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Morphological Processing in Children with Developmental Dyslexia: A Visual Masked Priming Study

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ABSTRACT

This study examined the processing of derivational morphology and its association with early phonological skills of 24 Dutch-speaking children with dyslexia and 46 controls matched for age. A masked priming experiment was conducted where the semantic overlap between morphologically related pairs was manipulated as part of a lexical decision task. Results suggest that morphological processing is intact in children with dyslexia when compared to age-matched controls. Significant priming effects were found in each group. Children with dyslexia were found to solely benefit from the morpho-semantic information, while the morpho-orthographic form the properties of morphemes-influenced controls. Due to the longitudinal nature of the data set, an examination of early phonological awareness's role in the later development of morphological processing skills was possible. In line with the psycholinguistic grain-size theory, fifth-grade morphological processing in children with dyslexia was found to be negatively correlated to earlier second-grade PA skills. A similar relation was not found among the controls. Results indicate a potential shift in the cognitive processes involved during reading to compensate for the observed phonological deficits of children with dyslexia.

Introduction

In our society, literacy has a considerable influence on everyday life. Hence, living with developmental dyslexia, a hereditary neurological disorder characterized by lifelong accuracy and/or fluency difficulties in decoding, word reading, and spelling despite average intelligence, and adequate educational opportunities (Ramus et al., 2003), greatly impacts individuals. Although considered persistent and lifelong, some individuals with dyslexia develop compensational strategies allowing them to overcome their reading difficulties (Cavalli, Duncan, Elbro, El Ahmadi, & Colé, 2017; Elbro & Arnbak, 1996; Law, Wouters, Ghesquière, 2015; for a review, see Haft, Myers, & Hoeft, 2016).

A greater reliance on morphological processing, the implicit use of a word's morphological structure during language processing, has been theorized as one such compensational strategy utilized by high-functioning individuals with dyslexia during initial word recognition (Cavalli et al., 2017; Elbro & Arnbak, 1996 & 2018; Law, 2015). The implicit decomposition of morphologically complex words into morphemes, the smallest linguistic units of meaning, is thought to provide additional information to the reader beyond just visual form. For

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instance, the initial processing of a word at the morpheme level offers a reader syntactic, semantic, and phonological information to support lexical access and ultimately word decoding, reading comprehension, and fluency achievement (Elbro 1989, Mahony et al., 2000; Nagy, Berninger, & Abbott, 2006). However, little is known regarding the visual morphological processing of individuals with dyslexia, especially among children. As a result, questions surrounding morphological processing development and its relative strength among children with dyslexia are still prevalent. A deeper understanding of these factors will further the characterization of compensatory factors in individuals with dyslexia and provide insights into potential new avenues of literacy and intervention instruction, which target the specific levels of morphological information utilized by children with dyslexia.

To address this gap, the present study will aim to broaden our understanding of how individuals with dyslexia implicitly process morphological structure during initial visual word recognition and its potential role as a compensatory factor. A carefully controlled lexical decision task with masked visual priming will be used to measure morphological processing of Dutch-speaking children with dyslexia and age-matched controls. The morphological complexity of the Dutch language has been indexed as falling between the more complex French language and English (Bane, 2008). Therefore, examining a Dutch-speaking population will provide a bridge to discuss the past French and English language investigations.

Morphological Processing

Reading is a complicated process involving complex cognitive skills to enable fluent and accurate decoding and comprehension (Carlisle, 2003). Early skilled reading requires adequate knowledge of a language's phonological principles to permit mappings between the written form and the phonological representation of words (Ehri, 2005). Although a significant predictor of early reading, phonological awareness's contribution to later reading growth has been noted to decline with age (Nagy et al., 2006), while the influence of other cognitive skills increases, such as morphological processing (Beyersmann, Castles & Coltheart, 2012, Casalis, Dusautoir, Colé, & Ducrot, 2009; Dawson, Rastle, & Ricketts, 2021, Quémart Casalis, & Colé, 2011, Schiff et al., 2012). According to the Morphological Pathways Framework (Levesque, Breadmore, & Deacon, 2021), morphological processing contributes to the initial, implicit, visual decomposition or "chunking" of morphologically complex words into morphemic subunits facilitating lexical access. Levesque and colleagues (2021) argue that the processing of text at the morpheme level supports word reading by offering multi-dimensional information which supports links between form (phonology and orthography) and meaning (semantics; Kirby & Bowers, 2018). These links are thought to support access to and create high-quality lexical representations, ultimately supporting word reading, reading comprehension, and reading fluency skills (Elbro 1989, Mahony et al., 2000; Nagy et al., 2006).

Evidence supporting such effects has been provided through morphological processing measures such as lexical decision tasks with masked visual priming (for a review, see Amenta & Crepaldi, 2012). Within this task, a participant is briefly (40–72 ms) and unknowingly presented with the prime word (i.e., teacher) before being required to indicate if the target (i.e., "TEACH") is a real word. Although not perceived by the participant, the morphologically related prime influences the processing of the target, so that target words such as "TEACH" are processed faster when following a morphologically related prime (i.e., *teacher–TEACH*) than an unrelated control prime (i.e., doctor-TEACH).

Furthermore, research utilizing these tasks have reported target word recognition being significantly facilitated by the brief presentation of both a semantically transparent derived prime (e.g., *teacher–TEACH*) and semantically opaque pseudo-derived prime (e.g., *corner–CORN*), while observing no facilitation from orthographic (e.g., scandal–SCAN) or semantic related control primes (e.g., *hound–DOG*) (Dutch: Diependaele, et al., 2009; Law, Veispak, Vanderauwera, & Ghesquière, 2018; English: Marslen-Wilson, Bozic, & Randall, 2008; Rastle, Davis, Marslen-Wilson, & Tyler, 2000; Italian: Burani, Marcolini, De Luca, & Zoccolotti, 2008; and Spanish: Duñabeitia, et al., 2007). These results have been taken as evidence of the rapid and highly automatized processing of visually presented morphologically derived and pseudo-derived words into their constituent morphemes based on the mere appearance of morphological complexity, independent of simple orthographic or semantic relations (Dutch: Law et al., 2018; English: Marslen-Wilson, et al., 2008; Italian: Burani et al., 2008; German: Hasenäcker, Beyersmann, & Schroeder, 2020; for neurological support see Cavalli et al., 2016).

Although widely investigated among typical reading adult populations, studies examining morphological priming effects in children are limited (e.g., Beyersmann et al., 2012, Casalis et al., 2009; Dawson et al., 2021, Quémart et al., 2011, Schiff et al., 2012). Of these few studies, results demonstrate the emergence of morphological processing effects in children after the acquisition of initial reading skills (Beyersmann et al., 2012, Dawson et al., 2017 & Dawson, Rastle, & Ricketts, 2021, Schiff et al., 2012). In a study of third and fifth grade English speaking children, Beyersmann and colleagues (2012) reported significant priming effects in the presence of morphologically derived primes that were semantically related to the target word (semantically transparent) (e.g., *teacher–TEACH*), while no priming effects were observed when targets followed a semantically opaque pseudo-derived prime (e.g., *corner–CORN) which* shared an orthographic relationship between the prime and target, while a semantic relation was absent (i.e., the meaning of "corn" is not represented in "corner"; however, it is orthographically related). *Based on these results,* Beyersmann and colleagues (2012) *concluded* the need for semantic information to facilitate *the* processing of morphemes among children – i.e., morpho-semantic processing (e.g., the "teach" in "teacher" is semantically related to the target TEACH). Similar observations of priming differences between pseudo-derived and semantically transparent morphologically derived primes (morphological condition) have been interpreted as the evidence of independent morpho-semantic and morpho-orthographic effects during early visual word recognition (Diependaele et al., 2005; 2011; Feldman et al., 2009; Law et al., 2018). According to the Morphological Pathways Framework (Levesque et al., 2021), morpho-orthographic and morpho-semantic processing are thought to connect Central Orthographic Processes and Lexical Representations during word reading by providing a pathway from knowledge about morphemes to decomposition (morpho-orthographic processing) and understanding of morphologically complex words ultimately supporting lexical access (morpho-semantic processing), with implications for broader text comprehension (Levesque Kieffer, & Deacon, 2017). However, debate exists concerning the requirement of a morpho-semantic relation between prime and targets to facilitate initial morphological processing among children. In a study of French-speaking third, fifth, and seventh-grade children, Quémart and colleagues (2011) reported significant prime effects where semantically transparent morphologically derived primes (e.g., *teacher–TEACH*), and semantically opaque pseudo-derived primes (e.g., *corner–CORN*) were presented, suggesting the processing of visually presented words into constituent morphemes based on morphological complexity alone – i.e., morpho-orthographic processing. However, reported differences in the developmental time course of morphological processing may result from linguistic differences across studies. For instance, the efficiency and ease of automatized visual morphological decomposition have been positively influenced by morphological complexity (Casalis, Quémart, & Duncan, 2015) and morphological productivity (Beyersmann et al., 2020) of the reader's language. Accordingly, as reported in Quémart and colleagues (2011), children learning to read in French, a morphologically rich language, may utilize morphological processing strategies earlier in development than children of less morphologically productive languages like English resulting in differences in observed patterns of prime effects.

Morphological Processing and Dyslexia

Morphological processing has been theorized to benefit struggling readers, such as individuals with developmental dyslexia (Law et al., 2015; 2018; Cavalli et al., 2017; Elbro & Arnbak, 1996). Persistent phonological processing deficits often characterize dyslexia (Ramus, 2003), which have been shown to delay the development of orthographic knowledge and orthographic processing skills (Marinus & De Jong, 2010), resulting in reduced word recognition skills. However, despite these difficulties, many individuals with dyslexia succeed in learning to read at a level that permits them to cope with the literacy demands required to succeed at a university level (see Cavalli et al., 2016; Law et al., 2015). It has been theorized that such success may result from a reliance on a compensatory system utilizing other, fully intact language, and cognitive abilities to support reading (for a review of potential factors, see Haft et al., 2016). Studies of high functioning adults with dyslexia have suggested that such a compensatory system may utilize semantic knowledge in a top-down process during word recognition (Cavalli et al., 2016; Stanovich, 1980) as well as morphological processing to help facilitate word recognition and lexical access (Burani et al., 2008; Cavalli et al., 2017; Elbro & Arnbak, 1996; Law et al., 2015; 2018; for a review of morphological and semantic skills among people with dyslexia, see Deacon, Tong, & Mimeau, 2019).

Theoretical support for morphological processing's role in compensation can be found in the dual-route cascade model (DRC) developed from the original dual-route model (DRM) by Coltheart, Rastle, Perry, Langdon, and Ziegler (2001). It has been theorized that when dealing with novel or less-automatized words, the phonological impairment observed in individuals with dyslexia would limit access to the sub-lexical route that involves decoding prior to lexical access. In a reconceptualization of the DRC, Grainger and Ziegler (2011) argued that an indirect lexical route might be achieved via large, commonly repeated, complex graphemes and morphemes, bypassing any difficulties in processing at the sub-lexical level.

Furthermore, according to the psycholinguistic grain-size theory, the availability of a specific processing unit during reading depends on the orthographic consistency and the availability of the spoken unit in oral language (Ziegler & Goswami, 2005). Following this reasoning, children and adults with dyslexia may utilize larger consistent grain-sized units such as morphemes while decoding, thus reducing demands of grapheme-phoneme conversion and circumventing their underlying phonological difficulties during word recognition (Ehri, 2005).

In support, Cavalli and colleagues (2017) reported the persistence of intact morphological abilities despite the presence of a phonological deficit among university students with dyslexia. Furthermore, Cavalli and colleagues noted that the magnitude of the dissociation between morphological and phonological abilities correlated with the reading level of individuals with dyslexia. These results were taken to support the above-theorized shift to a greater reliance on larger consistent grain-sized units such as morphemes in the presence of phonological difficulties. Although theoretically plausible, to date, no evidence of such a disassociation has been reported among children with dyslexia. In addition, few studies, including Cavalli and colleagues (2017), have examined the specific role of morpho-semantic and morpho-orthographic processing of individuals with dyslexia, limiting our understanding of morphological processing in individuals with dyslexia.

Of the few studies examining morphological processing of individuals with dyslexia, there is a growing consensus that children and adults with dyslexia have an intact ability to rapidly process written morphology (Burani et al., 2008; Cavalli et al., 2017; Elbro & Arnbak, 1996; Law & Ghesquière, 2017; Law et al., 2015, 2018; but see Deacon, Parrila, & Kirby, 2006; Lazaro et al., 2013). For instance, in Spanish, a language with a shallow orthography and a rich morphological system, Suárez-Coalla, Martínez-García, and Cuetos (2017) reported that primary school children with dyslexia and age-matched controls benefited equally from the presence of high-frequency base morphemes to initiate reading and writing responses. These results show that children with dyslexia are familiar with morphemes when reading morphologically complex and pseudo-derived words. Further support has been provided by Quémart and Casalis (2015), who reported significant morphological priming effects in French-speaking children with dyslexia, indicating sensitivity to the morphological structure and a level of morphological organization of the lexicon among children with dyslexia. Furthermore, Quémart and Casalis noted that children with dyslexia demonstrated significantly greater prime effects for morphological (e.g., *teacher–TEACH*) versus pseudo-derived conditions (e.g., corner–CORN), a pattern not observed in controls suggesting an earlier reliance on the morpho-semantic information during initial visual word recognition (for similar findings supporting intact morphological processing skills of adults with dyslexia, see Law et al., 2018 and Leikin & Hagit, 2006).

Morphological processing and a greater influence of morpho-semantic information have additionally been found to contribute to the reading outcomes of individuals with dyslexia. Elbro and Arnbak (1996) reported that the reading speed of adolescents with dyslexia benefited more from semantically transparent morphological structures than from matched control words, an effect not observed in matched controls. Furthermore, Elbro and Arnbak (1996) found that the reading rate of individuals with dyslexia significantly benefited when the presented text was deconstructed as morphemes compared to syllables, while an opposite trend was found for reading-level-matched controls. In a follow-up study of children with dyslexia, Arnbak and Elbro reported, when compared with controls, significantly higher gains in reading comprehension and the spelling of morphologically complex words in the treatment group receiving morpho-semantic-focused training.

Present Study

To date, only a handful of studies have examined visual morphological processing in children: either typical or dyslexic readers. The present study extends the previous findings in a morphologically rich and moderately phonologically transparent language, Dutch. Given the morphological richness of the language, children learning to read in Dutch may be more likely to develop visual morphological processing to support lexical access during the early stages of reading development (Fleischhauer, Bruns, & Grosche, 2021). However, the transparency of the Dutch orthography, which makes phoneme-grapheme conversions more reliable than languages such as English, may result in a reduced reliance on the use of morphemes to support early reading efficiency.

With a carefully controlled priming paradigm, this study will directly address when and how morpho-orthographic and morpho-semantic information is processed during visual word recognition in Dutch-speaking children with dyslexia and typical reading age-matched controls. The use of a priming paradigm will allow for the control of effects of explicit processing and strategic factors, allowing for an examination of rapid, automatized visual processing of morphologically complex text by children. The longitudinal nature of the data set allows examining the disassociation of early phonological processing difficulties from later morphological processing of children with dyslexia, as predicted by the psycholinguistic grain-size theory. Specifically, this paper addresses the following questions:

1. Do Dutch-speaking children with dyslexia make use of a word's morphological structure during initial visual word recognition?
2. Do individuals with and without dyslexia make use of morpho-orthographic and morpho-semantic information in the same way during initial visual word processing?
3. In accordance with the psycholinguistic grain-size theory, do early phonological processing difficulties disassociate from later morphological processing of children with dyslexia?

Research has demonstrated that the use of masked primes in a lexical decision paradigm is a powerful tool to investigate rapid and automatic word recognition (Quémart & Casalis, 2015; Rastle, et al., 2000). Using a balanced task design within this paradigm, effects of morphological, orthographic and semantic processing may be disentangled.

In line with the hypothesis that reading compensation of individuals with dyslexia may be supported by a greater reliance on the morphological structure of words, the present study assumed that children with dyslexia would be found to have intact morphological processing skills, supporting previous findings (Elbro & Arnbak, 1996; Quémart & Casalis, 2015). Therefore, it was also expected that a significant morphological priming effect in one or both of the morphological conditions would be observable while differing significantly from the orthographic and semantic control conditions. Additionally, based on the past work, we expected that these children would benefit from the semantic information within individual morphemes during the initial visual word recognition (Elbro & Arnbak, 1996; Quémart & Casalis, 2015). If a group of readers relies on the semantic information offered by the morphemes, we would expect to observe significant priming effects solely, or with greater effect, in the morphological condition than in the pseudo-derived condition.

Lastly, following the psycholinguistic grain-size theory and the work of Cavalli and colleagues (2017), who reported a dissociation between morphological and phonological processing of university students with dyslexia, early phonological processing difficulties were expected to result in a greater reliance on coarser linguistic grain size units, such as morphemes, during processing. Therefore, we hypothesized a negative relation between early phonological awareness (PA) skills and later morphological processing, as measured by the size of the prime effect.

Methods

Participants

In this study, 74 fifth-grade children (mean age: 127 months) participated. All children were recruited from a larger longitudinal project reported in Vanvooren, Poelmans, Hofmann, Ghesquière, and Wouters (2014) and Vanderauwera, Wouters, Vandermosten, and Ghesquière (2017). All children were born in 2006, native Dutch speakers, Caucasian, and found to have normal non-verbal IQ, that is, a standardized score ≥ 80 on the Wechsler Intelligence Scale for Children-III (WISC-III-NL) Block Design subtest (Kort et al., 2002). All participants were in a regular class that is offering the standard curriculum prescribed by the Flemish Government (for more information on the educational system of Flanders see: onderwijs.vlaanderen.be). All participants had normal bilateral hearing (Pure Tone Average of 20 dB HL or lower). Based on the parental/guardian questionnaires, all participants were found to have no history of brain damage, language problems, psychiatric symptoms, or uncorrected vision problems. All participants were found to be at low risk for developing ADHD, as determined by a minimum cut-off score of 9 out of 10 on the scale of hyperactivity in the strengths and difficulties questionnaire (Goodman & Goodman, 2009). Initial recruitment and categorization of participants were based on family risk for dyslexia. Based on the longitudinal data, children were retrospectively classified as typical readers (NR, n = 46) or children with dyslexia (DR, n = 24) based on timed, standardized word reading (Brus & Voeten, 1973) and pseudoword reading (Van den Bos, Spelberg, Scheepstra, & de Vries, 1994) tests that were obtained from these children during the first semester of the second, third, and fourth grade, and the second semester of the fifth grade. In line with the diagnostic criteria that are common rules for practice in Flanders and that were agreed upon in the Flemish Network for Learning Disabilities (Ghesquière, 2014), dyslexia was classified by applying both a severity (i.e., a word and pseudoword reading score below the 10th percentile) and persistence (i.e., at more than one consecutive time point) criterion. For any child who lacked in multiple testing points of reading data, dyslexia was determined by the possession of a clinical diagnosis as well as meeting the severity criteria for reading difficulties during the most recent testing wave (n = 4).

Two children with dyslexia were excluded from the analysis due to a technical issue during the priming task's administration, resulting in missing data points. Two other children with dyslexia were removed due to high error rates and slower than typical response times resulting in a significant proportion (43% and 39%) of reaction time data from the priming task being lost during cleaning.

The study was approved by the university hospital's local ethical committee at KU Leuven, Belgium, and is in accordance with the ethical standards described within the declaration of Helsinki. Parents had given their informed consent.

Background Measures

To provide a better understanding of each group's cognitive and literacy skills, all participants completed a testing battery of reading and cognitive assessments. All tests were administered in a single session between the two experimental morphological processing tasks. Table 1 reports descriptive statistics, *t* and *p*-values, and effect size from independent *t*-tests for each background measure.

Phonological Awareness (PA)

A Spoonerism task (Boets et al., 2010) was used to assess the phonological awareness skills of the participants in the second and fifth grades. The test consisted of 3 sets of 10 items. For all sets, the first five items resulted in the production of real words, while the remaining items resulted in the production of nonwords. Children were required to swap the consonant onset of single-syllable words in order

TABLE 1
Performance and Group Comparisons on Literacy and Cognitive Tasks

	Control (n = 46)		Dyslexic (n = 24)				
Measure (total scores)	*M*	*SD*	*M*	*SD*	*t*	*p*	Cohen's *d*
EMT (word reading)	69.3	10.9	46.0	13.2	8.343	<.001*	1.93
Klepel (nonword reading)	37.8	7.4	19.0	10.8	8.583	<.001*	2.03
Spoonerisms (PA-5th grade)	44.8	5.2	36.3	7.6	6.167	<.001*	1.31
Peabody	123	10.3	122	8.8	0.569	.571	0.01
	Control (n = 46)		Dyslexic (n = 20)				
Spoonerism (PA-2nd grade)	26.5	10.3	19.0	11.5	2.606	.011*	0.72
PA_Celf (PA-2nd grade)	37.5	3.9	32.2	4.9	4.701	<.001*	1.20

Notes. * significant *p*-value after applying the FDR procedure

to reveal two new words or nonwords (e.g., MUS-KAT becomes KUS-MAT). The maximum score was 30. Each correctly produced word and nonword was rewarded with one point; the task was discontinued after four consecutive errors within the second or third set of items. Internal consistency of 0.93 has been reported (Evers et al., 2012).

In the second grade, the phonological awareness subtest of the Clinical Evaluation of Language Fundamentals (CELF-4NL) (Kort, Schittekatte, & Compaan, 2010) was used as an additional measure of PA. Children's knowledge of the sound structure of the Dutch language and their ability to manipulate sound through identification, segmentation, blending, deletion, and substitution of words, syllables and phonemes, was assessed through 45 items. The test has been reported to have high internal consistency and a good test – retest variability (Kort et al., 2010).

Word and Non-word Reading

Word reading and non-word reading were assessed by two standardized tasks, administered at second and fifth grade. The two tasks consisted of the Dutch EMT, also known as the one minute test (Brus & Voeten, 1999) measuring real word reading accuracy and rate, and the Dutch nonword reading task known as the Klepel (Van den Bos, et al., 1994) measuring nonword reading rate and accuracy. These timed tasks required participants to read aloud as accurately and quickly as possible, a list of 116 Dutch (non-)words, within one minute for real words and two minutes for nonwords. Words were presented in order of increasing difficulty. The raw score was calculated as the number of correctly read (non)words in the time given. The EMT has been found to be a reliable measure (r = .87) (Brus & Voeten, 1999), while the Klepel has reported reliability of r = .91 (Van den Bos et al., 1994), both determined through the use of a parallel test method.

Receptive Vocabulary

The Dutch adaptation of the Peabody picture vocabulary test (Dunn and Dunn, 2005) is a widely used standardized measure of receptive vocabulary and reports an average test – retest reliability of .93 across age groups. The task consisted of 204 items. The children were presented four picture alternatives while the experimenter said a word out loud. The children were asked to choose the picture that best described the meaning of the word the experimenter had spoken out loud. A stop condition of nine or more mistakes within one set of 12 items was applied.

Morphological Processing

Stimuli and Design

Stimuli and the design of the task were adapted from the Dutch adult priming study of Law et al., (2018). Adaptation of Law and colleagues' initial task involved reducing the initial 72 ms SOA to 60ms to allow for a direct comparison of the results of Quémart and Casalis (2015). Additionally, a reduction in test length by 32 prime-target pairs (representing a 17% reduction) and an average increase of 19% in target word frequency was made to accommodate children's testing.

The experiment's design allowed for the manipulation of orthographic, morphological, and semantic links between prime-target pairs across four experimental conditions, each condition containing 16 prime-target pairs, creating a total of 64 experimental pairs. The conditions were the same as defined in Law et al., (2018) as follows:

1. Morphological (+M + S+O) (e.g., angstig–ANGST). An English equivalent would be teacher–TEACH. In this condition, prime-target pairs were morphologically related and morphologically decomposable (+M). The target was orthographically represented within the prime (+O) and semantically related to the prime (+S). For instance, the prime "teacher" could be decomposed by removing the suffix -er resulting in the base "teach" which is orthographically and semantically related to the target word.
2. Pseudo-derived (+M-S + O) (e.g., heerlijk – HEER). In this condition, primes and targets were not morphologically related as they share no semantic overlap (-S); however, primes did contain a plausible Dutch suffix that could be segmented into an apparent stem and productive derivational affix (+M). For instance, in the English example of corner–CORN, the pseudo-derived prime *corner* can be segmented into a stem of *corn* and the derivational affix *-er,* yet the resulting base would not share any semantic overlap with the target (the meaning of corn is not related in any way to the meaning of corner), even though they are orthographically the same.
3. Semantic control (-M + S-O) (e.g., schip-BOOT). Within this condition, the target and prime were semantically related (+S); however, the prime was not morphologically decomposable (-M) and shared no orthographic overlap with the target. An English equivalent would be hound–DOG.
4. Orthographic control (-M-S + O) (e.g., banket-BANK). In this condition, targets and primes were orthographically related (+O) in that the target was represented within the initial letter sequence of the prime. Within this condition, primes could not be parsed into existing Dutch morphemes (i.e., *–et* as in the example *banket* is not a suffix in Dutch). For instance, an English example would be scandal-SCAN, where the target *scan* can be observed orthographically within *scandal* yet the final syllable *dal* of the prime cannot be considered a possible derivational affix in English; thus, making it not morphologically decomposable (-M).

All targets were free morphemes, thus containing no real or plausible Dutch affixes. The morphological status of the primes was determined using the CELEX Dutch lexical database (Baayen, Piepenbrock, & Gulikers 1995). As in Marslen-Wilson et al. (2008), word pairs were considered morphologically decomposable (+M) when the derived form had a recognizable Dutch suffix that was attached to a potential stem, thus making them morphographically related (or potentially related) as seen in conditions 1 and 2. In both the morphological (condition 1) and the pseudo-derived condition (condition 2), the prime words were derived (or pseudo-derived) forms of the target. These derivations did not involve any phonological or orthographic modification of the base word.

Semantic relatedness of prime-target word pairs and unrelated filler pairs were rated on a 5-point scale from 1 (definitely not related) to 5 (definitely related) by 25 native Dutch-speaking graduate and postdoctoral students from both the Linguistics and Educational Sciences departments of the KU Leuven in Belgium. Prime-target pairs were deemed to be semantically related when word pairs received an average rating of 4 or greater, thus permitting their inclusion in the morphological and semantically related conditions (+M + S+O and –M + S+O). Prime-target pairs which received an average relatedness score of 2 or less were then used within the semantically unrelated condition (+M-S + O and –M-S + O).

To ensure consistency across conditions, targets were matched across the 4 conditions for lemma and word frequency, word length, neighborhood size, syllable count, family size, and family frequency (no significant differences were found between groups across all conditions, all *p*s > .100, with the exception of lemma frequency, where $p = 0.051$). Primes were matched across all four test conditions as no significant difference was found across measures of word frequency, lemma frequency, neighborhood size, and syllable length (*p*s > .056).

To provide a baseline for item reaction time, 64 target unrelated prime stimuli were created, allowing for the assessment of priming effects. In doing so, the initially created primes were pseudo-randomized around the targets (for a similar procedure, see Marslen-Wilson et al., 2008). Each new pairing was checked to ensure they did not share a morphological, semantic, or orthographic relationship (-M-O-S).

To reduce the proportion of related prime-target pairs, an additional set of 32 unrelated prime-target pairs were included as fillers in the experiment, generating a total of 160 prime-target pairs.

For the lexical decision task, 160 real Dutch word/nonword pairs were created. Nonword targets were orthographically and phonologically plausible sequences in the Dutch language (e.g., gump, cheme). Half of the primes of the word/nonword pairs were derived or pseudo-derived words. Orthographically related words preceded 64 of the nonword targets. An orthographically unrelated word preceded the remaining 96 nonword targets.

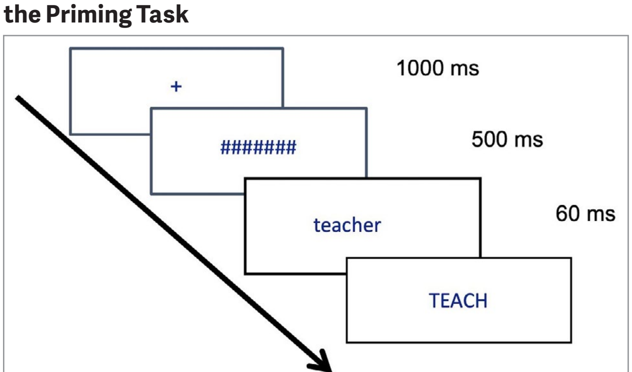
Following the procedure of Quémart and Casalis (2015), two presentation lists were created by dividing the 320 prime-target pairs into two 160 item lists, each containing equal proportions of items from the four experimental conditions. All the targets appeared once in each list with target words only represented once in each list. List 1 contained 80-word targets with each of the four experimental conditions equally represented. Half of the target words were primed with a related word, while the remaining target words were matched with an unrelated prime. For the creation of list 2, the prime relation status in list one was then reversed for all targets. Therefore, in list one, a subject would see the pair "angstig–ANGST" while in list two, they would be presented with "eigenaar–ANGST."

Procedure

Administration of the morphological processing task followed the procedure of Law et al., (2018). Both groups (the control and dyslexic reading subjects) were randomly assigned a list order for stimulus presentation (list one followed by list two or list two followed by list one). Cognitive and literacy tasks were administered between the presentation of the two experimental lists to minimize the repetition effects. Each participant completed both experimental lists.

PsychoPy2 software package (Peirce et al., 2019) running on a Dell Latitude D630 laptop computer was used to control the stimuli presentation and record reaction times and accuracy. Participants were instructed that they would see a list of words presented individually on the screen and that each word would be preceded by a fixation cross, followed by a series of hashtags. The participants were not alerted to the presence of the prime. Participants were asked to indicate, as quickly and as accurately as possible, if the string of letters following the hashtags was a real or not real word. Responses were logged by pressing one of two designated keys on the keyboard. Ten practice trials were displayed before each list presentation. Figure 1 depicts the presentation order and duration lengths of the stimuli presentation. Each trial began with a 1000 ms fixation cross (+) center on the screen which was then proceeded by a forward mask (######) displayed for 500 ms. Immediately after the mask, the prime was displayed in lowercase letters for an SOA of 60 ms (Quémart & Casalis, 2015) followed by the target word presented in upper case letters. All items were randomly displayed in black Calibri 42 type font on a white background. Reaction times were measured from the onset of the target presentation until the participant's response.

FIGURE 1
A Diagram Depicting the Stimuli Presentation during the Priming Task



Note. The color figure can be viewed in the online version of this article at http://ila.onlinelibrary.wiley.com.

Statistical Analyses

Statistical analyses were performed with SPSS 20.0 software (IBM Corp. 2011). All variables were found to be normally distributed as checked within each group by the Shapiro-Wilk's test for normality (p > 0.05) with the exception for both the EMT word reading scores and the fifth-grade Spoonerism scores. To approach a normal distribution, the EMT scores were transformed by a square root transformation, while a reflection and the logarithmic transformation were applied to the spoonerism task results. Both transformations resulted in a normal distribution, and so the transformed scores were used in the analyses. Homogeneity of variance was assessed by Levene's test for equality of variances. Group comparisons were investigated based upon an independent samples *t*-test. To avoid the likelihood of false-positive conclusions, the false discovery rate (FDR) procedure was applied to correct for multiple testing across all group comparisons (Benjamini & Hochberg, 1995). The FDR procedure is a simple sequential Bonferroni-type procedure. Although less strict than the Bonferroni procedure, it has been demonstrated to control for the false discovery rate for independent test statistics. Additionally, predictive relations were assessed through the use of Pearson correlations between the second-grade measures of PA and fifth-grade priming effects. To address any potential influence resulting from the unequal sample size between groups, an equally sized, matched, control was created to allow for the follow-up analyses. Typical reading participants were individually matched to the children with dyslexia based on age (months) and receptive vocabulary, as measured by the Peabody picture vocabulary test (Dunn and Dunn, 2005). No statistical differences between groups were found for age $M = 0.042$, 95% CI [−1.61, 1.70], $t(46) = 0.51$, $p = .960$; or vocabulary $M = 0.26$, 95% CI [−5.80, 4.72], $t(46) = -0.207$, $p = .837$. Furthermore, the matched control group was found to statistically differ (p <.001) from the dyslexic group on all other background measures described in Table 1.

Results

Morphological Processing

Mean reaction times of correctly identified items in each of the four experimental conditions were calculated for each reading group (control and dyslexic). Mean error and mean reaction times (RTs) to correctly responded items in each condition by participant group are presented in Table 2. Similar to Quémart and Casalis (2015), response times faster than 500 ms or slower than 3500 ms were removed. Priming effects for each condition were calculated as the difference between reaction times of the primed and unprimed presentation within each condition (see Table 2). Analysis across groups involved a 4 (condition: Morphological, Pseudo-derived, Semantic Control, Orthographic Control) X 2 (priming: Related vs Unrelated) X 2 (order of list presentation: 1 vs 2) X 2 (group) repeated measure ANOVA where log-transformed reaction times (RTs) acted as the dependent variable. As each condition contained highly selected and balanced items, rejection of the null hypotheses was based solely on a significant finding in the analyses by subjects (see Raaijmakers, Schrijnemakers, and Gremmen, 1999).

Do Dutch-speaking Children with Dyslexia Make Use of a Word's Morphological Structure during Initial Visual Word Recognition?

A four-way mixed ANOVA was run to understand the effects of condition (Morphological, Pseudo-derived, Semantic Control, Orthographic Control), priming (Related vs Unrelated), the order of list presentation (1-2 vs 2-1) and group (dyslexia vs control) on the reaction times (RTs) to complete the lexical judgment. There was a statistically significant three-way interaction between priming, condition and reading group, $F(3,201) = 2.805$, $p = .041$, partial $\eta^2 = .040$. No effect of list order was found and will, therefore, not be further discussed.

Post hoc analysis of the found three-way interaction revealed there was a statistically significant simple two-way interaction between condition and prime, within the dyslexic group, $F(3, 69) = 2.976$, $p = .037$, and partial $\eta^2 = .115$, indicating significant difference between primes between conditions, but not for controls, $F(3, 135) = 1.57$, $p = .199$, and partial $\eta^2 = .034$.

There was a statistically significant simple main effect of prime for children with dyslexia in the Morphological (+M + S+O) condition, $F(1, 23) = 10.964$, $p = .003$, and $\eta^2 = .323$ (priming effect of 132 ms), but no significant effects were found for the pseudo-derived (+M-S + O) or Semantic (-M + S-O) or Orthographic (-M-S + O) control conditions, $ps > .05$. A simple main effect of prime for typical reading controls was found in both the morphological (+M + S+O), $F(1, 45) = 5.451$, $p = .024$, and $\eta^2 = .108$ (prime effect of 38 ms) and Pseudo-derived (+M-S + O), $F(1, 45) = 4.978$, $p = .031$, and $\eta^2 = .100$ (prime effect of

TABLE 2
Mean (Standard Deviation) RTs (ms) for Control and Dyslexic Groups According to the Condition and Priming Relationship

	Control N = 46 RT	Matched Control N = 24 RT	DYS N = 24 RT
Morphological (M + S+O+)			
Related	954 (179)	937 (196)	1191 (315)
Unrelated	992 (201)	984 (214)	1323 (399)
Priming effect (ms)	38*	47*	132**
Pseudo-derived (M + S-O+)			
Related	1000 (204)	939 (173)	1300 (130)
Unrelated	1033 (180)	1017 (168)	1295 (146)
Priming effect (ms)	33*	78**	−5
Semantic Control (M-S + O-)			
Related	951 (178)	943 (192)	1201 (274)
Unrelated	967 (166)	954 (148)	1233 (292)
Priming effect (ms)	16	11	32
Orthographic Control (M-S-O+)			
Related	971 (174)	967 (173)	1154 (283)
Unrelated	962 (167)	922 (163)	1208 (274)
Priming effect (ms)	−9	−4	54

Note. RTs, reaction times; +/-M, Morphologically decomposable/not decomposable; +/-S, Semantically highly related/unrelated; +/-O: Orthographic overlap high/low. * p < .05, ** p < .01

34 ms) condition, but not for the Semantic (-M + S-O) or Orthographic (-M-S + O) control conditions, *p*s > .05.

These results, also presented in Table 2, demonstrate significant morphological priming effects in both groups and provide evidence of the utilization of morphological information among children with dyslexia within the initial stages of visual word recognition.

Do Individuals with and without Dyslexia Make Use of Morpho-Orthographic and Morpho-Semantic Information in the Same Way during Initial Visual Word Processing?

Analysis revealed a difference in pattern and size of prime effects between groups. The control group demonstrated priming in the morphological and pseudo-derivation conditions. In contrast, the dyslexic group demonstrated priming in the morphological condition only. Post hoc analyses using an FDR correction for multiple testing revealed no statistically significant mean difference between morphological and pseudo-derived condition prime effects within controls, 0.004s (95% CI, −.038 to 0.046) and $p = .838$. While a statistically significant difference between the same prime effects within the dyslexic readers was observed, 0.138s (95% CI, 0.43 to 0.234) and $p = .006$.

An examination across both groups of the magnitude of the priming effects of both the morphological condition and pseudo-derived conditions revealed a significant difference where individuals with dyslexia were found to produce a larger prime effect within the morphological condition when compared to controls (Morphological condition: ($t(68) = -2.608$; $p = .011$, $\eta^2 = .66$); pseudo-derived condition: ($t(68) = 1.224$; $p = .225$, $\eta^2 = .31$).

The dissociation in priming between the morphological and pseudo-derived conditions indicates that morpho-orthographic and morpho-semantic information of morphemes makes separate contributions to morphological processing in dyslexic readers. Results indicate that the processing of morphologically complex words is influenced by the morpho-semantic information of morphemes. While on the contrary, the lack of a significant difference between morphological and pseudo-derived conditions among controls demonstrates a reliance on morpho-orthographic information to support the early visual decomposition of morphologically complex words independent of morphemes' meaning (e.g., both *teacher* and *corner* are decomposed into morphemes).

To address any potential influence resulting from the unequal sample size between the groups on the analysis, the same three-way mixed ANOVA and post hoc analysis, as reported above, was performed with the matched controls and dyslexic group. The same pattern of results and significant effects were found. Results are presented alongside the full control group sample in Table 2.

Do Early Phonological Processing Difficulties Disassociate from Later Morphological Processing of Children with Dyslexia?

The relationship between morphological processing (MP), as measured by the priming effect, and performance on second-grade phonological awareness was analyzed with Pearson correlations within each group (see Table 3). Different patterns of significant relations between MP and phonological awareness were observed across the two groups. Within the control group, no prime effect was found to be related to earlier PA skills. However, within the dyslexic group, the fifth-grade prime effect reported for the morphological condition (+M + S+O) was found to be significantly negatively correlated to both measures of second-grade PA; spoonerisms ($r = -.553$, $p = .011$) and PA measured with the CELF ($r = -.531$, $p = .0018$). For the prime effect in the pseudo-derived condition (+M-S + O), no significant relation with PA was found.

Discussion

This study aimed to explore morphological processing of written text in children with dyslexia and to examine the relationship between early phonological awareness skills and later morphological processing. In testing morphological processing, we controlled for the effects of orthographic and semantic priming. We used morphological and pseudo-derived conditions to separate the difference in morpho-semantic and morpho-orthographic influences on early visual word recognition. To examine early predictors of morphological processing, we examined the relation between second-grade phonological awareness (PA) measures with the size of the morphological priming effects in the fifth grade.

Do Dutch-Speaking Children with Dyslexia Make use of a Word's Morphological Structure during Initial Visual Word Recognition?

Casalis, Colé, and Sopo (2004) suggested that individuals with dyslexia may rely on morphological decomposition during the process of initial visual word recognition. It is thought that, since people with dyslexia have impaired mapping schemes between graphemes and phonemes, they would achieve lexical access through reliance on larger salient morphological units early in life (for similar findings and argument see Law and Ghesquière, 2017; Leikin and Zur Hagit, 2006; and Tsesmeli and Seymour, 2006). However, from a theoretical point of view, it has been suggested that during early visual word processing, a hierarchical structure is employed, where the processing of

TABLE 3
Pearson Correlations between Measures of Second Grade Phonological Awareness (PA) and Prime Effect (PE) Measured in the Fifth Grade, Top right Reports Results within Dyslexia Group, Bottom Left Report Results within the Control Group

Measures	1	2	3	4
1. CELF (PA - 2nd grade)	--	**.651*** **	**−.531** **	**.248**
2. Spoonerisms (PA- 2nd grade)	.517***	--	**−.553** **	**−.159**
3. PE-Morphological (5th grade)	−.229	−.196	--	**.160**
4. PE- Pseudo-derived (5th grade)	−.177	−.141	.211	--

Note. *p < .05. **p < .01. ***p < .001.

smaller linguistic units (i.e., graphemes) are required to process larger-size orthographic units (Duncan, Seymour, & Hill, 1997). Yet, despite the presence of a phonological processing deficit, children with dyslexia in this study demonstrated a reliance on morphemes during early visual word recognition and rapid and automatic activation of morphological representations. Results demonstrated significant morphological priming effects in both children with dyslexia and typical reading controls. The observed priming effects can be attributed to the morphological relationship shared between prime and target since no significant effects were found for both the orthographic and semantic control conditions. Results of intact morphological processing support the work of Elbro and Arnbak (1996), Casalis et al., (2004); Burani et al. (2008), Law et al., (2018) and Quémart and Casalis (2015).

Do Individuals with and without Dyslexia Make use of Morpho-orthographic and Morpho-semantic Information in the Same Way during Initial Visual Word Processing?

According to the Morphological Pathways Framework (Levesque et al., 2021) both morpho-orthographic and morpho-semantic processing act as a means of connecting central orthographic processes and lexical representations during word reading. This study's second objective was to investigate these connections (morpho-orthographic and morpho-semantic processing) during visual word recognition in children with dyslexia. The design of the priming task allowed us to investigate whether morpho-semantic processing is required to trigger morphological decomposition, through a comparison of the priming effects in the morphological and pseudo-derived priming conditions.

We found that children with dyslexia did not demonstrate significant priming effects when targets paired with pseudo-derived primes; however, significant priming was observed when morpho-semantic information was present, as in the morphological condition (teacher–TEACH). Thus, morpho-orthographic processing alone is not sufficient to aid in facilitating morphological decomposition in children with dyslexia. In line with the study of Quémart and Casalis (2015), the results of this study demonstrated that readers with dyslexia rely more on the true morphological status of the orthographic unit than typical reading controls. Therefore, for readers with dyslexia, the rapid and automatic morphological decomposition during initial word recognition is dependent on the higher semantic interpretability present in the morphological condition. These results directly support the earlier proposed hypothesis of semantically structured morphological representations of individuals with dyslexia (Elbro & Arnbak, 1996). Additionally, these results are in line with neurological support for the role of the semantic properties of morphemes during reading in individuals with dyslexia. A recent MEG study by Cavalli and colleagues (2017) demonstrated a greater reliance on the semantic properties of morphemes among French-speaking adults with dyslexia when compared with controls. Results revealed a spatiotemporal reorganization of the reading network for people with dyslexia, in which morpho-semantic units were activated earlier in adults with dyslexia (100–200 ms) than controls (~400 ms). While controls showed early morpho-orthographic activation (~130 ms), people with dyslexia showed only late activation of morpho-orthographic and lexico-semantic processing (250 – 500 ms). Cavalli and colleagues argued that based on their results morphological processing acts as a compensatory mechanism facilitating, in a top-down way, basic bottom-up reading processes in high functioning adults.

Do early Phonological Processing Difficulties Disassociate from Later Morphological Processing of Children with Dyslexia?

Due to the longitudinal nature of the data set, an examination of early PA's role in the later development of morphological processing skills was possible. In line with the psycholinguistic grain-size theory (Ziegler & Goswami, 2005), this study found that the fifth-grade morphological processing in children with dyslexia negatively correlated to earlier second-grade PA skills. This relation was not found to be significant in typical reading controls. The presence of a negative relation was interpreted as supporting the compensatory theory that children with dyslexia, who struggle at the phoneme-grapheme level, may vary in the cognitive processes elicited while reading. As earlier proposed, in the presence of a phonological deficit, children with dyslexia may reduce the demands of grapheme-phoneme conversion during word recognition by using larger consistent grain-size units, such as morphemes, while decoding (Casalis et al., 2004; Ehri, 2005). The disassociation of these two skills was additionally noted by Cavalli and colleagues (2017), who reported that the magnitude of the dissociation correlated with the reading level. Taken together, this evidence supports the claim that compensation for phonological weaknesses among some individuals with dyslexia may be achieved by relying more on the processing of morphological information during initial visual word processing. However, it is worth noting that this observed dissociation may be limited to morphological processing during initial visual word recognition. For instance, in a longitudinal study of children with dyslexia, Law, Wouters, and Ghesquière (2017) reported a positive correlation between pre-reading PA and later oral morphological awareness skills (assessed through the sentence completion task: Wug test). This difference in findings raises questions concerning the relationship and developmental path of morphological processing and morphological awareness and their association with reading compensation.

These results may have implications for instructional design, suggesting a greater need for interventions that target the development of morphological processing skills over the more explicit manipulation of morphological awareness. Results of this study and past work support the potential of morphological instruction to support the growth in reading skills of children with dyslexia (Casalis et al., 2004; Elbro & Arnbak, 1996; Goodwin & Ahn, 2010). For instance, systematic reviews of the effects of morphological instruction on early literacy skills noted the positive effect explicit morphology instruction has on reducing oral language deficits in children, such as poor phonological skills, leading to improved word reading, spelling, reading comprehension, and vocabulary knowledge (Bowers, Kirby, & Deacon 2010; Goodwin & Ahn, 2010). Furthermore, Bowers and colleagues (2010) found more substantial morphological instruction effects in groups of less abled readers.

A review of morphological interventions by Carlisle (2010) identified several morphological instruction methods which may significantly improve literacy achievement. While most of these approaches were designed to support the explicit awareness and manipulation of morphemes, they may offer a means to support morphological processing and activation of morpho-sematic information indirectly. For instance, instruction and activities that aim to raise awareness of morphological structure may support morphological decomposition skills utilized during early visual word processing. Such training often includes game-like activities involving breaking words into constituent morphemes (Nunes, Bryant, & Olsson, 2003). Furthermore, knowledge of morphemes and morphological problem-solving training could potentially support the use of morpho-semantic information during early morphological processing. Such training may include teaching the meanings of affixes and bases while encouraging children to think about how the constituent morphemes contribute to a word's meaning or grammatical role (Baumann et al., 2002; 2003; Birgisdottir et al., 2006). However, few studies have examined the direct effect of morphological training on morphological processing of children, resulting in the need for further investigations using longitudinal and experimental designs to address questions about the potential effects of training on morphological processing.

Additionally, it is worth noting that past morphology-based interventions have reported the lack of teacher knowledge concerning morphology and confidence in teaching morphological skills during instruction as a barrier to the intervention's success (Nunes & Bryant, 2006; Hurry et al., 2005). In the primary school curriculum context, teachers tend to have implicit rather than explicit knowledge of fundamental morphological concepts, resulting in a lack of awareness of the underlying principles applied to reading and spelling (Hurry et al., 2005). As a result, Kirby and Bowers (2018) noted that any program aiming to support the morphological processing of children must also convince teachers of the value of teaching morphological skills and provide adequate resources and training for their morphological knowledge and confidence to teach morphological skills.

To conclude, our study provides new insights into the morphological processing of children with dyslexia. Results found intact morphological representations within both groups of children and indicate the rapid and automatic activation of these representations during the initial recognition of morphologically complex words. Supporting Quémart and Casalis (2015), differences were observed in children with dyslexia concerning the influence of morpho-semantic and morpho-orthographic information. A disassociation between early PA and later morphological processing was observed where second-grade PA was found to be negatively correlated with fifth-grade morphological priming effects in children with dyslexia. Results seem to indicate a potential developmental shift in the cognitive processes involved in reading, supporting a potential compensatory avenue through morphological processing despite the observed phonological deficits of children with dyslexia.

Conflict of Interest

All authors have no known conflict of interest to disclose.

Ethical Approval Statement

The research reported in this article meets ethical guidelines, including adherence to the legal requirements of the study country. Ethical approval was obtained from the KULeuven ethics committee and follows the tenants of the Declaration of Helsinki.

Permissions

No Third-party materials were included or used in this publication

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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