal IQ (WISC-V)	0.041*	0.19*	1.64
3. Phonological efficiency			
Phonological awareness	0.032	0.22*	2.04
Phonological STM		−0.11	8.62
4. Morphological awareness efficiency	0.002	−0.01	0.86
5. Morphological priming benefit	0.032*	−0.19*	0.10
Total R^2	0.46***		
Adjusted R^2	0.42***		

Note. WISC-V = Wechsler Intelligence Scale for Children, 5th ed.; STM = short-term memory.
* $p < .05$. *** $p < .001$.

Morphological Processing in Dyslexia

With respect to morphological processing, our study found that the adolescents with dyslexia have larger morphological priming effects compared to typical readers, and this finding is consistent with previous results found in both French adolescents (Quémart & Casalis, 2015) and adults (Cavalli, Colé, et al., 2017) with dyslexia. Several consequences of this result are noteworthy. First, this result confirms that individuals with dyslexia benefit from the very brief presentation of priming information before processing a word target. This result corroborates already related findings in the current literature (Cavalli et al., 2017; Law et al., 2015; Law & Ghesquière, 2021; Martin et al., 2014; Quémart & Casalis, 2015) and offers an avenue to better understand the processes involved in written word recognition in dyslexic readers. Second, morphological priming effects were observed in both groups but were larger in the dyslexic group than in controls. This larger morphological priming effect suggests that, when processing a word target, individuals with dyslexia benefit more from a morphologically related prime than typical readers. This result can be explained by several factors. First, since individuals with dyslexia had longer RTs on average, this could have provided more time for the preactivated prime to spread in the lexical network. However, this hypothesis seems unlikely because if it were true, then larger priming effects would also be observed in the other conditions, which was not the case. Another explanation could be offered based on the hypothesis of a different organization of word representations in the lexicon. In individuals with dyslexia, morphological information may be represented at the supralexical level (Quémart & Casalis, 2015), which codes the semantic overlap between morphologically related words. This may allow them to benefit more from morphologically related priming in order to process a target. Following this reasoning, adolescents with dyslexia may rely more on morphemes than on smaller grain-size units while decoding, thus reducing demands on the grapheme-phoneme conversion loop during the recognition of morphologically complex words. This mechanism might allow them to functionally bypasses their underlying phonological deficit.

Next, the present study failed to replicate a previous finding of a larger morpho-semantic effect in adults with dyslexia, which was taken as evidence of a potential compensatory mechanism, based on the semantic properties of morphemes (Cavalli, Colé, et al., 2017; Law et al., 2015; Martin et al., 2014). A potential explanation for this observed difference may be related to population sample differences between these studies (i.e., adolescents vs. university students). Indeed, for example, Cavalli and colleagues observed a larger morpho-semantic effect in a sample of university students with dyslexia, which could be argued to have reached some level of compensation, for instance with better vocabulary knowledge (Cavalli et al., 2016), enabling a certain level of success in a higher education program. Such samples may not be truly representative of the adult population of individuals with dyslexia (e.g., see Beddington et al., 2008).

Morphological Processing and Oral Reading Fluency

Interestingly, from a developmental perspective, children and adolescents with dyslexia have significant oral language deficits. For instance, in a recent meta-analysis, Snowling and Melby-Lervåg (2016) reported that children with a family-level risk for dyslexia, who went on to later be diagnosed with dyslexia, had more severe language impairments than "normal readers" already in preschool. However, these oral language skill difficulties in children with dyslexia were found to be nearly all resolved within the first few years of primary education, with the exception of vocabulary and morphological knowledge, where deficits might be observed until adolescence (Share & Silva, 1987). The interaction between phonological difficulties and potential oral language difficulties may explain the more heterogeneous profile of reading fluency among adolescents with dyslexia.

Our second analysis exploring the impact of reading level on morphological processing skills offers additional support for this perspective. Specifically, we found morphological priming levels to be inversely linked to reading fluency level (i.e., morphological priming increased when reading fluency level decreased). Hence, morphological priming benefits were more prevalent in individuals with low reading fluency level. These results are consistent with multiple previous findings in both adult readers (see, e.g., Beyersmann et al., 2015, 2016) and children (Hasenäcker et al., 2020). Additionally, the present study found participants with low reading fluency to have a larger orthographic priming effect compared to participants with high reading fluency. However, on the group comparison level (DYS vs. TR), this effect was only near significance and, in previous studies, was not present in adults (Cavalli, Colé, et al., 2017) or in adolescents (Quémart & Casalis, 2015). However, and interestingly, our result still corroborates other key previous research that found that orthographic priming differed according to reading level, suggesting a stronger orthographic priming effect in low-proficiency adult readers (Andrews & Hersch, 2010; Andrews & Lo, 2012; Welcome & Trammel, 2017). Taken together, these studies suggest that low-proficiency readers benefit more from the morphological and orthographic overlap, while highly proficient readers may be hindered by the lexical competition between the activation of the prime and the activation of the target. In this kind of hypothesis, the difference between highand low-proficiency readers lies in the depth versus superficiality of processing (orthography vs. lexicon/semantics) and hence the richness and strength of the lexicon and its connections. For example, university students with dyslexia demonstrate a semantic priming effect (depth), whereas adolescents with dyslexia demonstrate a greater morphology priming effect (superficial reliance).

The results from this noncategorical analysis (principally based on reading fluency level rather than a group split: control vs. dyslexic) are consistent with our previously presented results with the categorical approach and are more broadly consistent with the lierature that is almost systematically categorical in its approach. Therefore, and in agreement with Peterson and Pennington (2012), it appears that a continuous reading level approach does a good job of accounting for the group differences observed between individuals with and without dyslexia. Taken together, these results suggest that greater priming effects may be mediated by reading fluency, wherein lower reading fluency levels drive a greater reliance on morphological processing.

Crucially, this negative relationship could be explained by the spatiotemporal reorganization of the reading network in adults with dyslexia (see, e.g., Cavalli, Colé, et al., 2017, and other neuroimaging findings with diffusion tensor imaging, Vandermosten et al., 2012). In an MEG study, Cavalli, Colé, et al. (2017) showed a late priming effect for both orthographic and semantic priming compared to typical adult readers. The consequence of this late prelexical activation could be a slow lexical retrieval during reading (Helenius et al., 1999). In support of this hypothesis, Vandermosten and colleagues (2012) demonstrated lower fractional anisotropy (i.e., macrostructural white matter integrity measure) in the left arcuate fasciculus in adults with dyslexia compared to typical readers and an intact inferior fronto-occipital fasciculus. The arcuate fasciculus is known to support the link between visual input and phonological skills (Vandermosten et al., 2012). The inferior fronto-occipital fasciculus is linked to orthographic processing (Vandermosten et al., 2012) and semantic processing (Almairac et al., 2013; Duffau et al., 2005; Han et al., 2013), and recent evidence points toward an association with morphological processing (Yablonski et al., 2019). In fact, a recent functional MRI study is consistent with a stronger reliance of morpho-orthographic segmentation in Hebrew-speaking adults with dyslexia during the naming of a morphologically derived word without diacritics marks with a hyperactivation of the occipito-temporal cortex (Bitan et al., 2020), while Cavalli, Colé, et al. (2017) showed an early reliance on morpho-semantic process during a morphological processing task.

Morphology and Reading Fluency in Dyslexia: An Intricate Affair

Finally, the piecewise contributions of individual factors in explaining reading performance, such as group (dyslexic vs. normal reader), verbal IQ (WISC-V Vocabulary), phonological skills, morphological awareness, and morphological processing (priming benefits), were investigated. In the final model, group membership, verbal IQ, phonological awareness, and morphological priming were significant contributors to reading fluency, in that order of importance. The processing benefit from morphological priming was a significant explanatory variable of reading fluency and significantly increased the goodness of fit of the model most after group membership, followed by verbal IQ and phonological skills, respectively. The standardized beta coefficient and the correlation coefficient were negative for morphological priming benefit, meaning that the lower the reading fluency, the higher the benefit from this information. This result is consistent with the study of Cavalli, Colé, et al. (2017), in which the authors reported a negative correlation between an early morpho-semantic effect in frontal brain areas and reading fluency (assessed with the same Alouette test).

Only morphological awareness did not result in a significant contribution to reading fluency level, nor did it provide a significant correlation with the other cognitive skills. In light of the current literature, which shows a relationship between morphological awareness and reading fluency in adults (Law et al., 2015; Metsala et al., 2019) and adolescents (Chung et al., 2014; Kalindi & Chung, 2018), this absence of contribution is unexpected. First, this could be explained by the nature of the experimental task used herein: The current study utilized an oral presentation of items, whereas the tasks used in Law et al. and Metsala et al. utilized a written form. This difference makes it difficult to exclude the possibility that the weakness observed in morphological awareness among the dyslexic sample was due to their existing reading deficit rather than a deficit in their ability to explicitly manipulate morphemes. Moreover, in the study of Kalindi and Chung (2018), although the morphological awareness task used was an oral task, the importance of morphological knowledge could be specific to morpho-semantic languages like Chinese (Pan et al., 2016). Second, the task assessing reading fluency in the present study was the Alouette test (Lefavrais, 1967), a syntactically and grammatically correct text but with poor semantic input. This test is known to hinder compensation strategies of dyslexic individuals; as a result, we could propose the hypothesis that morphological awareness would be a better predictor of reading skills with implicated semantics (e.g., reading in context and reading comprehension). Indeed, the intervention study by Arnbak and Elbro (2000) showed a positive effect of morphological awareness training on reading comprehension and spelling but not on decoding. The meta-analysis of Goodwin and Ahn (2013) confirms these results, in showing that interventions for morphological awareness indeed improved skills in morphological awareness, phonological awareness, vocabulary, and spelling and reading comprehension but not reading fluency or word reading.

As noted previously, reading fluency scores ranged from high to low proficiency in both groups: dyslexic individuals and typical readers. The reliance on morphological processing seems to be especially important for individuals presenting low reading fluency regardless of a dyslexia diagnosis. As mentioned by Beyersmann and colleagues (2016; see also Grainger & Beyersmann, 2017, for a review), the modulation of morphological priming by reading level could be a sign of a better mapping in a whole-word orthographic representation by high-proficiency readers, while low-proficiency readers rely more on morpho-orthographic parsing. The dual route of orthographic processing (Grainger & Ziegler, 2011) provides a model to account for this phenomenon by considering morphemes as an alternative to phonemes in the fine grain route. Morpho-orthographic parsing may be considered as influential as phonological processing yet as a bottom-up processing route that allows access to morpho-semantic and whole-word representations. As the phonological processing route is known to be impaired in individuals with dyslexia, the morpho-orthographic route is recruited more substantially and is, therefore, more important in highly phonological impacted individuals who, by consequence, have lower reading fluency.

Limitations and Conclusion

Taken together, the present work supports the following hypotheses. First, individuals with low reading fluency seem to rely more on morphological processing during word recognition, and second, this stronger reliance on morphological processing could be a behavioral marker of a different neural reorganization in individuals with dyslexia. These assumptions require further investigations about the interaction between deficits in dyslexia and phonological skills, morphological skills, and reading output (as oral reading fluency).

Some of the limitations of the current study are as follows. First, as the study focused on older adolescents with dyslexia, the recruitment of perfectly reading-level-matched participants was limited due to a difficulty in fully matching vocabulary level or information processing speed. As a result, the present study lacked a reading level control group, limiting our ability to disentangle the contribution of reading experience in explaining morphological skills and its relation to reading fluency development. Additionally, despite the matched scores of vocabulary and verbal reasoning level across groups, we are unable to fully assert that the participants in both groups were free of other language impairments. Given the high rate of comorbidities between dyslexia and developmental language disorder, it will be interesting to investigate the potential difference in morphological abilities brought by language comprehension deficits.

Due to the concurrent nature of this study's design, we were limited in our ability to contribute to the debate specifically on the directionality of the relation reported between reading fluency and morphological processing. Future longitudinal studies are needed to disentangle the development, and the exact relation, between reading fluency and morphological processing. Finally, this study has been conducted in French adolescents with and without dyslexia, and one cannot exclude that the linguistic context might impact the results in the sense that some characteristics of the French language (or more broadly, Indo-European languages with alphabetic writing system) will limit generalization to other orthographies.

In conclusion, this study argues that the reliance on morphemes during reading is stronger in individuals with dyslexia but also in individuals with low reading fluency. Thus, the benefit of, or greater reliance on, morphological processing is particularly present in individuals with dyslexia but also present in individuals with a low reading fluency. This work raises questions pertaining to what the best kind of targeted oral-language rehabilitation would be to remediate reading levels in individuals with dyslexia. Although the current work is theoretically promising, further investigation is needed to more comprehensively understand the contribution of morphological skills in the compensation of reading difficulties and the different educational implications.

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