Word Morphology and Written Language Acquisition

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WORD MORPHOLOGY AND WRITTEN LANGUAGE ACQUISITION: INSIGHTS FROM TYPICAL AND ATYPICAL DEVELOPMENT IN DIFFERENT ORTHOGRAPHIES

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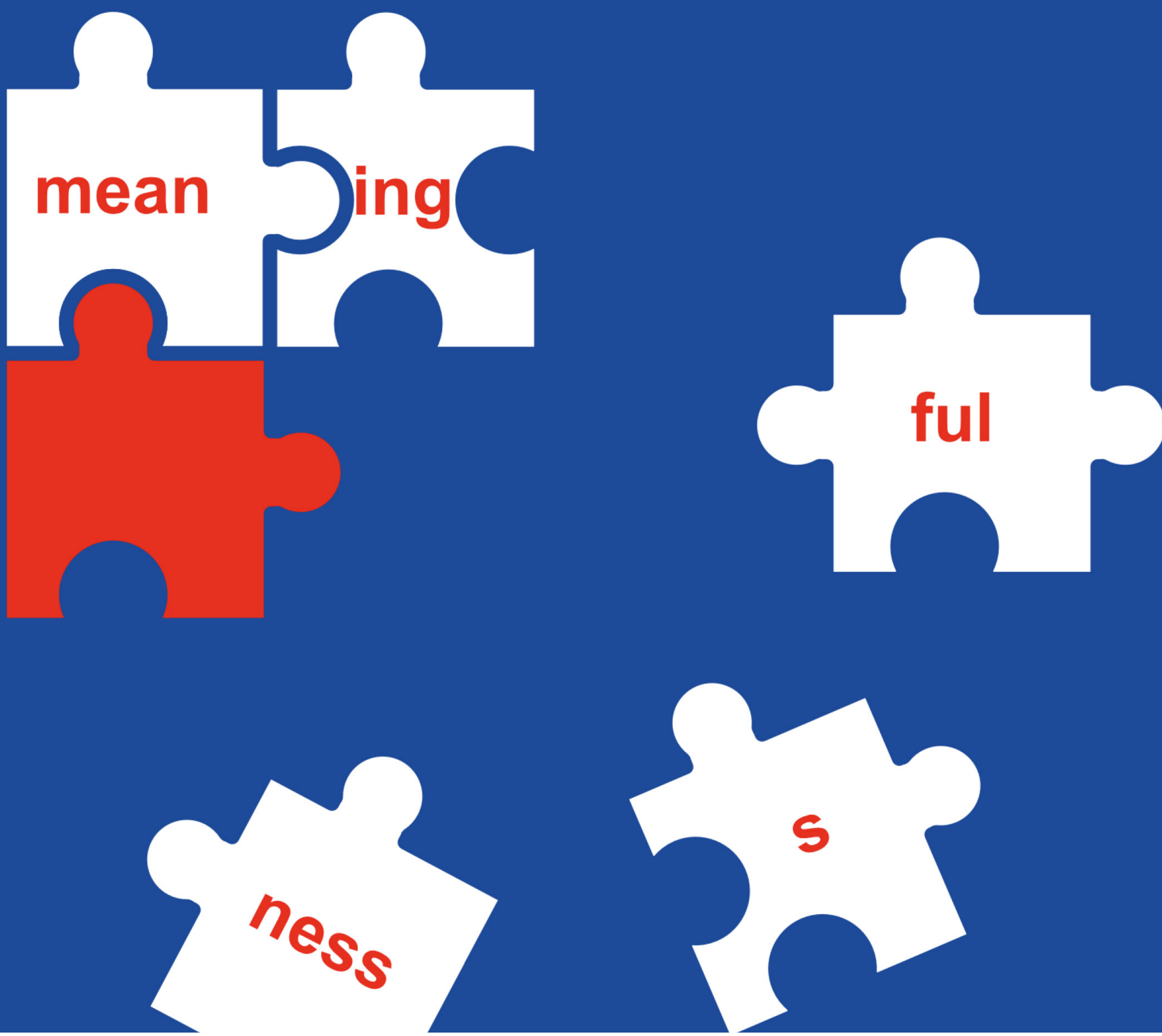

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WORD MORPHOLOGY AND WRITTEN LANGUAGE ACQUISITION: INSIGHTS FROM TYPICAL AND ATYPICAL DEVELOPMENT IN DIFFERENT ORTHOGRAPHIES

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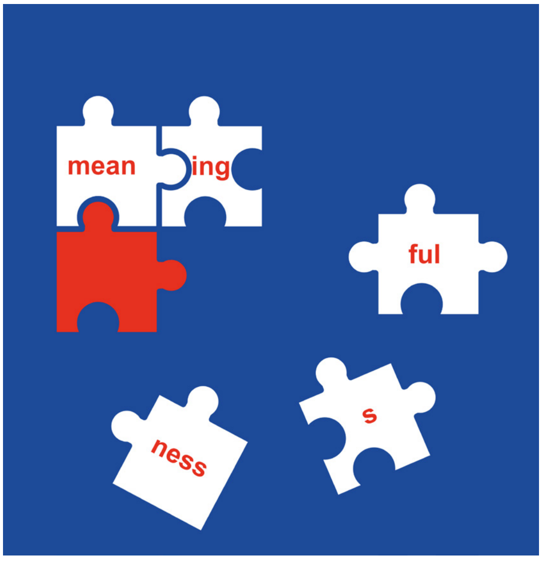

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This Research Topic explores the processing of morphemes, the smallest units of language that bear meaning and that combine to form more complex words. The articles gathered under this Research Topic investigate typical and atypical morphological processing by children and adolescents in ten different languages. These articles provide cross-linguistic and cross-script evidence of the early sensitivity of children to the morphemic structure of words, irrespective of whether they are struggling readers or typically developing. All in all, the collection allows for a better understanding of how morphological processing skills develop, providing valuable clues as to how this competence can be used as a tool to improve literacy acquisition in struggling readers.

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EDITORIAL
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Editorial: Word Morphology and Written Language Acquisition: Insights From Typical and Atypical Development in Different Orthographies

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Keywords: word morphology, developmental dyslexia, cross-linguistic perspective, literacy skills, morphological awareness training

Editorial on the Research Topic

Word Morphology and Written Language Acquisition: Insights From Typical and Atypical Development in Different Orthographies

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By gathering together a body of work, across a range of orthographies, on the relationship between morphological processing and reading acquisition, an overview of the development of this relationship begins to emerge. The articles in this research topic offer insights into the relationship between morphological processing and semantics, that take account of the typicality of the acquisition process and the nature and depth of the orthography in question.

The literature on metalinguistic awareness illustrates the early salience and accessibility of meaning. In contrast, sensitivity to speech sounds, phoneme awareness (PA), usually requires specialist instruction to achieve the level necessary for acquiring the decoding skills essential for efficient reading in alphabetic orthographies (Duncan et al., 2013). Preliminary evidence suggests that with early morphological awareness (MA), statistical learning during the acquisition of spoken language may elaborate a system sufficient to underpin early reading subject to the linguistic characteristics of that language (Duncan et al., 2009).

Of the studies in this research topic that speak to this question, Colé et al. report on the first months of reading the French orthography by children from low socio-economic backgrounds. They show that MA affected PA both directly and indirectly (via listening comprehension) but had no direct impact on early word reading (see Diamanti et al. for further discussion of early shared variance between metalinguistic tasks). Schiff and Saiegh-Haddad consider the transfer between varieties in diglossic Arabic and the implications for instruction. Their cross-sectional study found that prior to 8th grade, MA was lower for morphemes which occur only in the formal standard Arabic of schooling than for morphemes which also occur in everyday spoken Arabic. Two studies of Greek examine the longitudinal impact of preschool MA developed from spoken language on early reading, after controlling for PA. Diamanti et al. found that Kindergarten MA predicted Grade 1 reading comprehension. However, it did not predict reading fluency, possibly due to the ease of decoding the transparent Greek orthography. As Greek is more opaque for spelling than reading, an additional predictive link with Grade 1 spelling was of particular interest. The larger scale study by Manolitsis et al. demonstrated that this longitudinal link between MA and reading comprehension (but not fluency) extends into Grade 2, even after further controls for autoregression, letter knowledge and RAN.

Several research topic articles explore the process of mapping the morphemes learnt during language acquisition onto corresponding orthographic patterns. Children's reading of complex words is known to benefit from the identification of embedded morphemes. Deacon and Francis showed that base frequency influenced reading in grades 3 and 5 beyond the number (family size) and the summed frequency (family frequency) of words sharing the same base. In other words, exposure to the meaning of the base word rather than to occurrences of its orthographic pattern may drive representation of embedded bases. Data from experiments using the masked priming procedure with a similar age group have also shown that the form-meaning relationship drives morphemic parsing in English (Beyersmann et al., 2012), French (Beyersmann et al., 2015), and Hebrew (Schiff et al., 2012). In this research topic, Lin et al.'s work offers interesting data from Korean Hangul, an alpha-syllabary language written in a nonlinear spatial layout (similar to Chinese). The study revealed an early priming effect (SOA = 36 ms) among 6th graders for truly morphologically-related pairs (e.g., bravely-brave), and provided new clues on the cross-linguistic validity of morphemic effects. Eye movements were used by Traficante et al. to examine primary school children's reading of derived words embedded in sentences. The results suggested that base-word recognition might affect word processing in a complex interplay with whole-word representation. Readers' skills, base-word grammatical category and syntactic context were shown to influence this interplay. Haddad et al. addressed the hypothesis that morphemic parsing supports phonological processes, particularly in languages with a deep orthography. Hebrew can be more or less transparent according to the presence or absence, respectively, of diacritics. In grades 2–5, morphological effects were only found with bimorphemic words written with diacritics. The authors concluded that morphological and phonological segmentation occur simultaneously in Hebrew, rather than being alternative pathways.

The identification of a base word within a complex word is thought to be particularly useful for struggling readers. For these children, the base word may act as a decoding unit of intermediate grain-size, larger than a grapheme and smaller than the whole word. Suárez-Coalla et al. reported that both Spanish primary school children with and without dyslexia take advantage of the presence of a high-frequency base when reading derived words and pseudowords in this transparent orthography. In Italian, another transparent language, Burani et al. focused on how the length of the first morpheme affected derived word processing. Although 6th graders with dyslexia displayed no length effects, their typically-developing peers showed faster reading of low-frequency derived words when bases were longer. Base frequency (but not whole-word frequency) influenced the reading latencies and accuracy of both groups. This confirms previous evidence that young readers use morphemic parsing in reading low-frequency derived words. A relationship between the ability to recognize morphemic constituents and reading proficiency was also found in Chinese. Kalindi and Chung demonstrated that MA uniquely predicted reading proficiency in adolescents with and without dyslexia, despite adolescents with dyslexia having lower MA.

From such evidence of morphological influences on literacy acquisition, it follows that reading might be improved through morphological training. Even though children are prone to focus their attention on the base word, Deacon and Francis propose that it may be necessary to teach them explicitly about the relationship between a word and its morphological family. Two further contributions also offer interesting suggestions about possible morphological interventions. Both works come from languages with a very rich morphology and a transparent orthography. Tsesmeli based her training for Greek 1st and 2nd graders on word families, offering explicit instruction on morphological decomposition. This training proved to be effective in improving the spelling of compound words. A computerized training in morphological analysis devised by Bar-Kochva and Hasselhorn enhanced spelling more than reading fluency or comprehension among 5 and 6th graders with literacy difficulties who speak German as a second language.

To conclude, this research topic provides cross-script and cross-linguistic evidence to further understanding of how sensitivity to the morphemic structure of the words develops from the pre-school to secondary school years, how this competence might help in literacy acquisition, and whether intervention methods focused on morphology can offer useful tools to improve literacy in struggling readers. Together, the evidence highlights a role for morphology that is particularly important for developing readers, whether they are struggling or typically developing. We are confident that this research topic on morphology will expand a promising but still emergent field of investigation and contribute to work that seeks to model the acquisition of complex word decoding and comprehension skills.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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ORIGINAL RESEARCH
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What Is the Influence of Morphological Knowledge in the Early Stages of Reading Acquisition Among Low SES Children? A Graphical Modeling Approach

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Children from low-SES families are known to show delays in aspects of language development which underpin reading acquisition such as vocabulary and listening comprehension. Research on the development of morphological skills in this group is scarce, and no studies exist in French. The present study investigated the involvement of morphological knowledge in the very early stages of reading acquisition (decoding), before reading comprehension can be reliably assessed. We assessed listening comprehension, receptive vocabulary, phoneme awareness, morphological awareness as well as decoding, word reading and non-verbal IQ in 703 French first-graders from low-SES families after 3 months of formal schooling (November). Awareness of derivational morphology was assessed using three oral tasks: Relationship Judgment (e.g., do these words belong to the same family or not? heat-heater … ham-hammer); Lexical Sentence Completion [e.g., Someone who runs is a …? (runner)]; and Non-lexical Sentence Completion [e.g., Someone who lums is a…? (lummer)]. The tasks differ on implicit/explicit demands and also tap different kinds of morphological knowledge. The Judgement task measures the phonological and semantic properties of the morphological relationship and the Sentence Completion tasks measure knowledge of morphological production rules. Data were processed using a graphical modeling approach which offers key information about how skills known to be involved in learning to read are organized in memory. This modeling approach was therefore useful in revealing a potential network which expresses the conditional dependence structure between skills, after which recursive structural equation modeling was applied to test specific hypotheses. Six main conclusions can be drawn from these analyses about low SES reading acquisition: (1) listening comprehension is at the heart of the reading acquisition process; (2) word reading depends directly on phonemic awareness and indirectly on listening comprehension; (3) decoding depends on word reading; (4) Morphological awareness and vocabulary have an indirect influence on word reading via both listening comprehension and phoneme awareness; (5) the components of morphological awareness assessed by our tasks have independent relationships with listening comprehension; and (6) neither phonemic nor morphological awareness influence vocabulary directly. The implications of these results with regard to early reading acquisition among low SES groups are discussed.

Keywords: morphological awareness, vocabulary, phoneme awareness, reading acquisition, first-graders, low SES, graphical modeling, structural equation modeling

INTRODUCTION

An association between reading achievement and socio-economic status (SES) has been reported consistently across decades of research (Duncan and Seymour, 2000; O'Connor et al., 2009; Cabell et al., 2013; Hemmerechts et al., 2017). The achievement gap between the most and least advantaged children is apparent at kindergarten entry and persists throughout the school years (Kieffer, 2013). Children from low-SES families are also known to show delays in aspects of language development which underpin reading acquisition such as vocabulary and listening comprehension (Scarborough, 2001; Muter et al., 2004), and lower levels of skill in oral language production and comprehension, extending from early childhood into high school and beyond (Hoff, 2006; Huttenlocher et al., 2010; Fernald et al., 2013). The aspect of language that appears most susceptible to social disadvantage is vocabulary size when investigated using maternal report, spontaneous speech and standardized tests in assessing expressive and receptive vocabulary (Hoff, 2012; Fernald et al., 2013). Standardized language tests also reveal discrepancies between higher and lower SES children when measures of grammatical development and complex syntax comprehension are included (Dollaghan et al., 1999; Huttenlocher et al., 2002).

The interaction between oral language and reading acquisition has recently been receiving much attention among children from low SES families (Tse and Nicholson, 2014). Two oral language skills have been the main focus of this research, namely, vocabulary knowledge and phoneme awareness (Hoff, 2012). In contrast, few studies have focused on how morphological awareness develops in low SES groups or on the relationship between morphological awareness and reading acquisition (Apel and Diehm, 2014); indeed, with French-speaking children, there have been no studies conducted on these issues.

Morphological awareness has been defined as the ability to identify and manipulate the smallest segments of meaning within words (Carlisle, 1995). This skill has been associated in the general population with vocabulary learning and with reading acquisition beyond the initial stages of schooling (Anglin, 1993; Deacon and Kirby, 2004; Kirby et al., 2012). The present study investigated the very *early* stages of reading acquisition among low SES children with the aim of examining how morphological knowledge relates to other oral language components such as listening comprehension, vocabulary, and phonemic awareness which are known to impact reading development (for a review, see Kirby et al., 2008).

Predictors of First Grade Reading Skills in Typical Populations

As kindergarten and first grade is the ideal point at which to intervene to reduce the risk for low SES children of later reading difficulties (Suggate, 2016), it is important to understand how early language and literacy typically interact during this period. According to the well-known simple view of reading (SVR, Gough and Tunmer, 1986), reading comprehension can be decomposed broadly into two components, word recognition (D), and oral language comprehension, both of which are necessary and equal in importance, but which, nevertheless, represent distinct abilities (see also Hoover and Gough, 1990; Tunmer and Chapman, 2012). Word recognition is defined as the ability to rapidly generate the phonological or orthographic codes from a printed word in isolation to allow identification. Measures of this component are assumed to be developmentally constrained (Hoover and Gough, 1990; Tunmer and Greaney, 2010). In the early stages of learning to read, measures of both decoding and visual word recognition are useful to assess the grapheme-phoneme conversion skills required for independent reading as well as the orthographic skills which allow recognition and generalization of information across familiar words. In the SVR model, oral language comprehension (originally linguistic comprehension) represents all of the verbal abilities involved in the understanding of an oral message such as words, sentences and discourse (Kirby and Savage, 2008). Although still a matter of debate, the most commonly used oral language comprehension tests assess vocabulary knowledge and oral sentence processing abilities, also labeled listening comprehension (see Keenan et al., 2008; Thompson et al., 2015).

The SVR model offers a useful general framework for researchers trying to identify the abilities involved in reading acquisition during first grade. The model does not aim to explain the development of visual word recognition but rather to show how this skill contributes together with oral language comprehension to reading comprehension development. In the present study, we were interested in knowing how visual word recognition develops with respect to oral language comprehension in the very early stages of reading acquisition (after only 3 months of formal instruction, in November of Grade 1). Some studies have questioned the assumption in the SVR that the visual word recognition and oral language components are independent (see Tunmer and Chapman, 2012; Wagner et al., 2015). For example, Ouellette and Beers (2010) assessed typically developing first-graders on measures of phonemic awareness (the ability to consciously analyze oral words into their sound constituents (phonemes), which proved to be the best predictor of reading success; Landerl et al., 2013), pseudoword reading (decoding skills), irregular word reading, listening comprehension, receptive vocabulary, and reading comprehension. Using regression techniques, they found that both decoding skills and vocabulary (depth) contributed significant variance to irregular word recognition. While this study did not use a confirmatory factor analysis (CFA) to test whether individual differences in word recognition and oral language comprehension skills show "unity" or "diversity" (e.g., Miyake et al., 2000), these results suggested that the indicators of these constructs are generally correlated. The nature of these constructs and their relations should be further explored.

A substantial body of research indicates that from Grade 2 onwards, morphological awareness also contributes to reading competence (word recognition and reading comprehension) independently of vocabulary, phonological awareness and orthographic processing (Casalis and Louis-Alexandre, 2000; Carlisle, 2003; Deacon and Kirby, 2004; Carlisle and Stone, 2005; Roman et al., 2009; Bowers et al., 2010; Kirby et al., 2012). However, for first graders, the evidence is contradictory. With English-speaking children, Carlisle and Nomanbhoy (1993) showed that morphological skills predict word reading performance independently of phonological skills; although the proportion of variance explained is smaller, 4 and 33.6%, respectively (see also Wolter et al., 2009; Apel and Lawrence, 2011; Deacon, 2012; Kruk and Bergman, 2013; and with Dutch-speaking first graders, Rispens et al., 2008). Nonetheless, Kirby et al. (2012) failed to find any evidence that morphological awareness contributes significantly to word reading until the third grade (see also Law and Ghesquière, 2017). With French-speaking children, the evidence is also contradictory since Sanchez et al. (2012) reported a significant contribution from morphological awareness to word reading in first grade but Casalis and Louis-Alexandre (2000) did not find a similar result until the second grade. However, all of these studies are difficult to compare since they used different tasks, both in assessing word recognition and morphological awareness. It is likely that this contributes to the inconsistency across results as Apel et al. (2013b) have shown that the particular skills measured by different morphological awareness tasks impact on their ability to predict word reading performance.

Among the rare studies conducted on morphological awareness and the development of word-reading, very few have explored the relationship between morphological skills, phonological awareness and vocabulary and *how these skills interact in shaping early reading development*. One reason for this is that these studies have tended to rely on hierarchical regression techniques, which are very helpful in identifying the contribution of one skill in predicting the development of reading independently of other skills but are much less informative when it comes to explaining *how different skills interact in a network of "causal" relations to shape this development*. For example, in order to isolate the distinct contribution of morphological awareness to word reading among first-graders, Carlisle and Nomanbhoy (1993), Apel and Lawrence (2011), Wolter et al. (2009), and Kirby et al. (2012) all controlled for phonological awareness, while Sanchez et al. (2012) controlled for vocabulary and only Rispens et al. (2008) controlled for both phoneme awareness and vocabulary. This set of results showed that there are aspects of phonemic and morphological awareness and vocabulary that make independent contributions to word reading but the findings say nothing about direct or indirect interrelationships among these variables in shaping word reading development. Our study aims to look more closely at these interrelationships.

Predictors of First Grade Reading Skills in Low SES Groups

By studying 394 children from low SES families, Gentaz et al. (2013) were able to use multiple regression analyses to show that, at the end of first grade, reading comprehension performance as assessed by reading short sentences was explained by listening comprehension as assessed by oral sentence comprehension (8.89%), decoding (33.99%), and vocabulary (5.45%) skills (see also Gentaz et al., 2015). Although, the influence of decoding was the most important predictor, the authors did not carry out regression analysis on these decoding skills. In contrast, Fluss et al. (2009) with 1,062 first graders from low SES Parisian families found that the variance in decoding as measured by pseudoword reading was almost entirely accounted for by phonemic awareness and rapid naming (27% of the variance).

To our knowledge, only one study by Apel et al. (2013b) has focused on the development of morphological skills and their influence on the emergence of word reading among first-graders from low SES families. In their study of 44 English-speaking first-graders, morphological awareness did not explain any additional unique variance over and above phonemic awareness for either word or pseudoword reading. In another study with a larger sample ($N = 304$) and more variety in socioeconomic status levels (although predominantly lower SES), Kim et al. (2013) found that phonological and morphological awareness and vocabulary were each unique predictors of first grade word reading. The origin of the discrepancy between these results is unclear and requires further exploration as it could be due to differences in the tests used to measure morphological awareness or else sample differences such as size or SES composition.

The Present Research

Previous studies have reported contradictory results concerning the involvement of morphological awareness in the early phases of word reading among typically developing English- and French-speaking children. Even when studies have reported a clear effect of morphological awareness in word reading, there is no clear picture of the dependencies among morphological awareness, phoneme awareness and vocabulary. One reason for this might be that the majority of these studies used hierarchical regression analyses, involving only linear regression coefficients between a set of independent variables and a dependent variable.

An alternative approach yet to be conducted in this area would be to explore the co-variability among a large set of observed variables in terms of a smaller set of latent variables or factors. When applying this kind of reduction via exploratory or CFA, the assumption is made that an underlying causal model exists.

A further possibility would be to combine CFA and regression analysis. This combination often invokes a measurement model that defines factors using observed variables (indicators) and a structural model that imputes directed relationships between factors. This combination is known as Structural Equation Modeling (SEM) (Bollen, 1989), and is generally used when there is a theoretical model to be tested by comparing its predictions with the data. With second graders at risk for reading difficulties, Nagy et al. (2003) used structural equation modeling to evaluate the contribution of phonological and morphological awareness, vocabulary, and orthographic processing to word reading. Oral vocabulary and orthographic processing contributed uniquely to word reading and morphological awareness contributed uniquely to reading comprehension. As morphological awareness and vocabulary were significantly correlated, the authors concluded that morphological awareness may contribute indirectly to word recognition via oral vocabulary. Recently, with third graders, Levesque et al. (2017), found that morphological awareness displayed both direct and indirect (via word reading) pathways to reading comprehension (phonological awareness and non-verbal ability were included in the model). There was no effect of vocabulary on word recognition and reading comprehension when morphological awareness was taken into account.

In these studies, the SEM approach was largely confirmatory rather than exploratory. However, in practice, the dichotomy "confirmatory" vs. "exploratory" should not be viewed in terms of which method to use. In fact, these approaches are complementary: exploratory data analysis searches for patterns of relationships while confirmatory data analysis makes use of statistical hypothesis testing on predicted models (Kiiveri and Speed, 1982; Bollen, 1989).

Regression, CFA and SEM require prior knowledge to completely specify a model but often there is insufficient prior knowledge to do that. Although still uncommon in studies of reading, Graphical Modeling is a data-driven approach for identifying and exploratory modeling the network structure based on a set of multivariate variables. It uses graph theory that enable concise representations of associations between variables. Graphical models provide a framework for modeling how these variables are mutually related and how conditional independence structures can be represented graphically. As Malave (2008) observes "the graphical Gaussian model (Dempster, 1972; Whittaker, 1990; Lauritzen, 1996; Edwards, 2000) models the data as multivariate Gaussian, but constrains the inverse of the covariance matrix to have a zero for all pairs of variables which are conditionally independent" (their correlations are zero given the rest of the variables). The inverse of the covariance matrix (called the precision matrix) is related to the partial correlation matrix. Edwards (2000) explains this as follows: "two variables are independent given the remaining variables if, and only if, the corresponding element of the inverse covariance is zero." The graph of this model is formed by connecting two nodes with an edge if the corresponding partial correlations are not set to zero. Undirected relationships can also act as a starting point for further investigation with techniques such as SEM (see Kiiveri and Speed (1982) for a discussion of the relationship between partial correlation, graphical Gaussian models and SEM). Rosa et al. (2011) describe how "a recursive causal structure can be represented by a Directed Acyclic Graph (DAG), which is a set of variables (or nodes) connected by directed edges (arrows)," when they are not conditionally independent. Kiiveri and Speed (1982) introduced many examples of DAGs making several points concerning their parameterization, identification, estimation, fitting, and comparison. A DAG may be specified by three ways: prior knowledge incorporated in confirmatory approaches, guessing-and-testing, and discovery algorithms (Spirtes et al., 2001).

Numerous studies suggest that the early stages of word reading development depends crucially upon oral language skills. However, the majority of these studies focus on phonological skills, especially phonemic awareness as it appears to critically influence the development of reading skills (see for example, Hulme and Snowling, 2013). Little is known with regard to the exact influence of other oral language skills such as vocabulary, morphological awareness and listening comprehension and their mutual influence in the early stages of word reading and their relationship with phonemic awareness. In fact, some researchers suggest that oral language comprehension skills such as vocabulary, morphological awareness and listening comprehension may influence the development of reading comprehension (see Hulme and Snowling, 2013, for similar position). In order to show whether these skills can also contribute to the early acquisition of word reading, we assessed listening comprehension (comprehension of oral sentences), receptive vocabulary, phoneme awareness, morphological awareness together with decoding, word reading and non-verbal IQ in a large sample of 703 French first-graders from low-SES families after 3 months of formal instruction (November). Pseudowords and word reading were both assessed because cross-linguistic studies have shown that word reading skills can develop faster in more transparent orthographies than English (Seymour et al., 2003; but see also Moll et al., 2014). We used three oral tasks to assess morphological awareness of derivational morphology. The Relationship Judgment task (e.g., do these words belong to the same morphological family or not? heat-heater;... ham-hammer); the lexical Sentence Completion task [e.g., Someone who runs is a ...? (runner)]; and the non-lexical Sentence Completion task [e.g., Someone who lums is a...? (lummer)]. The tasks differ on implicit/explicit demands and also tap different kinds of morphological knowledge. The Judgement task measures the phonological and semantic properties of the morphological relationship and the Sentence Completion tasks measures knowledge of morphological production rules, with the non-lexical version assessing how well these rules can be generalized to novel items. These tasks were very frequently used in studies with first-graders (Carlisle and Nomanbhoy, 1993; Casalis and Louis-Alexandre, 2000; Rispens et al., 2008; Duncan et al., 2009; Wolter et al., 2009; Apel et al., 2013a; Kim et al., 2013; Apel and Diehm, 2014).

Overview of Data Analysis

Graph Modeling Analysis

In an exploratory data-driven analysis, data were processed using a graphical modeling approach (Vandenberghe et al., 2013; Massa et al., 2015) which gives crucial information about how skills known to be involved in learning to read are organized in memory. With this method we were able to identify what were the oral language skills involved in the acquisition of word reading skills and how they were related to each other (direct or indirect connections). We found that: (1) listening comprehension skills are at the heart of the reading acquisition process, (2) word reading and decoding skills depend directly on phonemic awareness and indirectly on listening comprehension, (3) the influence of higher order skills (vocabulary, morphological skills, non-verbal capacities) on word reading and decoding is not direct but rather indirect via listening comprehension, (4) morphological and phonological skills, combined to listening comprehension seem to have a directed and acyclic role in the acquisition of word reading and decoding skills (they are ordered into a dependence chain), (5) the components of morphological skills as assessed by our tasks (Relationship Judgment and Sentence Completion) have independent relationships with listening comprehension.

Directed Acyclic Graph Analysis

As stated above, the directed relationships may also be put in a parametric form (see Kiiveri and Speed, 1982) and used as the starting point for further analysis with SEM. We thus followed a confirmatory approach to test statistical hypotheses based on substantive theory and/or previous empirical research.

The general model we tested is as follows. Cutting and Scarborough (2012) provided a useful comprehensive general framework of reading comprehension where listening comprehension comprises several language skills such as vocabulary, morphological and syntactic as well as more general skills such as executive function. So, one can expect that the development of listening comprehension skills would be directly influenced by morphological and vocabulary knowledge as well as by non-verbal IQ. The three morphological awareness tasks we used may exert different influence on listening comprehension skills as they tap on different aspects of morphological knowledge.

Duncan et al. (2009) assessed these tasks with first to third French graders. They found that performance of the relationship judgment task was higher than that of the lexical and non-lexical sentence completion tasks. They claimed that it may be because the latter requires a more explicit level of awareness (Gombert, 1992) and also because the relationship judgement task can be done using a semantic strategy to accurately distinguish between word pairs like “heat-heater” and “ham-hammer.” Carlisle and Nomanbhoy (1993) reported findings that support this interpretation. They found that vocabulary accounted for a significant portion of variance of the relationship judgement task performance while that of phoneme awareness was not significant. For the lexical sentence completion task both vocabulary and phoneme awareness contributed significantly, suggesting that this morphological task assessing knowledge of morphological production rules is more heavily constrained by phonological factors. Moreover, Duncan et al. (2009) also reported that the lexical sentence completion task was easier for children than the non-lexical version implying that the altter increased the need for metalinguistic control over morphological knowledge. Fundamentally, the knowledge of morphological production rules measured by the lexical version of the sentence completion should directly influence the level of performance of the non-lexical version.

As pointed in the introduction, there is a huge literature showing that oral language development underpins reading acquisition. Importantly, Nation and Snowling (2004), for example, showed with children aged 8 years that both phonological skills (such as phonological awareness) and children’s oral language proficiency as measured by vocabulary, listening comprehension and semantic skills influence the course of word reading development. Interestingly beside phonological skills, semantic abilities may also influence decoding because of their predictive relationship with phonological awareness (Share et al., 1984; Wagner et al., 1993; Burgess and Lonigan, 1998; Lonigan et al., 1998, 2000; Bishop et al., 2004) and because phonological segmentation is stimulated as semantic knowledge increases (Carroll et al., 2003). Therefore, listening comprehension as a proxy of children’s oral language proficiency can determine the level of phoneme awareness skills.

However, contrary to the dominant view of word reading acquisition, which states that children’s phonological skills are the foundation upon which the decoding ability needed to develop further word reading proficiency is built (Nation and Snowling, 2004), our graphical modeling analysis showed that phoneme awareness influences word reading which in turn influences pseudoword reading (decoding). Following Share (1995, 1999), one can argue that in the very early stages of reading acquisition, when children have few grapheme-phoneme skills, they also can utilize top-down knowledge of word meanings to help with the process of decoding. Thus reading words would boost decoding skills.

This model additionally reports that vocabulary skills influence directly phonological skills. This is in line with Ouellette and Haley (2013)’s study which reported that oral vocabulary in kindergarten predicted unique variance of phonemic awareness into grade 1. These data were interpreted within the Lexical Restructuring Model (LRM, Metsala and Walley, 1998; Walley et al., 2003) which conceives oral vocabulary as the key contributor to phoneme awareness. Vocabulary growth needs phonemic representations of words to be accurate because of increasing number of phonologically similar words. As a consequence, vocabulary acquisition needs restructuring the phonemic level of word representations in the lexicon which in turn develops phoneme awareness.

The model also shows that one component of morphological awareness directly feeds the phoneme awareness skills. This result goes again the dominant view which states that during early reading acquisition, although there may be links between phonological and morphological awareness because both require the manipulation of parts of speech, a portion of morphological development may be dependent on phonological awareness (see Law and Ghesquière, 2017, for recent account). However, Carlisle (1995) and Fowler and Liberman (1995) have suggested that morphological awareness may encompass a larger range of abilities than phonological awareness, some of which may emerge early in development. Critically, the development of phonological awareness takes place in kindergarten and first grade, whereas morphological awareness may develop later in childhood (Mahony, 1994; Leong, 2000). From this point of view, because the development of morphological awareness is delayed relative to phonological awareness, phonological awareness may be extended by morphological awareness. In line with this interpretation, Carlisle (1995) suggests that morphological awareness may foster growth in phonological awareness as children learn to appreciate systematic phonological variations that occur in morphologically related words (i.e., singer, singing, sings).

MATERIALS AND METHODS

Participants

At the beginning of the first school year, the sample consisted of 703 French children (371 girls and 332 boys) with a mean age of 6 years 2 months (range: 5 years 9 months to 6 years 9 month). These children were attending 30 different elementary school classes, all in a "Priority Education Area," which reflects a low socio-economic catchment area exhibiting a variety of social difficulties. Thus, these children belonged to low socio-economic status families, defined according to the Government criteria, as those with high levels of unemployment or whose predominant experience is of low income. In addition, the families frequently are single parent families and often do not have French as the native language. The present study was conducted in accordance with the Declaration of Helsinki. It was conducted with the understanding and the written consent of each child's parent and in accordance with the ethical guidelines between the academic organization (LPNC-CNRS) and educational organizations.

Assessments

Each child was tested on the following domains: Listening comprehension, word and pseudoword reading skills, vocabulary, morphological awareness skills, phonemic awareness skill, and non-verbal IQ. The children were tested individually. Psychologists, who were trained and regularly supervised on site, were responsible for administering all of the tests. Each testing session for each child lasted ∼45 min and took place in a quiet room in the schools.

Non-verbal IQ

Non-verbal IQ was assessed with the Progressive Matrices Standard 47 (Raven et al., 1998) in which 36 problems were presented to the children. Each problem consisted in finding the missing part of an incomplete design among the six options provided.

Phonemic Awareness

The phonemic awareness task was composed of 11 items assessing phonemic segmentation skills (i.e., phonemic awareness). One test with two subtests assessed onset segmentation (6 items, 3 in each subtest): the children had to choose from four options what a reference word beginning with a consonantal cluster would become when (1) the onset is removed (e.g., for *"trois,"* the options were *"deux"*/*"oie"*/*"râteau"*/*"train,"* the correct response being "oie") and (2) when a part of the onset is removed (e.g., for *"croix,"* the options were *"poire"*/*"toit"*/*"noix"*/*"roi,"* the correct response being "roi"). The other phonemic test involved an oddity task: the children had to spot the odd one out of three words on the basis of the initial phoneme (e.g., *"coq"*/*"col"*/*"botte,"* odd word: *"botte,"*) or the final phoneme (e.g., *"car"*/*"selle"*/*"pelle,"* odd word: *"car,"*). All words were presented orally together with a picture. The phonology scale had 11 points.

Listening Comprehension

Listening comprehension was assessed at a syntactic-semantic level (ECoSSe: Lecocq, 1996). In this task, children were shown four pictures and had to choose the one that exactly depicted the situation described in a sentence read by the examiner. The listening comprehension scale had 25 points (one point per item) and the percentage of correct responses was calculated.

Vocabulary

Receptive vocabulary was assessed on a standardized vocabulary test (TVAP: Deltour and Hupkens, 1980). The children chose the picture (from six) that illustrated the word read aloud by the experimenter. There were 30 items, each scored on a scale from 0 to 2 (2 points are awarded for the choice of the correct response and 1 point for the approximate response, e.g., the picture of a "big house" for the item "castle"), making for a total possible score of 60 points.

Morphological Awareness

The morphological awareness skills were assessed using a test in which children had to perform a word relationship judgment task and a word completion task. In the word relationship judgment task 10 word pairs were presented to children who had to determine if the two words belong to the same family or not (e.g., "coureur/courir vs. coureur/courage). In the word completion task 20 sentences were presented to children in which they had to complete either ten words (i.e., lexical completion task) or ten pseudo words (i.e., non-lexical completion task) with a term from the same family (e.g., for the word sentence "*un homme qui coiffe est un...*" the child must answer "*coiffeur*" and for the pseudo word sentence *"un homme qui plude est un..."* the child must answer *"pludeur."* For all the tasks, a training phase was proposed to the children with 4 trials during which, in case of errors, the children were explained the concept of morphological family (word relationship judgment) or the meaning of the word. suffix (word completion task).

Reading

Reading skills were assessed through a 1-min test of words reading. There were 35 words made-up of one to six letters. Decoding skills were assessed through a 1-min test of pseudoword reading. There were 30 pseudowords made-up of one to five letters. The number of words correctly read in 1 min (wpm) was calculated. The words and pseudowords of these reading tasks all have a monomorphemic structure.

Data Analysis Plan

In recent years, there has been a strong interest in representing multivariate data as networks. One of these networks, the Markov network, is based on undirected acyclic graphs (Friedman, 2004), whereas directed graphs (directed acyclic graphs, i.e., DAGs) are Bayesian networks. Graph networks come from the process of high-dimensional data and provide a framework for modeling how several variables are mutually related and how conditional independence structures can be represented graphically. Traditional approaches to analyzing data from neuropsychological and behavioral sciences have conducted factor analyses, cluster analyses or multiple regression analyses. Factor analyses are useful for identifying factors that may contribute to several observed variables. Cluster analysis is a statistical technique used to identify groups of entities (observations or variables) that have similar characteristics. Graph analyses extend these approaches by testing the conditional independences of the selected assessments directly, without the need for assumptions about underlying hidden factors. Moreover, graph analysis goes beyond multiple regression analyses by capturing the interactions between all the variables rather than only the linear dependency of one measure on a set of explanatory variables (Massa et al., 2015).

The form of multivariate analysis known as Graphical modeling had its origina in the fields of physics and genetics (Gibbs, 1902; Wright, 1921), and is an approach that combines a statistical model with a mathematical object, a graph. The graph is defined as a pair $G = (V, E)$, where V is a set of *vertices* or *nodes* and E is a set of *edges* (Edwards, 2000). Højsgaard et al. (2012) explain that "each edge is associated with a pair of nodes…Edges may in general be directed, undirected or bidirected. Graphs are typically visualized by representing nodes by circles or points, and edges by lines, arrows, or bidirected arrows." The key tool in graphical modeling is the dependence graph. In the dependence graph the nodes represent random variables of a multivariate distribution. The nodes can be connected by different types of edges which reflect the statistical relations between the variables. For understanding graphical modeling, the notion of conditional independence is crucial. This example by Da et al. (2011) from probability theory helps to explain this concept: "two events X and Y are conditionally independent given a third event Z precisely, if the occurrence or non-occurrence of X and the occurrence or non-occurrence of Y are independent events in their conditional probability distribution given Z." In other words, if the value of Z is known, knowledge of whether X or Y occurs provides no information of the likelihood of Y or X occurring, respectively. That said, if two nodes X and Y are separated in the graph by a nodes Z, then the corresponding random variables X and Y are conditionally independent given Z. Importantly, "undirected edges represent associations between random variables and a missing edge reflects the fact that random variables are conditionally independent" (Massa et al. (2015), from their behavioral study using graph modeling). As statistical objects, graphs illustrate the variables, and parameters of models making it possible to read the independence structure of the model directly from the graph.

First, in this paper, the focus will be on undirected graphical models, i.e., graphical models where graphs have only undirected edges. In other words, no assumptions will be made about directed relations between any variables. This goal of this approach is to infer the structure of the dependence graph which gives the best description of the conditional independences and associations between all the variables. The undirected graph (i.e., so-called Markov graph) illustrates the correspondence between nodes and the conditional independence relations between all the variables (a Gaussian Markov graph is characterized by zeros in the inverse of the covariance matrix). In this study, to investigate this dependence graph we used the methods and their implementation provided by Højsgaard et al. (2012), by following the pipeline using R with *cran-r* packages. More precisely, we estimated the model parameters of the dependence graph using both the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) forests (Chow and Liu, 1968; Edwards et al., 2010). The former (AIC) is defined as $-2 \ln L + 2r$, where L is the maximized likelihood under the model and r is the number of parameters in the model, and the latter (BIC) as $-2 \ln L + \ln(N)r$. When working with graphical models, a "forest" or a "tree" (see Edwards et al., 2010, for a detailed distinction between "tree" and "forest" terminologies, but for a general definition, a forest may have several connected components, the trees) corresponds to a graph with n nodes and several k connected components. In modern terminology, trees and forests are special cases of undirected and acyclic graphs (i.e., graph with no cycles with a topological ordering, i.e., a sequence of the vertices such that every edge is directed from earlier to later in the sequence). To do so, we used the algorithm implemented in the *minForest* function in the *gRapHD-r* package. The graph obtained (see **Figure 1** in the Results section) corresponds to a minimal forest undirected and acyclic graph (i.e., exploratory and data-driven graph). This approach can be applied as an initial step toward identifying the overall dependence structure of high-dimensional data with uses including the detection of distinct connected components, neighborhoods, or interesting features, such as hub nodes (Edwards et al., 2010).

Second, to address theoretical questions, we applied a DAG and tested measurement and fit models by use of the structural equation modeling (SEM) method on the forest graph (see **Figure 2** in the results section). Structural modeling was performed using Latent Variable Analysis with *Lavaan-R* package. Model fitting was based on the correlation matrix (see **Table 1**) and indicators of fit (χ^2 statistic) tested whether the model was consistent with the covariation pattern among the observed variables. The χ^2 statistic measures the model's "badness of fit" compared to a saturated model. However, since the χ^2 is vulnerable to sample size and/or departure from multivariate normality (χ^2 tends to be significant when the sample size is large which means that the χ^2 statistic nearly always rejects the model when large samples are used, see Bentler and Bonnet, 1980), we also evaluated model fit based on different fit indices recommended in the literature (see Finkenauer et al., 1998). We used the Root Mean Square Error of Approximation as a measure for the discrepancy of the fit of the model per *df*

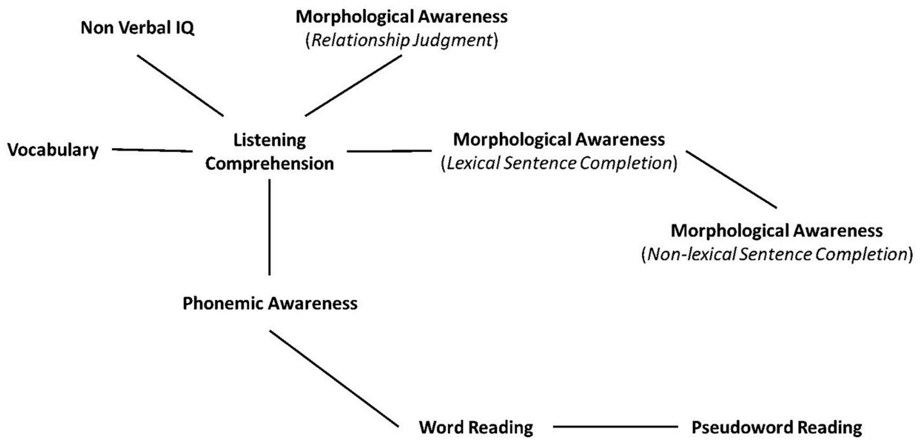

FIGURE 1 | Dependence graph (exploratory and undirected minimal forest) on all variables.

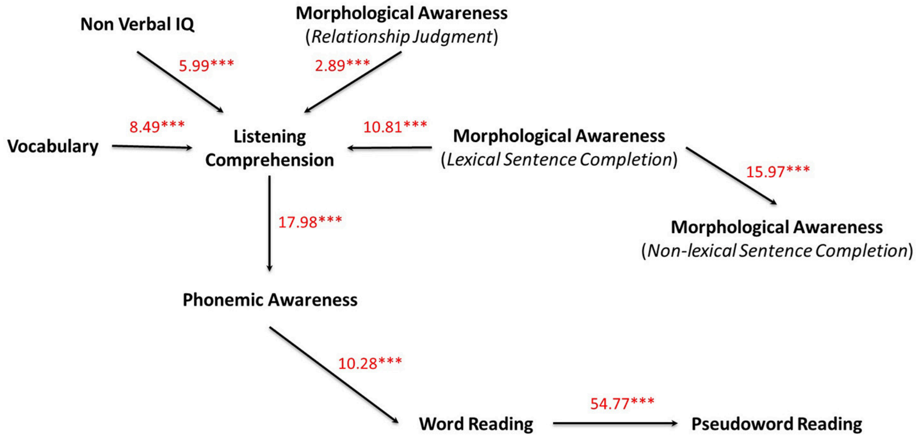

FIGURE 2 | Confirmatory and directed graph (DAG) on all variables. Standardized model parameters (z-transformed regression coefficients) obtained by structural equation method (Latent Variable Analysis Lavaan Package) are depicted on each directed edge with respective *p*-values (***$p < 0.001$).

used (RMSEA; see Steiger, 1990). The RMSEA also assesses the model's "badness of fit" (i.e., difference between the observed and predicted covariances) and traditionally researchers consider a RMSEA value of ∼0.08 or less to indicate a close fit in relation to the *df* (Hu and Bentler, 1998, see also Miyake et al., 2000). The other fit indices (Comparative Fit Index, CFI; Tucker-Lewis index, TLI; and Incremental Fit Index, IFI) are typically used to measure "goodness of fit" with values around or greater 0.90 or 0.95 are indicative of excellent model fit (Kline, 2015). Moreover, the Goodness of fit index (GFI) estimates how well the sample variances and covariances are reproduced by the proposed model. As for the CFI, which measures the covariance in the data reproduced by the model, for GFI, a value greater than 0.90 indicates an acceptable fit. Both AIC and BIC that take the goodness of fit as well as the number of estimated parameters into account were also introduced. After estimation of the parameters of the model, the standardized coefficients were entered on the structural DAG model paths (see **Figure 2**). The graph obtained corresponds to a minimal forest directed and acyclic graph (i.e., confirmatory and both theory- and graph-driven model). These paths can be considered as regression or path coefficients inferred from the observed correlations. A summary of fit indices for the DAG model is presented in **Table 2** in the Results section.

RESULTS

Descriptive statistics (means and standard deviations) are presented in **Table 1** along with both Pearson correlations among the variables presented below the diagonal line and the empirical partial correlations presented above the diagonal line.

The Empirical partial correlation matrix (above the diagonal line in **Table 2**) of the variables introduced (i.e., Listening comprehension, Word reading, Pseudoword reading, Phonemic awareness, Vocabulary, Morphological awareness (MA relationship judgment), Morphological awareness (MA lexical sentence completion), Morphological awareness (MA

TABLE 1 | Empirical partial correlation matrix of the variables (above the diagonal line), and Pearson correlation matrix (below the diagonal line).

	1	2	3	4	5	6	7	8	9
1.Listening Comprehension		0.01	−0.02	0.14***	0.27***	0.07	0.30***	0.12***	0.19***
2.Word Reading	0.26***		0.81***	0.11**	−0.01	0.01	0.00	0.03	0.09*
3.Pseudoword reading	0.26***	0.85***		0.05	0.00	0.05	0.06	0.03	0.01
4.Phonemic awareness	0.40***	0.38***	0.36***		0.15***	0.10**	0.03	0.06	0.02
5.Vocabulary	0.55***	0.22***	0.22***	0.38***		0.08*	0.28***	0.04	0.03
6.MA judgment	0.28***	0.23***	0.24***	0.27***	0.26***		0.01	0.09*	0.05
7.MA lexical	0.58***	0.28***	0.28***	0.35***	0.54***	0.25***		0.30***	−0.05
8.MA non-lexical	0.43***	0.27***	0.27***	0.31***	0.37***	0.25***	0.51***		0.02
9. Non-verbal IQ	0.31***	0.26***	0.24***	0.20***	0.20***	0.17***	0.17***	0.18***	
mean ($N = 703$)	79.9	6.5	6.2	7.1	37.2	12.6	5.2	2.4	20.5
Standard deviation	15.3	6.5	5.5	2.6	7.4	2.6	2.4	2.1	5.1

$*p < 0.05$; $**p < 0.01$; $***p < 0.001$.
Variables: MA, Morphological awareness; all others are transparent.
Means and standard deviations are presented at the bottom of the correlation matrix.

TABLE 2 | Comparison of generalized least square estimations of the three proposed models: The minForest Graph is the exploratory and undirected graphical model; the DAG is the confirmatory (SEM) and directed graph; and the Extended DAG is the theory-driven and directed graph including two direct contributions of Vocabulary and Morphological awareness (lexical sentence completion) to Phonemic awareness.

	***minForest* graph**	**DAG**	**Extended DAG**
χ^2 (df)	147.01*** $(19)^T$	174.92*** $(22)^{TT}$	127.01*** $(20)^{TT}$
AIC	34989.362	34858.334	34824.362
BIC	35100.800	34877.656	34846.444
RMSEA [95% CI]	0.094 [0.088–0.101]	0.094 [0.088–0.110]	0.088 [0.080–0.991]
CFI	0.93	0.91	0.93
GFI	0.94	0.92	0.94
TLI	0.90	0.88	0.90
IFI	0.93	0.91	0.93

$***p < 0.001$.
^{T}df in Gaussian Graphical Model = $1/2\ \{Tr(K'(\Sigma_0 - S))\}$ when $Y \sim N(0,K^{-1})$ and K' an estimate of K (the inverse of covariance matrix).
^{TT}The number of constraints in the recursive structural model, that is $[v*(v+1)/2-p]$ where v is the number of the observed variables, and p is the number of free parameters.

non-lexical sentence completion), and non-verbal IQ, reflects the pairwise correlation of the variables after taking into account all the remaining ones in the domain. It is note-worthy that while all the Pearson correlations are highly significant (all ps < 0.001), only a few partial correlations are significant. Among them, a strong coefficient (around 0.30; $p < 0.001$) was found between Listening comprehension and Vocabulary tasks ($r = 0.27$; $p < 0.001$), Listening comprehension and MA lexical sentence completion ($r = 0.30$; $p < 0.001$), Word reading and Pseudoword reading ($r = 0.81$; $p < 0.001$), MA lexical and non-lexical sentence completion ($r = 0.30$; $p < 0.001$), and Vocabulary and MA lexical sentence completion ($r = 0.28$; $p < 0.001$).

MinForest (Undirected Graph) Measurement Model

Figure 1 displays the estimated dependence minimal forest undirected and acyclic graph. Diagrammatic and idiosyncratic graph representations were removed for clarity and we presented nodes (or vertices) without circles or points but only with their respective task's name. However, edges are still represented by lines.

Here we illustrate how to interpret the graph with an example. The graph in **Figure 1** shows that node (or vertex) "Vocabulary" and "MA lexical sentence completion" are separated from node "Phonemic awareness" by node "Listening comprehension." This indicates that "Vocabulary" and "MA lexical sentence completion" are conditionally independent of "Phonemic awareness," given "Listening comprehension." Overall, the estimated dependence graph shows that most variables are associated with Listening comprehension. More precisely, Vocabulary, non-verbal IQ, MA relationship judgment, MA lexical sentence completion, and Phonemic awareness tasks were directly connected to Listening comprehension task. These associations imply that the overall Listening comprehension score is related to these 5 factors. Interestingly, when the Listening comprehension score was controlled for, there were no direct connections between MA relationship judgment and MA lexical sentence completion, suggesting some distinction between the processes involved in each tasks, as well as between Vocabulary and Phonemic awareness, suggesting a distinction between oral semantic skills (as estimated by the vocabulary task) and more abstract-level phonological processing skills (as estimated by the phonemic awareness task). In the same line, there was also no relation between Listening comprehension and Word reading when Phonemic awareness is controlled for. The *minForest* graph displayed in **Figure 1** is a model of 26 parameters, 9 nodes and 8 edges, with a likelihood ratio (LH; $-2*$Log-likelihood) of 34937.36 (AIC = 34989.362; BIC = 35100.800). The data-driven *minForest* undirected graph demonstrated acceptable model fit (see **Table 2**), with $\chi^2_{(19)} = 147.01$; $p < 0.001$; CFI = 0.93; GFI = 0.94; TLI = 0.90;

IFI = 0.93; and RMSEA [CI 95%] = 0.094 [0.088–0.101], although for excellent model fit, values greater than 0.90, even 0.95 for both TLI and IFI, and value below 0.08 for RMSEA, are recommended.

DAG Measurement Model

Based on the *minForest* graph and in the aim to address theoretical questions, we applied a DAG and tested measurement and fit model by use of recursive structural equation modeling (SEM) method (see Kiiveri and Speed, 1982). The confirmatory and directed graph (DAG) is displayed in **Figure 2**.

Results of the confirmatory and directed graph demonstrated acceptable model fit, with $\chi^2_{(22)} = 174.92$; $p < 0.001$; CFI = 0.91; GFI = 0.92; TLI = 0.88; IFI = 0.91; and RMSEA [95% CI] = 0.094 [0.088–0.110]. A summary of fit indices for the DAG model, along with the *minForest* model, is presented in **Table 2**. AIC and BIC relative to the DAG model were 34858.334 and 34877.656, respectively. Standardized coefficients were placed directly on the paths of the structural diagram. These path coefficients are inferred from the observed correlations, and the significance level of each parameter is indicated (all *ps* < 0.001). The standardized coefficients were ranged from 2.89 (MA relationship ➔ judgment Listening comprehension connection) to 54.77 (Word reading ➔ Pseudoword reading connection). Results also showed a strong connection between MA lexical sentence completion ➔ Listening comprehension (10.81) but also ➔ MA non-lexical sentence completion (15.97), and likewise between Listening comprehension ➔ Phonemic awareness (17.98) and between Phonemic awareness ➔ Word reading (10.28). Interestingly, although highly significant, the connection between Vocabulary ➔ Listening comprehension (8.49) was highest than those between MA relationship judgment ➔ Listening comprehension (10.81), suggesting that morphological awareness skills are highly predictive of listening comprehension skills in First grade readers.

Extended DAG Measurement Model

As can be seen in **Table 2**, the χ^2 statistic for both the *minForest* and DAG models did not reach $p > 0.05$ (especially because we had a large sample size) but some fit indices indicated an acceptable fit. To improve the global fit, we re-specified the initial model on the base of the modification indices (MI). A modification index is of use in seeking out a better model. Statistically, this index is a 1-df Chi-square test that indicates the extent to which the discrepancy between model and data can be reduced, as defined by a general fit function, when one parameter is added or freed or when one equality constraint is relaxed (Sorbom, 1986). These MIs suggest links to change in our structure. In other words, the large value indicates that more information can be gained from the data by introducing additional parameters into the model. According to the common SEM practice, these new parameters have to be justified by theoretical models (see the Introduction section). Therefore, in this section, we pursue a confirmatory and theoretically driven model-testing strategy which involves the addition of paths and the evaluation of changes in fit across tested models, consistent with common SEM practice (Kline, 2015). Following the confirmatory DAG model, theoretically plausible alternative were tested with the goal of identifying the most parsimonious and well-fitting model. **Figure 3** displays the "Extended DAG model." In this model, two direct paths have been added, one between nodes Vocabulary and Phonemic awareness, and one between nodes MA lexical sentence completion and Phonemic awareness. These two direct paths are directed to explain performances on Phonemic awareness task (depicted as blue arrows in **Figure 3**). These two direct paths resulted in different connections strength with a standardized coefficient of: 6.65 between Vocabulary ➔ Phonemic awareness; 7.43 between Listening comprehension ➔ Phonemic awareness; and 4.66 between MA lexical sentence completion ➔ Phonemic awareness.

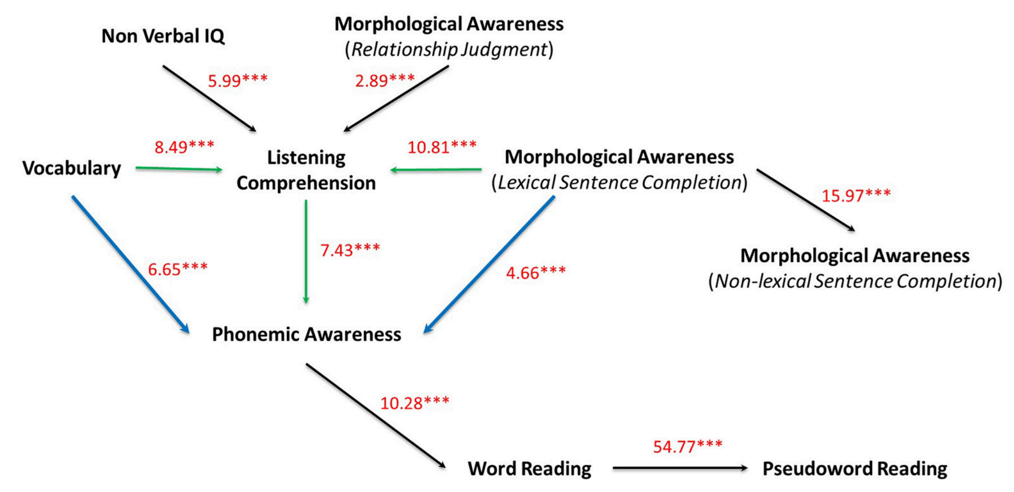

FIGURE 3 | Confirmatory and directed Extended graph (DAG) on all variables. Direct paths between Vocabulary and MA lexical sentence completion to Phonemic awareness are depicted in blue, indirect paths are depicted in green. Standardized model parameters (z-transformed regression coefficients) obtained by structural equation method are depicted on each directed edge with respective *p*-values (***$p < 0.001$).

To summarize the results obtained, a summary of fit indices for Extended DAG model, the DAG model, along with the *minForest* model, is presented in **Table 2**. As compared to the minForest and DAG models, results were more favorable for the Extended DAG model. First, the discrepancy per *df* is close to the recommended value of 0.08 (Miyake et al., 2000) with RMSEA of 0.088 and 95% CI [0.080–0.991]. Second, the χ^2 of the Extended DAG model is lower than for the *minForest* and DAG models representing a better fit [$\Delta\chi^2_{(2)} = 174.92–127.01$; $p < 0.001$]. Third, all the fit indices indicated an acceptable fit: CFI = 0.93; GFI = 0.94; TLI = 0.90; IFI = 0.93. and finally, AIC and BIC indices for the Extended DAG model (34824.362, and 34846.444, respectively), suggest that the Extended DAG model is the most parsimonious and well-fitting model, since a model that yields the smallest value of AIC is considered best (see for example Finkenauer et al., 1998).

DISCUSSION

The goal of this study was to investigate the involvement of morphological knowledge in the very early stages of reading acquisition, before reading comprehension can be assessed, among a very large sample of 703 French first-graders from low SES families. In particular, we wanted to identify the network of oral language skills (vocabulary, listening comprehension, phoneme awareness, morphological awareness) that influenced the acquisition of decoding (pseudoword naming) and word recognition (word naming) abilities. In doing so, we have introduced the use of a graphical modeling approach to the data. This powerful method allows examination of how these skills are directly and indirectly related; the potential correlational relationships between all these skills being taken into account at the same time. As advocated by Kiiveri and Speed (1982), we followed up the graphical modeling approach using SEM analysis, which allowed us to refine further our theoretical framework of the very early stages of reading. To our knowledge, this particular statistical analysis has never been applied to data collected on reading acquisition skills, and this may explain some of the new conclusions it appears to bring to the field.

Which Oral Language Skills Are Involved in the Early Stages of Low SES Reading Acquisition?

The results show that a set of oral language skills are involved, directly or indirectly, in the very early stages of decoding and word reading acquisition. In the results we obtained, listening comprehension is at the heart of this acquisition (this variable is called an unshielded collider in graphical modeling terminology, see Edwards, 2000). This has been often claimed (Hulme and Snowling, 2013) but has only been tested indirectly using regression analyses which control for verbal ability (for example, Lonigan et al., 2000). Some studies have also shown that one component of listening comprehension skills, namely vocabulary, predicted significant variance in irregular word reading in first grade, even after phonemic awareness and decoding were controlled for Ouellette and Beers (2010). Our graphical modeling approach showed that when all the correlations between all of the oral language components used in our study are taken into account, listening comprehension exerts a direct influence on the development of the main predictor of decoding and word reading skills, which is phoneme awareness (Law and Ghesquière, 2017).

We also found that phoneme awareness directly influenced visual word recognition, which in turn directly influenced decoding skills. This set of results may at first glance appear contradictory with a large body of evidence reporting that word decoding skills enhanced by phoneme awareness is one foundation of word reading skills (see for a review Ouellette and Beers, 2010; Sprenger-Charolles and Colé, 2013). However, it is important to remember here that the children in this sample are in the first 3 months of formal reading instruction and their grapheme-phoneme conversion skills may be too limited to read words on the basis of phonological information alone. As a result, lexical knowledge is likely to be involved in the early stages of the acquisition of the decoding process, as suggested in the graphical modeling analysis which showed that word reading skills exerted a direct and sole influence on pseudoword reading skills. Furthermore, at this very early stage of acquisition, all of the processes in the acquisition of decoding skills would appear to be dependent on lexical knowledge as the analysis also demonstrated that both listening comprehension and vocabulary have a direct influence on the development of phoneme awareness (and also morphological awareness). Ouellette and Beers (2010) reported that vocabulary and phoneme awareness explained unique variance of word reading skills in first grade but they did not show how these two skills exert their influence. Note that vocabulary also has an indirect influence on phoneme awareness via listening comprehension skills. Thus as Ouellette and Beers (2010), Metsala and Walley (1998) and Walley et al. (2003) (but see also, Hulme et al., 2002; Nation, 2008) claimed, vocabulary is a powerful determinant of the development of phoneme awareness, because vocabulary growth needs more accurate phonemic representations of words in order to avoid misleading recognition of very phonologically similar words. This process (accurate phonemic analysis) directly impacts the development of phoneme awareness.

Our data indicate that oral language skills are central to the very earliest phases of reading acquisition and expand upon the SVR model that considers word recognition and oral language comprehension skills to be distinct abilities. Our results show that they are not: decoding and word reading were influenced by the oral language skills examined in our study via phoneme awareness. However, contrary to Ouellette and Beers (2010) vocabulary did not exert a direct influence on word reading but rather operated indirectly via phoneme awareness. As explained above, this may be due to the fact that the children in the present study were at the very beginning of using decoding procedures. Thus we would like to outline the dominant position (for example, Hulme and Snowling, 2013), according to which semantic/lexical knowledge may only influence reading comprehension but rather think it will also influence word reading acquisition strongly although indirectly. This is in line with Laing and Hulme (1999) suggesting that lexical knowledge would be involved in very early reading acquisition, when they demonstrated that young children's efficiency at learning written abbreviations for words in the earliest stages of reading was dependent upon the imageability of those words.

What Influence Does Morphological Awareness Have in the Early Stages of Low SES Reading Acquisition?

Our data show that the components of morphological awareness tested (Relationship Judgment and Sentence Completion) are related independently to listening comprehension and are not directly connected to each other. The Relationship Judgment task was performed better than the Sentence Completion task (both lexical and non-lexical versions). This confirms the findings of Duncan et al. (2009) with both English-speaking and French-speaking first graders and suggests that these tasks measure different aspects of morphological knowledge. Indeed, Carlisle and Nomanbhoy (1993) demonstrated that these two tasks were explained by different factors: whereas Relationship Judgment was only explained by vocabulary, Sentence Completion was explained by both vocabulary and phoneme awareness. This is consistent with the observed influence of Sentence Completion on phoneme awareness in the present study. In line with Carlisle (1995), this direct relationship suggests that morphological awareness may foster growth in phonemic awareness as children learn to detect systematic phonological variations occurring in morphologically-related words, which are semantically motivated (as is the case in words sharing derivational affixes: suffixes and prefixes). Casalis and Colé (2009) reported results that partly support this interpretation from a training study with kindergarteners using phonological training, morphological training and also a control group, who did not receive any training. Oral language awareness tasks were used for the training and all three groups received pre- and post-tests in phonological and morphological awareness in order to study the potential transfer effects of the training (from morphology to phonology and vice versa). While phonological training helped children to segment speech into morphemic constituents (morphemic segmentation task), it did not have any effect on the derivational process itself (lexical production task). Likewise, morphological awareness training was not found to help children to segment words into phonemes but it did improve their sensitivity to sound (phoneme oddity task).

Of course, one cannot exclude the possibility that the explicit/implicit dimension differences can also explain some of the differences in task performance (Duncan et al., 2009). Moreover, as we hypothesized, the non-lexical sentence completion task is dependent on the morphological knowledge needed to perform the lexical version of the task. The more explicit manipulation of morphological knowledge required in the non-lexical version made the task more difficult as the results showed lower performance levels in the non-lexical task (for similar results, see Duncan et al., 2009).

Our results also show that morphological awareness has only an indirect influence on word reading skills through phoneme awareness and listening comprehension. The lack of a direct contribution from morphological awareness to word reading is consistent with results from typically developing French first-graders (Casalis and Louis-Alexandre, 2000) and from English-speaking first-graders from low SES families (Apel et al., 2013b). One can hypothesize that this result arose because children were in the very early stages of reading acquisition. Although one cannot exclude the possibility that the particular morphological tasks used may be partly responsible for this result (Apel et al., 2013b), it is important to note that we chose two morphological awareness tasks that had previously been shown by Carlisle and Nomanbhoy (1993) to explain variance in first grade word reading. So the interpretation we consider is that when a large range of oral language tasks is used (as it is our case), the contribution of each of skills might be spread over all the skills taken into account so that it would impact their own contribution.

Finally, we found that vocabulary and morphological awareness made independent contributions to word reading. For both variables, these contributions came via indirect links to listening comprehension as well as via direct links to phonemic awareness. This contrasts with numerous studies that have found that morphological awareness and vocabulary are strongly linked (e.g., Nagy et al., 2006; Sparks and Deacon, 2015). Ramirez et al. (2013) reported that kindergarten morphological awareness was related reciprocally to vocabulary; each made an independent contribution to development in the other. One reason for this discrepancy might be due to the low levels of vocabulary of the low SES children in our study (see Bara et al., 2007 for a more detailed report), which may have prevented direct links with morphological awareness. This would be in line with Spencer et al. (2015) who claimed that "*morphological awareness is an integral part of vocabulary knowledge and may even be considered an additional facet of an individual's depth of knowledge*" (p. 980). But another possibility is that, according to Tighe and Schatschneider (2015) using CFA to explore the relationship between vocabulary knowledge and morphological awareness in adult students, because the construct of morphological awareness is multidimensional, some aspects of this construct would be separate factors from vocabulary knowledge. So more researches are needed to further investigate these relationships.

Future research will also need to answer to one of the limitations of our study that did not take into account the potential influence of plurilingualism of the families of the children. Because, as Ramirez et al. (2013), pointed out in socially disadvantaged areas, linguistic and cultural minorities are often highly represented.

To conclude, our results show that the influence of higher-order skills (vocabulary, morphological awareness, non-verbal capacities) on the earliest phases of word reading and decoding is indirect via listening comprehension. This finding allows two apparently contradictory claims to be reconciled, namely, semantic factors influencing only reading acquisition vs. influencing word reading skills. Additionally, our results also raise concerns about the need for careful reporting of the timing of assessments during the first year of formal reading instruction when word reading and decoding develop so quickly.

The graphical modeling approach has enabled us to produce a clear picture of the network of oral language skills involved at the very outset of low SES reading acquisition. Our data showed that vocabulary knowledge and morphological awareness can be very powerful factors in the emergence of phoneme awareness. While most training studies have focused on only one of these skills (Apel et al., 2013a; Kim et al., 2013; Apel and Diehm, 2014), Ramirez et al. (2013) trained both skills in kindergarteners from low SES backgrounds but, nevertheless, were unable to identify their impact on the development of word reading skills. Morphological awareness tasks offer the means to tap the development of knowledge about both oral and written language. The Relationship Judgement task assesses awareness of the semantic relationship between words and as such is a powerful tool in learning new words from spoken language. The lexical Sentence Production task was also found to influence listening comprehension but interestingly also enhanced phoneme awareness. Therefore, our study indicates that morphology can have varied and specific influences on reading acquisition among low SES groups.

The results of this study as well as those of Apel et al. (2013a) show the importance of training morphological skills in children from low SES backgrounds. In France, in the reading manual Crocolivre (Gombert et al., 2000-2002) for children from 1st grade to 2nd grade, systematically teaches the morphology of words. This teaching should therefore be systematized from the beginning of the first grade.

AUTHOR CONTRIBUTIONS

PC: Experiment design, data collection and analysis, writing article; EC: Data analysis, writing article; LD: Writing article; AT: Data analysis; EG and LS-C: Experiment design, data collection; AE-A: Data analysis, writing article.

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Development and Relationships Between Phonological Awareness, Morphological Awareness and Word Reading in Spoken and Standard Arabic

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This study addressed the development of and the relationship between foundational metalinguistic skills and word reading skills in Arabic. It compared Arabic-speaking children's phonological awareness (PA), morphological awareness, and voweled and unvoweled word reading skills in spoken and standard language varieties separately in children across five grade levels from childhood to adolescence. Second, it investigated whether skills developed in the spoken variety of Arabic predict reading in the standard variety. Results indicate that although individual differences between students in PA are eliminated toward the end of elementary school in both spoken and standard language varieties, gaps in morphological awareness and in reading skills persisted through junior and high school years. The results also show that the gap in reading accuracy and fluency between Spoken Arabic (SpA) and Standard Arabic (StA) was evident in both voweled and unvoweled words. Finally, regression analyses showed that morphological awareness in SpA contributed to reading fluency in StA, i.e., children's early morphological awareness in SpA explained variance in children's gains in reading fluency in StA. These findings have important theoretical and practical contributions for Arabic reading theory in general and they extend the previous work regarding the cross-linguistic relevance of foundational metalinguistic skills in the first acquired language to reading in a second language, as in societal bilingualism contexts, or a second language variety, as in diglossic contexts.

Keywords: Arabic, diglossia, linguistic distance, phonological awareness, morphological awareness, word reading accuracy, word reading fluency

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INTRODUCTION

Arabic is a typical case of diglossia (Ferguson, 1959), which is a sociolinguistic context in which speakers within a single speech community simultaneously use two varieties of a language: one for everyday communication and another for formal interactions and writing. Diglossia is a widespread phenomenon (Myhill, 2014). In Arabic, children grow up speaking Spoken Arabic (SpA) for everyday speech at home and in the neighborhood and Standard Arabic (StA) for reading and writing, as well as for formal interaction, as within the classroom (Amara, 1995;

Saiegh-Haddad and Henkin-Roitfarb, 2014). While dialects of SpA are different between different nationality-based Arabic-speaking communities (e.g., Versteegh, 1997, 2001), StA is largely uniform across the Arabic-speaking world (Holes, 2004) and shares many linguistic characteristics such as phonology, morphology, syntax, and lexicon. At the same time, all SpA vernaculars are different from StA (Maamouri, 1998).

This linguistic distance traverses all linguistic domains and is remarkable in the phonology and in the lexicon. For instance, a recent study recorded 5-year-olds as they were interacting with each other on a regular kindergarten day. A corpus of about 4,500 different word types were collected and analyzed for their lexical–phonological distance from their equivalent form in StA. The analysis showed that only about 21% of the words in the spoken lexicon of children consisted of identical words, that is, words that maintain an identical lexico-phonological structure in StA, whereas the remaining words were divided almost evenly between cognate words (with overlapping phonological forms in SpA and StA) and completely different unique forms in SpA and StA (Saiegh-Haddad and Spolsky, 2014).

This linguistic distance between SpA and StA was also found to affect children's phonological processing skills, such as phonological awareness (PA), phonological processing, naming (Saiegh-Haddad, 2003, 2004, 2007; Saiegh-Haddad et al., 2011; Asaad and Eviatar, 2013; Saiegh-Haddad and Ghawi-Dakwar, 2017), children's lexical and morpho-syntactic skills, such as negation and inflection (Khamis-Dakwar and Froud, 2007; Khamis-Dakwar et al., 2012), and ultimately their reading skills (Saiegh-Haddad, 2005; Saiegh-Haddad and Schiff, 2016; Schiff and Saiegh-Haddad, 2017). These findings indicate difficulty among native-speaking children in constructing accurate and stable phonological representations for linguistic structures that are not within their spoken vernacular, which impacts processing at all linguistic levels. This diglossia effect has been argued to be a central feature of reading development in Arabic (Saiegh-Haddad and Everatt, 2017).

Besides linguistic distance between SpA and StA, reading acquisition in Arabic implicates another important feature. This is the use of diacritics in the Arabic orthography to encode phonological information necessary for reading accuracy. Orthography is defined as a set of principles that define the basic units of the writing system (Perfetti et al., 2007). However, orthographies vary in the nature of mapping of phonemes onto graphemes; a transparent orthography is considered easier to decode than an opaque orthography in which phoneme and letter correspondences are less regular (Schiff, 2012). Vowelization refers to the use of optional diacritics that the orthography employs to represent vowels and other features of word articulation including, in the case of Arabic, null vowelization, consonant gemination, as well as morpho-syntactic markers of case and mood. Saiegh-Haddad and Henkin-Roitfarb (2014) distinguish two systems of optional diacritics in Arabic. The first comprises phonemic diacritics which include the five diacritical marks mapping short vowels, consonant lengthening/doubling, and null vowelization; these diacritical marks can appear on almost all of the letters, and they map meaningful phonemic information about the word lexeme. The second set of diacritics, however, is morpho-syntactic; they appear at the end of the word stem and map syntactic roles and properties including case and mood. Morpho-syntactic inflections have disappeared from all dialects of SpA but have been preserved in StA (Maamouri, 1998). The modal endings of verbs and the case endings of definite nouns consist of the three Arabic short vowels and are orthographically represented using the same phonemic diacritics. However, the case endings of indefinite nouns are phonologically and orthographically distinct from the other diacritical marks (for a comprehensive discussion, see Saiegh-Haddad and Henkin-Roitfarb, 2014).

This two-layered system of optional diacritics results in two orthographies: a voweled orthography largely transparent: regular and consistent (Schmalz et al., 2015) and an unvoweled orthography, which is an abjad (Daniels, 1992) that is phonologically underspecified and maps only the consonants and long vowels of words, but is morphologically regular and maps both the root and the consonantal and long vowel material of word-patterns. Hence, the Arabic orthography may be considered shallow when it is used in its voweled form. However, due to its root and word-pattern morphological structure, and given the fact that all content words abide by a templatic vocalic pattern, it is possible to recover the phonological information encoded by diacritics, and which is missing in unvoweled Arabic, using the word-pattern morphological structure. This yields the unvoweled form morphologically regular and transparent, though it is phonologically underspecified and deep. For instance, the unvoweled orthographic form MTurk is orthographically deep because the short vowel in the first syllable is missing. However, the first consonant /m/ represented by the letter {M} and the long vowel /u:/ represented by the letter {U} (both represented by letters) indicate the word-pattern to the reader and, hence, the missing short vowel, which in this case can only be /a/. The default Arabic orthography is unvoweled, whereas vowelization is used in the teaching of reading as well as in religious and literary texts.

The question of role that diacritical vowelization has in reading in Arabic has been studied extensively. This research shows that diacritics facilitate reading accuracy and comprehension in both poor and skilled readers (Abu-Rabia and Siegel, 1995; Abu-Rabia, 1997a,b, 1998, 2001). More recent research, however, paints a different picture and shows that diacritic vowelization may result only in more accurate reading in the early grades and in reading disabled children (Schiff and Saiegh-Haddad, 2017). Moreover, diacritical vowelization has been found to reduce reading fluency across all grades from childhood to adolescence (Saiegh-Haddad and Schiff, 2016). It is noteworthy that early research on the role of diacritical vowelization did not distinguish between phonemic and morpho-syntactic diacritics, and this might explain some of the mixed patterns of results observed. Vowelization was also found to burden the perception of words (Abdulhadi et al., 2011; Eviatar and Ibrahim, 2014) and to increase the number and duration of eye fixations (Roman and Pavard, 1987).

The co-occurrence of diglossia and vowelization in Arabic, as in many Arabic-script-based orthographies in Africa (Mumin and Versteegh, 2014), provides a unique context for testing the independent and the interactive effect of these two factors on reading across development. It also allows an investigation of the relative role of metalinguistic factors, such as phonological and morphological awareness in reading in the two varieties and in the two orthographies. This is an important question because "vowelization determines the phonological transparency of the orthography that readers deal with, and this might interact with the effect of linguistic distance on reading in different age groups" (Saiegh-Haddad and Schiff, 2016, p. 4). Moreover, voweled Arabic is phonologically transparent but voweled Arabic is morphologically transparent. This suggests possible differences in the relative role of phonological versus morphological awareness skills to reading in the two orthographies across development (Saiegh-Haddad and Taha, 2017).

The role of linguistic distance and diacritic vowelization on Arabic reading has been the focus of many research studies (Ibrahim, 1983; Eviatar and Ibrahim, 2014; Schiff and Saiegh-Haddad, 2017). Rather than addressing this question, the current study focuses on the development and cross-variety relationships across the school years. It examines the development of and the relationships between PA, morphological awareness, and word reading (voweled and unvoweled) in Arabic across the school grades. The study also probes whether metalinguistic skills in SpA, the variety that children acquire first and use for everyday speech, predicts their reading in Standard Arabic, the language of literacy and which they usually acquire later. This question is critical because children first learn to read in a language that they do not speak, and therefore they graft StA reading on the oral language skills they have developed in SpA. The question of whether literacy-related skills that they develop in SpA predict their reading success in StA is important, and it has significant practical implications for instruction and assessment. Moreover, reading instruction in Arabic is agnostic of the linguistic distance between SpA and StA, and it often does not capitalize on children's metalinguistic and other literacy-related skills in SpA to leverage acquisition of reading in StA (Saiegh-Haddad and Everatt, 2017). It is to be remembered that SpA, as it is used in the context of this study, refers to linguistic structures (phonemes, morphemes, and words) that are used both in SpA and in StA, rather than structures that are only used within SpA and which are not encoded in Arabic orthography.

Phonological and Morphological Awareness Skills in Reading

Phonological awareness (PA) refers to one's awareness of, and access to, the sound structure of oral language (Adams, 1990; Torgesen et al., 1997). The role of PA in learning to read has been strongly established in both L1 and L2 (Wagner and Torgesen, 1987; August and Shanahan, 2006; Saiegh-Haddad and Geva, 2008) including in Arabic (al-Mannai and Everatt, 2005; Elbeheri and Everatt, 2007; Farran et al., 2012; Saiegh-Haddad and Taha, 2017). To acquire the alphabetic principle and to accurately map grapheme to phonemes, the child must acquire the ability to analyze, synthesize, and manipulate constituent phonemes (Stanovich, 1986). Indeed, research shows that PA is concurrently correlated with reading performance and also predicts future reading ability (Casalis and Colé, 2009). Specifically, kindergartners with strong PA skills make better progress in reading than children with low PA skills (Gough and Tunmer, 1986; Wagner and Torgesen, 1987; Torgesen et al., 1997). Moreover, individual differences in kindergartners' PA explain variations in reading abilities from kindergarten through fourth grade (Wagner et al., 1997). This suggests a causal connection between PA and individual differences in the ability to decode words and non-words (cf. Share, 1995).

Although phonological recoding at the level of grapheme-to-phoneme decoding is essential for the development of successful reading, alphabetic orthographies represent two layers of language: phonemes and morphemes. Therefore, awareness of morphemes should contribute to reading development in an alphabetic orthography besides awareness of phonemes (Verhoeven and Perfetti, 2003; Saiegh-Haddad and Geva, 2008). Moreover, typological differences between languages and orthographies are often noticeable in the morphological structure with some orthographies, like English, being scarce morphologically (often not depicting word-internal morphological structure), as against other orthographies like Arabic and Hebrew (Semitic languages) which are very rich morphologically and where the majority of words encode an internal morphological structure. Because writing systems are isomorphic (Verhoeven and Perfetti, 2003), that is they represent the morphological structure though to different degrees of explicitness, these differences in morphological richness are often also reflected in the orthographic structure of words in different languages and this, in turn, has repercussions for morphological awareness development and processing in reading and spelling in different languages (e.g., Bryant et al., 1999; Assink et al., 2000; Ravid and Bar-On, 2005; Gillis and Ravid, 2006; Saiegh-Haddad and Geva, 2008; Saiegh-Haddad, 2013; Taha and Saiegh-Haddad, 2016, 2017; Saiegh-Haddad and Taha, 2017). For example, In the Arabic writing system, the morphemic units in words are not concatenated as is the case in English or French. Because the root is inserted within fixed slots in the pattern, the word structure is represented and perceived differently from non-Semitic languages (Boudelaa, 2014).

Morphological awareness is defined as the ability to reflect on and manipulate the constituent morphemes of words, the smallest meaningful word units (Carlisle, 1995). Research shows that readers develop awareness of the morphological structure and demonstrate the understanding of morphological associations between words (Carlisle, 1995; Bryant et al., 2000; McBride-Chang et al., 2003). This ability has been shown to contribute to decoding, word recognition, and reading comprehension (Deacon and Kirby, 2004; Nagy et al., 2006; Ravid and Schiff, 2006a,b; Schiff et al., 2011). However, recent views suggest a two-way interaction between morphological awareness, reading comprehension (Perfetti et al., 2005; Deacon et al., 2014), and word reading accuracy (Deacon et al., 2013). As such, morphological awareness assists children comprehend written texts both through a direct relationship with reading comprehension and through a more indirect relationship by helping them to encode individual words, which, in turn, promote the skills of reading comprehension (Deacon et al., 2014).

In the Arabic writing system, the two basic morphemic units in words: the root and the word-pattern are not linearly concatenated, as is the case in English or French. Yet, they are regularly represented in the letter structure of the word as explained above. The root is a strong semantic entity and is a constituent of the stem of almost all content words in Arabic. All this implies the salience of the root in processing Semitic Arabic. In fact, the root and the word-pattern appear to be central to the way that words are organized in the Arabic lexicon (Boudelaa, 2014). It also appears to be implicated in early reading and spelling in Arabic (Saiegh-Haddad, 2013; Taha and Saiegh-Haddad, 2016, 2017), to be impaired in reading disabled readers (Abu-Rabia et al., 2003; Saiegh-Haddad and Taha, 2017), and to be used as a compensatory mechanism among reading disabled to aid their phonological deficits (Saiegh-Haddad and Taha, 2017).

Given the morphological richness of Arabic (Saiegh-Haddad and Henkin-Roitfarb, 2014) and the proliferation of morphology in the linguistic and orthographic representation of the word and, in turn, in word reading and spelling in Arabic (Abu-Rabia et al., 2003; Abu-Rabia, 2007; Saiegh-Haddad, 2013, 2017; Taha and Saiegh-Haddad, 2016, 2017; Saiegh-Haddad and Taha, 2017; Tibi and Kirby, 2017), the study of morphological processing in Arabic is highly warranted. Moreover, because there are differences between SpA and StA in inflectional morphology, with some StA inflectional categories not encoded in SpA, such as dual and plural feminine verbal forms, and in derivational morphology, with some StA word-patterns not used in SpA (Saiegh-Haddad and Henkin-Roitfarb, 2014), it is critical to study the role of morphological awareness in reading Arabic, as well as the relevance of SpA morphology in particular to reading in StA (Roman et al., 2009; Wolter et al., 2009).

The goal of the present study is to examine the development of PA and morphological awareness in SpA and StA separately. It further explores word reading in SpA among Arabic-speaking children compared with their StA word reading with the objective of probing quantitative differences between these abilities in the two language varieties and their relation to StA reading ability. The question of whether the children's SpA metalinguistic awareness and word reading show different developmental trajectories, and whether they show different patterns of relationships with reading in StA, has never been studied. Moreover, earlier research never addressed this question in the reading of voweled versus unvoweled words separately. These questions are critical given the fact that children are taught to read in StA whereas the language they master and naturally use is SpA, a language that differs from SpA in all linguistic domains including in the phonological and in the morphological structure. This developmental examination is also warranted given the phonological transparency of voweled Arabic, yet the morphological transparency of unvoweled Arabic. This might impact the relevance of phonological versus morphological awareness to reading in different grades an in voweled versus unvoweled Arabic.

The Current Study

To date, only one study has investigated the effect of diglossia on the development of reading skills in voweled and unvoweled SpA and StA among typically developing readers (Saiegh-Haddad and Schiff, 2016) and another tested this question in reading disabled children (Schiff and Saiegh-Haddad, 2017). The results of these studies underscore the role of diglossia and diacritical vowelization in understanding reading development in Arabic. The present study extends this previous investigation to the effect of diglossia on the skills of PA and morphological awareness as well. A second goal of this study is to investigate the contribution of PA and morphological awareness in SpA to StA word reading. We hypothesized that children would demonstrate a higher level of SpA than StA PA and morphological awareness because they experience greater exposure to SpA. We also predicted that SpA PA and morphological awareness would consistently provide a unique contribution to StA word reading. Finally, it was predicted that differences between SpA and StA phonological and morphological awareness would decrease with development, due to increasing exposure to StA through schooling. Moreover, the role of PA in predicting reading was expected to decrease with development, whereas the role of MA was expected to increase. It is noteworthy that SpA, as it is used in the context of this study, refers to linguistic structures (phonemes, morphemes, and words) that are used both in SpA and in StA, rather than to unique SpA structures that are not encoded in Arabic written language.

MATERIALS AND METHODS

Participants

A total of 100 students participated in the study: 20 second graders (age: M = 7;7, SD = 3.00 months), 20 fourth graders (age: M = 9;6, SD = 4.00), 20 sixth graders (age: M = 11;6, SD = 3.72), 20 eighth graders (age: M = 13;6, SD = 4.10), and 20 tenth graders (age: M = 15;5, SD = 3.08). There were 10 female and 10 male students in each grade level. All participants were native speakers of a local dialect of Palestinian Arabic spoken in the north of Israel and were sampled from two public schools in the north school district with an officially ranked middle socioeconomic background. No participant had reported neurological, language, or psycho-educational difficulties. Data collection took place during the winter–spring of 2016. Official authorization by the chief scientist of the Ministry of Education, as well as by Bar-Ilan University ethics committee was obtained. Written parental consent was obtained for all children participating in the study.

Materials

Phonological Awareness

Two sets of PA tasks were developed: one in SpA and another in StA. SpA tasks used phonological structures (phonemes and syllabic structures) that are used in both StA and the SpA vernacular used by the children, whereas StA tasks targeted phonological structures that are used only in StA. Phonological structures (mainly phonemes) that are used only in SpA were not targeted because these may not have a conventional orthographic representation, namely, a grapheme that represents them in the written language. Two tasks per language variety (SpA and StA) were developed: full phoneme segmentation equally targeting initial, final, and medial phonemes (*N* items = 15 per language variety; Cronbach alpha: SpA 0.89 and StA 0.90) and phoneme deletion (*N* items = 15 per language variety; Cronbach alpha: SpA 0.87 and StA 0.90). One score was assigned for completing each item correctly and a zero score for any kind of error. No partial scores were assigned. The PA score is a total score obtained on both the phoneme segmentation and the deletion tasks per each language variety separately. It is important to note that the correlation between the two tasks was high, and therefore we used a composite score.

Morphological Awareness

Two sets of morphological awareness tasks were developed: one in SpA (*N* items = 40) and another in StA (*N* items = 40; equal number of inflectional and derivational morphology) SpA tasks targeted morphological units that are used in both StA and the SpA vernacular used by the children (Cronbach's alpha: inflection 0.82, derivation 0.91), whereas StA tasks targeted morphemes that are used only in StA (Cronbach's alpha: inflection 0.81, derivation 0.90). The morphological tasks employed the *Word Analogy* format adapted from Nunes et al. (1997). This is an oral task in which students are required to produce a missing word that follows a certain pattern from a given set of word pairs. For example, run: runs; walk: ______ (walks). For example, for testing inflectional morphology, the following item was used: أحْضَرَ- أحْضَرنا .... أنجَزَ- He brought – We brought; He achieved, We _________, and for testing derivational morphology, the following item was used: كَتَب- كاتِب .... هَرَب- Wrote-writer; Ran-. . . . . . .

Word-Reading Measures

Twelve different word-level reading tasks were constructed that measured accuracy and fluency of reading SpA and StA voweled and unvoweled real and pseudowords (*N* = 110 items per task). For the real word reading tasks, we selected SpA words with identical word forms in StA and SpA (e.g., /*ba:b*/ "door,"/*na:m*/ "slept,"/*bi:ʔa*/ "environment," and /*ʔistaɣall*/ "exploited") and StA words that exist in StA but not in SpA. The latter word type comprised cognate words, which have similar forms in StA and SpA (e.g., StA /θ*alʒ*/- SpA /*taliʒ*/ "snow"), and unique words, which are used in StA but not in SpA (StA /*ʒara:*/- SpA /*rakad*/ "ran"). Words were matched on phonemic length (three to 12 phonemes), syllabic length (one to five syllables), orthographic length (three to ten letters), morphological structure (one to four morphemes), and on word familiarity/frequency as determined by 10 Arabic language experts based on a five-point scale. StA words across tasks were also matched on the type of the StA linguistic structure they encoded (phoneme, syllable structure, and morphological template). Words within tasks progressed in linguistic complexity and frequency. Separate lists of words were presented in the voweled (phonemic diacritics only) and unvoweled orthography. None of the unvoweled words were homographic or could be read in more than one way based on the specific diacritics that were missing. SpA and StA pseudowords were derived from the voweled words by changing one or two letters in the word while ensuring that the pseudowords abided by SpA and StA phonotactic rules, respectively (e.g., SpA /*xama:d*/ from the word /*šama:l*/ "north" and StA /«*ala:b*/ from the word /«*aha:b*/ "going"). Pseudowords across tasks were matched on phonemic length, orthographic length, and syllabic complexity.

Procedure

Tasks were administered individually by a Ph.D. student, a native speaker of the dialect targeted in this study. Task administration took place in a quiet room at school. The order of administration of the fluency and accuracy sets was counterbalanced, and tasks within each set were intermixed. Task administration started after three practice trials. To measure accuracy, participants were instructed to read the list of words as accurately as possible and testing was discontinued after five consecutive errors. Accuracy was calculated as the number of words read accurately out of the total number of words (110 items). To measure fluency, participants were instructed to read the list of words as accurately and as quickly as possible, and testing was discontinued after 1 min. Reading fluency was calculated as the number of words read accurately in the first 45 s of testing. Data collection took place in May, 2 months before the end of the school year. Analysis participants' performance on the reading accuracy tasks showed satisfactory Cronbach's alpha reliability levels exceeding 0.7.

RESULTS

Phonological and Morphological Awareness in SpA and StA Tests

In order to examine performances on the phonological and morphological awareness tests, two 5×2 repeated measures analyses of variance (ANOVA) were conducted, with grade (second, fourth, sixth, eighth, and tenth) as the between-subject variable, and language variety (SpA and StA) as the within-subject variable: one analysis for the PA and one for the morphological awareness.

Phonological Awareness in SpA and StA Tests

The main effect of language variety was found to be significant, indicating greater performance on the SpA than on the StA test. The main effect of group was also significant, indicating that the students in the higher grades performed better than those in the lower grades (**Table 1**).

The two-way interaction of grade × language variety was significant on the PA test. Bonferroni analysis indicated that the second and fourth grades performed better on the SpA compared to the StA. No significant differences between the performances on the SpA tests and the StA tests were found in the sixth, eighth, and tenth grades (**Figure 1**).

Morphological Awareness in SpA and StA Tests

The main effect of language variety was found to be significant, indicating greater performance on the SpA than on the StA test. The main effect of group was also significant, indicating that the

TABLE 1 | Means (and SD) of phonological, morphological, and morpho-syntax awareness in SpA and StA tests by grade.

		Language variety						
		SpA		*StA*				
Tests	**Grades**	***M***	***SD***	***M***	***SD***	***F* grade**	***F* language variety**	***F* interaction**
Phonological awareness	Second	47.48	28.43	25.82	20.92			
	Fourth	69.00	13.16	52.33	9.18			
	Sixth	60.83	15.93	58.17	17.59			
	Eighth	82.22	12.06	80.93	17.59			
	Tenth	82.54	9.66	82.00	10.40	30.11***	50.69***	13.45***
Morphological awareness	Second	73.25	16.62	56.06	16.29			
	Fourth	90.62	7.82	76.00	13.40			
	Sixth	91.00	10.34	81.82	15.65			
	Eighth	96.50	4.17	94.87	4.23			
	Tenth	97.25	4.21	92.56	7.47	29.67***	124.62***	11.87***

***$p < 0.001$.

students in the higher grades performed better than those in the lower grades (**Table 1**).

The two-way interaction of grade × language variety was significant on the morphological awareness test. Bonferroni analysis indicated that the second, the fourth, and the sixth grades performed better on the SpA compared to the StA. No significant differences between the performances on the SpA tests and the StA tests were found in the eighth and tenth grades (**Figure 2**).

Reading Accuracy and Fluency in Voweled and Unvoweled SpA and StA Tests

In order to examine performances on the reading accuracy and fluency tests, four 5×2 repeated measures analyses of variance (ANOVA) were conducted, with grade (second, fourth, sixth, eighth, and tenth) as the between-subject variable, and language variety (SpA and StA) as the within-subject variable: two analyses for the performances on the accuracy tests and two analyses for the performances on the fluency tests. For the reading accuracy tests, we also conducted two 5×2 repeated measures analyses of variance (ANOVA) for the item level, with grade as the within-participants variable and language variety as the between-participants variables.

Reading Accuracy in Voweled and Unvoweled SpA and StA Tests in the Subject Level

The main effects of language variety were found to be significant, indicating greater performance on the SpA than on the StA on the two reading accuracy tests. The main effects of group were also significant, indicating that the students in the higher grades performed better than those in the lower grades (**Table 2**).

The two-way interactions of grade × language variety were significant on both voweled and unvoweled reading accuracy tests. Bonferroni analyses on both tests indicated that the second, the fourth, and the sixth grades performed better on the SpA compared to the StA. No significant

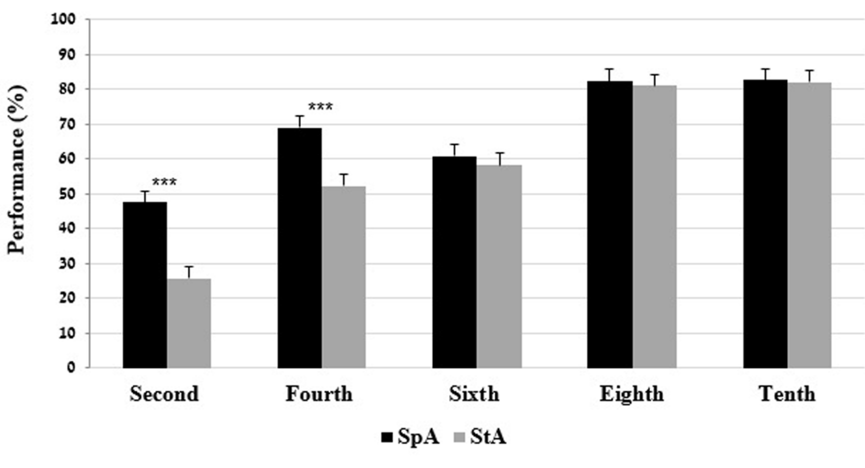

FIGURE 1 | Mean (and SE) performance on the phonological awareness test by grade and language variety. ***$p < 0.001$.

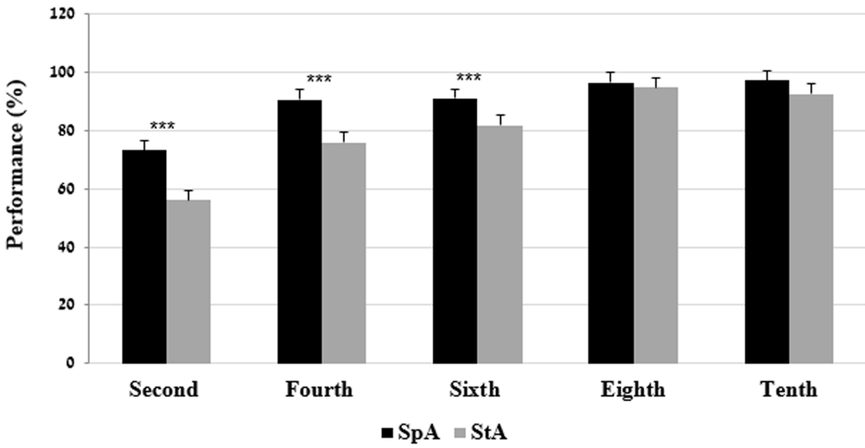

FIGURE 2 | Mean (and SE) performance on the morphological awareness test by grade and language variety. ***$p < 0.001$.

TABLE 2 | Means (and SD) of reading accuracy and fluency in voweled and unvoweled SpA and StA tests by grade.

		Language variety						
		SpA		*StA*				
Tests	**Grades**	***M***	***SD***	***M***	***SD***	***F* grade**	***F* language variety**	***F* interaction**
Phonological awareness	Second	47.48	28.43	25.82	20.92			
	Fourth	69.00	13.16	52.33	9.18			
	Sixth	60.83	15.93	58.17	17.59			
	Eighth	82.22	12.06	80.93	17.59			
	Tenth	82.54	9.66	82.00	10.40	30.11***	50.69***	13.45***
Morphological awareness	Second	73.25	16.62	56.06	16.29			
	Fourth	90.62	7.82	76.00	13.40			
	Sixth	91.00	10.34	81.82	15.65			
	Eighth	96.50	4.17	94.87	4.23			
	Tenth	97.25	4.21	92.56	7.47	29.67***	124.62***	11.87***

**$p < 0.01$, ***$p < 0.001$.

differences between the performances on the SpA tests and the StA tests were found in the eighth and tenth grades (**Figure 3**).

Reading Accuracy in Voweled and Unvoweled SpA and StA Tests in the Item Level

The main effects of language variety were found to be significant on both voweled and unvoweled reading accuracy tests [$F(1,10895) = 1074.62$, $p < 0.001$, $\eta_p^2 = 0.09$ and $F(1,10895) = 1174.48$, $p < 0.001$, $\eta_p^2 = 0.30$, respectively], indicating greater performance on the SpA than on the StA on the two reading accuracy tests. The main effects of group were also significant on both accuracy tests [$F(4,10895) = 1028.92$, $p < 0.001$, $\eta_p^2 = 0.27$ and $F(4,10895) = 524.97$, $p < 0.001$, $\eta_p^2 = 0.05$, respectively], indicating that the students in the higher grades performed better than those in the lower grades. The two-way interactions of grade × language variety were significant on both voweled and unvoweled reading accuracy tests [$F(4,10895) = 80.72$, $p < 0.001$, $\eta_p^2 = 0.03$ and $F(4,10895) = 29.16$, $p < 0.001$, $\eta_p^2 = 0.01$, respectively]. Bonferroni analyses on both tests indicated that the second, the fourth, and the sixth grades performed better on the SpA compared to the StA. No significant differences between the performances on the SpA tests and the StA tests were found in the eighth and the tenth grades.

Reading Fluency in Voweled and Unvoweled SpA and StA Tests

The main effects of language variety were found to be significant, indicating greater performance on the SpA than on the StA on the two reading fluency tests. The main effects of group were also significant, indicating that the students in the higher grades performed better than those in the lower grades (**Table 2**).

The two-way interactions of grade × language variety were significant on both voweled and unvoweled reading fluency tests. Bonferroni analyses indicated that on both the voweled and the unvoweled StA and SpA fluency tests, all the five grades performed better on the SpA compared to the StA (**Figure 4**).

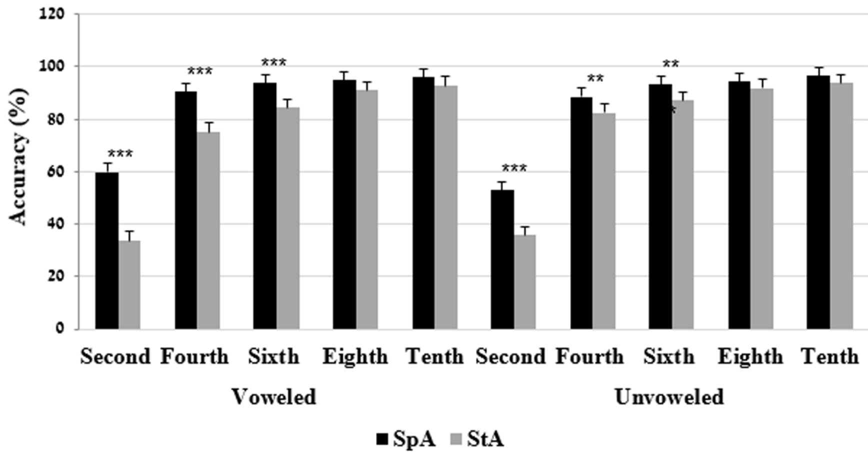

FIGURE 3 | Mean (and SE) performance on the accuracy test by grade and language variety. $^{**}p < 0.01$, $^{***}p < 0.001$.

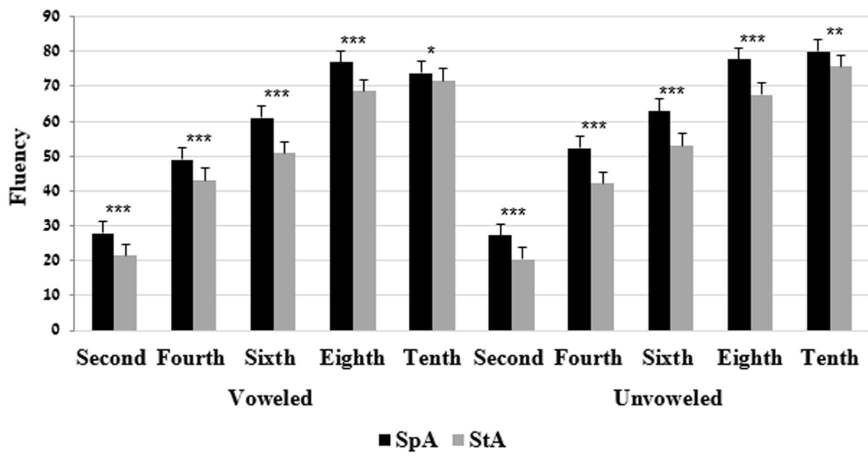

FIGURE 4 | Mean (and SE) performance on the fluency test by grade and language variety. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

Contribution of Participants' Grade and the Performances on the SpA Phonological and Morphological Awareness to the Prediction of the Performances on the Reading Accuracy and Fluency in the StA Tests

Pearson correlations were conducted in order to examine the correlations between the performances on the reading accuracy and fluency in the StA tests and the performances on the SpA phonological and morphological awareness tests (**Table 3**).

Table 3 indicates significant positive correlations that as the performances on the SpA phonological and morphological awareness tests increase, the performances on the reading accuracy and fluency in the StA tests increase, respectively.

In order to examine the contribution of the grade and the performances on the SpA phonological and morphological awareness tests to the prediction of the performances on the reading accuracy and fluency in the StA tests, we conducted four hierarchical regression analyses, two analyses for the prediction of the performance on the voweled and unvoweled reading accuracy tests and two analyses for the prediction of the performance on the voweled and unvoweled reading fluency tests. In the first step, the background characteristic – grade was entered. In the second step, the performance on the PA test were entered, and in the

TABLE 3 | Correlations between the performance on the reading accuracy and fluency in the StA tests and the performance on the SpA phonological, morphological, and morpho-syntax awareness tests.

		Phonological awareness	Morphological awareness
Accuracy	Voweled StA	0.70***	0.75***
	Unvoweled StA	0.66***	0.75***
Fluency	Voweled StA	0.62***	0.68***
	Unvoweled StA	0.60***	0.66***

$^{***}p < 0.001$.

third step, the performance on the morphological awareness test were entered. We entered the performance on the morphological awareness test in the third step in order to examine whether the performances would contribute significantly to the explained variances of the performances on the accuracy and fluency in the StA tests, beyond the background characteristic and the performance on the PA test (**Table 4**).

Table 4 indicates that the performances on the SpA PA tests added significantly 11.3 and 9.8% beyond the participants' grade to the prediction of the performance on the voweled and unvoweled StA accuracy tests (*p*s < 0.001) and 3.6 and 1.8% to the prediction of the performance on the voweled and unvoweled StA fluency tests (respectively). The positive beta coefficient of participants' grade and the performances on the SpA PA tests to the prediction of the performances on the voweled and the unvoweled StA accuracy and fluency tests indicated that as the grade and the performances on the SpA PA tests increase, the performances on the voweled and the unvoweled StA accuracy and fluency tests increase, respectively.

In the third step, the performances on the SpA morphological awareness tests added significantly 4.7 and 6.5% beyond the participants' grade and the performance on the PA test to the prediction of the performance on the voweled and unvoweled StA accuracy tests (*p*s < 0.001) and 1.9 and 1.6% to the prediction of the performance on the voweled and unvoweled StA fluency tests (*p*s < 0.01, respectively). The positive beta coefficient of the performances on the SpA morphological awareness tests to the prediction of the performances on the voweled and the unvoweled StA accuracy and fluency tests indicated that as the performances on the SpA morphological awareness tests increase, the performances on the voweled and the unvoweled StA accuracy and fluency tests increase, respectively.

Despite the low contribution of the performance on the morphological awareness test in the third step of the regression analyses, it should be noted that the significant contribution of the performance on the PA test to the prediction of the performance on the voweled and unvoweled StA accuracy and fluency tests is moderate and becomes non-significant while the performance on the morphological awareness was entered in the third step.

Mixed Effects Modeling

Using mixed effects' modeling indicated that the estimates for the fixed effect of the item level were decreased in 0.0035 and 0.0033 points per item for the accuracy in voweled and unvoweled SpA and StA tests, $p = 0.11$ and $p = 0.12$, respectively. Mixed effects' modeling analysis for the variance of the item level analysis indicated that the estimates were increased in 0.000019 and 0.000016 points per item for the accuracy in voweled and unvoweled SpA and StA tests, $p = 0.16$ and $p = 0.15$, respectively.

TABLE 4 | Results of mixed regressions for the performance on StA reading accuracy and fluency tests by participants' grade and SpA phonological, morphological and morpho-syntax awareness tests.

Dependent variables	Steps	Independent variables	*B*	SE *B*	β	*t*	R^2	ΔR^2
Voweled StA accuracy	**1**	Grade	6.70	0.58	0.76	11.54***	0.576***	0.576***
	2	Grade	4.74	0.60	0.54	7.91***		
		Phonological awareness	0.47	0.08	0.40	5.92***	0.689***	0.113***
	3	Grade	3.95	0.59	0.45	6.72***		
		Phonological awareness	0.24	0.09	0.20	2.55*		
		Morphological awareness	0.66	0.16	0.34	4.13***	0.736***	0.047***
Unvoweled StA accuracy	**1**	Grade	6.28	0.59	0.73	10.57***	0.533***	0.533***
	2	Grade	4.50	0.63	0.52	7.08***		
		Phonological awareness	0.43	0.08	0.38	5.09***	0.631***	0.098***
	3	Grade	3.59	0.61	0.42	5.84***		
		Phonological awareness	0.16	0.10	0.14	1.66		
		Morphological awareness	0.75	0.17	0.40	4.53***	0.696***	0.065***
Voweled StA fluency	**1**	Grade	6.29	0.40	0.84	15.54***	0.711***	0.711***
	2	Grade	5.36	0.46	0.72	11.74***		
		Phonological awareness	0.22	0.06	0.23	3.70***	0.747***	0.036***
	3	Grade	4.93	0.47	0.66	10.56***		
		Phonological awareness	0.10	0.07	0.10	1.31		
		Morphological awareness	0.36	0.13	0.22	2.83**	0.767***	0.019**
Unvoweled StA fluency	**1**	Grade	6.81	0.38	0.88	18.08***	0.769***	0.769***
	2	Grade	6.13	0.44	0.79	14.05***		
		Phonological awareness	0.16	0.06	0.16	2.85**	0.787***	0.018**
	3	Grade	5.72	0.45	0.74	12.82***		
		Phonological awareness	0.04	0.07	0.04	0.62		
		Morphological awareness	0.34	0.12	0.20	2.82**	0.803***	0.016**

**$p < 0.01$, ***$p < 0.001$.

DISCUSSION

The present study addressed PA, morphological awareness, and word reading in diglossic Arabic by investigating the development of these metalinguistic skills in SpA and StA, and examining the relationship between metalinguistic skills in SpA and reading in StA for both voweled (transparent) and unvoweled (opaque) words. The study also examined children from different age groups in the school system, thus providing a developmental point of view on the link between metalinguistic skills in general, and in relation to voweled and unvoweled word reading in Arabic.

Specifically, the first goal of the study was to explore performance differences on phonological and morphological awareness as well as word reading tasks among Arabic-speaking children, by comparing these tasks in SpA and StA. The examination of PA, morphological awareness, and word reading accuracy and fluency tasks yielded different results. The results showed an initial discrepancy in the second and fourth grades in PA and morphological awareness in SpA and StA words, in favor of the former, that was eliminated in the sixth and eighth grades for the two tasks, respectively. The rather quick improvement in PA compared to morphological awareness might relate to learner's gradual development in understanding the complex relations of form and meaning (Carlisle, 2010). This development of morphological awareness is effectively observed in first-, third-, and fifth-grade students. Previous research shows a significant increase between the first and fifth grades in the number of derived words that students' correctly defined (Anglin et al., 1993). These findings provide additional support for the claim that at the beginning of the reading acquisition process, children rely heavily on the phonological information that vowelization provides in order to decode words successfully. As readers acquire sufficient mastery in reading skills, the need decreases for vowelization to accurately decipher words.

The current study also showed that metalinguistic awareness in SpA was consistently higher than that in StA. These findings conform with reported evidence and they offer further evidence for the *Linguistic Affiliation Constraint* (Saiegh-Haddad, 2007) which was developed based on phonological processing research and predicts that linguistic affiliation with SpA versus StA has an effect on linguistic processing in Arabic such that any SpA structure will be easier to access and operate on than its parallel StA structure. The results also support the *diglossia effect* (Saiegh-Haddad, 2017), which is a processing advantage for SpA over StA structures and which is expected to emerge on any reading and metalinguistic awareness task that requires access to and/or operation on linguistic representation. The argument is that in as much as linguistic representation for StA structures is weak, given reduced experience with and practice of StA lexicon, phonology and grammar (Saiegh-Haddad et al., 2011) operations on such representations will suffer (Saiegh-Haddad, 2017).

With respect to reading, this study suggests a number of differences in the development of SpA and StA word reading skills. The results reveal that both word reading accuracy and fluency in Arabic are higher for SpA words than StA words. This advantage for SpA words over StA words was found to persist across development and to surface in the reading of both voweled and unvoweled words. This finding is cardinal, indicating the long-term impact of diglossia and its interplay with orthographic depth. Given the fact that the Arabic orthography, at least in its voweled form, is highly transparent, the results underscore the importance of another factor in word reading development in Arabic. This factor might be diglossia and the linguistic distance between SpA and StA word morphology. This finding might also be explained by the lack of efficiency in basic phonological and morphological processing skills in StA that might clarify some of the possible mechanisms by which diglossia might affect word reading accuracy and fluency in Arabic.

With respect to the role of vowelization in explaining differences in word reading accuracy and fluency skills between SpA and StA, the results showed that the gap in reading accuracy between SpA and StA was evident in the case of both unvoweled and voweled words. While it closes up in the eighth grade in reading accuracy of SpA voweled words, in the case of StA voweled words, the differences vanish when readers reach the tenth grade. In the fluency measures, the gap between unvoweled SpA and StA words remains in all grade levels we checked. This finding coincides with the prediction that differences between SpA and StA should be smaller when reading transparent words than opaque ones. Thus, in reading vowelized words, where successful decoding merely requires grapheme–phoneme correspondence, children reached a similar fluency level in SpA and StA. On the other hand, when reading unvoweled words, children reading StA words encountered greater difficulty in rapidly reading the words. Hence, Arabic-speaking children still seem to rely heavily on simple decoding skills while reading StA. While reading voweled words in Arabic is compatible with a heavy reliance on alphabetic mechanisms in reading and with high rates of reading accuracy (Seymour et al., 2003), this study indicates that the role of vowelization for building reading ability still remains essential in reading StA words.

The second goal of this study was to explore the connection between PA, morphological awareness in SpA, and word reading in StA. Examining these three aspects of language provided an opportunity to clarify the contribution of metalinguistic skills in SpA to StA word reading, as these aspects provide an opportunity to consider answers related to questions such as the following: what aspect is most important to be included in SpA intervention programs, or at what age is it beneficial to provide preventative instruction? Results of this study indicate that in addition to the expected role of SpA PA, SpA morphological awareness plays a cardinal role in StA word reading fluency. This finding is well aligned with the established claim that morphological awareness contributes to school-age students' performance reading and spelling words or pseudowords (Abu-Rabia et al., 2003; Abu-Rabia, 2007; Saiegh-Haddad, 2013; Taha and Saiegh-Haddad, 2016, 2017). Similar findings have been reported in English (e.g., Deacon and Kirby, 2004; Carlisle and Stone, 2005; Nunes et al., 2006), French (e.g., Casalis and Louis-Alexandre, 2000), Dutch (e.g., Assink et al., 2000), Chinese (e.g., Ku and Anderson, 2003; Chung and Hu, 2007), and Hebrew (Schiff and Lotem, 2011) – to name a few.

In addition to demonstrating a significant contribution of phonological and morphological awareness to reading in Arabic, the current results are particularly interesting given the design of the current study in which phonological and morphological skills were tested in SpA but reading was naturally conducted in StA. The evidence that SpA phonological and morphological awareness predicts StA reading supports earlier evidence of the role of metalinguistic awareness in L1 I predicting reading in L2 (August and Shanahan, 2006). Moreover, they extend previous evidence to diglossic setting like Arabic and supports the conception that it is possible to enhance reading in StA by raising awareness of SpA linguistic structures and without burdening the child with unfamiliar StA linguistic structures. Moreover, SpA and StA metalinguistic awareness tasks might tap not only into awareness of phonology or morphology but also of quality of phonological and morphological representations (Saiegh-Haddad, 2017) making these tasks less valid as measures of metalinguistic awareness.

Our findings, together with those of several previous studies, seem to suggest that morphological awareness is more a language- or variety-specific construct (Pasquarella et al., 2011; Luo et al., 2014). In other words, whether or not transfer from one variety to another would occur is largely influenced by similarities or differences in the morphological features of the two languages. Despite the fact that StA and SpA partly share word structures, StA morphological awareness requires operation on StA morphological structures. Inasmuch as these are low in quality, awareness of these structures is expected to suffer (Saiegh-Haddad, 2017), and therefore, transfer of reading skills between the two varieties is quite limited. It is possible that utilization of SpA structures in StA encoding depends on the demand of reading in StA. Perhaps, reading StA requires PA, whereas reading SpA requires more morphological awareness. In other words, reading StA might benefit more from recognizing inflections as a unit in reading compared with readers of SpA who might benefit more from phonemic segmentation.

The present data support previous reports of the link between diglossia, linguistic skills, and reading ability (Saiegh-Haddad and Schiff, 2016). The findings assert that children who grow up in diglossic context enter school with weaker phonological and morphological skills for the written language (StA) than for the language they use in everyday speech (SpA), and this has cascading consequences on the development of reading skills in general, and reading fluency. It appears that morphological awareness instruction in SpA might provide a stronger foundation for StA word-reading instruction than PA instruction or the standard literacy instruction. Further, in light of previous studies reporting either a direct (Deacon et al., 2014) or indirect (Kieffer and Box, 2013) impact that morphological awareness has on reading comprehension, it would be beneficial to wrap morphological awareness into the Arabic language arts curriculum as preventative treatment that would compensate for the deficits caused by diglossia. A next step, which would have both theoretical and applied values, would be to carry out intervention studies to test further the causal hypothesis and promote the use of developmental research in teaching (Taha and Saiegh-Haddad, 2016, 2017).

It is important to note some directions for further study. First, the present study focused only on phonological and morphological awareness skills as well as reading skills among children from mid-high socio-economic background. Because this study found evidence for differences in these skills, future research should examine the phonological and morphological awareness abilities as well as reading skills among children of different socioeconomic backgrounds, to explore whether the gaps found in this study increase among children from low socio-economic background. Second, the current study is cross-sectional in nature, thus in order to clarify whether the differences in the phonological and morphological awareness as well as reading abilities of children across grades indeed indicate a different developmental pattern, future studies should employ a longitudinal design and follow the same group of children over grades. Finally, future studies could potentially extend the investigation to other diglossic contexts.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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Preschool Phonological and Morphological Awareness As Longitudinal Predictors of Early Reading and Spelling Development in Greek

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Different language skills are considered fundamental for successful reading and spelling acquisition. Extensive evidence has highlighted the central role of phonological awareness in early literacy experiences. However, many orthographic systems also require the contribution of morphological awareness. The goal of this study was to examine the morphological and phonological awareness skills of preschool children as longitudinal predictors of reading and spelling ability by the end of first grade, controlling for the effects of receptive and expressive vocabulary skills. At Time 1 preschool children from kindergartens in the Greek regions of Attika, Crete, Macedonia, and Thessaly were assessed on tasks tapping receptive and expressive vocabulary, phonological awareness (syllable and phoneme), and morphological awareness (inflectional and derivational). Tasks were administered through an Android application for mobile devices (tablets) featuring automatic application of ceiling rules. At Time 2 one year later the same children attending first grade were assessed on measures of word and pseudoword reading, text reading fluency, text reading comprehension, and spelling. Complete data from 104 children are available. Hierarchical linear regression and commonality analyses were conducted for each outcome variable. Reading accuracy for both words and pseudowords was predicted not only by phonological awareness, as expected, but also by morphological awareness, suggesting that understanding the functional role of word parts supports the developing phonology–orthography mappings. However, only phonological awareness predicted text reading fluency at this age. Longitudinal prediction of reading comprehension by both receptive vocabulary and morphological awareness was already evident at this age, as expected. Finally, spelling was predicted by preschool phonological awareness, as expected, as well as by morphological awareness, the contribution of which is expected to increase due to the spelling demands of Greek inflectional and derivational suffixes introduced at later grades.

Keywords: morphological awareness, phonological awareness, reading, spelling, longitudinal study

INTRODUCTION

Reading and spelling are considerable cognitive undertakings that require the integration of written and spoken language. An overwhelming body of research evidence suggests that children's phonological awareness, which requires conscious reflection upon and explicit manipulation of the constituent speech sounds of language, is a necessary requirement for the acquisition of the alphabetic principle (Byrne, 1996) and a key skill for mastering decoding (National Reading Panel, 2000; Lonigan et al., 2009) and spelling across orthographies (Cataldo and Ellis, 1988; Ellis and Cataldo, 1990; Byrne and Fielding-Barnsley, 1991, 1993; Porpodas, 1999; Aidinis and Nunes, 2001; Caravolas et al., 2001, 2005; Cardoso-Martins and Pennington, 2004; Furnes and Samuelsson, 2010).

On the other hand, morphological awareness plays a fundamental role in mastering decoding, reading fluency, and comprehension (Deacon and Kirby, 2004; Kuo and Anderson, 2006; Tong et al., 2011; Kirby et al., 2012; Deacon et al., 2014; Muroya et al., 2017) and orthographic spelling (Deacon and Kirby, 2004; Deacon and Bryant, 2005, 2006; Desrochers et al., 2017) across orthographies (Wei et al., 2014; Rothou and Padeliadu, 2015; Grigorakis and Manolitsis, 2016; Pan et al., 2016; Vaknin-Nusbaum et al., 2016a,b; Muroya et al., 2017). Morphological awareness refers to (a) an explicit understanding of morphological relations between word forms and meanings, such as grammatical inflection and productive derivation, and (b) the ability to manipulate the morphological structure of words (Carlisle, 1995). The present study aimed to examine the predictive value of preschool morphological and phonological awareness in learning to read and spell.

Morphological Awareness and Literacy Development

It has been forcefully argued that reading comprehension cannot succeed unless the reader appreciates morphological word formation, that is, how differences in word forms relate to differences in meaning (Carlisle, 2003). This suggests that an explicit understanding of morphological relations, termed morphological awareness, is a prerequisite to skilled reading. In fact morphological awareness is related not only to reading comprehension, but also to spelling (e.g., Deacon et al., 2009; Casalis et al., 2011), vocabulary (McBride-Chang et al., 2005; Sparks and Deacon, 2015), and word and pseudoword reading (Deacon and Kirby, 2004; Kirby et al., 2012). The contribution of morphological awareness to spelling is robust to a multitude of control variables (Deacon et al., 2009) and includes both inflected and derived forms (Deacon et al., 2010) beyond the spelling of specific morphemes (Casalis et al., 2011).

Deacon and Kirby (2004) examined the role of both phonological and morphological awareness in learning to read for English-speaking Canadian children. They investigated the longitudinal prediction of Grades 3, 4, and 5 pseudoword reading, single word reading, and reading comprehension from Grade 2 phonological and morphological awareness. They found that morphological awareness made a small but unique contribution to all aspects of reading development – mainly pseudoword reading and reading comprehension – during the 3 years of middle elementary school, over and beyond the effect of phonological awareness. They argued that morphological awareness might have accounted for more variance in the reading variables if multiple measures of various formats and tapping a broader range of derivations and inflections had been used. The present study addressed this methodological limitation by assessing children in an elaborate and systematic battery of phonological and morphological awareness tasks.

In another study of English-speaking Canadian children, Deacon et al. (2009) examined the predictive value of morphological awareness, assessed in the early school years, for the prediction of spelling, assessed in middle elementary grades. They reported that Grade 2 morphological awareness accounted for approximately 8% of the variance in Grade 4 general spelling skills, beyond the effect of verbal and non-verbal intelligence, phonological awareness, verbal short-term memory, and rapid-automatized naming (RAN).

Few studies have studied the contribution of morphological awareness assessed before the onset of formal reading instruction. Casalis and Louis-Alexandre (2000) studied the longitudinal contribution of phonological and morphological awareness to decoding and reading comprehension. They assessed French-speaking kindergarten children in a variety of morphological awareness tasks measuring both inflectional and derivational morphology. Their findings showed strong correlations between phonological and morphological awareness tasks, as well as unique contributions of both skills to Grade 2 decoding skills and reading comprehension. However, they only analyzed the correlations for individual tasks and did not examine the overall effects of morphological and phonological awareness skills by considering all the corresponding tasks together. Therefore, the total magnitude of the longitudinal relationship remained unknown.

More recently, using latent variable modeling in Chinese, Pan et al. (2016) found that pre-literate syllable and morphological awareness predicted character reading, reading fluency, reading comprehension, and writing at the age of 11 years, beyond any effects of phonological awareness, but only indirectly, that is, through post-literate morphological awareness assessed at the ages of 7–10 years.

The longitudinal relation between early morphological awareness and reading and spelling skills has also been studied in Greek. Manolitsis (2006) found that morphological awareness, assessed in kindergarten, longitudinally predicted Grade 1 word reading but its contribution to accuracy was not significant when kindergarten phonological awareness was controlled for. Pittas and Nunes (2014) assessed first and third graders in three morphological awareness tasks: a pseudoword inflection task, a sentence analogy task, and a morphological relatedness task. They found a unique contribution of morphological awareness to reading – but not to spelling – assessed 8 months later, even after partialling out the effects of grade, verbal ability, phonological awareness, and initial reading level.

Grigorakis and Manolitsis (2016) examined the longitudinal prediction of Greek morphological spelling from morphological awareness measured before and at the beginning of formal literacy instruction. They assessed 229 kindergarten children 5–6 years old on a variety of morphological awareness tasks measuring their ability to recognize and manipulate inflections, derivations, and compound words. Spelling of inflectional suffixes in words and pseudowords was assessed at Grades 1 and 2. Morphological awareness was a significant longitudinal predictor of word spelling, surviving control for verbal and non-verbal intelligence, verbal short-term memory, receptive and expressive vocabulary, letter sound knowledge, RAN, and phonological awareness.

Finally, in a cross-linguistic study comparing English, French, and Greek, Desrochers et al. (2017) found that Greek children's morphological awareness skills at the beginning of Grade 2 were unique predictors of reading comprehension and spelling, but not of reading accuracy – as in English – and fluency – as in both English and French – at the end of the same grade.

Evidence for the importance of morphological awareness has also been provided by intervention studies. If morphological awareness forms a critical substrate for reading development, then training in morphological awareness, if successful, should lead to measurable improvements in reading performance. Due to their experimental – rather than correlational – nature, studies of morphological awareness training constitute an empirically crucial source of evidence regarding the connection between morphological awareness and literacy. Indeed, instruction in morphological awareness has been shown to result in benefits across literacy domains, especially when combined with phonological awareness training (e.g., Lyster, 2002; Lyster et al., 2016; Manolitsis, 2017; see meta-analyses and systematic reviews in Reed, 2008; Bowers et al., 2010; Carlisle, 2010; Goodwin and Ahn, 2010, 2013).

However, even though dozens of morphological awareness studies have accumulated to date, as seen in the aforementioned reviews, a confident conclusion remains unwarranted because it has been challenging to establish the specificity of training. The majority of studies have failed to employ an active control group receiving instruction of similar structure and intensity but non-morphological in content. Indeed, many studies have simply compared the experimental group to a passive control group not receiving any special instruction but following the regular classroom program. When active control groups are employed the benefits to literacy from morphological training are not significantly stronger (e.g., comparing against phonological awareness training; Lyster, 2002; Lyster et al., 2016).

An additional difficulty with the theoretical interpretation of the majority of these training studies is that they have relied, at least in part, on printed materials or strategies potentially exploiting the orthographic knowledge of participants, thereby obscuring the origin of the observed effects. That is, although the focus of the instruction was on the morphological aspects of words, if training took place using written words then children may have exhibited literacy gains due to the fact that they received a form of reading or spelling instruction rather than to morphological awareness *per se*.

In sum, despite the recent surge in interest in the relationship between morphological awareness and reading skill development, and the strong evidence for its importance, the relevant literature has not conclusively established the precedence, or necessity, of morphological awareness for reading development and for particular reading skills. Many studies have examined concurrent correlations and most have assessed children in elementary grades, for which reciprocal effects may have contributed to the reported findings. That is, if morphological awareness is assessed after the onset of reading instruction, it is possible that exposure to the various printed word types may have contributed to the further development of morphological awareness. Therefore, a finding of robust correlations may conceivably be due to an inverse direction of causation than typically hypothesized.

Although longitudinal studies are one step toward addressing this shortcoming, it is also critical that the first assessment of morphological awareness takes place before the onset of reading instruction, to minimize effects of exposure to print. This requires the development and validation of appropriate testing materials for preschoolers that arguably address metalinguistic morphological skills. In the present study we have thus examined the longitudinal prediction of early (Grade 1) reading skills by preschool morphological awareness, controlling for phonological awareness and vocabulary. To obtain a more nearly complete picture of the importance of morphological awareness for reading skill development, we have applied a comprehensive battery of reading outcomes, including word and pseudoword accuracy, reading fluency, reading comprehension, as well as spelling.

Development and Assessment of Morphological Awareness

Typical language development involves unconscious use of morphology. Very young children produce overgeneralizations, such as "buyed" (instead of "bought"). The production of these errors suggests a gradual development in understanding the rules of inflectional morphology (Berko, 1958; Selby, 1972). Nonetheless, the boundary between tacit knowledge of morphological processes and conscious morphological awareness has not been sufficiently investigated. In many cases it is not clear whether differences in measures of morphological awareness reflect differences in metalinguistic awareness or in implicit morphological knowledge (Nagy et al., 2014). Metalinguistic awareness is thought to be a special kind of linguistic functioning, beyond language acquisition, which develops in middle childhood (Tunmer et al., 1984).

The morphological processes of grammatical inflection and productive derivation seem to follow a similar but non-simultaneous developmental progression. Evidence shows that awareness of inflectional morphology is acquired in the first school years (Diakogiorgi et al., 2005; Kuo and Anderson, 2006), whereas awareness of derivational morphology develops toward the fourth year (Anglin, 1993; Carlisle, 2000), and continues to grow throughout the school years (Berko, 1958; Anglin, 1993; Berninger et al., 2010). Carlisle (1995) suggested that children's awareness of derivational morphology makes a transition from an implicit to an explicit level at the ages of kindergarten and first grade.

Morphological awareness tasks have been classified according to their cognitive and meta-cognitive requirements, which may operate at either an implicit or an explicit level (Deacon et al., 2008). Lexical judgment tasks, which require children to decide whether two words are related or not, have been widely used to assess implicit morphological skills (e.g., Mahony et al., 2000; Duncan et al., 2009), whereas analogy and production tasks have been used to tap explicit skills (e.g., Berko, 1958; Derwing, 1976; Nunes et al., 1997; Carlisle, 2000; Kirby et al., 2012). Production tasks have also been differentiated between implicit and explicit (Casalis and Louis-Alexandre, 2000).

Diamanti et al. (in press) recently examined the development of morphological awareness in Greek children 4–7 years old. They compared the domains of inflectional and derivational morphology, adopting a distinction between two levels, namely epilinguistic control and metalinguistic awareness. Epilinguistic control refers to an intermediate level of elementary awareness that has been posited to intervene developmentally between the acquisition of the linguistic skill and the acquisition of metalinguistic awareness (Gombert, 1992). In contrast, metalinguistic awareness refers to the individual's ability to reflect upon and consciously manipulate morphemes, as well as the ability to deliberately apply word formation rules. Following Carlisle (1995), epilinguistic control is evidenced in judgment tasks, whereas full-blown metalinguistic awareness is evidenced in production tasks (see Diamanti et al., in press, for further discussion). In addition to the expected performance increase with age, Diamanti et al. (in press) found that a single factor sufficed and accounted for 0.59 of the variance in the four tasks, consistent with a common developmental path underlying both domains and both levels of morphological awareness. In comparison of the developmental growth curves among tasks, they found that production of derivational morphemes was more difficult than production of inflectional morphemes and judgment of derivational morphemes, whereas the differences between the two inflectional tasks and between the two judgment tasks were not significant.

Given these findings, Diamanti et al. (in press) suggested that at these ages epilinguistic control is similarly effective for the two morphological domains whereas full metalinguistic awareness of derivational morphology trails behind that of inflectional morphology, at least as measured by these specific tasks. Thus, on the one hand, this study highlighted the need for early tracking and distinctions among levels and domains of morphological awareness. On the other hand, it demonstrated the reliability and validity of the materials used and the potential of this combination of subscales to form a reliable and coherent scale for overall wide-range assessment of morphological awareness in the preschool and early elementary school age range. The present study is a follow-up of a subset of the children in that study, who attended preschool at the time and were assessed again 1 year later, in Grade 1, on reading-related outcome variables.

Relevant Properties of Greek

This subsection is reproduced from Diamanti et al. (in press). Greek is a language with rich inflectional and derivational morphology (see Ralli, 2003) and relatively consistent orthography (Protopapas and Vlahou, 2009). Nouns and adjectives are obligatorily inflected for gender, number, and case via fusional suffixation. For example, the noun χορός (/xoros/ "dance") is composed of the stem χορ – (/xor/ expressing the core semantics) and the inflectional suffix – ος (/os/ signifying masculine singular nominative case). Verb forms also include a stem and an obligatory inflectional ending, both of which may be simple or complex. Verbs are inflected for voice, aspect, tense, number, and person [Ralli, 2003; see Klairis and Babiniotis (2004) and Holton et al. (2012) for comprehensive descriptions]. For example, the verb χορεύω (/xorevo/ "I dance") is composed of the same stem χορ – (/xor/), the derivational affix – εύ – (/ev/ forming a verb from a noun), and the inflectional suffix – ω (/o/ signifying first person singular).

Distinct inflectional classes are recognized for both nouns/adjectives and verbs, each with its own set of suffixation and stem alternation rules (Ralli, 2003, 2005; Holton et al., 2012). Word formation in Greek also includes systematic derivational processes, especially for nouns (based on verb stems) and adjectives (based on verb and noun stems). Compounding is also highly productive, as new adjectives, nouns, and verbs can be created from existing stems and words [see Ralli (2003, 2005) for more information].

Morphology has extensive orthographic consequences in Greek, insofar as derivational and grammatical suffixes are associated with specific spellings, which also serve to disambiguate homonyms. Knowledge of the inflectional type is often required for correct spelling of adjective, noun, and verb suffixes [see Protopapas (2017) for more information and references]. Therefore, it seems reasonable to hypothesize that an understanding of morphological processes will be especially beneficial in learning to spell, and particularly useful in spelling the inflectional suffixes (Grigorakis and Manolitsis, 2016). This is important in light of the fact that Greek morphological spelling is known to be challenging, including both inflectional and – especially – derivational suffixes (Protopapas et al., 2013a; Diamanti et al., 2014).

A small amount of instructional activity related to morphological awareness takes place informally in the Kindergarten curriculum as part of vocabulary instruction, in the context of shared book reading and retelling, including discussion about word types such as diminutive derivation and number inflection, along with phonological awareness activities such as letter–sound association and identification. Systematic decoding is taught in Grade 1, so that most children are able to read by mid-grade, after which point some instruction related to morphological awareness appears, for example teaching the distinct spellings of noun and verb vowel endings (i.e., inflectional suffixes).

Most Greek children have mastered the inflectional paradigms of the language to a large extent by the age of entering elementary education, at least as far as the suffixes with orthographic consequences are concerned (i.e., case, gender, and number, for adjectives and nouns, and person and number, for verbs). Normally developing kindergarten children approach ceiling performance in the production of verb past tense and noun gender, number, and case (Mastropavlou, 2006) although persistent difficulties with verb aspectual formation and noun gender are observed in certain word classes with unusual properties (Stavrakaki and Clahsen, 2009; Varlokosta and Nerantzini, 2013, 2015). Thus, morphological acquisition is largely but not entirely completed by Grade 1.

MATERIALS AND METHODS

Participants

The study sample consisted of 104 children (54 girls and 50 boys) assessed at the middle of kindergarten (February–March; age $M = 67.3$ months; $SD = 3.6$) and again at the end of Grade 1 (April–May; about 14 months later). They were native speakers of Greek and did not have any diagnosed developmental delay or emotional disorder prohibiting them from enrollment in typical (general) education settings. They were recruited from schools in rural (17%), semi-urban (19%), and urban (63%) areas of four geographically dispersed provinces of Greece, including a variety of socioeconomic and ethnic backgrounds. Sample demographics represent a close approximation to the Greek population (77% urban and 23% rural) based on the 2011 census.

Permission to conduct the study in these public schools was granted by the Ministry of Education following formal review and approval of the study plan by the Research Office of the Educational Policy Institute. Parental and school approval, as well as the child's oral assent, were obtained prior to test administration. Participants were not specifically selected; rather, consent forms were distributed to entire classrooms and children who returned the signed parental consent were included in the study.

Materials

Time 1 (predictor) measures included receptive and expressive vocabulary, and phonological and morphological awareness. These tasks were administered through an Android application (app) for mobile devices (tablets) featuring automatic application of ceiling rules. Time 2 (outcome) measures included word and pseudoword reading accuracy, text reading fluency and comprehension, and spelling. The four reading outcome measures were from "ΔΑΔΑ," a standardized reading test by Padeliadu et al. (in press).

Receptive Vocabulary

Four different images were displayed while a recorded spoken word was played out by the app, and the child was asked to choose the image that best represented the word that was heard. The three other images corresponded to a word from the same semantic category, a phonologically similar word, and an unrelated word. Words were appropriate for children in preschool and early elementary grades (including animals, objects, actions, adjectives, abstract concepts, etc.) and were presented in order of increasing difficulty (determined by Rasch analysis of pilot data from 237 children on 65 original items). Scoring was recorded automatically, amounting to the number of correct responses. The number of items was $N = 30$ and the reliability of the scale (Cronbach's coefficient of internal consistency) was $\alpha = 0.88$.

Expressive Vocabulary

This was a word definition task, in which each child was asked to give a brief definition of a series of words. Words were selected to cover a range of abilities for children in preschool and early elementary grades, including a variety of semantic and grammatical categories (animals, food, professions, objects, actions, abstract concepts, etc.), based on the results of a pilot study (parallel to that for receptive vocabulary, with 50 original items). Manual off-line scoring matched other similar tasks (i.e., WISC vocabulary), such that a proper word definition received two points, whereas examples of word use or descriptions were scored with 1 or 0, depending on word understanding and richness of expression ($N = 28$; $\alpha = 0.91$).

Phonological Awareness

This was a composite score corresponding to the total number of items correctly responded to in a series of eight tasks assessing initial syllable matching ($n = 7$ items; Cronbach's $\alpha = 0.84$), initial phoneme matching ($n = 7$; $\alpha = 0.84$), syllable blending ($n = 5$; $\alpha = 0.89$), phoneme blending ($n = 7$; $\alpha = 0.93$), syllable segmentation ($n = 6$; $\alpha = 0.95$), phoneme segmentation ($n = 7$; $\alpha = 0.95$), syllable deletion ($n = 7$; $\alpha = 0.94$), and phoneme deletion ($n = 7$; $\alpha = 0.92$). For the total scale, as entered in the analyses, $N = 53$, $\alpha = 0.97$.

In the initial syllable (or phoneme) matching tasks, children heard the label of a displayed target image and the labels of three other simultaneously displayed images and had to choose which of the three images began with the same syllable (phoneme) as the target image. In the blending tasks, children had to compose words from a series of syllables (phonemes) that were heard individually. In the syllable (phoneme) segmentation tasks children heard a word and were then asked to pronounce the individual syllables (phonemes) it comprised. Finally, in the syllable (phoneme) deletion, children were asked to listen carefully to a word and then to repeat it omitting a specific syllable (phoneme).

Morphological Awareness

This was a composite score corresponding to the total number of items correctly responded to in a series of three tasks assessing judgment ($n = 8$ items; $\alpha = 0.80$) and production ($n = 11$ items; $\alpha = 0.73$) of inflectional suffixes and production of derivational suffixes ($n = 16$ items; $\alpha = 0.94$). For the total scale, as entered in the analyses, $N = 35$, $\alpha = 0.93$. The following description of the tasks is based on Diamanti et al. (in press).

Inflectional morphemes judgment task

Children saw a picture displaying either one or two turtles performing an action while listening to two sentences spoken by two penguin figures displayed next to the action picture. Children had to choose the sentence matching the picture by pointing at one of the two penguins after hearing the sentences. Each pair of sentences contained one pseudoword differing in inflectional suffix, which was either singular or plural. For example, given a picture of two turtles taking photographs, the two sentences were "the turtles *skeni*$_{3rd.sg}$ photos" and "the turtles *skenoun*$_{3rd.pl}$ photos." The correct sentence is the second one because the inflectional suffix of the pseudoverb denotes the plural form and agrees with the subject, thus matching the picture. Given a picture of a turtle holding two rulers, the two sentences were "the turtle is holding the$_{acc.sg}$ *serapa*$_{acc.sg}$" and "the turtle is holding the$_{acc.pl}$ *serapes*$_{acc.pl}$" (the critical pseudoword is denoted by italics). The correct sentence is the second one because the inflectional suffix of the pseudonoun denotes the plural form and matches the picture.

Inflectional morphemes production task

Children saw a pair of pictures, illustrating actions performed by turtles differing in the number of agents or patients of the depicted action, while listening to a verbal description including a pseudoword (a pseudoverb in eight sentences, for the action, and a pseudo-noun in three sentences, for the object). Children were then provided with the beginning of a second sentence, matching the second picture, up to the subject of the verb, and were asked to change the pseudoword number (from singular to plural or from plural to singular) accordingly. For example, given a picture of two turtles with sunglasses and a picture of one turtle with sunglasses, the sentence and prompt would be "The turtles *menane*$_{3rd.pl}$ glasses. The turtle..." and the child should say "*menai*$_{3rd.sg}$ glasses"; given a picture of a turtle waving at a monkey and a picture of a turtle waving at two monkeys, the sentence and prompt would be "The turtle is greeting the$_{acc.sg}$ *reipou*$_{acc.sg}$. The turtle is greeting the$_{acc.pl}$" and the child should say "*reipoudes*$_{acc.pl}$" (the critical pseudoword is denoted by italics).

Derivational morphemes production task

Children saw a picture while listening to a sentence with a critical word (a different one for each sentence) and the beginning of a second sentence that was syntactically altered and required manipulation of a derivational morpheme on the critical word to be completed correctly (e.g., "The sea deepens. The sea is..." requiring "deep"; "Miriam always teases her friends. Miriam is a..." requiring "teaser" /piraxtiri/, derived from /pirazo/). The task targeted a variety of derivational morphemes, denoting property, profession, establishment/institution, material, collection, comparatives, action, device, nationality/origin, etc.

Word Reading Accuracy

The word decoding test of the ΔΑΔΑ decoding subscale was used, which consists of 57 words two to seven syllables long, with gradually increasing number of syllables and semantic complexity and decreasing frequency of occurrence, printed vertically. Words were nouns, adjectives, passive participles, and verbs. A stopping criterion of five consecutive errors was applied. The number of words read correctly was noted. The internal consistency of the entire "decoding" factor of ΔΑΔΑ (which also includes pseudoword decoding, word/pseudoword discrimination, and word identification) as reported for elementary grades is high ($\omega = 0.90$, $H = 0.91$).

Pseudoword Reading Accuracy

The pseudoword decoding subtest of the ΔΑΔΑ decoding subscale was used, which consists of 40 non-words two to six syllables long, with gradually increasing number of syllables and phonological complexity, printed vertically. A stopping criterion of five consecutive errors was applied. The number of non-words read correctly was noted.

Reading Fluency

A grade-appropriate 247-word passage with an ancient Greek mythological theme from the reading fluency subscale of ΔΑΔΑ was used. Children were asked to read the passage as quickly and as accurately as they could. The score of the test was the number of words read correctly within 1 min.

Reading Comprehension

The first three passages from the reading comprehension subscale of ΔΑΔΑ were used, which were short and appropriate for the age of the participants, with gradually increasing semantic and syntactic difficulty. The first and second passages were narratives, while the third one was expository. Children had to answer seven multiple-choice questions for each passage while having the texts available. The questions required meaning abstraction based on vocabulary knowledge, as well as literal and inferencing skills. The score was the total number of questions answered correctly for all three passages (out of a total of 21 questions). The internal consistency of the entire "comprehension" factor of ΔΑΔΑ (which includes three more passages, for a total of six) as reported for elementary grades is satisfactory ($\omega = 0.89$, $H = 0.64$).

Spelling

Spelling ability was assessed using a standardized spelling-to-dictation test (Mouzaki et al., 2010), which includes 60 words dictated in isolation and in a sentence at a child-determined pace. A stopping criterion of six consecutive errors was applied. Each word was scored with one point for accurate spelling.

Procedure

All measures were administered individually by specially trained research assistants, following a common procedure, in a quiet room at the children's kindergarten (Time 1) or school (Time 2). Time 1 (predictor) measures were administered in two to three sessions of 40–45 min within 2 weeks (in the context of a variety of other tasks not reported here) using a tablet app custom made for this purpose. All visual and auditory stimuli were provided by the app as images and pre-recorded utterances. Scoring was automated when possible (i.e., evaluation of selection accuracy), or entered manually after administration when human judgment was necessary (i.e., evaluation of spoken responses). Time 2 (outcome) measures were administered individually in one 40–45-min-long session in the traditional (paper and pencil) format.

RESULTS

There were no missing data for this group of participants ($N = 104$ in all analyses). Visual examination of univariate quantile–quantile plots and bivariate scatterplots revealed six extreme outliers (two low values in receptive vocabulary, one low and one high in fluency, and two high in spelling), which were replaced by winsorized values at the appropriate percentile ($1/N$ for single values and $2/N$ for two values) in order to retain a full data set. **Table 1** displays descriptive statistics following this minor cleanup. Despite some mild deviations from normality, no extreme values of skew or kurtosis were observed. **Table 2** displays the intercorrelations among all variables. Age was not significantly correlated with morphological awareness ($r = 0.033$, $p = 0.740$) or with any of the outcome variables (all $p > 0.11$), probably due to the restricted age range in this sample. Therefore, age was not entered as a predictor in the regression models.

For each outcome variable, a hierarchical regression analysis was conducted in three steps: receptive and expressive vocabulary were entered at the first step, as proxies for language development and verbal ability in general; phonological awareness was entered at the second step, and morphological awareness at the third and final step. This was done in order to quantify the specific contribution of metalinguistic skills beyond general language skills, and in particular the specific contribution of morphological awareness beyond the – already well known – effect of phonological awareness, which in this way also acts as a proxy for general metalinguistic skill. **Table 3** displays the results of these analyses, including the total and additional variance accounted for at each step (rightmost columns), the coefficients in the final multiple regression models for each outcome variable including all predictors (leftmost columns), and the proportions of shared and unique variance accounted for by each predictor in the final models (commonality analysis; middle columns).

Residual diagnostics are shown in **Figure 1**, indicating no severe deviations from normality and no overly influential data points. There was a significant unique contribution of morphological awareness, beyond vocabulary and phonological

TABLE 1 | Descriptive statistics for predictor and dependent variables.

							Shapiro–Wilks			
Variable	***M***	***M%***	**mdn**	***SD***	**Min**	**Max**	***W***	***p***	**Skewness**	**Kurtosis**
Preschool (predictor) variables										
Age (months)	67.3		67.0	3.6	56	74	0.965	0.007	−0.22	−0.44
Receptive vocabulary	23.7	79.0	25.0	4.6	10	30	0.902	<0.001	−1.11	0.85
Expressive vocabulary	25.2	90.0	26.5	8.6	3	44	0.986	0.340	−0.33	−0.28
Phonological awareness	26.5	50.0	24.0	10.3	2	51	0.976	0.053	0.34	−0.18
Morphological awareness	20.1	57.4	21.0	7.9	5	34	0.946	<0.001	−0.28	−1.13
Grade 1 (outcome) variables										
Word accuracy	38.8	68.1	43.0	13.4	5	57	0.890	<0.001	−0.95	−0.15
Pseudoword accuracy	28.1	70.3	30.0	8.3	5	40	0.910	<0.001	−1.04	0.70
Reading fluency	41.7		39.0	16.3	9	93	0.958	0.002	0.77	1.08
Reading comprehension	14.4	68.5	15.0	3.8	2	21	0.954	0.001	−0.73	0.53
Spelling	15.2	25.3	15.0	5.2	4	29	0.973	0.029	0.44	0.50

M% = mean percent correct; mdn = median; Min and Max refer to the lowest and highest observed value, respectively, after winsorization of outliers (see text). Shapiro–Wilks test of normality. For all measures, number of participants N = 104.

TABLE 2 | Intercorrelations among all variables.

	Variable	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Preschool (predictor) variables										
(1)	Age (months)	0.272	0.179	0.229	0.033	0.031	0.057	0.082	0.148	0.155
(2)	Receptive vocabulary		0.420	0.270	0.307	0.160	0.211	0.230	0.440	0.206
(3)	Expressive vocabulary			0.251	0.229	0.042	0.103	0.049	0.318	0.039
(4)	Phonological awareness				0.472	0.316	0.363	0.409	0.298	0.431
(5)	Morphological awareness					0.482	0.473	0.284	0.470	0.392
Grade 1 (outcome) variables										
(6)	Word accuracy						0.773	0.525	0.392	0.452
(7)	Pseudoword accuracy							0.459	0.376	0.423
(8)	Reading fluency								0.332	0.693
(9)	Reading comprehension									0.360
(10)	Spelling									

Pearson's r correlation coefficients; N = 104; correlations of 0.193 or greater are significant at p < 0.05; and greater than 0.273 at p < 0.005.

awareness, to every outcome variable except fluency, for which only phonological awareness made a significant unique contribution. The unique contribution of morphological awareness was sizeable (9–14% of variance, depending on outcome measure) and was accompanied by additional, comparable proportions of variance (9–15%) shared with the other measures, bringing up the total longitudinal predicted variance from morphological awareness to more than 20% of reading (and spelling) outcomes (except fluency).

DISCUSSION

In this longitudinal study we have investigated the prediction of reading and spelling outcomes near the end of Grade 1 by language and metalinguistic skills assessed in preschool 14 months earlier. Morphological awareness had a significant unique contribution to all outcome variables except reading fluency. This finding confirms the important role of morphological awareness for reading development and extends it to a younger age than usually studied.

Our results are consistent with the findings of Casalis and Louis-Alexandre (2000), who studied early reading performance longitudinally predicted by preschool phonological and morphological awareness in French, and found both a strong correlation between phonological and morphological awareness at these ages as well as longitudinal relationships between both of them and early reading. Our results are also compatible with those of Grigorakis and Manolitsis (2016), who examined the prediction of Grade 1 inflectional spelling by preschool phonological and morphological awareness in Greek, and found a significant longitudinal contribution of morphological awareness beyond phonological awareness and other control variables.

In particular with respect to spelling, one might expect an especially important role of morphological awareness in Greek (Grigorakis and Manolitsis, 2016), because, as noted above, many inflectional and derivational affixes are associated with specific spellings (and, indeed, some of them are homophonous and can only be disambiguated by spelling). This hypothesis cannot be evaluated in the current study because our strong result ($\Delta R^2 = 0.085$, $p < 0.001$) emerged using a standardized spelling test including many words with difficult stems and not giving particular weight to grammatical (i.e., inflectional suffix) spelling. This might be taken to imply that the relationship between morphological awareness and spelling is not specific to suffixes. However, our results do not speak to the issue of a suffix-specific relationship: It may well be the case that morphological awareness is especially necessary – or beneficial – for spelling inflectional suffixes, and this could only be discerned in comparison with

TABLE 3 | Results of regression analyses for the longitudinal prediction of Grade 1 reading skills.

	Multiple regression		Commonality (variance)			Hierarchical regression			
Preschool predictor	**β**	***p***	**Unique**	**Common**	**Total**	**Step**	R^2	ΔR^2	***p***
Word accuracy									
Receptive vocabulary	0.018	0.951	<0.001	0.017	0.017	1	0.018		0.410
Expressive vocabulary	−0.148	0.336	0.007	−0.005	0.002				
Phonological awareness	0.169	0.198	0.013	0.087	0.100	2	0.106	0.089	0.002
Morphological awareness	0.748	<0.001	0.144	0.088	0.232	3	0.250	0.144	<0.001
Pseudoword accuracy									
Receptive vocabulary	0.047	0.794	0.001	0.029	0.030	1	0.031		0.207
Expressive vocabulary	−0.042	0.659	0.002	0.009	0.011				
Phonological awareness	0.147	0.071	0.025	0.107	0.132	2	0.138	0.108	0.001
Morphological awareness	0.409	<0.001	0.112	0.112	0.224	3	0.251	0.112	<0.001
Fluency									
Receptive vocabulary	0.663	0.065	0.027	0.055	0.081	1	0.081		0.014
Expressive vocabulary	−0.174	0.354	0.007	0.005	0.012				
Phonological awareness	0.527	0.001	0.084	0.108	0.192	2	0.227	0.146	<0.001
Morphological awareness	0.333	0.115	0.019	0.106	0.125	3	0.247	0.019	0.115
Comprehension									
Receptive vocabulary	0.215	0.007	0.052	0.127	0.179	1	0.202		<0.001
Expressive vocabulary	0.052	0.208	0.011	0.090	0.101				
Phonological awareness	0.012	0.731	0.001	0.088	0.089	2	0.231	0.029	0.056
Morphological awareness	0.168	<0.001	0.091	0.130	0.221	3	0.322	0.091	<0.001
Spelling									
Receptive vocabulary	0.170	0.115	0.017	0.057	0.074	1	0.075		0.019
Expressive vocabulary	−0.079	0.163	0.014	−0.007	0.007				
Phonological awareness	0.143	0.003	0.061	0.144	0.206	2	0.240	0.165	<0.001
Morphological awareness	0.223	0.001	0.085	0.153	0.238	3	0.325	0.085	0.001

appropriately designed spelling tests assessing performance on particular kinds of suffixes. Such studies should be performed with older children, because suffix-specific spelling knowledge is taught after Grade 1. At any rate, our findings suggest that there is also a more general sense in which early metalinguistic awareness supports the development of spelling skill. Whether this relates to language or cognitive skills required for metalinguistic task performance is not known. Future studies must use appropriate latent constructs to examine whether these observed longitudinal relationships are direct or mediated by other, more general, constructs.

Our findings seem to be somewhat at odds with those of Manolitsis (2006), who found that preschool morphological awareness longitudinally predicted Grade 1 single word reading speed, but not accuracy, after controlling for phonological awareness. We have not measured single word reading speed, so this finding is not directly comparable to our measure of text reading fluency. The difference in the longitudinal prediction of word reading accuracy is difficult to explain conclusively without more information; it may be attributable to differences in the task content or task reliabilities. In particular, two of the morphological awareness tests used by Manolitsis had internal reliabilities less than 0.70, whereas the third one was a compound inversion task, unlike the ones we used here. Despite these differences, Manolitsis also found largely shared longitudinal contributions from preschool phonological and morphological awareness to Grade 1 word reading. In other words his general pattern of findings was not inconsistent with ours.

Vocabulary made a significant unique contribution only in the prediction of reading comprehension, and this was largely accounted for by the receptive (picture selection) rather than the expressive (verbal definitions) measure. This finding is consistent with the role of vocabulary in the development of reading comprehension that has been revealed in middle elementary grades in Greek (Protopapas et al., 2007, 2013b). Vocabulary was not related to Grade 1 reading accuracy performance, even when entered in the first step of the regression. In contrast, its significant Step 1 contribution to fluency and spelling was eventually trumped by morphological awareness due to shared variance related to these outcomes. This suggests that these morphological awareness tests capture language skills variance that is relevant for reading development at this age (cf. Hjetland et al., submitted).

It has long been known that phonological and morphological awareness share much of their variance at this age (e.g., Carlisle and Nomanbhoy, 1993) and thus it is no surprise that their contribution to reading performance is largely shared (e.g., Manolitsis, 2006). In our study, phonological awareness made a significant contribution to all reading outcomes (marginal for comprehension) when entered after vocabulary, as expected. However, this was only significant for fluency and spelling, in which it included a substantial unique contribution (6–8%). In contrast, the contribution of phonological awareness to word and pseudoword accuracy and reading comprehension was largely shared with morphological awareness, ending up non-significant in the final multiple regression models. In particular, the unique contribution of phonological awareness to word and pseudoword reading accuracy, in the presence of morphological awareness, was less than 3% of the variance. One way to interpret this, going beyond any shared content between materials in phonological and morphological awareness tasks, is to consider the extent to which these morphological awareness tests may also capture more general metalinguistic skill variance that is relevant for learning to read.

This finding raises the interesting possibility that the predictive power of phonological awareness for reading development may not be entirely due to its phonological nature but perhaps in part because it concerns metalinguistic skill, which, in turn, depends on earlier language skill development. It will be necessary to examine whether this finding holds up in follow-up research, in Greek and other languages, and in a wider range of ages. One reason it has not been found in the few studies that have examined the longitudinal prediction of early reading outcomes by preschool skills may have to do with psychometric issues. Specifically, tests of morphological awareness tend to be of lower reliability than tests of phonological awareness, and

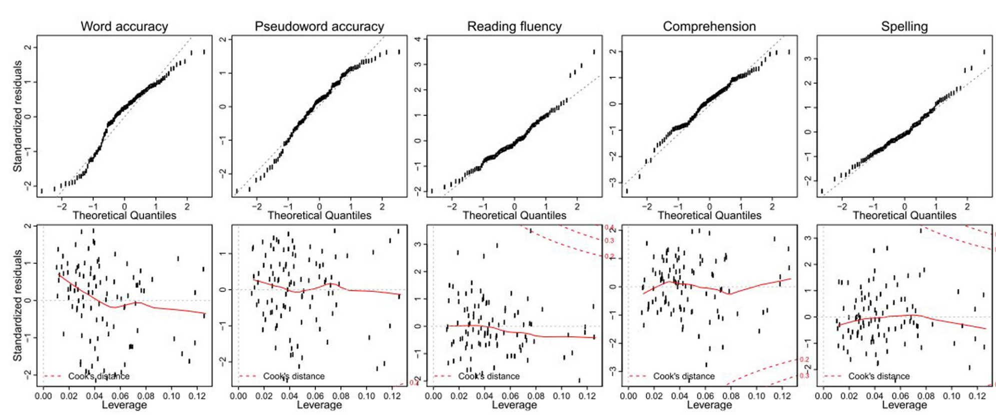

FIGURE 1 | Multiple regression diagnostics. **(Top)** Quantile–quantile plots of standardized residuals for the longitudinal prediction of each outcome variable. **(Bottom)** Corresponding leverage-residual plots with overlaid smooth trend, also displaying Cook's distance curves at values of 0.2 and 0.3.

therefore may not pick up all the variance that can properly be attributed to a well-defined morphological awareness construct due to measurement noise. Our study stands out for the very high reliability of both the phonological and morphological awareness measures, allowing the regression models to capture substantial proportions of the reliable variance in the dependent variables. Ideally, future studies should include multiple highly reliable tasks as indices of corresponding latent constructs in order to examine the relative contribution of different metalinguistic skills to early reading outcomes as free from measurement noise as possible.

In this work we have treated phonological and morphological awareness as unitary constructs, by combining responses from multiple subtasks examining specific aspects of these domains. This methodological choice is supported by the very high reliability of the aggregated tasks. It is also supported by strong evidence in favor of phonological awareness being a unidimensional construct (e.g., Schatschneider et al., 1999; Anthony and Lonigan, 2004; also in Greek: Papadopoulos et al., 2009, 2012). Similarly, with respect to the morphological tasks, covering both inflectional and derivational morphology, and both judgment and production tasks, Diamanti et al. (in press) found that a single factor sufficed and accounted for 59% of the total variance, consistent with a unidimensional construct for morphological awareness as well [Muse (2005) as cited in Tighe and Schatschneider (2015)].

Our study joins the long list of studies, mentioned in the introduction, in suggesting that an explicit understanding of linguistic structure is substantially predictive of future reading performance. It provides an important confirmation of the importance of morphological awareness for reading development, by testing preliterate children, for whom a reverse effect (of reading experience on the development of morphological awareness) is unlikely, and by employing highly reliable tests covering different aspects of the target construct, such as a variety of suffixes and functions and tasks of different formats and demands. In addition, our findings bring out differences in the relevance of phonological and morphological awareness for the prediction of different reading (and spelling) tasks, at least for the age tested, that is, beginner readers.

Finally, the present study raises the intriguing possibility that the general cognitive demands of metalinguistic tasks may be of utmost importance for the prediction of reading development, whereas the linguistic content of the tasks may be of secondary importance or critical for specific associations with particular reading skills. Given the increasing prominence of morphological awareness study in the reading literature, we expect that this issue will be further investigated and clarified in future comprehensive studies.

ETHICS STATEMENT

This study was carried out in accordance with the guidelines of the American Psychological Association for treatment of human participants, with written informed consent obtained from the parents (or legal guardians) of all children participants, approval by the school authorities, and oral assent of the children prior to test administration. The protocol was approved by the Greek Ministry of Education, following positive recommendation of the Institute of Educational Policy.

AUTHOR CONTRIBUTIONS

VD conceptualized this study. VD, AM, AR, FA, and SP contributed to the design and implementation of data collection. AP conducted the statistical analysis of the data. VD and AP drafted the manuscript. All authors have contributed to the writing and revising of the manuscript and agree to be accountable for the content of the work.

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The Longitudinal Contribution of Early Morphological Awareness Skills to Reading Fluency and Comprehension in Greek

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The purpose of this longitudinal study was to examine the role of three morphological awareness (MA) skills (inflection, derivation, and compounding) in word reading fluency and reading comprehension in a relatively transparent orthography (Greek). Two hundred and fifteen (104 girls; M_{age} = 67.40 months, at kindergarten) Greek children were followed from kindergarten (K) to grade 2 (G2). In K and grade 1 (G1), they were tested on measures of MA (two inflectional, two derivational, and three compounding), letter knowledge, phonological awareness, rapid automatized naming (RAN), and general cognitive ability (vocabulary and non-verbal IQ). At the end of G1 and G2, they were also tested on word reading fluency and reading comprehension. The results of hierarchical regression analyses showed that the inflectional and derivational aspects of MA in K as well as all aspects of MA in G1 accounted for 2–5% of unique variance in reading comprehension. None of the MA skills predicted word reading fluency, after controlling for the effects of vocabulary and RAN. These findings suggest that the MA skills, even when assessed as early as in kindergarten, play a significant role in reading comprehension development.

Keywords: morphological awareness, reading fluency, reading comprehension, vocabulary, phonological awareness, rapid automatized naming, Greek

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INTRODUCTION

To date, several studies have shown that morphological awareness (MA) (the awareness of morphemic structures of words and the ability to reflect on them) is an important predictor of reading ability (e.g., Carlisle, 2003; Reichle and Perfetti, 2003; Deacon and Kirby, 2004; McCutchen et al., 2009; Tibi and Kirby, 2017; see also Ruan et al., 2017, for a meta-analysis) surviving the statistical control of other key predictors of reading ability such as vocabulary, phonological awareness, rapid automatized naming (RAN), and orthographic knowledge (e.g., McBride-Chang et al., 2005; Roman et al., 2009; Deacon, 2012; Desrochers et al., 2017).

However, previous studies examining the relationship of MA with reading ability have some important limitations. First, most previous studies have only examined a limited number of MA skills[1] (see Rispens et al., 2008; Apel et al., 2013; Tibi and Kirby, 2017, for a few exceptions) and,

[1]Morphological awareness skills vary according to the morphological processes they tap such as inflection, derivation, and lexical compounding, or according to the cognitive processes used to demonstrate a manipulation of words' morphemic structure such as segmentation, production, judgment, analogical reasoning, identification of word relatives, and oral vs. written skills. In the present study, we were interested in different morphological awareness skills based on their morphological processes.

as a result, different studies have operationalized MA with different tasks. It remains unclear if different aspects of MA predict reading ability the same way. Second, most of the studies reporting a connection between MA and reading ability have administered tasks based either on the explicitness of the morphological information (analogy, judgment, production) (e.g., Carlisle, 1995; Roman et al., 2009) or the representational level of morphological processes (inflection, derivation, and compounding) (e.g., Casalis and Louis-Alexandre, 2000; Vaknin-Nusbaum et al., 2016). However, assessing both the representational level of morphological processes and the explicitness of morphological information (e.g., examining the inflectional awareness by an analogy and a production task) can give us clearer evidence about the distinct roles of morphological processes in reading development. Finally, because most previous studies have examined the role of MA in reading after children had received formal reading instruction, it is possible that the observed effects were confounded by the effects of earlier reading ability on MA (e.g., Deacon et al., 2013; Kruk and Bergman, 2013; Cheng et al., 2016). Thus, the purpose of this study was to examine the role of three MA skills (inflectional, derivational, and compounding) in reading fluency and comprehension in a sample of Greek children followed from kindergarten to grade 2.

Morphological Awareness and Reading Development

A number of studies have shown that MA predicts reading ability, particularly beyond the initial phases of learning to read (e.g., Deacon and Kirby, 2004; Roman et al., 2009; Kirby et al., 2012; Kieffer et al., 2013; Kim et al., 2013; Deacon et al., 2014; Pittas and Nunes, 2014; Desrochers et al., 2017). Similar positive relationships have been reported in intervention studies of MA (see e.g., Bowers et al., 2010, for a meta-analysis). Even though the majority of studies on MA have been conducted in English, there is now ample evidence that MA is important for reading ability across a wide range of languages such as Arabic (Tibi and Kirby, 2017), Chinese (Ku and Anderson, 2003), Dutch (Rispens et al., 2008), French (Casalis and Louis-Alexandre, 2000), Greek (Rothou and Padeliadu, 2015), Hebrew (Vaknin-Nusbaum et al., 2016), Japanese (Muroya et al., 2017), and Korean (Cho et al., 2011). Nunes and Hatano (2004) further argued that despite the different orthographic characteristics of different languages, MA is important for reading across languages.

A significant contribution of MA to reading ability is implied in the propositions of most contemporary theories of reading development (e.g., Frith, 1980; Marsh et al., 1981; Ehri, 2005; Seymour, 2005). For example, theories of reading development have postulated that during the later phases of reading development there is a shift in the strategies used for word reading from phonological recoding to the employment of larger linguistic units represented by morphemes. Recently, Kirby and Bowers (2017) also proposed that MA predicts reading because of the central role of morphology in binding the semantic, phonological, and orthographic information of words and in regulating these connections and the quality of words' representation. Indeed, several studies in English have reported a significant effect of MA on both reading accuracy (e.g., Mann and Singson, 2003; Deacon and Kirby, 2004) and fluency (e.g., Apel and Diehm, 2014; Desrochers et al., 2017). However, theories of reading development suffer from an anglocentric focus (Share, 2008) and what we would expect for English may not apply to other languages with a more transparent orthography (e.g., Finnish, Greek).

Interestingly, the two behavioral studies that have examined the role of MA in word reading accuracy (Rothou and Padeliadu, 2015) and fluency (Desrochers et al., 2017) in Greek as well as the one that examined the effects of MA in decoding speed and accuracy in Finnish (Müller and Brady, 2001) have concluded that MA is not important for word reading in these languages. A similar conclusion was reached by some eye-movement studies for the role of morphology on word reading speed in Finnish and Dutch (e.g., Bertram and Hyönä, 2003; Kuperman et al., 2009, 2010; however, see also Häikiö et al., 2011).

The few behavioral studies in transparent orthographies have either examined inflectional skills (Müller and Brady, 2001; Rothou and Padeliadu, 2015) or general MA by combining the inflectional and derivational scores (Desrochers et al., 2017), and, therefore, we do not know if other MA skills (e.g., compounding) predict word reading fluency in these orthographies. If Greek children rely on orthographic knowledge (the ability to form, store and access phonological representations) to read fluently (e.g., Georgiou et al., 2008) and the orthographic units can represent morphemes as well, then MA should predict reading fluency. In contrast, if Greek children read fluently by converting the letters to sounds more efficiently (this expectation is based on the psycholinguistic grain size theory; Ziegler and Goswami, 2005), then MA should not predict reading fluency.

The method of reading instruction may also explain the non-significant effects of MA in word reading in transparent orthographies. More specifically, children in Finland and Greece receive phonics instruction to learn to read (e.g., Aro, 2006; Protopapas, 2017). This may give an unfair advantage to phonological awareness over MA. Indeed, several studies in transparent orthographies (including Finnish and Greek) have shown that phonological awareness predicts word reading fluency in grades 1 and 2 (e.g., Georgiou et al., 2008; Puolakanaho et al., 2008; Papadopoulos et al., 2009; Ziegler et al., 2010; Caravolas et al., 2012).

In contrast to reading fluency, a significant contribution of MA to reading comprehension would be expected based on the fact that words, beyond their phonetic aspects, carry morphological information and morphemes disclose the meaning of words (e.g., DeFrancis, 1989; Levesque et al., 2017). According to the lexical quality hypothesis (Perfetti, 2007), reading comprehension can be benefited largely from the knowledge of the components of words. These components include knowledge about word forms (e.g., grammatical class) and meaning representations. Building on this theoretical account, Levesque et al. (2017) further proposed that children's morphological skills may actively contribute to the analysis of morphologically complex words' meaning in order to influence the understanding of text. In support of the theoretical links between MA and reading comprehension, several studies have shown that general measures of MA predict reading comprehension (e.g., Carlisle, 1995; Carlisle and Fleming, 2003; Nagy et al., 2006; Kirby et al., 2012; Kieffer et al., 2013; Deacon et al., 2014; Pittas and Nunes, 2014; Desrochers et al., 2017; Levesque et al., 2017).

In addition, there is some evidence for the contribution of specific MA skills to reading comprehension, although this evidence is derived mostly from studies with school-age children. For example, Casalis and Louis-Alexandre (2000) found that inflectional awareness in kindergarten predicts reading comprehension in grade 2. Deacon and Kirby (2004) also found that inflectional awareness in grade 2 predicts reading comprehension in grades 4 and 5, and that the effects remain significant even after controlling for the effects of prior reading comprehension. Similarly, cross-sectional (e.g., Carlisle, 2000; Vaknin-Nusbaum et al., 2016; Deacon et al., 2017) and longitudinal (e.g., Carlisle, 1995; Casalis and Louis-Alexandre, 2000) studies have reported significant effects of derivational awareness on reading comprehension. In contrast to inflectional and derivational awareness, little is known about the relationship of compounding awareness with reading comprehension. To our knowledge, only Nagy et al. (2003) examined the role of compounding awareness in reading comprehension in English and included children at risk for reading difficulties[2].

Clearly, longitudinal studies that look into the different representational processes of MA and their contribution to word reading fluency and reading comprehension are currently missing. A number of studies have focused on the link between MA and word reading accuracy (e.g., Singson et al., 2000; Deacon and Kirby, 2004; Rothou and Padeliadu, 2015), but there is lack of studies on reading fluency, which is used as the main reading outcome in transparent orthographies in which reading accuracy reaches ceiling soon after children receive formal reading instruction (e.g., Seymour et al., 2003; Duncan et al., 2013). For example, several studies have shown that by grade 2 Greek children score above 90% in word reading accuracy[3] (e.g., Nikolopoulos et al., 2006; Papadopoulos et al., 2009; Protopapas and Gerakaki, 2009; Sarris and Dimakos, 2015). In addition, we need more studies examining the role of different MA skills in reading comprehension

The Present Study

The purpose of the present study was to examine the role of three MA skills (inflectional, derivational, and compounding) in reading fluency and reading comprehension in a sample of Greek children followed from kindergarten to grade 2. Special attention was paid to the inclusion of a number of known predictors of reading ability (non-verbal IQ, vocabulary, phonological awareness, RAN; see Georgiou et al., 2008; Manolitsis et al., 2009; Caravolas et al., 2012; Hulme and Snowling, 2013) in order to provide a rather conservative test of the effects of MA skills on reading fluency and comprehension.

Our study aimed to answer the following two questions:

(1) Do skills representing different morphological processes (inflection, derivation, and compounding) in kindergarten and grade 1 predict reading fluency in grades 1 and 2? Based on the findings of previous studies (e.g., Müller and Brady, 2001; Desrochers et al., 2017) and in light of the method of reading instruction in Greece, we expected that none of the MA skills would predict word reading fluency, after controlling for the effects of letter knowledge, phonological awareness, and RAN.
(2) Do skills representing different morphological processes (inflection, derivation, and compounding) in kindergarten and grade 1 predict reading comprehension in grades 1 and 2? We hypothesized that all MA skills would predict reading comprehension in grade 2, but not in grade 1. This is because children's performance in reading comprehension in grade 1 is heavily influenced by their decoding skills (children who do not decode cannot comprehend text) and we control for the effects of key predictors of decoding such as letter knowledge, phonological awareness, and RAN. Because most Greek children master decoding by grade 2 (e.g., Seymour et al., 2003; Papadopoulos et al., 2009), the influence of the literacy-related skills (letter knowledge, phonological awareness, and RAN) on reading comprehension should diminish, and this should allow other skills such as MA to make a significant contribution[4].

The Morphological Features of Greek Language

Greek is a morphologically rich language characterized as a fusional type of language (Ralli, 2005), which has more than one morpheme per word and inflectional morphemes may convey multiple grammatical, syntactic, and semantic information. Greek has been estimated to have 41 inflectional suffixes for nouns (Kalamboukis, 1995). Inflectional morphemes are representing the grammatical markers of words for denoting words' gender, person/number, tense, aspect, case. For example, there are inflectional markers to denote three different genders (masculine, feminine, and neuter) and four different cases (nominative, genitive, accusative, and vocative) for nouns and adjectives, two different numbers for nouns, adjectives and verbs, eight tenses, two voices (active, medium-passive), and three different aspects (perfective, imperfective, and perfect) for verbs (Holton et al., 2004).

[2]We did not consider the studies conducted in Chinese here (e.g., McBride-Chang et al., 2005; Li and Wu, 2015; Cheng et al., 2016; Su et al., 2017), because compounding awareness in Chinese is different from compounding awareness in alphabetic orthographies (Ruan et al., 2017).

[3]A small lexicality effect would be expected based on (a) cross-linguistic evidence provided by Seymour et al. (2003) for shallow orthographies with simple syllable structure such as Greek and (b) the findings of Greek studies which reported lower achievement for reading non-words (accuracy rates ranged from 70 to 90%) than for reading real words (Protopapas et al., 2007; Georgiou et al., 2008, 2012b; Papadopoulos et al., 2009; Papadimitriou and Vlachos, 2014; Sarris and Dimakos, 2015).

[4]A similar finding has been reported regarding the contribution of decoding and oral language skills to reading comprehension as part of the "Simple View of Reading" theoretical account. More specifically, studies have shown that as children grow older the contribution of decoding to reading comprehension decreases and the contribution of oral language skills increases (e.g., Adlof et al., 2006; Torppa et al., 2016).

In addition, there is a variety of derivational morphemes (prefixes and suffixes), although less productive than inflectional morphemes, which interact with inflectional morphemes in order to create new words (nouns, verbs, adjectives, and adverbs) added in stems[5] (see Ralli, 2003). Derivational morphemes may change word's grammatical category (e.g., /χor-ós/ 'dance' "noun" → /χor-év-o/ 'I am dancing' "verb"), but not in every case (see for example the prefix /dia/ added in the verb /γráfo/ 'write', resulting in the new verb /diaγráfo/ 'delete' with a different meaning from the initial root verb) (Ralli, 2005).

The lexical compounding system in Greek, which is much richer than in languages such as English and French, is a productive system in which the stem (and not the word as in other languages) plays a decisive role in word formation (for a detailed description of the Greek compounding system see Ralli, 2013). Compounding processes interact actively with inflectional and derivational processes of the Greek morphology to create one-word compounds by including lexical elements (lexemes) which "may be realized as stems, or words" (Ralli, 2013, p. 10). Greek compounds in their vast majority include a stem as the first lexical element, which is a part of a word without its inflectional ending morpheme and a stem or word as the second element depending on whether the compound's both inflectional ending and its stress is different or identical with the ending and the stress of the second element, respectively. The two lexical elements of Greek compounds are linked with a semantically empty vowel /o/[6], which is the compound marker [e.g., /trel-o-kóritso/ mad girl < trel(os) + koríts(i)], that ensures the transition from the first to the second element in a compound formation (Ralli, 2003, 2005) and its absence [/aγriànθropos/ 'wild man' < áγri(os) + ánθropos] occurs rarely due mainly to phonological or morphological grounds (Dalalakis, 1996; Ralli, 2013). The one-word compounds in Greek are classified mainly into the following categories according to their lexical elements. The two basic categories are (a) those who combine two stems [e.g., /trapez-o-mádil-o/ 'tablecloth' < trapéz(i) 'table' + madíl(i) 'handkerchief'] called as [stem-stem] type, (b) those who combine two stems of which the second one is followed by an inflectional suffix making the second element, which is stressed appropriately, to stand as a whole word[7] [e.g., /katsik-o-kléftis/ 'goat-thief' < /katsík(a) 'goat' + kléft(is) 'thief'] called as [stem-word] type. The two less frequent categories consist of (c) two full word forms with the first element of the compound to be an uninflected word (e.g., /eksóporta/ 'outdoor' < ékso 'out' + pórta 'door', /ksana-pézo/ 'replay' < ksaná 'again' + pézo 'play') called as [word-word] type and (d) an uninflected word with a stem [e.g., /katosèdono/ 'bedsheet' < káto 'down' + sedón(i) 'sheet'] called as [word-stem] type. To sum up, Greek compounds have three basic characteristics: (a) compounds receive stress, which does not always concur with the stress of the constituent parts, (b) compounds' meaning may not be derived from the meaning of the constituent parts and (c) compounds' constituent parts are usually stems and not words with the first part to be always an uninflected item (Dalalakis, 1996; Ralli, 2005, 2013). Based on these morphological characteristics of Greek language (see more in Dalalakis, 1996; Ralli, 2003), one would expect MA to be important for reading development, even as early as in grades 1 and 2.

[5]In this study we worked on the assumption that there is no formal distinction between root and stem in Modern Greek language, because "the borders between roots and stems have been blurred, and there is no synchronically motivated distinction between the two" (Ralli, 2013, p. 8). Thus, we use here the term 'stems' instead of 'roots' to refer to the basic lexical units of Greek words, which cannot occur on their own and they need inflectional affixes in order to stand as independent words.

[6]According to a less prominent view, the /o/ is a connecting morpheme (Dalalakis, 1996).

[7]Those compounds who combine two stems of which the second one is followed by an inflectional suffix, which may make the second element to stand as a whole word, if it is stressed appropriately, belongs to the first category of the [stem-stem] type (e.g., /psar-ó-varka/ 'fishing boat' < /psári/ 'fish' + /várka/ 'boat').

MATERIALS AND METHODS

Participants

To recruit our participants we first sent letters of information to the parents of all children attending 10 kindergarten schools in Heraklion, a typical urban city in Greece. Two hundred twenty-nine children (117 males and 112 females; $M_{age} = 67.26$ months, $SD = 3.38$, at the first time of measurement) with parental consent participated in the study and were followed in grade 1 ($M_{age} = 79.39$ months, $SD = 3.33$) and in grade 2 ($M_{age} = 91.40$ months, $SD = 3.34$). The children were native speakers of Greek and none had a formal diagnosis of intellectual, emotional, or sensory difficulties. By grade 2, our sample consisted of 215 children. Fourteen children (6.1% of the initial sample) withdrew from the study because their families moved to a different district and could not be located. In order to examine if the performance of the children who withdrew from the study differed significantly from the rest of the children, we performed *t*-tests on all their kindergarten performance scores. None of the *t*-tests reached significance (all $ps > 0.15$). Thus, the final sample consisted of 215 children (111 males and 104 females; $M_{age} = 67.40$ months, $SD = 3.33$, at the first time of measurement).

Mother's educational level was recorded for the purpose of a different project and it was as follows: 7.2% of the mothers attended only elementary school, 11.3% attended only junior high school, 43.3% obtained a high school degree, 17.5% obtained a college degree and 20.6% obtained a university degree. Based on the National Statistics of Greece (National Statistical Service of Greece, 2007), the mother's educational level in our study was representative of that of urban regions in Greece.

Measures

Non-verbal IQ

The Raven's Coloured Progressive Matrices (Raven, 1956) was used as a measure of non-verbal IQ. The task was administered only in kindergarten and required participants to select one of six options that best completed a matrix with a part missing. A participant's score was the total number correct. Cronbach's alpha reliability has been reported to be 0.90 (Sideridis et al., 2016).

Vocabulary

The Peabody Picture Vocabulary Test-Revised (Dunn and Dunn, 1981), which was adapted into Greek by Simos et al. (2011), was administered only in kindergarten to assess vocabulary knowledge. Participants were shown four pictures and the examiner said a word to describe one of the four pictures. Participants were then asked to look at the quadrant of pictures and point to the one that represented the word provided by the examiner. A participant's score was the total number correct, since no standardized scores in Greek population have been established yet. The Cronbach's alpha reliability coefficient in our sample was 0.96.

Letter Knowledge

This task was administered only in kindergarten and required participants to provide the sound of each of the 24 uppercase and lowercase Greek letters. The letters were arranged randomly on an A4 paper. The maximum score was 48. Letter name knowledge was not assessed because children in Greece are not taught the letter names (e.g., *alpha, beta*) before the end of grade 1. The Cronbach's alpha reliability coefficient in our sample was 0.94.

Rapid Automatized Naming (RAN)

Rapid automatized naming was assessed in kindergarten with an Object Naming task and in grade 1 with a Digit Naming task. Both tasks were adapted in Greek from the Comprehensive Test of Phonological Processing (Wagner et al., 1999). Children were asked to name as fast as possible six recurring pictures (*apple, cat, key, ball, hen,* and *tree*) or numbers (4, 7, 8, 5, 2, and 3) that were arranged in semi-random order in four rows of nine. Prior to time testing, children were asked to name the objects or digits in a practice trial to ensure familiarity with the stimuli. Children named the objects or digits twice (in the second card, the items were rearranged). A participant's score in Object and Digit Naming was the number of items in the task (36) divided by the average time to name both cards. Wagner et al. (1999) reported test–retest reliability for Object and Digit Naming to be 0.87 and 0.91, respectively.

Phonological Awareness

Syllable deletion with words (administered in kindergarten) and phoneme deletion with non-words (administered in both kindergarten and grade 1) were used to assess phonological awareness. In the syllable deletion task (Manolitsis, 2000), children were presented with a two- or three-syllable word and then asked to delete the first syllable from it and say what was left (e.g., Say /lemoni/ [lemon] without saying /le/ is /moni/ [alone]). In all 10 items, the part of the word that remained after deleting a syllable was a real word. A participant's score was the total number of correct items. No discontinuation rule was applied in this measure. The Cronbach's alpha reliability coefficient in our sample was 0.94. In the phoneme deletion task (Porpodas, 2008), children were presented with a one-syllable pseudoword (2–4 phonemes) and then asked to remove a phoneme from it and say what was left. The position of the phoneme to be removed varied across the 24 items: in 13 items it involved the initial phoneme (e.g., Say /lo/ without saying /l/ is o) and in 11 items it involved the final phoneme (e.g., Say /las/ without saying /s/ is la). A participant's score was the total number correct. A discontinuation rule of three consecutive errors was applied in this measure. The Cronbach's alpha reliability coefficient in our sample was 0.95 in kindergarten and 0.91 in grade 1.

Morphological Awareness

Seven tasks (two for derivational morphology, two for inflectional morphology, and three for compounding morphology), adapted into Greek by the second author from similar tasks in English and other languages (see below for more information), were given orally[8] to the participants in kindergarten and grade 1 (see Appendix). A participant's score in all tasks was the total number correct. No discontinuation rule was applied in these measures.

Word analogy

The word analogy task was adapted into Greek from Nunes et al. (1997) and was used as a measure of inflectional and derivational morphology. Children were asked to identify a morphological relationship between one pair of words and apply the same relationship to complete a second pair of words. It consisted of two conditions, inflectional and derivational, and it was preceded by four practice items (two for each condition). The inflectional condition (e.g., "walk-walked", "help-. . .") consisted of 10 items with several transformations of noun/inflection and verb/inflection. In five items, the stem of inflected word types remained unchanged [e.g., /γiatrós/ : /γiatrí/ :: /aetós/ : (/aetí/), for an English example 'doctor' : 'doctors' :: 'eagle' – ('eagles')] and in the other five items there was a change of the stem [e.g., /éklepsa/ : /klévo :: /éγrapsa/ : (/γráfo/), for an English example 'stole' : 'steal' :: 'wrote' : (write")] that was based exclusively on morphological rules and not on phonological similarities. The derivational condition (e.g., "high: height":: "deep : . . ...") consisted also of 10 items with several transformations: transforming a base word into a derived word adding a suffix or a prefix and transforming a derived word into a base word. In five items, the stem of the base words remained unchanged after affixation [e.g., /ómorf-os/ : /omorf-iá/ :: /nóstim-os/ : (/nostim-iá/), for an English example (baker' : 'bakery' :: 'tasteful' : ('tasty')] and in the other five items there was a change of the stem during transformation [e.g., /krív-o/ : /kri-ménos/ :: /váf-o/ : (/va-ménos/), for an English example "tolerate : tolerance" :: 'fly' : ('flight')]. The maximum score in each condition was 10. The order of the items within the two conditions was counterbalanced to avoid practice effects. The Cronbach's alpha reliability coefficient in our sample was 0.86 in kindergarten and 0.85 in grade 1.

Production of inflected forms

This task was adapted into Greek from the "Production of Word Forms Test" (Carlisle and Nomanbhoy, 1993) and was used to assess children's awareness of inflectional morphology.

[8]In contrast to other studies that examined the role of morphology to reading development using written tasks (e.g., Häikiö et al., 2011; Kieffer et al., 2013; Vaknin-Nusbaum et al., 2016), we used oral tasks, in order to avoid the possible effects of reading ability on morphological awareness.

Children were provided with a target word and then asked to produce the correct inflected form of the target word in order to complete a grammatically, semantically, and morphologically correct sentence (e.g., "Dog. I saw ten ..."). This task consisted of 20 items with several transformations of nominal and verbal inflection, and it was preceded by four practice items. Ten items required a transformation of nouns [e.g., /maθítries/. /I aðelfi mu íne (maθítria)/, for an English example "Students. My sister is a (student)"] or of verbs [e.g., /Kaθaríz-o/. /Ta peðiá tóra (kaθaríz-un)/, for an English example "We clean. My aunt now (cleans)"] without any change on their stem. Another 10 items required transformation of verb tenses with a change on their stem [e.g., /lúst-ika/. /Tóra eγü (lúz-ome)/, for an English example "Slept. Today, for a moment I (sleep)"]. The maximum score in this task was 20. The Cronbach's alpha reliability coefficient in our sample was 0.78 in kindergarten and 0.73 in grade 1.

Manipulation of derived forms

This task was adapted into Greek from the "Test of Morphological Structure: Derivation – Decomposition" (Carlisle, 2000) and was used to assess children's awareness of derivational morphology. It consisted of two subscales: the derivation subscale and the decomposition subscale and it was preceded by four practice items (two for each subscale). In the first one (derivation), which contained 10 items, children were provided with a target base word and then asked to produce the correct derived form by transforming the base word with suffixation in order to complete a short sentence [e.g., /psár-i/. /O θíos mu íne (psar-ás)/, for an English example "Farm. My uncle is a (farm-er)"]. The second subscale (decomposition), also consisting of 10 items, required children to make changes from a target derived word to a base word in order to complete a sentence [e.g., /ékt-os/. /Ta γatákia ítan (éksi)/, for an English example "Sixth. The kittens were (six)"]. In each subscale, half of the items required changes in the stem of the target base word or of the target derived word. The maximum score in this task was 20. The Cronbach's alpha reliability coefficient in our sample was 0.80 in kindergarten and 0.79 in grade 1.

Compound word segmentation

This task was adapted into Greek from the "Analyses of Compound Words" task (Lyster, 2002) and the "Morphemic-Segmentation Test" (Casalis and Louis-Alexandre, 2000), and was used to assess children's awareness of lexical compounding. The task consisted of 16 items and it was preceded by three practice items. Children were asked to pronounce separately the two lexical elements of a compound word (e.g., Can you guess which words made the big word "doorbell"?). We designed two conditions for this task. In half of the items, the lexical elements of the compounds were two uninflected stems [e.g., /riz-ó-γal-o/ 'rice pudding' < ríz(i) 'rice' + γál(a) 'milk'] and in the other half the lexical elements consisted of an uninflected stem combined with a stem followed by an inflectional suffix which can stand as a whole word [e.g., /petr-o-pólemos/ 'stone throwing' < pétr(a) 'stone' + pólem(os) 'war']. Therefore, participants had to segment the two stems, making proper transformations in order to pronounce them as whole words [e.g., /alat-o-píper-o/ 'salt and pepper' → the child must answer: alát(i) 'salt' and piper(i) 'pepper']. The maximum score in this task was 16. The Cronbach's alpha reliability coefficient in our sample was 0.88 in kindergarten and 0.87 in grade 1.

Compound word reversal

This task was adapted into Greek from the "Morpheme-Reversal Task" (Elbro, 1989) and it was used to assess children's awareness of lexical compounding. The task consisted of 10 items and three practice items. Children were asked to reverse a compound word and to pronounce the new compound [e.g., /pikr-ó-γlikos/ ronounce the new compound /γlik-ó-pikros/, 'bittersweet' → 'sweet bitter' < pikr(ós) 'bitter' + γlik(ós) 'sweet']. This requires children to first recognize the two lexical elements of each compound word. Then children were asked to make a transformation in which the second element of the initial compound had to be put first and the first element second in order to create a new compound. Most of the resulting new compounds were not "legitimate" words in the Greek vocabulary, although all they convey a meaning that is easily understood by native speakers. All of the compounds consisted of two stems. The maximum score in this task was 10. The Cronbach's alpha reliability coefficient in our sample was 0.87 in both kindergarten and grade 1.

Compound word production

This task is similar to the "Compound Structure Test" (Nagy et al., 2003) and it was initially developed in Greek by Tzakosta (2009) to assess children's awareness of lexical compounding. The task consisted of 15 items and three practice items. Children were provided with two target words and were asked to pronounce the compound word that could be derived from the two words. In five items, the two target words were given in the same order as in the resulting compound (e.g., What word is formed from /çióni/ 'snow' and /ánθropos/ 'man'? → /çionanθropos/ 'snowman'), in five items the two target words were given in the opposite order from that of the resulting compound (e.g., "What would we call the /çimós/ 'juice' of the /domatàs/ 'tomato'? → /domat-o-çimós/ 'tomatojuice'), and in the last five items the two target words were creating a legitimate compound that does not exist in Greek (e.g., "What would we call the /trípa/ 'hole' of the /lemóni/ 'lemon'? → /lemon-ó-tripa/ 'lemonhole'). Children had to transform appropriately the target words into stems in order to pronounce successfully the resulting compound. The maximum score in this task was 15. The Cronbach's alpha reliability coefficient in our sample was 0.81 in kindergarten and 0.85 in grade 1.

Reading Fluency

The word reading efficiency (WRE) from the Test of Word Reading Efficiency (Torgesen et al., 1999; see Georgiou et al., 2012a, for the Greek adaptation) was used in grades 1 and 2 to assess reading fluency. Children were asked to read a list of 104 real words as fast and accurately as possible within a 45-s time limit. A participant's score was the total number of correctly read words within the specified time limit. Georgiou et al. (2012a) reported test–retest reliability for WRE to be 0.92 for elementary school children.

Reading Comprehension

To assess reading comprehension we used two standardized tests (one in each grade) that follow the same format and are group administered. The "Test of First Reading Comprehension" was designed by Porpodas (2008) and was used here in grade 1. The test consisted of 16 sentences of increasing difficulty and was preceded by four practice items. Children were asked to silently read each sentence and choose (by circling) among three alternative words the one that would correctly complete the sentence. In turn, the "Test for Detecting Reading Ability" was designed by Tafa (1995) and was used here in grade 2, because it is more suitable for children of this age. The test is timed (40 min are allowed for completion) and also uses a cloze format, whereby the children were asked to choose and underline from four alternative words the one that would correctly complete the sentence they had silently read. The test consisted of 42 sentences of increasing difficulty and was preceded by four practice items. The Cronbach's alpha reliability coefficient in our sample was 0.89 in grade 1 and 0.91 in grade 2.

Procedure

All participants were tested individually in a separate room in their schools during school hours by the second author and a graduate student who had experience in psychological testing. In kindergarten, testing lasted roughly one and a half hours and was completed in three sessions of 30 min each. In grade 1, testing lasted 1 h and was completed in three sessions. In grade 2, testing lasted 1 h and was completed in two sessions. In both grades 1 and 2, the reading comprehension task was administered in groups of 10–15 participants. Again, the administration of this task took place in a quiet room in school.

RESULTS

Descriptive Analysis

Descriptive statistics for the measures used in the study are shown in **Table 1**. There were no missing data and all the analyses were performed with a full dataset of 215 participants. An examination of the distributional properties of the measures revealed that they were within acceptable levels (Kim, 2013). Before running any further analyses, the number of variables was reduced in order to limit task-specific variability. Particularly, we calculated composite scores for (a) inflectional, derivational and compounding morphology in kindergarten and grade 1, and (b) for phonological awareness in kindergarten. In kindergarten, the two phonological awareness tasks correlated 0.55 with each other. Likewise, the measures that made up each MA skill correlated higher than 0.50 with each other. In grade 1, the MA measures contributing to each composite score correlated 0.52 or higher with each other. In all instances, the composite scores were calculated by averaging the *z*-scores of the respective component measures.

Table 2 displays the zero-order correlations among all variables used in the following hierarchical regression analyses. The three MA skills in both measurement points correlated highly with each other cross-sectionally (*r*s ranged from 0.76 to 82) and longitudinally (*r*s ranged from 0.70 to 89). The three MA skills correlated moderately with word reading fluency (*r*s ranged from 0.32 to 0.47) and moderately to strongly with reading comprehension (*r*s ranged from 0.44 to 0.65).

Predicting Word Reading Fluency and Reading Comprehension

Next, we performed hierarchical regression analyses to examine the contribution of MA skills to future reading fluency and comprehension. Specifically, we ran three separate models with the kindergarten predictors (**Table 3**) and three separate models with the grade 1 predictors (**Table 4**). In Model 1, we entered non-verbal IQ, vocabulary, and mother's education as control variables at step 1 of the regression equation. At step 2, we entered as a block the literacy-related skills (letter-sound knowledge – only in kindergarten -, phonological awareness, and RAN). Finally, at step 3, we entered the MA skills one at a time. In Model 2, we repeated the steps 1 and 2 of Model 1 and entered the MA skills as a block at step 3 of the regression equation. Finally, in Model 3, we entered the control variables at step 1, the autoregressor (reading fluency or comprehension at an earlier point in time) at step 2, and the MA skills at step 3 of the regression equation (they were entered one at a time). **Tables 3**, **4** present the standardized beta coefficients, significance levels, and R^2 changes in word reading fluency and reading comprehension.

The results with the kindergarten predictors (see **Table 3**) showed first that none of the MA skills was a significant predictor of word reading fluency. Second, the awareness of inflectional and derivational morphology accounted for a small, but still significant, amount of variance (1 and 2%, respectively) in reading comprehension in grade 2, but not in grade 1. These effects remained significant, even after partialing out the effects of reading comprehension in grade 1 (autoregressor). Interestingly, when all three MA skills in kindergarten were entered as a block in the regression equation (see Model 2 of **Table 3**), they did not account for more unique variance in reading comprehension than when entered individually. In fact, the results of this analysis showed that only derivational morphology remained a significant predictor of reading comprehension.

The results with the grade 1 predictors (see **Table 4**) showed that none of the MA skills was a significant predictor of word reading fluency. In contrast, they accounted for a significant amount of variance in reading comprehension (2 to 4%; see Model 1 of **Table 4**). Similar to the findings of **Table 3**, the joint contribution of the three MA skills to reading comprehension did not substantially surpass their individual contribution (see Model 2 of **Table 4**). Again, only derivational morphology remained a significant predictor of reading comprehension when entered at the same step with the rest of the MA skills.

DISCUSSION

The present longitudinal study examined the role of specific MA processes (inflection, derivation, and lexical compounding)

TABLE 1 | Descriptive statistics for all variables across grades.

	Kindergarten		Grade 1		Grade 2		Maximum score
Measures	*M*	*SD*	*M*	*SD*	*M*	SD	
Non-verbal IQ (raw scores)	16.78	3.65					36
Non-verbal IQ	97.46	12.94					
Vocabulary[a]	67.37	19.22					173
Letter-sound knowledge	21.62	16.49					48
Phonological awareness							
Syllable deletion	3.17	3.79					10
Phoneme deletion	1.78	4.01	12.61	7.82			24
Rapid automatized naming[b]							
Objects	0.67	0.16					–
Digits			1.41	0.35			–
Inflectional morphology							
Word analogy (inflections)	3.75	2.58	6.06	2.50			10
Production of inflected types	11.38	3.83	13.22	3.25			20
Derivational morphology							
Word analogy (derivations)	3.36	2.42	5.21	2.59			10
Manipulation of derived types	10.66	4.25	13.94	3.74			20
Compounding morphology							
Compounds segmentation	6.37	4.26	8.58	3.99			16
Compounds reversal	1.86	2.61	3.33	3.14			10
Compounds production	4.10	3.24	5.63	3.54			15
Reading comprehension			10.43	4.80	21.11	8.37	16[1]/42[2]
Word reading fluency			22.22	10.21	39.10	11.71	104

[1]*Maximum score for grade 1;* [2]*maximum score for grade 2;* [a]*raw scores;* [b]*items per second.*

TABLE 2 | Correlations between the variables across grades.

Kindergarten	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Measures																		
(1) Non-verbal																		
(2) Vocabulary	0.40																	
(3) Mother's Ed	0.14	0.30																
(4) Letter sound	0.29	0.50	0.42															
(5) RAN	0.22	0.37	0.20	0.47														
(6) PA	0.31	0.46	0.33	0.64	0.48													
(7) InflA	0.33	0.57	0.36	0.58	0.50	0.59												
(8) DerA	0.31	0.59	0.33	0.57	0.45	0.60	0.84											
(9) CompA	0.33	0.65	0.36	0.69	0.49	0.67	0.76	0.80										
Grade 1																		
(10) RAN	0.26	0.26	0.34	0.50	0.63	0.48	0.36	0.34	0.36									
(11) PA	0.29	0.45	0.33	0.59	0.39	0.52	0.54	0.52	0.58	0.44								
(12) InflA	0.31	0.62	0.38	0.56	0.38	0.54	0.75	0.71	0.74	0.29	0.61							
(13) DerA	0.32	0.63	0.38	0.61	0.38	0.61	0.70	0.78	0.79	0.31	0.61	0.80						
(14) CompA	0.30	0.64	0.36	0.68	0.42	0.66	0.74	0.75	0.89	0.39	0.66	0.79	0.82					
(15) WRE	0.27	0.33	0.33	0.57	0.54	0.54	0.40	0.36	0.47	0.74	0.59	0.39	0.43	0.52				
(16) Read Comp	0.32	0.48	0.42	0.53	0.39	0.43	0.44	0.44	0.52	0.41	0.56	0.56	0.57	0.55	0.51			
Grade 2																		
(17) WRE	0.19	0.33	0.31	0.53	0.51	0.43	0.34	0.32	0.41	0.67	0.52	0.35	0.37	0.43	0.83	0.48		
(18) Read Comp	0.30	0.61	0.44	0.64	0.43	0.58	0.59	0.61	0.65	0.48	0.60	0.64	0.68	0.69	0.61	0.60	0.58	

Ed, education; RAN, rapid naming; InfA, inflectional awareness; DerA, derivational awareness; CompA, compounding awareness; PA, phonological awareness; WRE, word reading efficiency; ReadComp, reading comprehension; For Pearson r's > 0.14, p < 0.05; for r's > 0.18, p < 0.01; for r's > 0.24, p < 0.001.

in word reading fluency and reading comprehension in Greek. Importantly, the longitudinal contribution of these skills was tested in the presence of other key predictors of reading ability such as general cognitive ability (non-verbal IQ and vocabulary), letter-sound knowledge, phonological awareness, RAN, and even of reading ability at an earlier point in time (autoregressor). Our results showed that the contribution of MA skills varies as a function of the reading outcome; being significant only when predicting reading comprehension.

In line with our hypothesis and with the findings of previous studies (e.g., Müller and Brady, 2001; Manolitsis, 2006; Kirby et al., 2012; Desrochers et al., 2017) MA skills did not predict word reading fluency in grades 1 and 2, after controlling for the effects of general cognitive ability, mother's education, and literacy-related skills. An explanation might be that faster readers in grade 2 do not use morphological information for reading words efficiently. Häikiö et al. (2011), for example, showed that that the most advanced grade 2 Finnish readers read compound words through a whole word processing and not by using a morphologically based strategy. An alternative explanation might be that Greek children read fluently by speeding up the process of phonological recoding (what would be expected based on the psycholinguistic grain size theory; Ziegler and Goswami, 2005). Presumably, if decoding becomes fast enough, children should read individual words fluently. A similar argument was made by de Jong (2011) using discrete and serial RAN to predict discrete and serial word reading. Specifically, de Jong (2011) showed that in grades 1 and 2, serial RAN was more strongly related to serial and discrete word reading than discrete naming. This implies that children process individual letters in words serially (the same way they name the stimuli in serial RAN). However, this finding may also be an artifact of the method of teaching reading in Greece. Given that phonics is the preferred method of teaching reading, children would be more inclined to sound out the words than rely on larger orthographic (and morphological) units.

Our findings are in contrast to the findings of previous cross-sectional studies (Rispens et al., 2008; Apel et al., 2013) showing significant effects of derivational awareness on word reading fluency. Beyond the obvious difference in the design of the studies (our study was longitudinal), the contradictory findings may be due to the use of control variables in the present study and more specifically of RAN. To our knowledge, this is the first time the effects of RAN on word reading fluency have been controlled for before examining the role of MA skills in a longitudinal study (but see Müller and Brady, 2001; Roman et al., 2009; for cross-sectional studies). This is critical because RAN is one of the best (if not the best) predictors of word reading fluency in transparent orthographies (e.g., de Jong and van der Leij, 1999; Di Filippo et al., 2005; Landerl and Wimmer, 2008; Georgiou et al., 2012b) and because Object Naming requires semantic processing over and above access to phonological

TABLE 3 | Results of hierarchical regression analyses with measures in kindergarten as predictors of reading skills in grades 1 and 2.

Kindergarten measures	Reading comprehension Grade 1		Reading comprehension Grade 2		Word reading fluency Grade 1		Word reading fluency Grade 2	
	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2
Model 1								
(1) Control variables		0.35***		0.49***		0.21***		0.19***
Non-verbal IQ	0.11		0.06		0.13		0.06	
Vocabulary	0.37***		0.54***		0.27**		0.29***	
Mother's education	0.29***		0.27***		0.23**		0.22**	
(2) Literacy-related skills		0.08***		0.11***		0.25***		0.21***
RAN	0.12		0.09		0.30***		0.32***	
Letter-sound knowledge	0.24**		0.24**		0.21***		0.32***	
Phonological awareness	0.08		0.18*		0.25***		0.04	
(3) Morphological awareness								
(a) Inflectional	0.01	0.00	0.17*	0.01*	−0.12	0.01	−0.15	0.01
(b) Derivational	0.03	0.00	0.21*	0.02*	−0.14	0.01	−0.13	0.01
(c) Compounding	0.08	0.00	0.10	0.00	−0.09	0.00	−0.15	0.01
Model 2								
(3) Morphological awareness		0.00		0.02*		0.01		0.01
Inflectional	−0.04		0.06		−0.04		−0.10	
Derivational	0.02		0.20*		−0.12		−0.02	
Compounding	0.09		−0.06		−0.02		−0.08	
Model 3								
(2) Autoregressor[1]			0.38***	0.09***			0.83***	0.52***
(3) Morphological awareness								
(a) Inflectional			0.27***	0.04***			0.01	0.00
(b) Derivational			0.30***	0.05***			−0.05	0.00
(c) Compounding			0.13	0.01			−0.07	0.00

*The beta coefficients reported are taken from the step in the regression equation in which the predictor variables were entered. [1]The autoregressor for the outcome variable 'reading comprehension' and 'word reading fluency' in grade 2 was the corresponding measure in grade 1. *p < 0.05, **p < 0.01, *** p < 0.001.*

representations (e.g., Poulsen and Elbro, 2013; Liu and Georgiou, 2017).

In contrast to reading fluency, reading comprehension in grades 1 and 2 was predicted by the MA skills, even when they were measured in kindergarten and after controlling for the effects of other known predictors of reading comprehension such as vocabulary and phonological awareness. Although this is certainly not the first study to show that morphological skills predict reading comprehension (e.g., Nagy et al., 2003, 2006; Kirby et al., 2012; Deacon et al., 2014; Pittas and Nunes, 2014; Levesque et al., 2017), we have shown for the first time that both inflectional and derivational processes of MA in kindergarten contribute uniquely to reading comprehension 2 years later. The contribution of MA skills to reading comprehension in grade 2 doubled when these skills were assessed in grade 1 (whereas kindergarten measures of MA accounted for 1–2% of unique variance, grade 1 measures accounted for 2–4% of unique variance). The findings were also in line with our hypothesis that MA skills would predict reading comprehension in grade 2, but not in grade 1. This pattern of findings is similar to that of Carlisle (1995) showing no effects of MA from kindergarten to reading comprehension in grade 1, as well as to that of Casalis and Louis-Alexandre (2000) showing a unique effect of inflectional skills in kindergarten and of derivational skills in grade 1 on reading comprehension in grade 2.

Lexical compounding awareness was an important predictor of reading comprehension only when assessed in grade 1. It is possible that this aspect of MA, which reflects children's ability to manipulate intensively compound's words morphemic structure, is still underdeveloped in kindergarten and cannot contribute to future reading comprehension. The Greek compounding system is more complex than that of other European languages such as French and English (see Ralli, 2013) and this may be one of the reasons why lexical compounding contributes to reading comprehension in Greek; manipulating the structure of compound words gives children an opportunity to infer the meaning of Greek polysyllabic compound words.

Some limitations of the present study are worth mentioning. First, we used an existing measure to assess children's word reading fluency. This has two important implications: First, because the words were read in isolation (not in context), this may have reduced the role of MA. Second, the first 40 or so words in the task are mostly one or two (stem + inflectional suffix) morpheme words. Again, this may have reduced our chances to find significant effects of MA on word reading fluency. Besides, it has been argued that morphological skills are important for word reading accuracy or fluency when the words to be read are multimorphemic or complex (e.g., Deacon et al., 2011; Carlisle and Kearnes, 2017). In fact, a recent study by Grigorakis and Manolitsis (2017) showed that MA in kindergarten was a significant predictor of compound words reading fluency in Greek, but not of derived words fluency

TABLE 4 | Results of hierarchical regression analyses with morphological awareness measures in grade 1 as predictors of reading skills in grade 2.

Measures	Reading comprehension Grade 2		Word reading fluency Grade 2	
	β	Δ*R2*	β	Δ*R2*
Model 1				
(1) Control variables (kindergarten)		0.49***		0.19***
Non-verbal IQ	0.06		0.06	
Vocabulary	0.54***		0.29***	
Mother's education	0.27***		0.22**	
(2) Literacy-related skills (grade 1)		0.13***		0.37***
RAN	0.21***		0.57***	
Phonological Awareness	0.30***		0.23***	
(3) Morphological awareness (grade 1)				
(a) Inflectional	0.27***	0.03*	−0.06	0.00
(b) Derivational	0.30***	0.04*	−0.06	0.00
(c) Compounding	0.22**	0.02**	−0.07	0.00
Model 2				
(3) Morphological awareness (grade 1)		0.05***		0.00
Inflectional	0.17		−0.02	
Derivational	0.24**		−0.03	
Compounding	−0.03		−0.03	
Model 3				
(2) Autoregressor[1]	0.38***	0.09***		0.52***
(3) Morphological awareness (grade 1)				
(a) Inflectional	0.30***	0.04***	0.00	0.00
(b) Derivational	0.33***	0.05***	−0.06	0.00
(c) Compounding	0.30***	0.04***	−0.07	0.00

*The beta coefficients reported are taken from the step in the regression equation in which the predictor variables were entered; [1]The autoregressor for the outcome variable 'reading comprehension' and 'word reading fluency' in grade 2 was the corresponding measure in grade 1. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.*

(they are morphologically simpler than compounds[9]). Second, we administered only one type of reading comprehension measures (they both followed a cloze format). To the extent different types of reading comprehension measures are affected by different cognitive-linguistic skills (e.g., Cutting and Scarborough, 2006; Kendeou et al., 2012), our findings may not generalize to other reading comprehension outcomes. Third, because reading accuracy in Greek reaches ceiling soon after formal reading instruction (e.g., Seymour et al., 2003; Tafa and Manolitsis, 2008; Papadopoulos et al., 2009), we did not administer a reading accuracy task in our study, but only reading fluency tasks that require both accuracy and speed. Fourth, the weak effects of lexical compounding awareness – assessed in Kindergarten – on later reading skills may be due to the low performance of children on the morphological compounding tasks. Although the tasks measuring lexical compounding awareness are difficult for young children (e.g., Rispens et al., 2008; Manolitsis, 2017), we included multiple measures of this construct in order to capture even the most demanding parts of MA skills. Finally, we acknowledge that our classification of the MA tasks is not the only one. Deacon et al. (2008), for example, proposed a taxonomy of MA tasks that takes into account also the format of presentation (oral vs. written). Certainly, this warrants further investigation in a future study.

CONCLUSION

Our findings add to a growing body of research in different languages showing that MA skills are important for reading comprehension development. This has some important psychoeducational implications. First, it implies that if we were to assess MA in kindergarten we would increase our chances to identify children at-risk for reading comprehension deficits. In fact, a couple of studies have shown that poor comprehenders experience difficulties in MA (Tong et al., 2011; Adlof and Catts, 2015). Second, our findings suggest that the "whole is not better than the part"; the joint contribution of all morphological aspects to reading comprehension was not any better than the contribution of derivational morphology alone. This suggest that if researchers cannot test children on all MA aspects, they may achieve the same goal by administering only derivational morphology tasks. Third, our findings suggest that early intervention of MA may have a positive effect on children's future reading comprehension (see Lyster et al., 2016, for some promising findings). Finally, our findings suggest that Greek teachers should perhaps reconsider the way they teach reading by complementing phonics instruction with some MA activities (see Bowers and Bowers, 2017 and Manolitsis, 2017, on how this can be achieved). This would be more in accord with the findings of several studies showing that MA is important for reading comprehension as well as with the characteristics of Greek orthography.

[9] Greek compound words bear an inflectional suffix at the right lexical element, while they may involve simultaneously a lexical element which could be a derived item [e.g., /anem-o-ðarmèn-os/ 'wind-swept' < ánem(os) 'wind' + ðarmèn(os) 'beaten']. On the other hand, derived words in Greek usually has a simpler construction with the presence of a single stem and an affix (prefix or suffix) [e.g., /angelúði/ 'litlle angel' < angel(os) - úði, /anáksios/ 'unworthy' < an - áksios] and a shorter length than compounds (for differences among compounding, derivation and inflection in Greek, see Ralli, 2013).

ETHICS STATEMENT

The study was approved by the Institute of Education of the Ministry of Education in Greece as well as the Research Ethics Committee of the Department of Preschool Education at the University of Crete. Written consent from parents and schools was also obtained prior to testing.

AUTHOR CONTRIBUTIONS

The three authors contributed to the present manuscript in the following way: GM supervised the data collection, ran the analyses, and wrote most of the paper. IG conceptualized the research project, developed the MA measures in Greek, collected the data in schools, and wrote parts of the paper. GG contributed to the interpretation of the findings and to the writing of the paper.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2017.01793/full#supplementary-material

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How Children Become Sensitive to the Morphological Structure of the Words That They Read

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Background: We tested the predictions of models of word reading development as to the effects of repeated exposure on reading of derived words.

Aim: Our goal was to examine the impacts of variables that quantify different aspects of this exposure: base frequency, family frequency, and family size.

Methods and Samples: In Experiment 1, we asked 75 children in Grades 3 and 5 to read derived words with low surface frequencies (e.g., *questionable*) that varied in base frequency, family frequency, and family size. In Experiment 2, we asked 41 adults to read the same set of words.

Results: In Experiment 1, only base frequency made a contribution to word reading accuracy that was independent of the other two variables of interest (family size and family frequency) and the control variables (surface frequency, semantic relatedness, and neighborhood size). In Experiment 2, a similar pattern of results emerged, this time on reading speed.

Conclusion: Together, results of these two studies suggest that base frequency has a special role in both children's and adults' reading of derived words. These findings suggest that it plays a specific role in development and maintenance of sensitivity to morphological structure in reading.

Keywords: morphology, derived words, reading, elementary school, base frequency, family size, family frequency

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INTRODUCTION

The English language encodes the minimal units of sound (i.e., phonemes) and of meaning (i.e., morphemes) in the spelling of words (Chomsky and Halle, 1968). A large body of research demonstrates that an appreciation of the phonological basis of print is central to young children's reading development (e.g., Share, 1995; National Reading Panel, 2000; Ehri, 2005). To support their reading, children are likely to benefit from an appreciation of the morphological basis of words in print, at least by the upper elementary school period. Over 40% of the unfamiliar words that Grade 5 students encounter in texts are derived from more frequent words (Nagy et al., 1993). Derived words are morphologically complex forms that typically involve a change in word class from their base forms; for example, the adverb *seriously* is derived from the more frequent adjectival base *serious*. There is clear evidence that children are sensitive to the morphological structure of derived words in their reading (e.g., Mann and Singson, 2003). This is demonstrated, for example, through increased accuracy or speed in reading derived words than control words (e.g., *hilly* vs. *silly*, the former of which can be divided into the morphemes *hill* + *y;* Carlisle and Stone, 2005). Deacon et al. (2011) found that Grades 4 and 6 children were more accurate and faster in reading derived words with high than with low base frequencies. We present here the results of an investigation designed to add precision to theoretical models of the development of sensitivity to morphological structure of words in reading.

Models of the development of both reading and lexical representation point to a key role of repeated exposure to morphemes in the establishment of sensitivity to morphological structure of words. As an example, Ehri (2005) suggests that repeated exposure to the letter-patterns that make up morphemes allow children to consolidate these units in their reading. Similarly, Schreuder and Baayen (1995) suggest that the representation of morphologically complex words emerges through monitoring the developing lexicon for connections between form and meaning. The implication of form in this model of lexical representation suggests that it could apply equally to reading as to lexical representation. The processes described in both of these models predict a role of repeated exposure to morphemes and morphologically complex words in establishing sensitivity to the morphological structure of words.

These predictions of effects of repeated exposure leave us wondering which aspects of exposure impact children's sensitivity to the morphological structure of words, especially as it relates to reading. It could be that repeated exposure to the diversity in form across multiple members of the same morphological family (e.g., *prediction*, *predictable*, *predictability*...) enables development of sensitivity to the morphological structure of these words in reading. Family size is a count of the number of morphological relatives of a base, while family frequency is the summed frequency of those morphological relatives (e.g., Taft, 1979). Of the two, family frequency likely more closely approximates frequency of exposure to all members of the morphological family. The variety across family members might be key to the extraction of letter-patterns that represent morphemes (Ehri, 1995) and to the detection of form and meaning co-occurrences (Schreuder and Baayen, 1995). Testing the effects of family size and family frequency would determine whether exposure to the diversity in morphological family members plays a role in the establishment of sensitivity to morphological structure in reading.

Alternatively, development of sensitivity to morphological structure in reading might be influenced by exposure to isolated instances of the base form, such as *predict*. Exposure to the base on its own might be the most potent form of repeated exposure to morphemic letter-patterns (e.g., Ehri, 2005) and to form and meaning co-occurrences (e.g., Schreuder and Baayen, 1995). If this is the case, we would expect the frequency of the base to play a privileged role in children's reading of derived words. Testing these theoretically driven predictions requires an empirical study designed to separate the effects of base frequency, family size and family frequency on derived word reading.

Multiple studies show impacts of base frequency on English-speaking children's reading of derived words. Mann and Singson (2003) found that third and sixth Grade children were more accurate in reading derived words with high than with low base frequencies. Similar effects emerged in Deacon et al.'s (2011) study of children in Grades 4, 6, and 8, particularly with low frequency derived forms. Similar effects emerged in Carlisle and Stone's (2005) study of Grades 4 and 5 children, although no such effects emerged in Grades 2 and 3. These studies present initial evidence of effects of base frequency on children's reading of derived words, at least by the middle of the elementary school years; notably, none of these studies controlled for or investigate effects of either family frequency or family size.

Turning to these other variables, Carlisle and Katz (2006) showed effects of both family frequency and family size on children's reading of derived words. Grades 4 and 6 English-speaking children were faster and more accurate in reading sets of words with high than with low family frequencies. These word sets also differed in base frequency and family size. The children were also faster and more accurate in reading words with large than small families (see also Perdijk et al., 2012 in Dutch). These word sets also differed in base and derived word frequency. Carlisle and Katz's further analyses showed strong relationships between base frequency and family frequency, as well as between family size and surface frequency. As such, Carlisle and Katz urge caution in interpreting effects uncovered in their study. As an example, they note that "because the small and large families differed in base word frequency, interpretation of the results of this analysis is not clear-cut" (p. 684). Studies of children's reading have not yet isolated the effects of base frequency, family size, and family frequency, which is key to specifying models.

Recent studies of adult lexical representation have made clear progress in disentangling these effects. Ford et al. (2010) used correlational analyses at the item level to investigate the continuous, rather than binary, effects of variables. With this approach, Ford et al. (2010) found that family size and base frequency each had an independent effect on lexical decision response times (see also Burani and Caramazza, 1987). Family frequency counts were not included in these analyses. This evidence of independent effects of family size is consistent with that of other studies. In contrast, independent effects of base frequency have not always emerged in such studies (Schreuder and Baayen, 1997; Bertram et al., 2000). The analytic approach taken by Ford et al. (2010) in studies of adult lexical representation could be useful in isolating the aspects of repeated exposure on sensitivity to morphological structure of words in reading.

The current study was designed to provide the requisite empirical data to specify the aspects of repeated exposure to morphologically complex words that determine child and adult sensitivity to the morphological structure of words in reading. We used a correlational design to evaluate the independent effects of each of base frequency, family size and family frequency on derived word reading in a manner that controls for their likely inter-correlation (e.g., Carlisle and Katz, 2006). In two separate studies, we evaluate the effects of base frequency, family size and family frequency, beyond control variables, on children's (Experiment 1) and adults' (Experiment 2) reading of low frequency derived words. We focus on low frequency derived forms given evidence of morphemic effects particularly on these forms (e.g., Carlisle and Stone, 2005).

We predict that exposure to the base on its own is required to establish sensitivity to morphological structure in word reading, as reflected in independent effects of base frequency. While it is possible that children are able to extract morphological structure across family members, we suspect that repeated exposure to precisely the same form is required to support the detection of shared form and meaning (e.g., Schreuder and Baayen, 1997). In testing such a prediction, it is critical to statistically control for the possibility that effects of base frequency are due to sheer repetition of the orthographic or phonological form, without attention to morphology. As such, we control for orthographic neighborhood size to limit the influence of orthographic familiarity effects that are not specific to either the base form or morphological relatives (see e.g., Perdijk et al., 2012). This also effectively controls for phonological influences. Further, and following on Ford et al. (2010), we include controls for semantic relatedness in order to disentangle morphemic from semantic effects (see also Schreuder and Baayen, 1997; De Jong et al., 2000). We also include controls for surface frequency given the demonstrated impacts of frequency on children's and adults' reading (Spieler and Balota, 1997; Spencer, 2010).

EXPERIMENT 1

In the first experiment, we tested the influence of base frequency, family size, and family frequency on children's accuracy in reading derived words. We recruited children in Grades 3 and 5, an age at which they should be sensitive to the morphemic structure of written words (Ehri, 2005). Mid to late elementary years is also a period during which children are learning rapidly about the many derived words both in print and in oral language (Carlisle, 1988; Anglin, 1993; Nagy et al., 1993; Carlisle, 2000). Finally, Grades 3 and 5 are years in which we expect children to be able to manage the task demands of reading derived words out loud. Examining the independent influence of these three variables in children's reading of derived words will specify the aspects of repeated exposure that support the development of children's sensitivity to the morphemic structure of derived words in their reading.

Method

Participants

We recruited 43 children in Grades 3 and 32 in Grade 5 from two rural schools on the east coast of North America. Mean age of the children was 8;11 years (*SD* = 3.9 months) in Grade 3 and 10;11 years (*SD* = 4.2 months) in Grade 5. All children had parental consent and parents reported children as speaking English as a first language. All children were enrolled in standard English curriculum. We have no reason to believe that any were bilingual. The children read within the normal range for their age (standard scores within 85 to 115 on standardized tasks); mean standard word reading scores (Woodcock, 1998) were 100.12 (*SD* = 12.49) and 93.06 (*SD* = 10.84) in Grades 3 and 5, respectively.

Materials

We selected 48 derived words based on children's word frequencies (Zeno, 1995; see Appendix). All target words had a low surface frequency that ranged from 1 to 3 words/million words across the 12 grade levels in the corpus (U). To ensure developmental appropriateness, all words ended in one of 6 suffixes (*-ment*, *-ness*, *-ly*, *-ful*, *-able,* and *-less*). All of these were rated one of the 20 most common suffixes (Blevins, 2001) and they were all highly productive. There were no phonological or orthographic changes between the base and derived forms (e.g., *adapt-adaptable*), as both variables are known to affect children's processing (e.g., Carlisle, 1988).

The 48 words varied in family size, family frequency, and base frequency. Following on prior research with children, all inflected, derived, and compound family members of the base were included in calculations of family size and family frequency (Carlisle and Katz, 2006). We also calculated these values a second time in which we included only derived and compound family members (following on Ford et al., 2010). We obtained Latent Semantic Analysis semantic relatedness values for the base-derived word pairs (Landauer et al., 1998); these correlate highly with subjective ratings of semantic relatedness (Rastle et al., 2000). To control for orthographic familiarity that is not specific to the base or morphological relatives, we calculated neighborhood sizes for the base and derived forms. Words of the same length with a letter substitution at one position were considered to be neighbors (e.g., Coltheart et al., 1977).

Procedure

We asked the children to read the 48 words as part of a larger battery of tasks administered individually to students in a quiet area of their schools. In this derived word reading task, each word was presented on a computer screen using DirectRT (Jarvis, 2000). Children saw a fixation point on the screen for one second. Next, each target word appeared on a black screen in white 40 point Arial font. Each word was presented once and disappeared 500 ms after the child read it aloud. Words were displayed for a maximum of 8000 ms. Children read three practice words prior to reading the set of experimental items. The experimenter recorded children's reading accuracy.

Results

Across both grades, children read an average of 55% (*SD* = 24%) of words correctly (51 and 61% in Grades 3 and 5, respectively). Reliability for accuracy was high (alpha = 0.89). Analyses focused on accuracy. Accuracy was deemed appropriate in this study given that the scores obtained from the children clearly demonstrate that their ability to read these words is still developing (e.g., Carlisle and Katz, 2006). Interpretable analyses of speed rely on high levels of accuracy.

Correlations

In all correlational and linear regression analyses, we report analyses in text and tables with calculations of family size and family frequency with all inflected, derived, and compound family members. This is the standard approach in prior studies with children (e.g., Carlisle and Katz, 2006). We confirm these results in analyses with calculations of family size and family frequency that include only derived and compound family members; this is standard approach in prior studies with adults; Ford et al., 2010).

TABLE 1 | Correlations between measures of family size, base frequency, family frequency, surface frequency, semantic relatedness, neighborhood size of the derived word, and neighborhood size of the base word.

Variable	Family size	Base frequency	Family frequency	Surface frequency	Semantic relatedness	Neighborhood size (derived)	Neighborhood size (base)
Family size	1	0.337*	0.663***	0.027	0.102	−0.017	0.211
Base frequency	–	1	0.574***	0.033	0.058	−0.046	0.128
Family frequency	–	–	1	−0.174	−0.037	−0.163	0.143
Surface frequency	–	–	–	1	0.005	0.149	0.352*
Semantic relatedness	–	–	–	–	1	0.110	−0.178
Neighborhood size (derived)	–	–	–	–	–	1	0.335*
Neighborhood size (base)	–	–	–	–	–	–	1

**p* < 0.05, ***p* < 0.01, ****p* < 0.001. *Correlations with family size and family frequency counts are reported for values calculated with all compound, derived, and inflected members (Carlisle and Katz, 2006).*

Pearson correlations across items are shown in **Table 1**. These are calculated on a by-item basis to determine how word features, such as base frequency and family size, are related within words. Base frequency was highly correlated with both family frequency and family size, and family frequency and family size are also significantly correlated with one another. All correlations between experimental variables were below 0.70, ensuring that there were no multicollinearity concerns (Tabachnick and Fidell, 2007).

Linear Regression Analyses

We conducted linear regression analyses to determine if base frequency, family size, and family frequency each contributed to children's derived word reading accuracy. These analyses with mean accuracy for each derived word (following on Carlisle and Katz, 2006) were conducted on a by-items basis (following on Ford et al., 2010).

We examined data for missing values and distribution normality (Tabachnick and Fidell, 2007). The one missing value was corrected with missing value replacement. Skew in base frequency, family frequency, family size, and surface frequency was corrected with square root, log, square root, and inverse transformations, respectively. Analyses below are reported with the transformed data; analyses with raw data revealed the same pattern of results.

The linear regression analyses are reported in **Table 2**. In these analyses, we included surface frequency, semantic relatedness, and neighborhood size of the base and derived forms as the first step in each equation (following on Ford et al., 2010). In three separate linear regression analyses, we rotated the order of entry of family size, base frequency, and family frequency at each of Steps 2, 3, and 4. Results at Step 2 show the effects of each of these variables after the control variables only. Each of base frequency, family frequency, and family size made a significant contribution to children's accuracy in reading derived words, after our control variables. Results at Step 4 evaluate the unique effects of each of base frequency, family frequency, and family size. Only base frequency emerged as a unique predictor (at 8.3%) of children's derived word reading accuracy, beyond the substantial control variables.

We computed interaction terms with grade (Pedhazur and Schmelkin, 1991) to evaluate possible differences in effects across our two grades. Each interaction term was included as the fifth step in a separate linear regression, following on the four-step regressions described above. None of the interaction terms were significant; beta values ranged from −0.079 to −0.049, *t*'s from −0.647 to −0.400, and all *p*'s > 0.519. The absence of interactions suggests that the pattern of findings did not differ by grade.

We confirmed all linear regressions analyses with family size and family frequency variables calculated with only derived and compound family members (as is standard in adult research; Schreuder and Baayen, 1997; Ford et al., 2010). Again, base frequency emerged as the only unique predictor of children's derived word reading accuracy. As before, this contribution

TABLE 2 | Summary of linear regression analyses predicting word accuracy for children in Grades 3 and 5.

Step	Predictor	B	ΔR^2	Predictor	B	ΔR^2	Predictor	B	ΔR^2
1	Surface frequency	−0.152	0.241*						
	Semantic relatedness	0.204							
	N size of base	0.537							
	N size of derived form	−0.050							
2	Family size	0.206	0.039	Base frequency	0.376	0.137*	Family frequency	0.275	0.066^
3	Family frequency	0.241	0.028	Family size	0.099	0.008	Base frequency	0.337	0.073*
4	Base frequency	0.349	0.077*	Family frequency	−0.004	0.000	Family size	0.101	0.005

*^p < 0.1, *p < 0.05; reported Beta weights are Step Betas. N, neighborhood. Values at Step 2 show the effects of each of family size, base frequency and family frequency after controlling for surface frequency, semantic relatedness and the neighborhood size of the base word and its derived form. Values at Step 4 show the effects of each of family size, base frequency and family frequency after controlling for surface frequency and semantic relatedness, in addition to the other two variables.*

survived controls for surface frequency, semantic relatedness, family frequency and family size.

Discussion

Our first experiment investigated the unique influences of base frequency, family size and family frequency on Grades 3 and 5 children's derived word reading accuracy. Our analyses addressed the interrelationships between these variables (Carlisle and Katz, 2006). Our results suggest that only base frequency had a unique impact on derived word reading accuracy, beyond the influence of the others. These results were consistent across our two groups of late elementary school children, as reflected in the absence of interactions. These results were also consistent across different metrics of family size and family frequency (e.g., Schreuder and Baayen, 1997; Carlisle and Katz, 2006) and beyond multiple control variables.

EXPERIMENT 2

The results of Experiment 1 with children suggest a unique influence of base frequency on children's derived word reading accuracy beyond that of family size and family frequency. This independent influence of base frequency is similar to that uncovered in Ford et al.'s (2010) study with adults. This comparability in results across studies suggests developmental stability. Nevertheless, it would be useful to confirm the pattern of results with adults in precisely the same paradigm—that of word reading, rather than lexical decision. Further, it would be important to do so with controls for both family size and family frequency, the latter of which was omitted from Ford et al.'s (2010) analyses. This was the goal of our second experiment.

Method

Participants

We recruited 41 undergraduate students at a large research-intensive university on the east coast of North America. All had English as a first language. The mean age of the participants was 21;00 years (*SD* = 2;05 years).

Materials

The materials were identical to those in Experiment 1.

Procedure

Participants were tested in a quiet room in the Psychology department; all other aspects of the procedure were identical to those in Experiment 1.

Results

Across participants, 99% (*SD* = 2%) of words were read correctly. Given this high level of accuracy, analyses focused on word reading speed. Correlational analyses of item features (such as base frequency and family size) are the same as for Experiment 1 (see **Table 1**), given that the same items are included. As in Experiment 1, there were no concerns with multicollinearity (Tabachnick and Fidell, 2007).

Linear Regression Analyses

Analyses were conducted by-items, with the mean speed of reading for each derived word was the focus of the analyses. The data was examined for missing values and distribution normality. As with the children's data, skew in base frequency, family frequency, family size, and surface frequency variables was corrected with square root, log, square root, and inverse transformations, respectively. Analyses are reported with the transformed data; analyses with raw data revealed the same pattern of results.

Three linear regression analyses examined whether each of base frequency, family size, and family frequency made a significant contribution to adults' speed of derived word reading, after controlling for surface frequency and semantic relatedness. Accordingly, surface frequency, semantic relatedness, and neighborhood size of the base and derived forms were entered as the first step in the equation. These analyses are reported in **Table 3**. As before, each of family size, base frequency, and family frequency were rotated in Steps 2, 3, and 4 in the regression analyses. Results at Step 2 show that only base frequency made a significant contribution to adults' speed of reading derived words, beyond semantic relatedness, surface frequency, and neighborhood size of the base and derived forms. Results at Step 4 show that the unique effects of each of base frequency, family size and family frequency. Only base frequency emerged as a unique predictor (at 9.3%) of adults' speed of derived word reading.

The same pattern of results emerged when linear regressions were conducted with family frequency and family size counts that

TABLE 3 | Summary of linear regression analyses predicting word reading speed for adults.

Step	Predictor	B	ΔR^2	Predictor	B	ΔR^2	Predictor	B	ΔR^2
1	Surface frequency	0.217	0.166^						
	Semantic relatedness	−0.242							
	N size of base	−0.415							
	N size of derived form	0.054							
2	Family size	−0.143	0.019	Base frequency	−0.335	0.108*	Family frequency	−0.171	0.026
3	Family frequency	−0.132	0.009	Family size	−0.043	0.002	Base frequency	−0.360	0.084*
4	Base frequency	−0.373	0.088*	Family frequency	0.129	0.006	Family size	−0.111	0.006

*^p < 0.1, *p < 0.05; reported Beta weights are Step Betas. N, neighborhood. Values at Step 2 show the effects of each of family size, base frequency and family frequency after controlling for surface frequency, semantic relatedness and the neighborhood size of the base word and its derived form. Values at Step 4 show the effects of each of family size, base frequency and family frequency after controlling for surface frequency and semantic relatedness, in addition to the other two variables.*

included only derived and compound family members (following on prior adult research, Schreuder and Baayen, 1997; Ford et al., 2010).

Discussion

Our second experiment investigated the influence of base frequency, family size and family frequency on adults' reading of derived words. As in Experiment 1 with children, only base frequency had a unique influence beyond all others; these effects emerged in Experiment 2 on the dependent variable of speed of reading. These results confirm similarity in the unique influence of base frequency across age levels (adults vs. children) and across measurement type (speed vs. accuracy).

GENERAL DISCUSSION

Current models of reading development (e.g., Ehri, 2005) propose a role for repeated exposure to morphemes in the establishment of sensitivity to morphemic information in children's reading. Our work was designed to specify the impacts of this morphemic exposure. We did so by extending prior investigations into the effects of a single morphemic variable (e.g., base frequency in Deacon et al., 2011) and evaluating the unique effects of each of family size, family frequency, and base frequency on reading of derived words. Our experimental approach included controls for surface frequency and semantic relatedness (e.g., Ford et al., 2010), as well as neighborhood size (Perdijk et al., 2012). Experiment 1 examined these effects on Grades 3 and 5 children's derived word reading accuracy and Experiment 2 investigated these effects on adults' derived word reading speed. In both experiments, only base frequency had a unique impact on derived word reading that survived our multiple controls, including family size and family frequency.

Our finding of an independent effect of base frequency on children's accuracy in derived word reading extends prior studies. Several prior studies with factorial designs have demonstrated effects of base frequency on children's reading of derived words (Mann and Singson, 2003; Carlisle and Stone, 2005). These did not, however, control for family size and family frequency. Amongst others, Carlisle and Katz (2006) noted that there is clear overlap in the relationships between these variables, and pointed to the need to investigate their independent effects on children's reading of derived words. The results of Experiment 1 show robust effects of base frequency on children's derived word reading accuracy that survive controls for family size and family frequency, in addition to surface frequency, semantic relatedness, and neighborhood size. These results emerge across Grades 3 and 5 and across the two different metrics of family size and frequency (e.g., Carlisle and Katz, 2006; Ford et al., 2010).

Unique effects of base frequency on derived word reading also emerged in our study of adults' reading speed. As in the data with children, these effects emerged following controls for family size and family frequency, in addition to semantic relatedness, surface frequency, and neighborhood size. The parallel results across Experiments 1 and 2 suggest consistency in the effects of base frequency in the development and consolidation of morphemic effects on derived word reading. The emergence of these effects in accuracy in children and in speed with adults is in keeping with the age level at which we measured these effects. The mid-range accuracy levels for the Grade 3 and 5 children (roughly 55%) shows that skill in reading these words is clearly still developing. In contrast, the high rates of accuracy for the adults (roughly 99%) suggest that these participants had likely reached some degree of automaticity in reading these words. Despite differences in the metric in which they emerge, the consistency of results point to stability in the factors affecting both developing and skilled derived word reading.

Our findings of the unique effects of base frequency on adults' derived word reading extend prior research. There is a good deal of related research on lexical representation. In such a study, Ford et al. (2010) demonstrated effects of base frequency, following controls for semantic relatedness, surface frequency and family size, in adults' lexical decisions for derived words. Our results show that these base frequency effects survive an additional control for family frequency, at least when tested in a word reading paradigm. That said, our results are perhaps surprising given the findings of other prior studies demonstrating impacts of family size independently of base frequency and family frequency on adult lexical decision (e.g., Schreuder and Baayen, 1997). To apply these results to understanding of lexical representation, it would be important to replicate our study in a lexical decision paradigm. Our results suggest that there are clear effects of base frequency on adults' speed in reading derived words, suggesting effects on adults' representations as they are applied to word reading.

These findings have clear theoretical implications. Prominent developmental models have highlighted the importance of repeated exposure to morphemes (Schreuder and Baayen, 1995; Ehri, 2005). In the Introduction, we outlined the two most plausible alternative ways in which repeated exposure to morphemes might influence the development of children's sensitivity to morphological structure in derived word reading. Repeated exposure might occur across members of the same morphological family (as would be reflected in family size and/or family frequency effects) or through exposure to an isolated base form (as would be reflected in a base frequency effect). We found that only the effects of base frequency were independent of others, both in child and adult readers. These unique effects of base frequency on children's reading suggest that isolated exposure to a base word is particularly influential for the development of sensitivity to morphemic structure in reading. Critically, these effects emerged beyond controls for neighborhood size; neighborhood size of the base reflects any likely influences of exposure to simple orthographic patterns. As such, remaining effects are likely to be due to exposure to base morphemes, rather than simple letter-patterns. Consistency in these effects in adults suggests that this exposure to isolated bases is also important in the maintenance of this sensitivity. Consistent exposure to base forms on their own appears central to the detection and retention of form-meaning connections.

These findings also have clear educational implications. It perhaps seems intuitive that teaching children about morphemes should occur across the presentation of multiple related family members. Our data show, however, that children do not appear to pick up on these commonalities, at least not in an implicit manner. Children might need explicit teaching about connections in meaning across morphological families, perhaps with special attention to the shared base. Of course, such educational implications need empirical testing.

We also need to interpret our results in accordance with their limitations. One lies in the cross-sectional nature of our study. Our results can speak to the factors that influence derived word reading at each of Grades 3 and 5 and in adulthood, but it cannot address directly the factors that influence development across these years. We believe that the consistent pattern of findings across these age levels suggests consistency in the factors that influence change over time; a longitudinal study is needed to confirm this suggestion. Another limitation lies in the nature of the items that we tested. Our conclusions apply specifically to low frequency derived words with no phonological or orthographic changes between base and derived forms. It would be important to extend this investigation to other word types. Finally, in our focus on item-level factors, this experiment did not assess possible child level factors; a much larger sample would be needed to do so. Possible variables for investigation include vocabulary and word reading (see e.g., Levesque et al., 2017).

CONCLUSION

Our results suggest a unique role for base frequency in the establishment and maintenance of sensitivity to morphemic information in derived word reading. Models have specified repeated exposure as central to the establishment of morphemic sensitivity in reading (e.g., Ehri, 2005). The results from our two experiments suggest that it is exposure to the base on its own supports the development of morphemic sensitivity in children's derived word reading accuracy and its maintenance in adults' speed of reading.

ETHICS STATEMENT

The research protocol was approved by the Social Sciences and Humanities Research Ethics Board of Dalhousie University. Child assent and parental consent was obtained for all participating children, in addition to consent for all participating adults.

AUTHOR CONTRIBUTIONS

SHD led the writing of the manuscript. KF led data analysis.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: http://journal.frontiersin.org/article/10.3389/fpsyg.2017.01469/full#supplementary-material

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The Time Course of Activation of Semantic and Orthographic Information in Morphological Decomposition by Korean Adults and Developing Readers

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The current study examined the involvement of semantic and orthographic information in the processing of derived words in Korean Hangul. Sixth grade children and adults participated in four masked priming lexical decision experiments in which the prime duration varied from 36, 48, 57, and 72 ms (in Experiments, 1, 2, 3, and 4, respectively). Morphological (M), semantic (S), and orthographic (O) relatedness between prime-target pairs were manipulated. There were four types of Korean prime-target pairs: (1) -M-S+O: *도시락-도시, scandal-scan*, (2) +M-S+O: *구두쇠-구두, archer-arch*, (3) +M+S+O: *음악가-음악, bravely-brave*, and (4) -M+S-O: *반대이의, accuse-blame*. There were several key findings: (1) adults showed significant priming effects at 57 and 72 ms in +M+S+O and significant priming effects at 72 ms in +M-S+O; (2) less skilled readers showed significant facilitation at 36 ms in +M+S+O; and (3) in -M-S+O, both skilled and less skilled readers show significant inhibition across four prime durations. The different time course of +M+S+O priming for adults and children may be due to developing readers' smaller lexicon and less competition for semantic activation of the monosyllabic suffix (e.g., *가* in *음악가*), which is a homograph in Korean Hangul. The consistent orthographic inhibition for both age groups suggest that orthographic information is activated early and continues to play an important role throughout the course of Korean visual word recognition. The current study extends previous research with readers of Roman alphabets to readers of an alpha-syllabary orthography written in a non-linear spatial layout with more clear-cut syllable boundaries. Taken together, it appears that the involvement of semantic and orthographic information in the decomposition of morphologically complex word may vary depending on the characteristics of the orthography.

Keywords: Korean, morphological decomposition, semantic information, orthographic information, developing readers

INTRODUCTION

There are two main theoretical approaches to explain how morphologically complex words are represented and processed. First, the localist approach of Obligatory Decomposition, put forth by Taft and his colleagues (Taft and Forster, 1975; e.g., Taft, 1979, 2004; Taft and Ardasinski, 2006) considered morphological decomposition to be achieved through the analysis of sublexical orthographic information and it would be applied indiscriminately to affixed (e.g., *teacher*) or pseudo-affixed words (e.g., *corner*). Second, the distributed-connectionist approach (Rueckl and Raveh, 1999; Plaut and Gonnerman, 2000) proposes that learned representations of complex words mediate form and meaning. The learned internal representations develop to the extent of semantic overlap between stem and whole word. Therefore, pseudo-affixed words (e.g., *corner*) or semantically opaque complex words (e.g., *witness*) have representations that are different from those of their stems in these models. This approach would predict that only semantically transparent complex words are decomposed and able to activate the representations of the stems.

Studies employing the partial repetition priming paradigm showed that lexical decision of the target word (e.g., *brave*) was facilitated by the prior presentation of an inflectionally or derivationally related prime (e.g., *bravely*) across a variety of languages and orthographies (Hebrew: Frost et al., 1997; English: Marslen-Wilson and Tyler, 1997, 1998; Marslen-Wilson and Zhou, 1999; French: Longtin and Meunier, 2005; Meunier and Longtin, 2007; Korean: Kim et al., 2015). However, it is unclear whether decomposition is obligatory for all morphological structures or whether it is semantically based since the *brave-bravely* pair not only is morphologically related but also related in semantics and orthography (i.e., +M+S+O in which M stands for morphology, S stands for semantics, and O stands for orthography). Therefore, one critical question in this line of research concerns whether decomposition is morphological, orthographic, or semantic-based, or a combination of two or more factors. Previous studies examining this research question have mostly involved Roman alphabetic orthographies (e.g., English, Dutch, and French) with adult population (e.g., Rastle et al., 2004; Marslen-Wilson et al., 2008). The goal of the current study was to investigate the influence of semantic and orthographic factors on morphological decomposition by comparing several prime/target conditions with adult and developing readers of Korean, a non-Roman alphabetic orthography.

Morphological Decomposition in Adult Readers

The masked priming paradigm (Forster and Davis, 1984) has been commonly used to examine how semantic and orthographic information affects morphological decomposition at the earliest stage of visual word recognition. In masked priming, a forward mask (e.g., #####) is briefly presented, followed by the prime word (e.g., *department*), which may or may not be followed by a backward mask, and finally the target word (e.g., *DEPART*) is presented. The presence of the mask greatly reduces the visibility of the prime and if prime duration is short, participants may not consciously perceive the prime. Comparing the priming effects of +M+S+O (e.g., *teacher-TEACH*) and +M-S+O (related in morphology and form but semantically unrelated, e.g., *corner-CORN*) would reveal whether semantic transparency is necessary for decomposition. Comparing the priming effects of +M-S+O and -M-S+O (merely orthographically overlapped e.g., *dialog-DIAL* because *-og* is not a suffix) would indicate whether morphological structure is necessary for decomposition. Finally, varying the duration of +M-S+O primes would reveal the time course of activation of semantic information during the processing of morphologically complex words. Previous masked priming studies have generally produced two consistent findings. First, +M-S+O produced stronger priming effects than -M-S+O, suggesting that morphological decomposition is not merely orthographic and it appears to be triggered solely by the presence of affixes (Rastle et al., 2004; Rastle and Davis, 2008). Second, priming effects for +M-S+O is significant only with short prime duration suggests that morpho-orthographic segmentation occurs independent of meaning and fades away as primes become visible (Rastle et al., 2000).

Previous research showed that prime-target pairs with semantically transparent relationship (e.g., *cleaner-CLEAN* +M+S+O) and those with apparent morphological relationship but not clear semantic relationship (e.g., *dealer-DEAL* +M-S+O) produced significant and equivalent priming effects at 42 ms prime duration (Rastle et al., 2004). Even when the primes could not be parsed perfectly into stem and affix (e.g., *fetish-FETE*), significant priming effects were still shown at 42 ms prime duration, suggesting that morpho-orthographic decomposition occurs for complex words without clear morphemic boundaries (McCormick et al., 2008). In a masked transposed-letter (TL) priming study, significant priming effects were found in non-word TL stems combined with real suffixes (e.g., *ish* as in *wranish-WARN*) but not in non-word TL stems combined with non-morphemic endings (e.g., *el* as in *wranel-WARN*) with 40 ms prime duration (Beyersmann et al., 2011). In addition to readers of English, morpho-orthographic segmentation was observed in readers of other alphabetic orthographies including French (Longtin et al., 2003), Russian (Kazanina et al., 2008) and Dutch (Diependaele et al., 2005). Although studies (Feldman and Soltano, 1999; Rastle et al., 2000, 2004; Badecker and Allen, 2002; Boudelaa and Marslen-Wilson, 2005; Longtin and Meunier, 2005; Marslen-Wilson et al., 2008) have found significant facilitation for +M+S+O and +M-S+O primes in short prime durations (e.g., 43 and 72 ms), when primes were clearly visible (>200 ms prime duration) in visual priming or in cross-modal priming in which participants were consciously aware of the primes [(Longtin et al., 2003), Experiment 2; Gonnerman et al., 2007; Rueckl and Aicher, 2008], significant facilitation only occurred for +M+S+O (i.e., *TEACHER-teach*) but not for +M-S+O (i.e., *CORNER-corn*). The form-then-meaning hypothesis in word recognition assumes that a word's orthographic form must be processed before its meaning can become available (Feldman et al., 2009). Affixes may be represented as highly productive sublexical morphemic units that are accessed at very early stages of visual word recognition (Beyersmann et al., 2011). A letter chunk that successfully matches an affix representation (e.g., *-ish* in *wranish*) is rapidly identified. After affix-stripping, the remaining letter strings *wran* (even if it is a non-word) activate the representation of *warn*, producing priming. Since the priming effect cannot be attributed to form or semantic overlap between *wranish* and *WARN*, it seems that orthographic analysis is dependent on morphemic structure and it arises at a very early stage before meaning is involved.

In contrast to the facilitative priming effects produced by primes with morphologically decomposable endings (e.g., *corner*-CORN), target words preceded by orthographically overlapped primes with non-morphological endings have generally produced an inhibitory or null effect (e.g., *market-MARK, scandal-SCAN*, neither *-et* nor *-dal* is a suffix in English) (e.g., Rastle et al., 2000, 2004; Marslen-Wilson et al., 2008). Based on the localist approach (Taft and Forster, 1975; Taft, 1979, 2004; Taft and Ardasinski, 2006), non-decomposable endings cannot be stripped from the stem and therefore, words like *market* and *scandal* are processed as whole words. Based on the connectionist approach (Rueckl and Raveh, 1999; Plaut and Gonnerman, 2000), the lexical representations of *market* and *MARK* are not connected since their degree of semantic overlap is very low. Both theoretical approaches would suggest that activation of the lexical representation of the prime would create competition for the activation of the representation of the target word, slowing down lexical decision.

Taken together, previous literature suggests that morphological decomposition occurs automatically and rapidly at the early stage (e.g., shorter than 72 ms) of word recognition. This decomposition process is likely to be based on the orthographic analysis of whether the stimulus contains morphemic structure, irrespective of its lexical, semantic, or syntactic characteristics (Rastle and Davis, 2008). When semantic information is activated, later in the stage of word recognition (e.g., >200 ms), decomposition switched from orthographic-based to semantic-based.

Morphological Decomposition in Developing Readers

To date, only a handful of studies have used the priming paradigm to examine morphological processing in children (Feldman et al., 2002; Rabin and Deacon, 2008; Casalis et al., 2009; Quémart and Casalis, 2014, 2015). Understanding how developing readers process morphologically complex words is important because previous research has shown that morphological awareness in earlier grades predicts reading achievement in later grades (Deacon and Kirby, 2004; Tong et al., 2009; Lam et al., 2012) and morphology training could lead to significant gains in children's word recognition abilities (Chow et al., 2008; Wu et al., 2009). In addition, strong associations have been found between the abilities to manipulate inflectional and derivational morphemes and children's vocabulary knowledge (Champion, 1997; Kuo and Anderson, 2006). Since children have smaller vocabulary size than adults, morphological processing could be fundamentally different between developing and expert readers.

Particularly relevant to the current research question of morphological decomposition, Quémart et al. (2011) found non-semantic-based decomposition in young children. French third, fifth, and seventh graders showed significant priming effects in +M+S+O (e.g., *singer-SING*) +M-S+O (e.g., *corner-CORN*) at 60 and 250 ms prime durations, although the magnitude of priming was significantly greater in +M+S+O at 250 ms. At 800 ms, significant facilitation was observed in +M+S+O and -M+S-O (e.g., *tulip-FLOWER*) but not in +M-S+O. These results provided evidence for morpho-orthographic decomposition among young readers at the early stage of word processing (until 250 ms) while semantic activation only plays a crucial role in morphological processing in the later time course (800 ms). However, in another masked priming study with 57 ms prime duration in Hebrew-speaking fourth and seventh graders (Schiff et al., 2012), while both age groups of children showed significant priming effect in the +M+S condition, only the seventh graders showed significant priming effect in the +M-S condition. These results were inconsistent with Quémart et al. (2011) who found significant facilitation in +M-S+O at 60 ms prime duration in French third and fifth graders. This discrepancy in previous studies may be due to the different characteristics of the orthography, suggesting that there may be cross-linguistic differences in how semantic and orthographic information influences morphological decomposition. The current study aimed to extend these findings to developing readers of Korean, an agglutinative language with a transparent non-Roman alphabetic orthography.

Morphological Processing in Korean Readers

Few studies have examined the influence of semantic and orthographic factors on morphological decomposition in both adult and developing readers of other writing systems. For example, research with adult Hebrew readers has found root primes facilitated the naming and lexical decision of target words that are derived from these words (Frost et al., 1997; Deutsch et al., 1998). Zhou et al. (1999) investigated the interaction between morphological and orthographic information in reading Chinese compound words. +M+S+O primes (e.g., 华丽 *magnificent*– 华贵 *luxurious*) showed facilitation with 57 ms or 200 ms prime durations while -M-S+O prims(e.g., 华侨 *overseas Chinese*– 华贵 *luxurious*) showed inhibition with 200 ms prime duration. Since this study used compound words and Chinese has very limited derivation, these results are less comparable to previous studies using Roman alphabets. Therefore, the current study chose to focus on Korean Hangul for two reasons. First, Korean Hangul is written in a non-linear spatial layout, similar to Chinese characters. Korean graphemes are composed in a square-like block (each corresponding to a syllable), in which the graphemes are arranged left to right and top to bottom. Note that a Hangul letter is not a stroke, some letters may be composed of more than one stroke. A Hangul letter is also not a syllable, each syllable is composed of more than one letter. A Hangul letter is similar to an alphabetic letter in terms of its function.

Each Hangul letter represents a grapheme and corresponds to a phoneme.

Because the Hangul syllable blocks are separated, there is a clear syllable boundary for a Hangul word (e.g., 안녕하십니까 /an nyeong ha sim ni ka/, *hello*). This visually prominent syllable boundary makes the morpheme boundary in Korean Hangul more clear-cut than that in English. This unique feature of the Korean writing system may encourage morphological decomposition to a greater degree than English in which the morpheme boundary can be blurred in words, such as "writer" or "desirable."

The second reason for choosing Korean was that it has a very rich morphology. Particularly, Korean Hangul has very productive, derivational complex word formation, similar to English. Most derivations are generated through affixation. Suffixes are more important than prefixes in deriving new words in Hangul: they are more productive and carry more syntactic functions (Sohn, 1999). For example, the suffix 이 can be added to an adjective, such as 넓 (wide) to form a noun 넓이 (width). The suffix 이 can also be added to a verb, such as 먹 (eat) to form a noun 먹이 (food). This feature of Korean derivation allows us to study morphological processing using the masked priming paradigm similar to previous studies (e.g., Rastle et al., 2000, 2004; Marslen-Wilson et al., 2008) and make the results comparable to those obtained from Roman alphabets.

The Korean language has a simple syllable structure in which there are no initial consonant clusters in syllables; final consonant clusters are limited. Most of words contain one to three syllables. This simpler syllable structure may pose less of a phonemic-level phonological decoding challenge for learning to read Korean in comparison to learning to read English. The grapheme-to-phoneme correspondence in Korean is almost one-to-one except for a few phonological alternations depending on the context that involved changing the sound of the final consonant in a syllable. The highly transparent Korean orthography may put a heavier weight on morphemic information in learning to read.

The Present Study

Native-Korean speaking children in sixth grade and adults were tested using the masked priming paradigm. There were five types of Korean prime-target pairs: (1) orthographically overlapped only (-M-S+O: *도시락-도시*, *scandal-scan*), (2) orthographically overlapped, morphologically decomposable but semantically unrelated (+M-S+O: *구두쇠-구두*, *archer-arch*), (3) morphologically decomposable, semantically related, and orthographically overlapped (+M+S+O: *음악가-음악*, *bravely-brave*), (4) semantically related only (−M+S-O: *반대-이의*, *accuse-blame*), and (5) unrelated (-M-S-O: *장식품–음악*, *ornament-music*).

Following the study by Marslen-Wilson et al. (2008) with adults, we selected three prime durations: 36, 48, and 72 ms. In addition, we added a prime duration of 57 ms based on the study by Castles et al. (1999) with children in grades 2–6. Since Castle et al. were able to show robust form priming effects at 57 ms with second graders and Quémart and Casalis (2014) showed priming effects at 60 ms with third graders, it is expected that the 12-years-old children in the current study would be able to show priming effects at shorter prime durations. The shorter prime durations would allow us to locate the potential earliest time point at which automatic activation of morphological information occurs in children and adults.

The current study was guided by the following research questions: (1) what is the time course of activation of semantic and orthographic information in reading Korean derived words? and (2) what are the differences between Korean skilled and less skilled readers in their sensitivity to semantic and orthographic information in morphological processing? For the first question research, based on previous research with English readers (e.g., Rastle et al., 2000, 2004; Marslen-Wilson et al., 2008), we hypothesized that for Korean adults readers, if morpho-orthographic decomposition occurs at an earlier time course when the primes are unlikely to be visible, there should be facilitative priming effects, similar in magnitude, in both +M+S+O and +M-S+O at 36, 48, and 57 ms (i.e., significantly shorter response latencies and higher accuracy in these conditions compared to -M-S-O). If the involvement of semantic information arises at a later stage, priming effects should be stronger in +M+S+O than in +M-S+O at 72 ms prime duration. In addition, the -M-S+O condition would produce an inhibitory (i.e., significantly longer response times and lower accuracy in this condition compared to -M-S-O) or non-significant priming effect since orthographic overlap alone is not sufficient to facilitate word recognition and could even trigger lexical competition mechanisms.

For the second research question, based on the studies with French fourth graders by Casalis et al. (2009) we hypothesized that Korean sixth graders would show facilitative priming effects in +M+S+O, indicating semantic-based decomposition, as well as inhibitory priming effect in -M-S+O at 72 ms prime duration, suggesting that the orthographic overlap prime creates competition for the activation of the intended lexical representation for the target word. In addition, based on Quémart et al.'s (2011) study with Grade 3–7 French children, we hypothesized that, Korean Grade 6 children would show facilitative priming effects in +M+S+O and +M-S+O at 57 ms, suggesting that morpho-orthographic decomposition may also arise rapidly in less skilled readers. There may also be a significant priming effect -M+S-O at 72 ms since semantic information tends to be activated later in the time course. To the best of our knowledge, no previous studies have used 36 or 48 ms prime durations with young children. However, grade 6 children may be able to show patterns of priming effects at these shorter prime durations that are similar to adults (i.e., facilitation in +M+S+O and +M-S+O and inhibition in -M-S+O) considering that they were more advanced/readers compared to children at lower grades.

In the following four experiments, we compared skilled vs. less skilled native Korean-speaking readers on their activation of semantic and orthographic information in reading Korean derived words at 36, 48, 57, and 72 ms prime durations, respectively.

EXPERIMENT 1

Participants

The participants were native Korean-speaking children in grade 6 and adults. Our decision to recruit sixth graders was based on a pilot study including fourth graders using the same experimental materials, in which we could not observe any reliable priming effects. Grade 6 children, on the other hand, have reading skills that are distinguishable from adults yet are cognitively developed enough to show robust effects in the following masked priming experiment with very short prime durations. There were 28 children ($M_{\text{age}} = 12.0$, $SD = 0.4$, 19 boys) and 32 adults ($M_{\text{age}} = 23.9$, $SD = 4.0$, 15 males). The children participants were recruited from an elementary school in a predominantly middle-class suburb area of Seoul, South Korea. The adult participants were recruited from major universities in Seoul. Based on reports from schoolteachers, the children did not have any reading difficulties. All of the participants had normal or corrected-to-normal vision and thus had no difficulty with reading words on a computer monitor.

Ethics Statement

The current study was approved by the Institutional Review Board (IRB) at the authors' institutions. Written informed consent was obtained from all adult participants and from parents of all non-adult participants prior to the experiments.

Design and Materials

A 2 (age: sixth graders and adults) × 2 (prime type: related [experimental] and unrelated [control]) × 4 (condition: -M-S+O vs. +M-S+O vs. +M+S+O vs. -M+S-O) design was employed. The prime duration was 36 ms. Age group was a between-participant factor while condition and prime type were within-participant factors. Critical stimuli consisted of prime-target pairs co-varying in morphological decomposability, semantic relatedness, and orthographic relatedness. There were four types of prime-target pairs: (1) orthographically overlapped only (-M-S+O: *도시락-도시, scandal-scan*), (2) orthographically overlapped, morphologically decomposable but semantically unrelated (+M-S+O: *구두쇠-구두, archer-arch*), (3) morphologically decomposable, semantically related, and orthographically overlapped (+M+S+O: *음악가-음악, bravely-brave*), and (4) semantically related only (–M+S-O: *반대이의, accuse-blame*). There were a total of 88 related prime-target pairs (22 in each condition) (**Appendix A**). In addition, 88 unrelated primes for each target word (e.g., *장식품 [ornament]–음악 [music]*) were created. Two item lists were constructed so that participants did not see the same target item more than once. Specifically, if the target was preceded by the related prime in List 1, then it was preceded by the unrelated prime in List 2, and vice versa. Participants were randomly assigned to one of the two lists. In addition, forty-four unrelated prime-target pairs (22 suffixed prime-target pairs and 22 non-suffixed prime-target pairs) were generated to lower the ratio of relatedness proportion (0.33) in order to reduce the possibility of participants guessing the characteristics of the experimental items. However, these unrelated prime-target pairs were not included in the lexical decision task for children participants to shorten the length of the experiment. In addition, to ensure the same number of "Yes" and "No" responses, 132 word–non-word pairs were generated for adults and 88 of those word–non-word pairs were used for children.

TABLE 1 | Descriptive statistics of the semantic relatedness ratings for the four experimental conditions.

	Semantically related conditions		Semantically unrelated conditions	
Condition	+M+S+O	-M+S-O	-M-S+O	+M-S+O
Mean	7.12	7.14	1.51	1.78
SD	0.34	0.78	0.40	0.57

The manipulation of semantic relatedness between prime-target pairs was based on pre-experimental ratings. Six native Korean speakers from the same population where the adult participants were drawn rated how related the prime was to the meaning of the target on a 9-point Likert scale, with 1 being not related at all in meaning and 9 being very related in meaning (**Table 1**). Only items with mean semantic relatedness ratings at 6 or above were included in the semantically related conditions (+M+S+O and -M+S-O) and items with mean ratings at 3 or below were included in the semantically unrelated conditions (+M-S+O and -M-S+O). *T*-test results showed that the semantic relatedness ratings between the derived primes and stem targets were significantly higher in the +M+S+O condition than in the +M-S+O condition [$t_{(42)} = -37.76$, $p < 0.01$]. Also, there was no significant difference in semantic relatedness ratings between +M-S+O and -M-S+O [$t_{(42)} = -1.79$, $p = 0.08$] and between +M+S+O and -M+S-O [$t_{(42)} = -0.12$, $p = 0.91$].

Furthermore, primes and targets were matched as closely as possible across the four conditions for the number of graphemes and frequencies (general frequency, children's visual word frequency, and syllable frequency). General frequencies were obtained from a database provided by the National Academy of the Korean Language with a frequency count of 1 per 1.5 million (available on http://www.korean.go.kr). Since this general frequency may not truly reflect children's daily exposure to visual words, textbook frequency obtained from the same database was used to calculate frequency information for children. The textbook frequency was based on 20 elementary school textbooks and 10 middle school textbooks (including nine seventh grade textbooks and one ninth grade textbook). ANOVA (**Table 2**) showed that the four conditions were closely matched on the number of graphemes in the primes, general and textbook frequency comparing among the primes and among the target words (all ps > 0.1). However, there was a significant difference in the number of graphemes in targets ($p < 0.01$) in which the number of graphemes in +M+S+O and -M+S-O were significant larger than that in -M-S+O. This was because the target words in -M-S+O were a combination of monosyllabic and disyllabic words whereas target words in the other conditions were

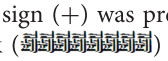
TABLE 2 | Stimulus characteristics for items across the four conditions.

Property	Conditions				ANOVA
	-M-S+O	+M-S+O	+M+S+O	-M+S-O	
Number of graphemes (T)	3.27	3.86	5.00	4.64	$F_{(3, 84)} = 15.86, p < 0.01$
Number of graphemes (P)	6.18	6.55	7.86	7.59	$F_{(3, 84)} = 0.50$, n.s.
General frequency (T)	367.45	257.14	300.27	243.23	$F_{(3, 84)} = 0.30$, n.s.
General frequency (P)	30.14	29.91	66.55	67.64	$F_{(3, 84)} = 0.75$, n.s.
Textbook frequency (T)	20.55	25.41	25.09	14.73	$F_{(3, 84)} = 0.48$, n.s.
Textbook frequency (P)	1.86	3.32	5.73	3.68	$F_{(3, 84)} = 0.34$, n.s.
Syllable frequency for suffix	26,486	40,765	39,912	N/A	$F_{(3, 63)} = 0.72$, n.s.

T, target; P, prime.

majority disyllabic. Furthermore, general frequency and textbook frequency were matched between the related (experimental) primes and unrelated (control) primes [$t_{(180)} = -0.015$, $p = 0.99$, $t_{(180)} = 0.15$, $p = 0.88$, respectively]. Finally, syllable frequencies for the suffixes across the conditions (except -M+S-O since items in this condition do not have suffixes) were well-matched. Syllable frequency for disyllabic suffixes was calculated by averaging the frequency of the first and second syllable. For example, the suffix for the derived word 하마터면 is 터면 and 터면 has two syllables (터 and 면) but one morpheme (터면). There were three such items in -M-S+O, two in +M-S+O, and one in +M+S+O. One-way ANOVA showed no significant difference in syllable frequency across the three conditions ($p > 0.1$).

Procedure

Participants were randomly assigned to each prime duration to minimize the influence of reading abilities on their lexical decision performance. The masked priming lexical decision experiment (Forster and Davis, 1984) was implemented in E-prime (Schneider et al., 2002), which automatically randomized the order of the trials and collected accuracy and response time data. In each trial, the fixation sign (+) was presented for 250 ms, followed by a forward mask () for 800 ms to minimize prime visibility. Then the prime word (e.g., *음악가 [musician]*) was presented for 36 ms and immediately followed by the target (e.g., *음악 [music]*). The participants were instructed to respond as accurately and quickly as possible by pressing the "O" key with the right index finger if they determined the visual target was a real word, and the "X" key with the left index finger if they determined the target was a non-word. The answer keys were the same for all participants regardless of handedness. The target disappeared as soon as a response was made or after 3,000 ms from the onset of the target. Before starting the experimental session, each participant performed eight practice trials with feedback to familiarize with the procedure. Participants were given a short break after half of the trials.

Data Analysis

Response time (RT) data for incorrect responses were excluded from analysis (5.4% of data loss). RT data that were below 400 ms and 2.5 standard deviations above the individual means were also deleted (additional 3.1% of data loss). RT data were log-transformed to improve normality. All subsequent analyses were carried out in R Studio, an open-source programming environment for statistical computing (R Development Core Team, 2008). Unaveraged RT data were submitted to generalized linear mixed-effects modeling using the lmerTest package (Kuznetsova et al., 2013). Accuracy data were submitted to the same modeling method but with the binomial function and p-values were based on the *Wald* z distribution using the car package (Fox and Weisberg, 2011). Planned multiple comparisons of means were conducted using the Simultaneous Tests for General Linear Hypotheses from the multcomp package (Hothorn et al., 2008) with Tukey contrasts and adjusted p-values. The model was built based on a forward algorithm in which the baseline model was a regression line of log RT or accuracy rates with random intercepts for subjects and items. Each fixed effect, including age group (Grade 6 vs. adults), prime type (related vs. unrelated), condition (-M-S+O vs. +M-S+O vs. +M+S+O vs. -M-S+O), and list (1 vs. 2), and interaction terms were individually added to the model and tested by comparing the log likelihood ratio to that of the simpler model. Only effects that significantly improved the model fit were retained. After the fixed effects and interaction terms had been established, a random slope was individually added for each of the significant fixed effects. Random slopes that did not significantly improve the model fit were removed.

Motivated by our theoretical question of the difference in the time course of morphological processing between developing and skilled readers, we also separated the data by age group and compared the priming effects (the difference in RT and accuracy rates between related and unrelated conditions) of each experimental condition. Both log RT and accuracy data (**Tables 3**, **4**; **Figures 1**, **2**, respectively) were analyzed in each prime duration and each age group using mixed-effect models with main effects of prime type and condition, an interaction between the two, and random intercepts for subjects and items. Planned multiple comparisons were conducted for the interaction between prime type and condition.

TABLE 3 | Mean RT (ms) and standard deviation of Grade 6 children and adults across the four experiments.

SOA (ms)	Condition	Grade 6			Adults		
		Unrelated	Related	Priming	Unrelated	Related	Priming
36	-M-S+O	842 (252)	888 (287)	−46	654 (188)	666 (202)	−12
	-M+S-O	810 (236)	801 (233)	9	631 (178)	624 (179)	7
	+M-S+O	842 (253)	831 (284)	11	655 (189)	652 (218)	3
	+M+S+O	813 (252)	772 (248)	41*	615 (182)	607 (194)	8
48	-M-S+O	878 (280)	907 (292)	−29	660 (162)	719 (230)	−59***
	-M+S-O	904 (280)	855 (286)	49*	651 (184)	637 (181)	14
	+M-S+O	842 (234)	852 (275)	−11	685 (208)	670 (216)	15
	+M+S+O	839 (249)	803 (254)	37^	633 (158)	618 (184)	15
57	-M-S+O	840 (261)	870 (259)	−30	660 (176)	692 (187)	−32**
	-M+S-O	835 (261)	846 (298)	−11	644 (159)	637 (185)	7
	+M-S+O	878 (292)	811 (240)	67^	664 (207)	675 (228)	−11
	+M+S+O	813 (290)	784 (228)	29	625 (188)	594 (159)	31**
72	-M-S+O	893 (303)	887 (287)	6	672 (163)	682 (173)	−10
	-M+S-O	836 (257)	816 (272)	20	657 (172)	633 (164)	24
	+M-S+O	829 (238)	816 (237)	13	668 (153)	649 (174)	19*
	+M+S+O	801 (239)	794 (250)	7	622 (152)	590 (121)	32*

*^p < 0.1; *p < 0.05; **p < 0.01; ***p < 0.001. Priming is the difference between unrelated and related conditions. Positive values indicate facilitation and negative values indicate inhibition.*

TABLE 4 | Mean accuracy rates and standard deviation of Grade 6 children and adults across the four experiments.

Prime duration (ms)	Condition	Grade 6			Adults		
		Unrelated	Related	Priming	Unrelated	Related	Priming
36	-M-S+O	0.942 (0.235)	0.873 (0.333)	−0.068*	0.952 (0.215)	0.912 (0.284)	−0.040^
	-M+S-O	0.918 (0.274)	0.935 (0.246)	0.017	0.974 (0.158)	0.986 (0.119)	0.011
	+M-S+O	0.935 (0.247)	0.935 (0.247)	0.000	0.957 (0.202)	0.935 (0.247)	−0.023
	+M+S+O	0.942 (0.235)	0.945 (0.229)	0.003	0.983 (0.130)	0.986 (0.119)	0.003
48	-M-S+O	0.946 (0.226)	0.882 (0.323)	−0.064**	0.943 (0.232)	0.946 (0.226)	0.003
	-M+S-O	0.933 (0.250)	0.952 (0.214)	0.019	0.989 (0.106)	0.986 (0.119)	−0.003
	+M-S+O	0.956 (0.206)	0.970 (0.170)	0.015	0.983 (0.130)	0.969 (0.174)	−0.014
	+M+S+O	0.939 (0.239)	0.943 (0.233)	0.003	0.991 (0.092)	0.989 (0.106)	−0.003
57	-M-S+O	0.918 (0.275)	0.894 (0.308)	−0.024	0.970 (0.170)	0.932 (0.253)	−0.039*
	-M+S-O	0.911 (0.285)	0.943 (0.232)	0.032	0.980 (0.140)	0.991 (0.092)	0.011
	+M-S+O	0.953 (0.213)	0.920 (0.271)	−0.032	0.983 (0.130)	0.966 (0.182)	−0.017
	+M+S+O	0.945 (0.227)	0.948 (0.221)	0.003	0.989 (0.106)	0.986 (0.119)	−0.003
72	-M-S+O	0.938 (0.242)	0.853 (0.355)	−0.085***	0.957 (0.202)	0.935 (0.247)	−0.023
	-M+S-O	0.956 (0.205)	0.949 (0.221)	−0.008	0.977 (0.149)	0.989 (0.106)	0.011
	+M-S+O	0.973 (0.163)	0.943 (0.233)	−0.030	0.988 (0.111)	0.988 (0.111)	0.000
	+M+S+O	0.986 (0.118)	0.941 (0.237)	−0.045	0.991 (0.092)	0.980 (0.140)	−0.011

*^p < 0.1; *p < 0.05; **p < 0.01; ***p < 0.001. Priming is the difference between unrelated and related conditions. Positive values indicate facilitation and negative values indicate interference.*

A similar data analysis procedure was used for all subsequent experiments. Given the large amount of comparisons, we focused our discussion on significant results only.

Results and Discussion

The most parsimonious model with the best fit to the RT data (4,815 data points, **Table 5**, upper part) included effects of age group, prime type, condition, a two-way interaction between prime type and condition, a by-subject random slope for age group and a random intercept for item. The most parsimonious model with the best fit to the accuracy data (5,252 data points, **Table 5**, lower part) included main effects of age group, prime type, and condition, a two-way interaction between age and condition, and a two-way interaction between prime type and

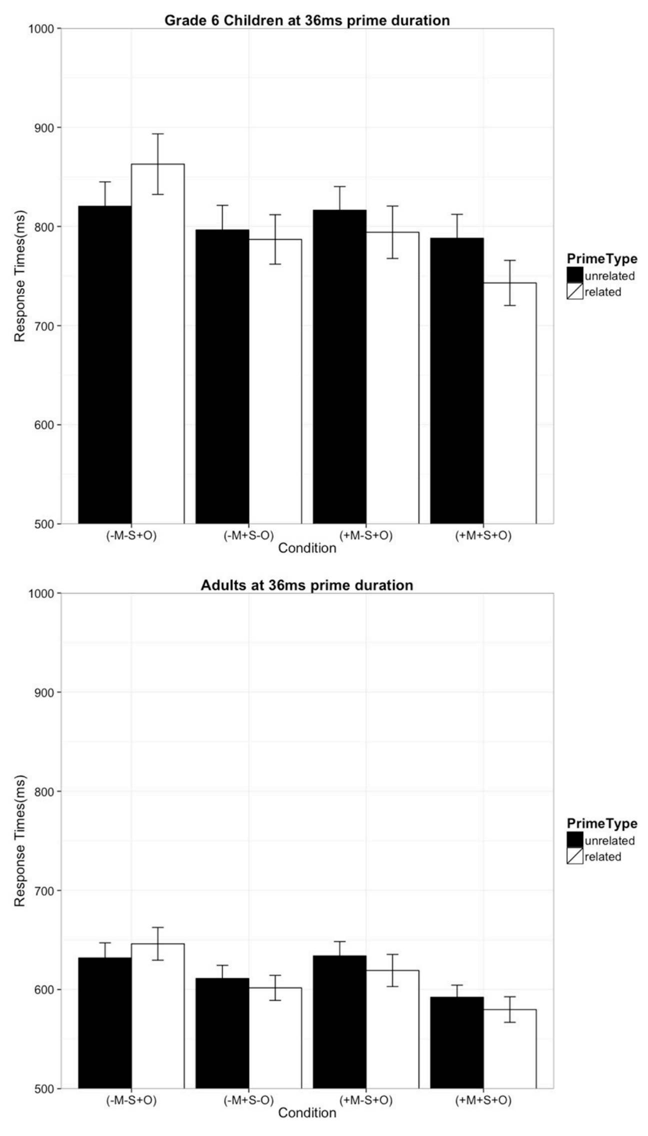


FIGURE 1 | Priming effects in reaction times in Experiment 1.

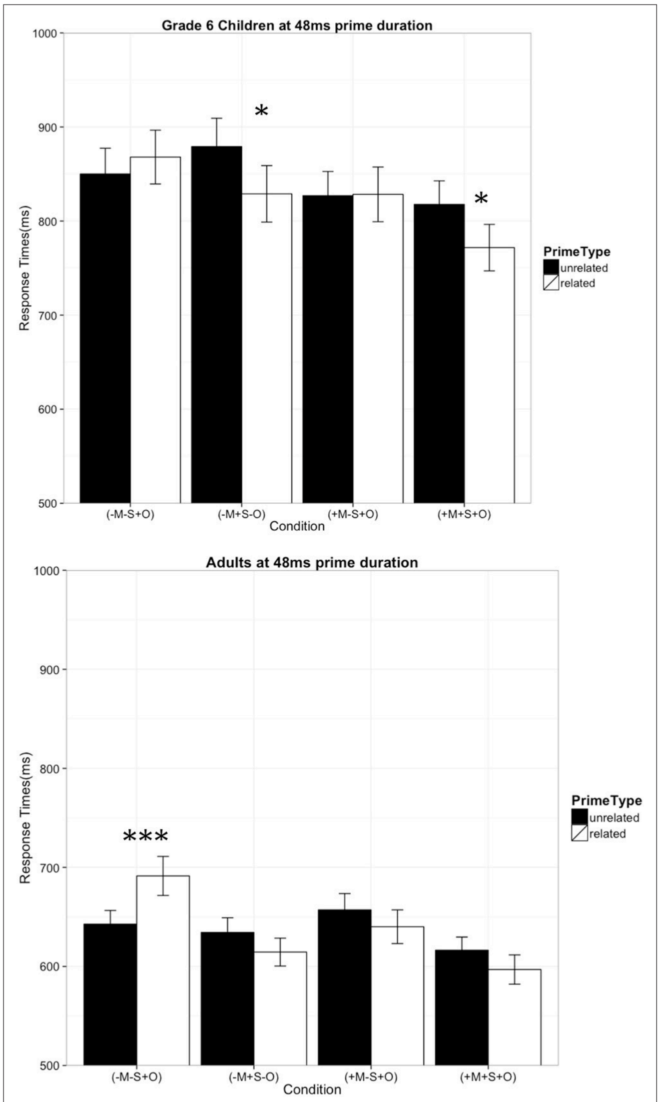


FIGURE 2 | Priming effects in reaction times in Experiment 2 (*$p < 0.05$, ***$p < 0.001$).

condition, and a three-way interaction among age group, prime type, and condition, a by-subject random intercept and a by-item random intercept.

Planned comparison showed that, at 36 ms prime duration, RT data showed a significant facilitative priming effect (41 ms) in +M+S+O ($p = 0.024$) for grade 6 children only. For accuracy, grade 6 children showed a significant inhibitive priming effect in -M-S+O at 36 ms (−6.8%, $p = 0.011$) while adults showed a marginally significant inhibitive priming effect in -M-S+O (−4%, $p = 0.07$). These results suggest that morphological decomposition for semantically related and orthographically overlapped primes (e.g., 음악가-음악, *bravely-brave*) occurred as early as 36 ms for Korean children. In addition, orthographic information was activated at 36 ms and interfered with children's word recognition at this very early stage.

EXPERIMENT 2

Participants

Twenty-eight grade 6 children ($M_{age} = 11.9$, $SD = 0.6$, 12 boys) and 32 adults ($M_{age} = 28.0$, $SD = 3.6$, 15 males) recruited from the same participants pool as that in Experiment 1.

Design, Materials and Procedure

The same design, materials and procedure were used as those in Experiment 1, except that the prime duration was changed to 48 ms.

Results and Discussion

The loss of RT data due to incorrect responses was 4.1% and there was an additional 3.7% loss after removal of RT data that were below 400 ms and 2.5 standard deviations above the individual means. The most parsimonious model with the best fit to the RT data (4,701 data points, **Table 6**, upper part) included effects of age group, prime type, condition, a two-way interaction between prime type and condition, a two-way interaction between age and condition, a by-subject random slope for age group and a random intercept for item. The most parsimonious model with the best fit to the accuracy data (5,084 data points, **Table 6**, lower part) included main effects of age group, prime type, and condition, a two-way interaction between age and condition, and a two-way interaction between prime type and condition, and a three-way interaction among age group, prime type, and condition, a by-subject random intercept and a by-item random intercept.

At 48 ms prime duration, for RT data, grade 6 children showed a significant facilitative priming effect (49 ms) in -M+S-O ($p = 0.037$) and a marginally significant facilitative priming effect (37 ms) in +M+S+O ($p = 0.086$). Adults showed a significant inhibitive priming effect (−59 ms) in -M-S+O ($p < 0.001$). For accuracy data, children showed a significant inhibitive priming effect in -M-S+O (−6.4%, $p = 0.008$) while adults did not show any significant priming effect. These results suggest semantic information was activated as early as 48 ms for developing readers. Furthermore, both children and adults were sensitive to orthographic information at this early stage of word recognition.

TABLE 5 | Results from the ANOVA approach to linear mixed-effects model analysis of log RT and accuracy rates in Experiment 1 with 36 ms prime duration.

Fixed effects	Sum Sq	Mean Sq	Num DF	Den DF	*F*-value	Pr(>F)
Log RT						
Age group	0.556	0.556	1	26.5	81.186	<0.001
Prime type	0.036	0.036	1	4668.5	5.270	0.021
Condition	0.150	0.050	3	83.8	7.302	<0.001
Prime type × Condition	0.164	0.055	3	4668.5	8.000	<0.001

Fixed effects	Sum Sq	Mean Sq	Num DF	*F*-value	Pr(>F)
Accuracy					
Age group	14.560	14.560	1	14.560	<0.001
Prime type	4.781	4.781	4	4.781	0.052
Condition	5.962	1.987	3	1.987	0.118
Prime type × Condition	12.805	4.268	4	4.268	0.004
Age group × Condition	15.621	5.207	3	5.207	0.001

Age group = sixth graders vs. adults. Prime type = related vs. unrelated. Condition = -M-S+O vs. +M-S+O vs. +M+S+O vs. -M+S-O.

TABLE 6 | Results from the ANOVA approach to linear mixed-effects model analysis of log RT and accuracy rates in Experiment 2 with 48 ms prime duration.

Fixed effects	Sum Sq	Mean Sq	Num DF	Den DF	*F*-value	Pr(>F)
Log RT						
Age group	0.491	0.491	1	34.1	70.918	<0.001
Prime type	0.054	0.054	1	4552.1	7.775	0.005
Condition	0.114	0.038	3	81.6	5.479	<0.001
Age group × Condition	0.141	0.046	3	4584.3	6.765	<0.001
Prime type × Condition	0.290	0.097	3	4552.3	6.765	<0.001

Fixed effects	Sum Sq	Mean Sq	Num DF	*F*-value	Pr(>F)
Accuracy					
Age group	26.990	26.990	1	26.990	<0.001
Prime type	1.343	1.343	1	1.343	0.321
Condition	6.856	2.285	3	2.285	0.077
Prime type × Condition	3.320	1.107	3	1.107	0.342
Age group × Condition	12.464	4.155	3	4.155	0.004

Age group = sixth graders vs. adults. Prime type = related vs. unrelated. Condition = -M-S+O vs. +M-S+O vs. +M+S+O vs. -M+S-O.

TABLE 7 | Results from the ANOVA approach to linear mixed-effects model analysis of log RT and accuracy rates in Experiment 3 with 57 ms prime duration.

Fixed effects	Sum Sq	Mean Sq	Num DF	Den DF	*F*-value	Pr(>F)
Log RT						
Age group	0.451	0.451	1	61.8	65.120	<0.001
Prime type	0.015	0.015	1	4787.8	2.158	0.142
Condition	0.148	0.049	3	83.9	7.114	<0.001
Age × Prime type	0.004	0.004	1	4784.7	0.594	0.441
Age group × Condition	0.055	0.018	3	4811.8	2.654	0.047
Prime type × Condition	0.169	0.056	3	4787.8	8.153	<0.001
Age group × Prime type × Condition	0.068	0.023	3	4784.8	3.280	0.020

Fixed effects	Sum Sq	Mean Sq	Num DF	*F*-value	Pr(>F)
Accuracy					
Age group	25.085	25.085	1	25.085	<0.001
Prime type	3.379	3.379	1	3.379	0.102
Condition	6.798	2.266	3	2.266	0.083
Prime type × Condition	12.412	4.37	3	4.137	0.005
Age group × Condition	9.119	3.039	3	3.039	0.024

Age group = sixth graders vs. adults. Prime type = related vs. unrelated. Condition = -M-S+O vs. +M-S+O vs. +M+S+O vs. -M+S-O.

EXPERIMENT 3

Participants

Thirty-two grade 6 children ($M_{\text{age}} = 12.0$, $SD = 0.5$, 14 boys) and 32 adults ($M_{\text{age}} = 24.1$, $SD = 2.8$, 15 males) were recruited from the same participants pool as that in Experiments 1 and 2.

Design, Materials and Procedure

The same design, materials and procedure were used as those in Experiments 1 and 2, except that the prime duration was changed to 57 ms.

Results and Discussion

The loss of RT data due to incorrect responses was 4.7% and there was an additional 3.5% loss after removal of RT data that were below 400 ms and 2.5 standard deviations above the individual means. The most parsimonious model with the best fit to the RT data (4,935 data points, **Table 7**, upper part) included effects of age group, prime type, condition, a two-way interaction between prime type and condition, a two-way interaction between age and condition, a three-way interaction among age group, prime type, and condition, and two random intercepts for subjects and items. The most parsimonious model with the best fit to the accuracy data (5,364 data points, **Table 7**, lower part) included effects of age group, prime type, condition, a two-way interaction between age and condition, and a two-way interaction between prime type and condition, and random intercepts for subjects and items.

At 57 ms prime duration, for RT data, grade 6 children showed a marginally significant facilitative priming effect (67 ms) in +M-S+O ($p = 0.073$) (**Figure 3**). Adults showed a significant inhibitive priming effect (−32 ms) in -M-S+O ($p = 0.006$) and a significant facilitative priming effect (31 ms) in +M+S+O ($p = 0.009$). For accuracy data, only adults showed a significant inhibitive priming effect in -M-S+O (−3.9%, $p = 0.018$). Similar to Experiment 2, the activation of orthographic information continued to play a role in adult readers' word recognition at 57 ms. In addition, morphological decomposition of semantically and orthographically primes occurred at 57 ms for adult readers, which is at a later stage compared children who showed significant priming effect in +M+S+O at 36 ms in Experiment 1.

EXPERIMENT 4

Participants

Twenty-eight grade 6 children ($M_{\text{age}} = 12.0$, $SD = 0.5$, 14 boys) and 32 adults ($M_{\text{age}} = 24.6$, $SD = 4.9$, 14 males) were recruited from the same participants pool as that in Experiments 1, 2, and 3.

Design, Materials and Procedure

The same design, materials and procedure were used as those in Experiments 1, 2, and 3, except that the prime duration was changed to 72 ms.

Results and Discussion

The loss of RT data due to incorrect responses was 3.9% and there was an additional 3.9% loss after removal of RT data that were below 400 ms and 2.5 standard deviations above the individual means. The most parsimonious model with the best fit to the RT data (4,563 data points, **Table 8** upper part) included effects of age group, prime type, condition, a two-way interaction between prime type and condition, a two-way interaction between age and condition, a by-subject random slope and a random intercepts for items. The most parsimonious model with the best fit to the accuracy data (4,935 data points, **Table 8** lower part) included effects of age group, prime type, condition, a two-way interaction between prime type and condition, and random intercepts for subjects and items.

At 72 ms prime duration, none of the planned comparisons for RT data was statistically significant (all $ps > 0.3$) for grade 6 children (**Figure 4**). In contrast, for adults, there were

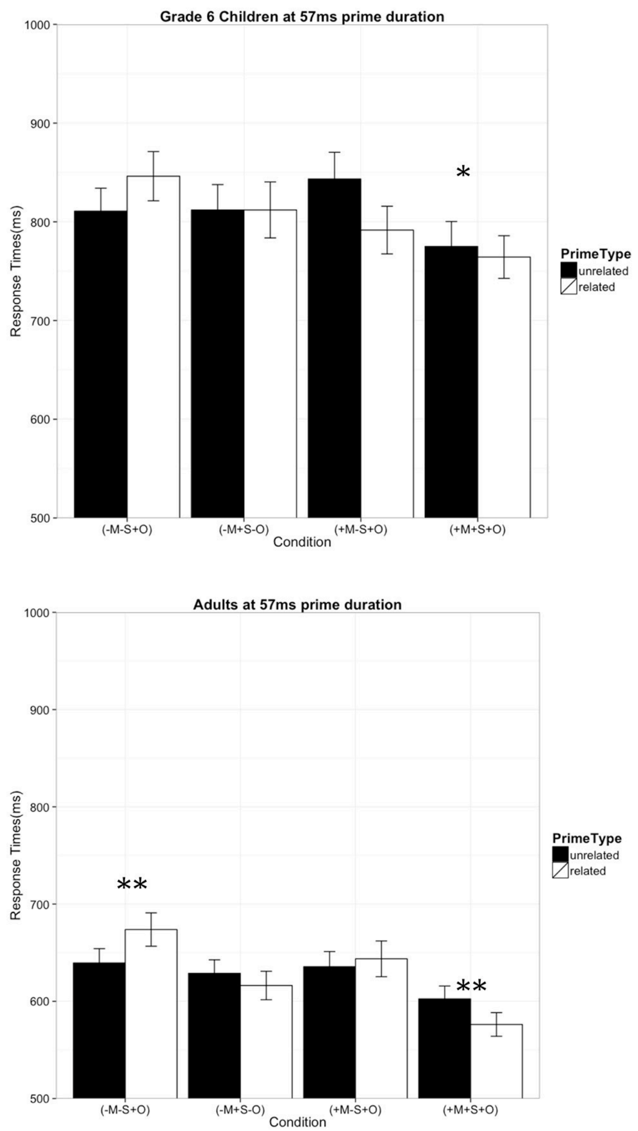


FIGURE 3 | Priming effects in reaction times in Experiment 3 (*$p < 0.05$, **$p < 0.01$).

significant facilitative priming effects in both +M-S+O (19 ms, $p = 0.045$) and +M+S+O (31 ms, $p = 0.038$). For accuracy data, the only significant finding was an inhibitive effect in -M-S+O (−8.5%, $p < 0.001$) for children. These results suggest that morphological decomposition independent of semantic information (e.g., *구두쇠-구두, archer-arch*) occurred at 72 ms for adult readers while orthographic information was activated at this stage of word recognition for developing readers.

GENERAL DISCUSSION

The current study aimed to investigate the influence of morphological, orthographic, and semantic information at the early stage of visual word recognition in developing and adult readers of Korean. Using the masked priming paradigm with four prime durations between 36 and 72 ms, we manipulated morphological decomposability, semantic relatedness, and orthographic overlap between prime-target pairs. The following discussion only focuses on the significant findings. First, adult readers showed a significant facilitative priming effect at 57 ms prime duration only in the +M+S+O condition while significant facilitation was observed in both +M+S+O (e.g., *bravely-BRAVE*) and +M-S+O (e.g., *archer-ARCH*) at 72 ms. The finding that "archer" could lead to faster response of "arch" suggests that Korean adult readers decompose derived words into stem and suffix (i.e., arch + er) on the basis of morpho-orthographic analysis even though the prime-target pair had a semantically opaque relationship. The second key finding is that Korean sixth graders showed significant facilitation in +M+S+O at 36 ms prime duration, suggesting that morphological decomposition occurs rapidly for less skilled readers of a non-Roman alphabetic writing system. Third, sixth graders showed a significant facilitative priming effect in -M+S-O at 48 ms, suggesting that semantic information was activated relatively early in Korean children's visual word recognition. Finally, both adults and grade 6 children showed significant inhibitory priming effects in -M-S+O across different prime durations. These results suggest that orthographic information was activated early in both developing and skilled readers and the inhibition may stem from lexical competition among orthographically similar candidates.

Morpho-Orthographic Decomposition in Korean

The first key finding of significant facilitation in both +M+S+O and +M-S+O at 72 ms prime duration in adult readers provides evidence for morpho-orthographic decomposition in Korean. This adds to a growing body of research focusing on Roman and Cyrillic alphabets (e.g., English: Rastle et al., 2000; 2004, Marslen-Wilson et al., 2008; French: Longtin et al., 2003; Russian: Kazanina et al., 2008). This result demonstrated that the early visual word recognition of Korean Hangul, an orthography written in a non-linear spatial layout with clear syllable boundaries, is based on morphological structure and independent of meaning.

On the other hand, a significant priming effect in +M+S+O at 57 ms prime duration suggests that meaning-dependent morphological decomposition also occurs at the early stage of word recognition. This finding is generally consistent with previous masked morphological priming studies involving Korean. For example, Kim et al. (2015) found a facilitative priming effect for derived real words at 47 ms for monolingual Korean-speaking adults. Similarly, Kim and Wang (2014) observed a significant priming effect at 36 ms for Korean-English bilingual adults using Korean primes and English target words. It appears that morpho-orthographic decomposition in Korean occurs at a slightly later time course (i.e., 72 ms) compared to the results from English speakers [i.e., 42 ms in Rastle et al. (2004) and 36 ms in Marslen-Wilson et al.

TABLE 8 | Results from the ANOVA approach to linear mixed-effects model analysis of log RT and accuracy rates in Experiment 4 with 72 ms prime duration.

Fixed effects	Sum Sq	Mean Sq	Num DF	Den DF	*F*-value	Pr(>F)
Log RT						
Age group	0.451	0.451	1	31.7	73.225	<0.001
Prime type	0.076	0.076	1	4418.1	12.396	<0.001
Condition	0.173	0.058	3	82.9	9.350	<0.001
Prime type × Condition	0.047	0.016	3	4418.5	2.557	0.053
Age group × Condition	0.064	0.022	3	4451.3	3.500	0.015

Fixed effects	Sum Sq	Mean Sq	Num DF	*F*-value	Pr(>F)
Accuracy					
Age group	29.344	29.344	1	29.344	<0.001
Prime type	14.282	14.282	1	14.282	<0.001
Condition	12.2198	4.073	3	4.073	0.008
Prime type × Condition	7.396	2.465	3	2.465	0.051

Age group = sixth graders vs. adults. Prime type = related vs. unrelated. Condition = -M-S+O vs. +M-S+O vs. +M+S+O vs. -M+S-O.

(2008)]. One possible explanation for these different findings is the need to integrate semantic information in morphological decomposition due to the large number of homographs in the Korean orthography. Homographs refer to words with the same spelling (but not necessarily the same pronunciation) but having different meanings and origins. In the current study, 91% of the derived words across the three +O conditions have monosyllabic suffixes and syllables with more than one meaning (Yi, 2009). For example, 음악가 [musician] is decomposed into 음악 [music] + 가 [-ian]; 가 is a homograph with several different meanings, such as [edge], [approval], [man], and [street], and all of them may be activated. It takes time to resolve the semantic ambiguity for the target suffix 가, which should be [man] in the current example. Prime durations <72 ms may not be sufficient for Korean adults to select the correct meaning for the suffix in the prime word, resulting in null priming effects for 36, 48, and 57 ms prime durations. In contrast to Korean, most English derivational suffixes only have one meaning (except for *-er* which can mean [more] or [person]). For example, *-ful* means [full of] as in *joyful* while *-less* means [without] as in *careless*. Therefore, activation of the semantic representation for the suffix may be much quicker for English readers. These cross-linguistic variations in writing systems may help partially explain the differences in the time course of morpho-orthographic decomposition between readers of Korean and readers of English.

Morphological Effects in Developing Readers

The second key finding is the significant facilitation in +M+S+O observed in sixth grade children at 36 ms prime duration. To the best of our knowledge, the shortest prime duration used in previous research with children was 57 ms by Castles et al. (1999) with English-speaking children in grades 2–6. Our results with Korean-speaking children demonstrated that 36 ms prime duration was sufficient to produce robust effects in a masked priming paradigm for developing readers in upper grades. More importantly, these results suggest that Korean developing readers decompose derived words into stem and suffix as early as 36 ms. A possible explanation for the early occurrence of the morphological priming effect is the clear-cut syllable boundary of the Korean orthography (e.g., 안녕하십니까). This visually prominent syllable boundary makes the morpheme boundary in Korean Hangul more salient, thus, encouraging morphological decomposition to a greater degree than English in which the morpheme boundary can be blurred (e.g., *writer*).

In contrast to adults who showed significant facilitation in +M+S+O at 57 ms prime duration, this significant priming effect was observed in sixth grade children at 36 ms. One possible explanation for the different time course between developing and adult readers is that less skilled readers have a smaller mental lexicon, hence, they may not know or be able to activate all of the different meanings of the monosyllabic suffix, a homograph in nature, within a short amount of time. For example, children may be slower to access the different meanings of 가 (e.g., [edge], [approval], [man], and [street]), resulting in less semantic competition and faster activation of the intended semantic representation (e.g., [man]) of the target word (e.g., 음악가 [musician]) which facilitates word recognition. Therefore, sixth graders showed earlier morphological priming effects in +M+S+O compared to adults.

Semantic and Orthographic Effects in Adult and Developing Readers

The third key finding is that grade 6 children showed significant facilitation for -M+S-O primes at 48 ms prime duration, suggesting the relatively early activation of semantic information in visual word recognition of developing readers of Korean. This finding is different from previous studies with French-speaking children (Bonnotte and Casalis, 2009; e.g., Quémart et al., 2011) in which semantic related primes did not speed up lexical decision of target words at 60 ms prime duration but did facilitate lexical judgment at 250 and 800 ms. We speculate

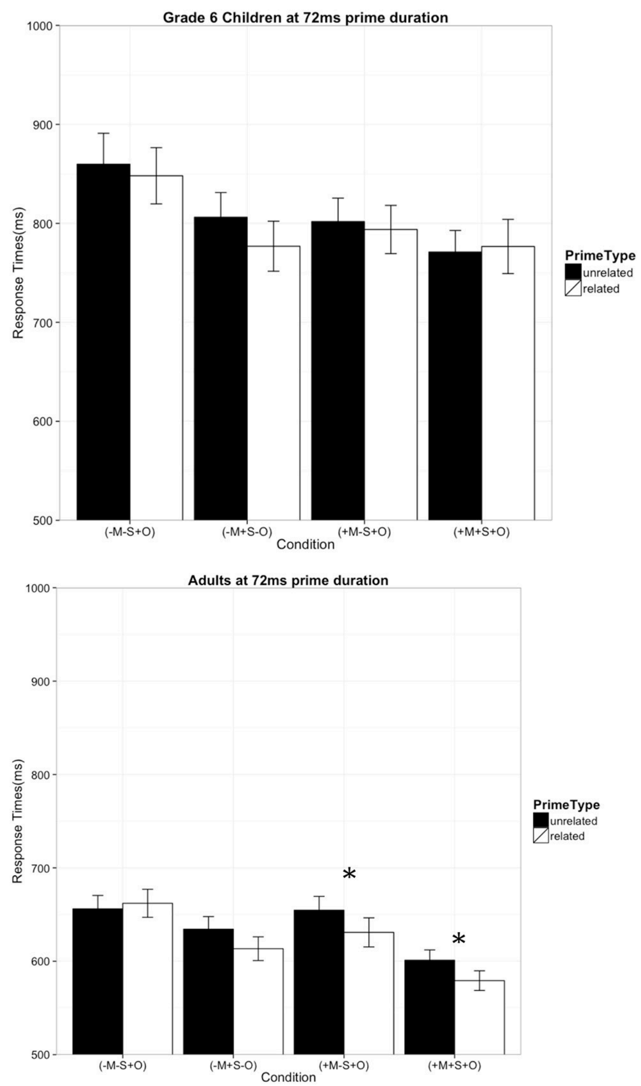


FIGURE 4 | Priming effects in reaction times in Experiment 4 (*$p < 0.05$).

that one potential reason for the difference in the time course of semantic activation may be the saliency of semantic information in the Korean language. There are three types of words in the Korean vocabulary: native words (∼35%), Sino-Korean words (about 60%), and loan words (about 5%). Sino-Korean words were originated from or influenced by *hanja* (i.e., Chinese characters). In contrast to alphabetic writing systems in which each grapheme maps onto a phoneme, each Chinese character maps onto a morpheme. In fact, previous research with Chinese adult readers showed significant semantic priming effects as early as 57 ms (Zhou and Marslen-Wilson, 2000) when reading single characters as well as Chinese compound words. Considering that two-thirds of the Korean vocabulary is loaned from Chinese or words coined using *hanja*, semantic information may be particularly salient to Korean readers compared to readers of alphabetic writing systems. It is common practice in South Korea for children to receive private tutoring in learning to read Hanja, whereas adults may be much more exposed to Hangul only (Pae, 2017, personal communication). In the current study, we did not have a report from the parents on whether their children were receiving *hanja* tutoring or the amount of *hanja* exposure. Future research can collect information about Korean readers' *hanja* exposure and compare semantic priming effects between those with extensive exposure to *hanja* and those with limited exposure. If experiences with *hanja* indeed play a role in the activation of semantic information in word recognition, children with more *hanja* exposure should have greater or earlier semantic priming effect than children with less *hanja* exposure.

The fourth key finding is the robust significant inhibition in -M-S+O observed in both skilled and less skilled readers. Specifically, this inhibitory effect occurred as early as 36 ms prime duration for developing readers and at 48 ms for adult readers. These results are consistent with previous research with adult English readers (Bijeljac-Babic et al., 1997; Brysbaert et al., 2000; Davis and Lupker, 2006). These lexical inhibition effects can be explained by the Interactive Activation (IA) model (McClelland and Rumelhart, 1981; Rumelhart and McClelland, 1982), which assumes that there are three levels of representations including a feature level, a letter level, and a word level. The representational units at lower levels feed activation and inhibition to higher levels. For example, when the unit representing the letter "도" at the first letter position receives activation from the feature level, it sends activation to all word level units in which the word has "도" as an onset while simultaneously sends inhibition to all word level units in which the word has other letters at the onset position. In addition, when the target word (e.g., 도시 *city*) is presented and its corresponding word unit is activated, it sends inhibition to all other word-level units which have received some activation from the letter-level units (e.g., 도시락 *lunch box*). To the best of our knowledge, the current study is one of the first to observe lexical inhibition in Korean adult and developing readers. It appears that the IA model can be extended to explain word recognition in a non-Roman alphabetic orthography, such as Korean and this lexical selection processes is also present in developing readers with a smaller lexicon.

Limitations and Future Directions

One of the few noteworthy limitations in the current study was that prime durations longer than 72 ms were not included in the masked priming lexical decision task. Presenting the prime for 200 ms or longer may increase the probability of finding significant semantic effects in adult readers. Besides making methodological modifications, future research should replicate the masked priming paradigm with other non-Indo-European agglutinative languages, such as Japanese to examine the generalizability of the current findings.

The current study showed significant morphological priming effects at 36 ms prime duration for sixth graders. In addition, Quémart et al. (2011) showed significant facilitation with +M+S+O and +M-S+O primes at 60 ms prime duration for third graders. Future research should consider adapting the masked priming lexical decision task with shorter prime durations for younger children (i.e., fourth graders) to examine the earliest time course of morphological decomposition among children with less advanced reading abilities.

A number of studies have demonstrated that children rely on their knowledge of morphological information when they read morphologically complex words across a variety of languages (e.g., English: Deacon et al., 2011; Dutch: Verhoeven and Schreuder, 2011; Italian: Marcolini et al., 2011; Angelelli et al., 2014; Spanish: Lázaro et al., 2013). Particularly, children were faster to read aloud and make lexical judgment for words with high-frequency root morphemes than those with low-frequency root morphemes. Moreover, the ability to apply this morpheme-based strategy appears to be a function of reading skills since dyslexic children were less sensitive to the frequency effect (Lázaro et al., 2013). However, since these studies were conducted with developing readers of Roman alphabets, it is not clear whether their findings can be generalized to readers of other types of alphabets or orthography. It would be worthwhile for future studies to include measures of word reading and reading comprehension abilities to examine the relationship between reading acquisition and morphological processing in developing readers of other alphabetic systems.

The current study recruited only a small sample size of children in each experiment ($N = 28$ in 36 ms, 28 in 48 ms, 32 in 57 ms, and 28 in 72 ms prime duration, respectively). Future research needs to be creative and to use a simpler design with more trials in each condition and with a larger sample size. Another limitation is that we did not collect information about children's reading levels, thus we were unable to match it across prime durations. Since prime duration was treated as a between-participants variable, it is important for future research to closely match children participants' reading level across prime durations. Finally, future research should allow the participants to use their dominant hands for "yes" responses.

Conclusion

The current study made several important theoretical contributions to the literature. First, the current study is one of the first to examine the involvement of semantic and orthographic information in the processing of derived words for both skilled and less skilled readers of a non-Roman alphabetic orthography. Second, the current study is one of the first to vary four prime durations (e.g., 36–72 ms) in a masked priming lexical decision task for developing readers. Results showed significant morphological priming effects for sixth graders at 36 ms and for skilled readers at 57 ms, suggesting that morphological decomposition arises earlier for less skilled readers, probably due to their smaller lexicon and less competition for semantic activation for the monosyllabic suffix, which is a homograph in the Hangul orthography. Third, the current study showed that semantic-based morphological decomposition occurs earlier than orthographic-based decomposition for Korean skilled readers and semantic priming effect arises early for sixth grade children at 48 ms prime duration. Korean readers may be particularly sensitive to semantic information due to the large number of words originated from Hanja or Chinese characters. Finally, both adults and children showed significant inhibition for orthographically overlapped primes with non-morphological endings across the four prime durations, suggesting that orthographic information plays an important role throughout the early to later stage of Korean visual word recognition. The current study extends previous research with readers of Roman and Cyrillic alphabets to readers of an alpha-syllabary orthography written in a non-linear spatial layout, showing that the involvement of semantic and orthographic information in morphological processing may vary depending on characteristics of the orthography. While semantic activation may occur later in the time course of English word recognition, it appears to occur earlier and plays a more important role in Korean word recognition.

AUTHOR CONTRIBUTIONS

MW and IK conceived and designed the experiments. IK performed the experiments. CL analyzed the data. CL and MW wrote the paper.

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Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

APPENDIX A

TABLE A1 | Stimuli used in the masked priming lexical decision task.

Condition	Prime	Target	Condition	Prime	Target
-M-S+O	아가미 gill	아가 baby	+M-S+O	구두쇠 miser	구두 shoes
	달걀 egg	달 moon		곰보 pockmarked person	곰 bear
	씨름 wrestling	씨 seed		방정식 equation	방정 a rash act
	고사리 bracken	고사 exam		고무적 encouraging	고무 rubber
	방울 bell	방 room		가시적 visibility	가시 thorn
	도시락 lunch box	도시 city		귀퉁이 corner	귀 ear
	다리미 iron	다리 leg		사랑채 detached house	사랑 love
	자격 qualification	자 ruler		고리짝 a wicker trunk	고리 ring
	사투리 dialect	사투 desperate struggle		배우자 spouse	배우 actor
	잠수 diving	잠 sleep		지구력 spadework	지구 phlegm
	하마터면 almost	하마 hippo		이유기 the weaning period	이유 reason
	비밀 secret	비 rain		손님 gueset	손 hand
	주사위 dice	주사 injection		개성 individuality	개 dog
	피곤 fatigue	피 blood		유리식 a rational expression	유리 glass
	버스럭 rustle	버스 bus		피로연 reception	피로 fatigue
	빵긋 with a smile	빵 bread		토박이 natives	토 postposition
	거리끼다 stand in the way	거리 distance		야유회 picnic	야유 banter
	별명 nickname	별 star		지진아 retarded child	지진 earthquake
	부리나케 in a hurry	부리 beak		무용담 heroic episode	무용 dance
	실신 faint	실 thread		돌쇠 servant	돌 stone
	목축 farming	목 neck		철학 philosophy	철 iron
	색출 track down	색 color		조리개 aperture	조리 cook
+M+S+O	가위질 scissoring	가위 scissor	-M+S-O	반대 opposite	이의 objection
	정치가 politics	정치 politician		사탕 candy	과자 cookie

(Continued)

TABLE A1 | Continued

Condition	Prime	Target	Condition	Prime	Target
	매력적	매력		학업	공부
	attractive	attract		learning	study
	문화적	문화		삭제	제거
	cultural	culture		deletion	removal
	장난감	장난		동그라미	원
	toy	game		circle	circle
	멋쟁이	멋		가난	빈곤
	dandy	stylishness		poverty	poverty
	음악가	음악		요괴	괴물
	musician	music		goblin	monster
	개인용	개인		소원	희망
	personal	individual		wish	hope
	기대감	기대		결핍	부족
	expectation	expect		insufficiency	lack
	영화관	영화		식사	밥
	movie theater	movie		meal	rice
	맛깔	맛		부엌	주방
	taste	taste		kitchen	kitchen
	미술품	미술		뚜껑	마개
	art work	art		lid	cork
	동물원	동물		부탁	요구
	zoo	animal		asking	request
	수영복	수영		누나	언니
	swimwuit	swimming		sister	sister
	응원단	응원		가게	상점
	cheer group	cheering		store	store
	일기장	일기		열매	과일
	diary	diary		fruit	fruit
	음식점	음식		안정	평화
	restaurant	food		stability	peace
	요리사	요리		아우성	소란
	chef	cooking		shout	disturbance
	선생님	선생		도서	책
	teacher	teacher		book	book
	연락처	연락		천사	요정
	contact address	contact		angel	fairy
	사냥꾼	사냥		불평	원망
	hunter	hunting		complaint	blame
	치료제	치료		머저리	바보
	medicine	cure		jerk	fool

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Effects of Reading Proficiency and of Base and Whole-Word Frequency on Reading Noun- and Verb-Derived Words: An Eye-Tracking Study in Italian Primary School Children

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The aim of this study is to assess the role of readers' proficiency and of the base-word distributional properties on eye-movement behavior. Sixty-two typically developing children, attending 3rd, 4th, and 5th grade, were asked to read derived words in a sentence context. Target words were nouns derived from noun bases (e.g., *umorista*, 'humorist'), which in Italian are shared by few derived words, and nouns derived from verb bases (e.g., *punizione*, 'punishment'), which are shared by about 50 different inflected forms and several derived words. Data shows that base and word frequency affected first-fixation duration for nouns derived from noun bases, but in an opposite way: base frequency had a facilitative effect on first fixation, whereas word frequency exerted an inhibitory effect. These results were interpreted as a competition between early accessed base words (e.g., *camino*, chimney) and target words (e.g., *caminetto*, fireplace). For nouns derived from verb bases, an inhibitory base frequency effect but no word frequency effect was observed. These results suggest that syntactic context, calling for a noun in the target position, lead to an inhibitory effect when a verb base was detected, and made it difficult for readers to access the corresponding base+suffix combination (whole word) in the very early processing phases. Gaze duration was mainly affected by word frequency and length: for nouns derived from noun bases, this interaction was modulated by proficiency, as length effect was stronger for less proficient readers, while they were processing low-frequency words. For nouns derived from verb bases, though, all children, irrespective of their reading ability, showed sensitivity to the interaction within frequency of base+suffix combination (word frequency) and target length. Results of this study are consistent with those of other Italian studies that contrasted noun and verb processing, and confirm that distributional properties of morphemic constituents have a significant impact on the strategies used for processing morphologically complex words.

Keywords: reading acquisition, word morphology, eye movements, verb-derived nouns, noun-derived nouns, word frequency, reading proficiency, derived words

INTRODUCTION

Over the past 40 years (see Clifton et al., 2016 for a review), several studies on eye movements found that information uptake is graded, involving the extraction of graphemic details near fixation, and of coarse-grained information from the parafovea. Furthermore, Rayner's work (e.g., Liversedge et al., 2004; Dambacher et al., 2013) demonstrated that "experienced readers look essentially at every word in text, and that the ability to extract visual information quickly and efficiently is the foundation of skilled reading" (Clifton et al., 2016, p. 2). Research carried out in this field provides strong evidence that linguistic processing primarily influences eye movements during reading. In particular, Rayner and co-workers demonstrated that three major lexical and semantic properties influence how easily written words are processed: word frequency (e.g., Rayner and Duffy, 1986), word length (e.g., Juhasz et al., 2008), and predictability in context (e.g., Ehrlich and Rayner, 1981) ("the big three" of lexical processing).

The deep relationship between lexical processing and eye-movement behavior, proved by the studies that investigated eye-movements in reading, had great consequence on research strategy: the more the way lexical processing influences the eye-movement behavior is learned, the more it is possible to use eye-movement measures to investigate basic language processing. In this research field, several variables are analyzed, but the main variables, considered measures of initial and spatially localized processing, are first-fixation duration and gaze duration (Liversedge et al., 1998). The former is the time the reader initially spends fixating the target word, and "it is generally taken to be the very earliest point at which we might expect to see an effect due to experimental manipulation" (Liversedge et al., 1998, p. 58). Gaze duration "is defined as the sum of all the fixations made in a region until the point of fixation leaves the region" (*ibidem*). "Visual (e.g., the amount of contrast, font size), lexical (e.g., frequency), and contextual (e.g., predictability) properties of words yield a graded effect on fixation durations (e.g., as word frequency decreases, fixation durations increase)" (Dambacher et al., 2013, p. 1468).

For what concerns morphologically complex words, "eye movements can give a clear insight into the time course of morphological processing" (Bertram, 2011, p. 92). In particular, the first of multiple fixations on the target word is likely to reflect an early processing stage, whereas gaze duration can be considered an index of later processing (Bertram, 2011). Studies on eye movements in reading Finnish and English compounds embedded in sentences (Hyönä and Pollatsek, 1998; Pollatsek et al., 2000, 2011; Andrews et al., 2004; Pollatsek and Hyönä, 2005) found a significant effect of first-constituent frequency on first-fixation duration, whereas gaze duration was affected by the frequency of both first and second constituents, as well as by whole word frequency. The general assumption of studies involving morphologically complex words is that the first-constituent frequency effect is evidence of a decomposition process; consequently, first-fixation duration is likely to be involved in early morphemic parsing. As for whole-word effects, they are usually considered to be diagnostic of whole-word access. So, it can be assumed that gaze duration taps into lexical access. Concurrent whole-word and morphological effects are evidence of the fact that storage and computation interact in complex word recognition.

Data from more recent research shows a more complex pattern of results on the variables affecting early stages of compound processing. Bertram and Hyönä (2003) found an effect of compound-word length and proposed that when long compounds are processed, first-fixation duration is affected by first constituent frequency. On the contrary, when reading short compounds, readers start to analyze the whole-word string, so the whole-word frequency effect emerges. Studies on Dutch compounds (Kuperman et al., 2008, 2009) pointed out the role of the interaction between compound frequency and first-constituent frequency, as they showed that the higher the whole-word frequency of a compound the smaller the role of the first-constituent frequency in first-fixation duration. Marelli and Luzzatti (2012) data confirmed this interaction in Italian, and showed that the first-constituent frequency effect is also modulated by the semantic transparency of the compound: the higher the semantic transparency is, the greater the facilitation effect of first-constituent frequency on first-fixation duration. More recently, the role of semantic transparency in processing derived words was pointed out by Amenta et al. (2015): their results showed that stem frequency has a facilitating effect on first-fixation duration only when the target word is embedded in sentences prompting a semantically transparent interpretation of the word, whereas a stem-frequency effect is inhibitory when the sentence context prompts an opaque interpretation of the target word.

Data supporting this complex pattern of results also come from studies on derived words. Niswander-Klement and Pollatsek (2006) found root frequency effects only for long prefixed words (about eight letters long), but not for short prefixed words (about six letters long). In contrast, whole-word frequency effects were found for short prefixed words, but not for the long ones. Consistently with the previous results, Kuperman et al. (2010) found an interaction between whole-word frequency and length of the suffix in a large regression study on Dutch derived words: the shorter the suffix is, the stronger the whole-word frequency effect on reading times. Furthermore, the study found that also the amount of information carried by the word-base and the size of the morphological family of the suffix affect the reading times. The authors interpreted the latter result as a *relative entropy* effect of the morphemes embedded in the morphologically complex words. In particular, words containing most salient suffixes, i.e., affixes that occur in a larger and more frequent number of words, are processed faster.

Evidence from eye-movement research mirrors what has been reported in several studies, employing different experimental procedures, in languages with rich morphology systems. Kostić and Katz (1987), in Serbo-Croatian, found differences in lexical decision times for nouns, adjectives, and verbs: the authors referred this effect to the number of inflectional alternatives available for each grammatical class. Differences in processing verbs and nouns were found also in Hebrew (Deutsch et al., 1998). This evidence led the authors to suggest that, beyond semantic and syntactic components, the distributional properties of constituents may play a significant role in word processing: "When a morpheme is common to more words in the language, its impact on processes of morphological decomposition is prominent" (Deutsch et al., 1998, p. 1252).

The Italian language can be very informative in testing this claim, as verb roots are shared by about 50 different inflected forms and several derived words (e.g., *punizione*, 'punishment' from *punire*, 'to punish'), whereas noun roots can be inflected in 2 to 4 forms and are shared by fewer derived words. For this reason, it may be expected that verb processing is a more demanding task than noun processing, as the identification of the target word within a large morphological family is likely to require more difficult selection processes than identification within a small morphological family.

In Italian, skilled adult readers tend to recognize and read aloud verbs more slowly than nouns and adjectives. Moreover, latency for verbs, but not for nouns or adjectives, is correlated with their base frequency (Colombo and Burani, 2002; Traficante and Burani, 2003). Differences in processing nouns and verbs were also found in several studies on adults suffering from acquired language disorders (Zingeser and Berndt, 1990; Chen and Bates, 1998; Luzzatti et al., 2002; Crepaldi et al., 2006; see for a review Crepaldi et al., 2011). However, some studies showed that verb and noun processing were deeply influenced also by type of task and experimental paradigm: even noun production can be more difficult than verb production in a Grammatical-Class Switching Task[1] (GCST), both in skilled adult readers (Marangolo et al., 2006; Berlingeri et al., 2008) and in people suffering from Parkinson's Disease (Di Tella et al., 2018; Silveri et al., 2018). Data from fMRI, reported in these studies, shows that the grammatical category (either verbs or nouns), which is associated to the longest reaction times, triggers a greater activation of the left inferior frontal gyrus. In other words, it seems that processing difficulties cannot be referred to grammatical category as such, but to the complexity of selection and inhibition processes required by the task.

The complex system for extracting information from written words develops during reading acquisition. So, in the early phases of learning to read, children show a pattern of eye-movements that is only partially similar to the pattern observed in skilled adult readers: they tend to make longer fixations and shorter saccades, with more frequent regressions to earlier parts of the text, and are more likely to re-fixate in proximity to the end of the word (see Bellocchi et al., 2013 for a review). Moreover, several studies showed that children have a smaller perceptual span, i.e., Moreover, several previous studies in the "region from which useful information can be obtained during fixation in reading" (Rayner, 1986, p. 212). Due to their reduced perceptual span, children are supposed to be prone to process morphologically complex stimuli through morphemic constituents, even in the case of short complex words, in order to acquire as much information as possible during a single fixation (Bertram and Hyönä, 2003). Häikiö et al. (2011) studied the role of morphology in reading acquisition by measuring children's eye movements while reading sentences containing either a hyphenated (e.g., *ulko-ovi*, 'front door') or concatenated (e.g., *autopeli,* 'racing game') compound. The participants were Finnish second, fourth, and sixth graders (8, 10, and 12 years old, respectively). Fast second-graders and all fourth- and sixth-graders read concatenated compounds faster than hyphenated compounds: this suggests that they prefer to process concatenated compounds via whole-word representations. In contrast, fixation durations of slow-reading children attending second grade were shorter for hyphenated than concatenated compounds. Such a result supports the idea that these children process all compounds via constituent morphemes and that hyphenation comes to aid in the process. Häikiö et al. (2011) results show that the lower the reading ability, the higher the probability of morphemic parsing.

Grainger and Ziegler (2011) model offers a useful framework to describe the role of morphemic representations during reading acquisition. According to this model, readers who are beginners start from learning associations between letters and sounds: orthographic input is processed letter-by-letter, in a laborious serial procedure of phonological recoding. Then, the repeated exposure to printed words leads to the development of two different types of orthographic codes, fine- and coarse-grained representations, that optimize the mapping from letters to meaning. Letters that co-occur very often in a language, which is typically the case for morphemic constituents (e.g., '-er'), can be grouped in chunks, forming higher-level orthographic representations, in which the information about the ordering of letters in the string is preserved (fine-grained orthography). Chunking leads to an improvement in reading performance, as it reduces the number of units to be processed. However, to speed up the process further, skilled readers learn to process the string of letters only for uptaking information about the presence of letter combinations without precise positional information (coarse-grained orthography). In this way the mapping between printed word and meaning is realized 'at a glance,' according to distributional properties of the word features in the language (diagnosticity).

Indeed, data from developmental literature proved that the presence of morphemic constituents may help word processing in struggling readers and in skilled young readers when either low-frequency words or pseudowords must be read. This suggests that morphemes may act as distributional cues that can be efficiently exploited to facilitate reading (Mann and Singson, 2003; Carlisle and Stone, 2005; Burani et al., 2008; Jarmulowicz et al., 2008; Burani, 2010; Deacon et al., 2011; Marcolini et al., 2011; Traficante et al., 2011; Traficante, 2012; Deacon and Francis, 2017). However, helpfulness of morphemic constituents may vary according to the consistency of grapheme-to-phoneme correspondence and of morphological richness of the language.

Casalis et al. (2015), through a direct comparison between English and French, found that, in a lexical decision task, the recognition of a root [R] within a word tends to slow down the response time, irrespective of the presence of a suffix [S] (e.g., *farmer* [R+S+], *window* [R+S−] > *murder* [R−S+], *narrow* [R−S−]) only in English 4th grade children,

[1] In GCST, participants are presented either with a verb (e.g., to observe) and are asked to produce the corresponding derived noun (e.g., observation), or with a noun (e.g., production) and are required to produce the verb base (e.g., to produce).

whereas the same condition (e.g., *fermier*, *boutique*) did not lead to the same effect in French children, matched by grade with their English peers. On the contrary, in both languages, children are slower and less accurate in rejecting pseudowords containing a stem and/or a suffix. In Italian, a shallow orthography language with rich morphology, the facilitative role of root frequency in word reading has been found, in typically developing children, only for low-frequency words, whereas in poor readers it has been observed for both high- and low-frequency words (Marcolini et al., 2011). However, when reading aloud pseudowords, all Italian children, irrespective of their reading skills, gained advantage in latency for the presence of a root (e.g., **bagnezza* [R+S+], **bagnezzo* [R+S−] < **bognezza* [R−S+], **bognezzo* [R−S−]) and increased their accuracy from the presence of both a root and a suffix (i.e., **bagnezza*, **bagnezzo*, **bognezza* > **bognezzo*) (Traficante et al., 2011).

Recently, we assessed the role of distributional properties of morphemic constituents on reading words, by asking 4th and 5th graders to read aloud nouns derived from verb- and from noun-bases. Latency data showed that roots occurring in many word forms, like verb roots, are more likely to trigger morphemic parsing than roots embedded in few forms, like noun roots (Traficante et al., 2014; see also Traficante and Burani, 2003). In fact, in a reading-aloud task, base frequency and word frequency effects were found only for words derived from verb bases (e.g., '*fallimento,*' failure). The base frequency effect seemed to suggest that young readers (4th and 5th graders) exploit verb bases as a head-start for word naming; however, in a task involving input and output processes, the advantage of such a head-start might be counterbalanced by the low probability of finding the specific 'base+suffix' combination. As a consequence, for deverbal items a strong word frequency effect emerged: the higher the frequency of the 'base+suffix' combination (i.e., word frequency, see Baayen, 2010), the faster the onset of the response. However, words derived from verb bases were read more slowly than words derived from noun bases, thus confirming that the parsing procedure is time-costly. For nouns embedding noun bases (e.g., '*artista,*' artist) no lexical effect, but only word length effect was detected on RTs. This result was interpreted as the effect of a sublexical strategy applied by Italian children in reading low-frequency words derived from a noun base, which would not trigger morphemic parsing. Data on accuracy confirmed that reading nouns derived from verb bases is more difficult than reading nouns derived from noun bases, but showed a different picture on the role of morpho-lexical variables. In fact, both base frequency and whole-word frequency influenced reading accuracy, irrespective of the base-word category: higher frequency values were associated with higher accuracy not only for nouns derived from a verb, but also for nouns derived from a noun. These results on accuracy confirm that verb bases trigger morphemic parsing, but suggest that also noun bases and whole-word representations of words derived from noun bases should be accessed at some point of the word processing.

To better analyze the processes involved in reading derived words, in the present study we analyzed eye-movements in reading aloud the same derived words used in Traficante et al. (2014) study. In this case they were embedded in sentences, according to the experimental procedure usually adopted in eye-movements studies. Considering the above-mentioned literature on eye movements in reading complex words, this technique is expected to allow us to directly assess the role of base word as a head-start in early processing stages (through the testing of base-word frequency effect on first-fixation duration) and to get some clue on the later processing stages (through the analysis of base- and whole-word effects on gaze-duration, which should mirror reading latency). As for nouns derived from verb bases, it was expected to find, from eye-movement analysis, data confirming the use of morphemic constituents in word recognition, i.e., morpho-lexical effects on both first-fixation duration and gaze duration. Yet, for nouns derived from noun bases, contrasting results from latency and accuracy observed in the previous study make predictions less clear. On one hand, the presence of morpho-lexical effects on accuracy suggests that representations of morphemic constituents should play a role in programming pronunciation of the target word; as a consequence, base and whole-word frequency are expected to influence at least gaze duration. On the other hand, the lack of morpho-lexical effects on latency, which was affected only by length in letters, might be due to complex effects, on which eye-movements analysis is supposed to shed light.

Finally, we chose to consider the role of proficiency in reading, beyond the school grade attended by children, because Häikiö et al. (2011) results suggest that, in early stages of learning to read, orthographic skills can modulate the use of morphemic constituents, irrespective of grade. In this vein, also Beyersmann et al. (2015) showed that morphological effects were modulated by reading proficiency, in a masked-priming paradigm, and not by grade. Moreover, several previous studies in Italian (e.g., Marcolini et al., 2011) found that poor readers are more prone to use morphemic parsing than skilled readers, even though attending the same school grade. The prediction for the present study is that the lower the proficiency, the more likely it is to observe lexical effects on first fixation duration, as a consequence of using a base word as a head start in early processing of the target word, before accessing the whole word.

MATERIALS AND METHODS

Participants

Sixty-two children (35 Female; 56%), attending 3rd (N = 20), 4th (N = 22), and 5th grade (N = 20) (mean age = 8.98 years; SD = 0.81) were recruited in three different primary schools in Northern Italy. All children were born in Italy, attended school regularly and had normal or corrected-to-normal vision. None of them had been signaled for neurodevelopmental disorders according to DSM-5 (American Psychiatric Association, 2013).

The present study was approved by the Scientific and Ethics Committee of the Department of Psychology of Catholic University of Milan, in accordance with the Helsinki Declaration and all children's parents gave informed written consent to the study.

Materials

Experimental Stimuli

Seventy suffixed nouns (see Traficante et al., 2014) were selected from the derived words listed in the *Elementary lexicon: Statistical data on written and read Italian language in primary school children* (Marconi et al., 1993), according to the following criteria: (i) having the base word listed in the *Elementary lexicon*; (ii) bearing a semantically transparent derivation, according to a rating scale administered to 20 undergraduate students (M = 4.9, range = 2.4–6.6 on a 1–7 Likert scale); (iii) being phonologically transparent with respect to its base; (iv) ending with frequent and productive derivational suffixes; (v) being stressed on the penultimate syllable. Only words derived from noun-base or verb-base were selected. As a result, two sets of derived words were obtained: 41 nouns derived from noun-base (e.g., 'artista', artist), and 29 nouns derived from verb-base (e.g., 'punizione', punishment) (**Table 1**).

A brief sentence (mean length in characters = 47.04; minimum = 32, maximum = 53) was generated for each target word, following two main criteria: (i) the position of the target word had to be in the middle of the sentence; (ii) the predictability of the target word in the sentence context was low (see **Supplementary Material**).

In order to exclude a difference in the extent to which target words were predictable given the preceding context, we estimated their contextual plausibility by means of distributional systems. These types of computational models, widely used in cognitive science (a famous example being *Latent Semantic Analysis*; Landauer and Dumais, 1997), characterize words as semantic vectors, in turn induced by an analysis of lexical co-occurrences in text corpora. For the present purposes, we applied the WEISS2 system developed for Italian by Marelli (2017) using the word2vec learning algorithm (Mikolov et al., 2013). The representations for sentence contexts were obtained by summing the vectors of the words they include, following an established tradition in computational semantics (Mitchell and Lapata, 2010). Contextual plausibility was then computed as the cosine proximity between the context vector and the target-word vector: the higher this value, the more plausible the target word will be, given the preceding context. These estimates resulted to be similar in noun-base targets (M = 0.175, SD = 0.082) *vis-a-vis* verb-base targets (M = 0.140, SD = 0.081). Indeed, the contextual-plausibility distribution between the targets of either category was not significantly different (p = 0.18 at the Kolmogorv–Smirnoff test).

TABLE 1 | Mean and standard deviations (in parentheses) for the main psycholinguistic features of the stimuli.

		Nouns derived from noun bases (*N* = 41) (e.g., *artista,* artist)	Nouns derived from verb bases (*N* = 29) (e.g., *creazione*, creation)
Number of forms in the inflectional paradigm of the base		2–4	>50
Word length	*M*	8.07	9.48
	SD	(1.1)	(1.5)
Word frequency[a]	*M*	13.78	37.75
	SD	(16.0)	(39.1)
Root length	*M*	4.41	4.97
	SD	(1.1)	(1.3)
Base frequency [a]	*M*	102.21	141.28
	SD	(107.76)	(124.5)

[a]*Frequency measures are calculated on 1 million occurrences from a corpus of written Italian (Bertinetto et al., 2005).*

Word and Non-word Reading

To assess children's proficiency in reading, the *Word and Non-word Reading Test* (Zoccolotti et al., 2005) was administered. It is a standard test made up of two lists of non-words (short: 4–5 letters; long: 8–10 letters) and four lists of words, varied in length (short: 4–5 letters; long: 8–10 letters) and in frequency (high and low frequency). Speed and accuracy in reading are assessed according to national norms.

Non-verbal Intelligence

Raven's *Colored Progressive Matrices* (Raven, 1947; Italian adaptation, Belacchi et al., 2008) were administered to assess non-verbal reasoning abilities. All participants showed a performance within normative range.

Apparatus

Each sentence was displayed on a 22-inch monitor, connected to a Dell Notebook PC W76CU interfaced with an SMI (Senso-Motoric Instruments) RED500 device, having high spatial (<0.4° of visual angle) and temporal (500 Hz) resolution. Viewing was binocular and the experiment was implemented and run through Experiment Center 3.0 software (2010).

Procedure

Participants were seated approximately 60 cm from the monitor and the eye-tracker was calibrated by asking the children to track a black dot moving on the screen through nine different locations. Data on gaze accuracy measured during the calibration phase showed an average error on the horizontal axis of 0.43 degree between the actual gaze point and the point measured by the eye-tracker, approximately in line with the technical features declared by SMI for RED-500 device.

After setting the best calibration for each participant, they were asked to read aloud the sentences displayed in the middle of the screen. Sentences appeared centered in a single row, in black mono-spaced font (Consolas 24), in lower-case, on a white background and were presented one at a time in random order. Eighteen sentences were followed by a comprehension question with a multiple choice response. Reading was recorded and the rate of presentation was manually adapted by the experimenter according to the reading speed of each individual. Accuracy in reading target words was coded after transcription of the children's productions.

Data Analysis

To get an index of proficiency in reading, a *factor* analysis was performed on the reading speed measured on the six lists of the *Word and Non-word reading test* (Zoccolotti et al., 2005). A one-factor solution emerged, with a unique factor loading higher than 1 (λ = 4.78) and with 79.68% of explained variance. Factor scores were saved as a new variable, proficiency, negatively oriented: the higher the value, the lower the proficiency, as it derives from reading times. In all the analyses, the role of this variable was tested over and above the role of grade, in order to disentangle the effect of literacy exposure and explicit learning (grade) from the effect of reading skills and implicit learning (proficiency).

The raw eye-movement data was processed using Be-Gaze 3.0 software (2011). Only data from target words that were correctly read and that received at least 1 fixation was considered. For each target word two measures were analyzed: (i) First-fixation duration (FFD), i.e., the duration of the first of several fixations; (ii) Gaze duration (GD), i.e., the sum of all first-pass fixations. The first measure has been traditionally referred to early stages of processing, the latter to later stages of processing.

As we were interested in testing the effects of several psycholinguistic characteristics of the items, in interaction with individual differences within participants in reading skills, a linear multiple regression analysis approach was adopted. Mixed-effects models (Baayen et al., 2008), the most updated statistical procedure applied in the field, which offers the opportunity to take into account the random effects due to variability within participants and items, were used to analyze the fixed effects of proficiency (factor scores), base-word category ("noun" and "verb"), word length (standardized measure of length in letters), word frequency (logarithmically transformed), root length (standardized residuals from the regression of root length on word length), and base frequency (logarithmically transformed) on FFD and GD (both measures were logarithmically transformed). Analyses were carried out by means of R (R Development Core Team, 2009), and implemented in the lme4 R package (Bates et al., 2015). Subjects and items were considered as random intercepts. All mixed-effects models were tested with a model-criticism procedure, excluding outlier points on the basis of standardized residuals (with 2.5 *SD* as threshold) (Baayen, 2008). Statistics of the refitted models are reported. The *p*-values were computed adopting the Satterthwaite approximation for degrees of freedom (Satterthwaite, 1946) as implemented in the lmerTest R package (Kuznetsova et al., 2015).

Effects of psycholinguistic features on accuracy, computed as the proportion of correct responses after removing technical failures, were analyzed through Generalized linear mixed model fit by maximum likelihood (Laplace Approximation) (Jaeger, 2008).

Post hoc probing of significant interactions between categorical (noun vs. verb base) and continuous variables (word length, word frequency, root length, and base frequency) was carried out, according to Aiken and West (1991) suggestion: "because one of the predictor variables is categorical, the simple slopes of interest will be those evaluated at values of the dummy (or effect) variables that correspond to the separate groups" (Aiken and West, 1991, p. 130).

RESULTS

Only 2.6% of data points in which the eye-tracker did not record any fixation on the corresponding target word, were not considered in the analyses (see Brysbaert and Stevens, 2018 for power analysis in mixed-effects models).

Accuracy

The total number of valid observations on which analyses on accuracy were carried out was 4250: 2486 for nouns derived from a noun-base and 1764 for nouns derived from a verb-base, respectively.

The rate of accuracy in reading target words was high (92%), thus confirming that in Italian typically developing children learn to read correctly in early school years, thanks to the high consistency of the grapheme-to-phoneme correspondence rules of the Italian language. However, it is worth noting that 5th graders showed an accuracy rate (96%) higher than 3rd (Tukey's HSD: p = 0.048) and 4th graders (Tukey's HSD: p = 0.039) (90% of accuracy each) ($F_{2,59}$ = 4.02, p = 0.023).

The analysis carried out by means of generalized linear mixed models, assessing the effects of grade and of all lexical variables (Model 1), showed the effect of grade (b = 0.5601, z = 2.630, p = 0.008) and word frequency (b = 0.1532, z = 1.97, p = 0.048) on accuracy: the higher the grade and word frequency the more accurate children's production. However, an alternative model (Model 2), in which proficiency was added as covariate to the previous one[2], showed a better fit index[3] (AIC_{model1} = 2108.8, AIC_{model2} = 2099.8; χ^2 = 10.978, df = 1, p < 0.001). In Model 2, grade effect did not reach significance level anymore (b = 0.1930, z = 0.892, p = 0.372), but proficiency was the strongest predictor of accuracy (b = −0.5865, z = −3.432, p < 0.001), and the role of word frequency was confirmed (b = 0.1559, z = 2.018, p = 0.043): the higher the proficiency[4] and word frequency, the higher the accuracy.

First-Fixation Duration

For the study of effects on FFD, only target words correctly read and undergoing more than one fixation were considered (N = 3627), as only in these cases FFD can be unambiguously referred to an early processing stage (Marelli and Luzzatti, 2012).

One-way ANOVA and *post hoc* analysis carried out on first fixation duration by grade (**Table 2**) showed a significant difference between 3rd and 5th graders (Tukey's HSD: p = 0.041), whereas 4th graders did not differ from the other children. Mean first-fixation duration was quite similar for the two types

[2]Correlation coefficient between grade and proficiency is 0.448, so it was possible to include both variables in the same model.

[3]Akaike Information Criterion (AIC): AIC = 2k − 2ln(L), where k = number of parameters and L = maximum likelihood.

[4]Remember that proficiency measure is negatively oriented.

of derived words: for nouns derived from a noun base the mean duration was 218.3 ms (*SD* = 159.4), and for nouns derived from a verb base the mean duration was 225.3 ms (*SD* = 164.9).

A completely different picture turned out from mixed-effects models, in which grade and base-word category were considered in interaction with word length, word frequency, root length, and base frequency (Model 1). Results showed significant main effects of grade ($b = -0.0781$, $t = -2.313$, $p = 0.024$; $F = 5.35$, $p = 0.024$), i.e., higher grade was associated to faster first fixation duration, and of word frequency ($b = 0.0142$, $t = 2.040$, $p = 0.045$; $F = 4.16$, $p = 0.045$), i.e., higher word frequency was associated to longer first fixation. Base-word frequency and base-word category affected first fixation duration both as main effects (base frequency: $b = -0.0274$, $t = -2.553$, $p = 0.013$; $F = 0.28$, $p = 0.60$; base category: $b = -0.2289$, $t = -2.667$, $p = 0.009$; $F = 7.11$, $p = 0.009$) and in interaction with each other ($b = 0.0460$, $t = 2.962$, $p = 0.004$; $F = 8.77$, $p = 0.004$). In Model 2 proficiency was added to the list of covariates and the model fit significantly improved ($AIC_{model1} = 6329.2$, $AIC_{model2} = 6322.0$; $\chi^2 = 9.213$, $df = 1$, $p = 0.002$). In this model, the significance of grade effect disappeared, and proficiency emerged as the strongest predictor of first fixation ($b = 0.0891$, $t = 3.074$, $p = 0.003$; $F = 9.45$, $p = 0.003$). In the model run after removing grade factor, base-word category was involved in a four-way interaction with proficiency, word length, and word frequency ($b = -0.033$, $t = -2.071$, $p = 0.038$; $F = 3.60$, $p = 0.058$), and it also interacted with base-word frequency ($b = 0.045$, $t = 2.535$, $p = 0.01$; $F = 5.84$, $p = 0.016$). To better explore these interactions, conditional effects were decomposed (see Aiken and West, 1991). Models assessing effects of proficiency, word frequency, word length and base frequency were carried out on dataset split by base-word category.

For words derived from noun base ($N = 2102$), the three-way interaction within proficiency, word length, and word frequency was positive, and was far from a significance level ($b = 0.0147$, $t = 1.286$, $p = 0.199$; $F = 1.65$, $p = 0.199$). Neither two-way interactions nor main effect of word length reached a significance level. The final model (**Table 3**) showed that the lower proficiency was, the longer the first-fixation duration ($b = 0.087$, $t = 3.28$, $p = 0.002$; $F = 11.38$, $p = 0.001$), and word frequency had an inhibitory effect ($b = 0.021$, $t = 2.09$, $p = 0.04$; $F = 4.62$, $p = 0.038$). On the contrary, the main effect of base-word frequency was significant and higher frequency was associated with shorter first-fixation duration ($b = -0.033$, $t = -2.78$, $p = 0.008$; $F = 7.35$, $p = 0.01$). From a qualitative point of view, errors consisted of the production of a base word without suffix, e.g., 'testa' (head) instead of 'test*ata*' (headboard), 'palazzo' (palace, hall) instead of 'palazz*etto*' (sports center). So, we can hypothesize a strong competition between base- and whole-word representations in the early processing phases.

For nouns derived from verb base ($N = 1525$), three-way interaction within proficiency, word length, and word frequency was negatively oriented and far from significance level ($b = -0.0123$, $t = -1.102$, $p = 0.27$; $F = 1.22$, $p = 0.27$). Also for these stimuli, neither two-way interactions nor word-length effects were significant, whereas a proficiency effect emerged ($b = 0.1145$, $t = 4.03$, $p < 0.001$; $F = 15.37$, $p < 0.001$) in the expected direction. However, differently from words derived from noun base, the word frequency effect was far from significance level ($b = 0.006$, $t = 0.636$, $p = 0.53$; $F = 0.40$, $p = 0.52$). The base-word frequency approached a significance level, but in the opposite direction from that observed in the other set of stimuli ($b = 0.0217$, $t = 1.829$, $p = 0.067$; $F = 4.13$, $p = 0.04$): higher base-word frequency was associated to slower first fixation. The null effect of word frequency suggests that, for these derived words, first fixation cannot be informative enough to activate any base+suffix representation, even though the base-word frequency effect suggests that verb-base recognition may occur, thus producing an inhibitory effect.

TABLE 2 | First fixation duration (ms): descriptive statistics and comparison within grades.

Grade	*N*	*M*	*SD*	*Minimum*	*Maximum*	*F*	*p*
3rd	20	246	77.3	145	386	3.13	0.051
4th	22	227	53.5	117	343		
5th	20	199	45.0	129	276		

TABLE 3 | Words derived from noun base: mixed-effects on *first-fixation duration.*

Random effects	**Variance**	***SD***			
Item (Intercept)	0.0004	0.0201			
Subjects (Intercept)	0.0335	0.1829			
Residual	0.3189	0.5646			
Fixed effects	**Estimate**	***SE***	***t*-Value**	***F*-Value**	***p*-Value**
(Intercept)	5.30147	0.05906	89.750		
Proficiency	0.08739	0.02665	3.282	11.388	0.001
Word frequency	0.02139	0.01027	2.088	4.62	0.038
Base-word frequency	−0.03259	0.01172	−2.783	7.35	0.01

TABLE 4 | Gaze duration (ms): descriptive statistics and comparison within grades.

Grade	N	M	SD	Minimum	Maximum	F	p
3rd	20	1158	314.2	728	1903	4.00	0.023
4th	22	1079	295.8	553	2415		
5th	20	838	472.0	506	1550		

Gaze Duration

Analyses on gaze duration were carried out on a total of 3904 observations, i.e., all words with at least 1 fixation, that were correctly pronounced: 2281 for noun-base targets and 1623 for verb-base targets.

Like for accuracy, the only significant difference in mean gaze duration was observed between 5th and 3rd grade children (Tukey's HSD: $p = 0.024$). Fourth graders did not differ from 3rd to 5th graders (**Table 4**). Mean gaze duration for nouns derived from noun base was shorter than for nouns derived from verb base, but the difference did not reach a significance level (noun base: $M = 953.1$ ms, $SD = 272.5$; verb base: $M = 1024.1$ ms, $SD = 261.6$).

Also for gaze duration, however, mixed-effects models, carried out to assess the main effects of grade, base-word category, word length, word frequency, root length and base frequency, and the interactions within these variables, offered a complex pattern of results. In Model 1, grade affected gaze duration in a three-way interaction with base category and whole-word frequency ($b = -0.044$, $t = -2.31$, $p = 0.02$; $F = 5.62$, $p = 0.018$). In Model 2, proficiency was added to the analysis, gaining an improvement in fit index ($AIC_{model1} = 5932.0$, $AIC_{model2} = 5902.8$; $\chi^2 = 53.149$, $df = 1$, $p < 0.001$). The main effect of proficiency was highly significant ($b = 0.263$, $t = 4.124$, $p < 0.001$; $F = 34.2$, $p < 0.001$), whereas all the effects involving grade became not-significant. Due to this lack of significance of grade factor, further analyses were carried out without the variable grade. In the final model, base-word category was involved in two three-way interactions: with proficiency and word frequency ($b = 0.051$, $t = 3.31$, $p < 0.001$; $F = 10.98$, $p = 0.001$), and with proficiency and base frequency ($b = -0.037$, $t = -2.43$, $p = 0.015$; $F = 5.73$, $p = 0.017$). Moreover, the three-way interaction within proficiency, word length, and word frequency was highly significant ($b = -0.0268$, $t = -2.84$, $p = 0.005$; $F = 8.52$, $p = 0.003$). Also in this case, in order to analyze lower-level interactions, further analyses were carried out separately for words derived from noun base and words derived from verb base, to decompose conditional effects.

For nouns derived from noun base (**Table 5**), mixed-effects model, tested with a model criticism procedure, showed a strong effect of proficiency ($b = 0.2429$, $t = 4.30$, $p < 0.001$; $F = 18.39$, $p < 0.001$), in the expected direction: when proficiency is lower, gaze duration is longer. The three-way interaction among proficiency, word length and word frequency reached significance level ($b = -0.0263$, $t = -2.76$, $p = 0.006$; $F = 7.86$, $p < 0.01$), as well as the embedded two-way interactions within proficiency and word length ($b = 0.0936$, $t = 2.79$, $p = 0.005$; $F = 8.17$, $p < 0.01$), and proficiency and word frequency ($b = -0.0395$, $t = -3.85$, $p < 0.001$; $F = 12.9$, $p < 0.001$).

Following Bauer and Curran (2005) suggestions, interactions were explored by graphical techniques. **Figure 1** shows the three-way interaction: when reading proficiency was low (left panel of **Figure 1**), the inhibitory effect of word length (from −1.89 to 1.612 *z*, corresponding to quantiles of the standardized length in letters) on gaze duration was mitigated by word frequency. In fact, such inhibitory effect was very evident for low frequency words, and tended to disappear for

TABLE 5 | Words derived from noun base: mixed-effects on *gaze duration.*

Random effects	Variance	SD			
Item (Intercept)	0.0725	0.2693			
Subjects (Intercept)	0.0507	0.2254			
Residual	0.2384	0.4883			
Fixed effects	**Estimate**	**SE**	**t-Value**	**F-Value**	**p-Value**
(Intercept)	6.9050	0.1977	34.930		
Proficiency	0.2429	0.0564	4.297	18.39	< 0.001
Word length	0.0213	0.0102	2.088	1.89	0.18
Word frequency	−0.0747	0.0416	−1.793	3.23	0.08
Base frequency	0.0056	0.0392	0.143	0.03	0.86
Proficiency*Base frequency	0.0243	0.0097	2.504	5.27	0.02
Word length*Word frequency	−0.0334	0.0387	−0.862	0.68	0.41
Proficiency*Word length	0.0936	0.0332	2.787	8.17	< 0.01
Proficiency*Word frequency	−0.0395	0.0102	−3.854	12.9	< 0.001
Proficiency*Word length*Word frequency	−0.0263	0.0094	−2.755	7.86	< 0.01

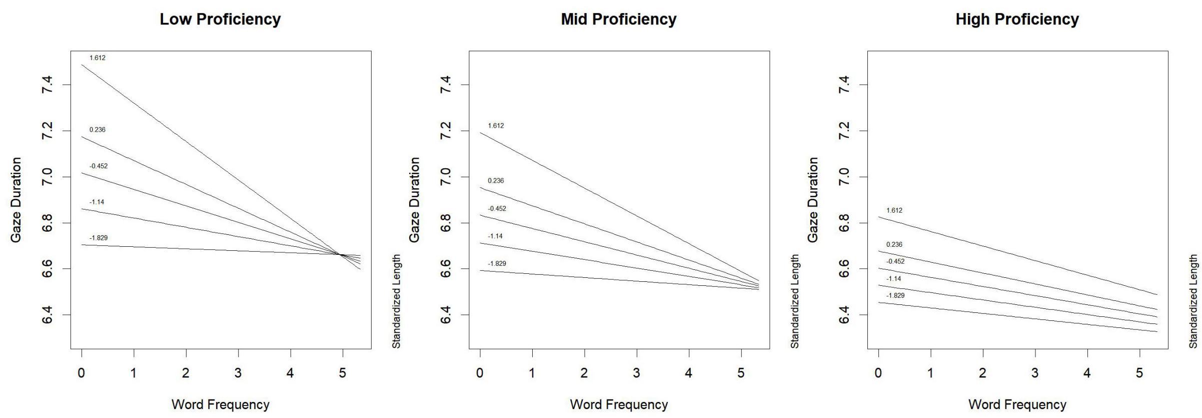

FIGURE 1 | Words derived from noun base: effect of proficiency *by* word frequency *by* word length interaction on gaze duration.

high-frequency words. This result suggests that the lower the reading proficiency the higher the probability that low-frequency words are read through fine-grained orthography representations (Grainger and Ziegler, 2011), thus being negatively affected by length in letters. On the contrary, high-frequency words are likely to activate coarse-grained representations, which are less affected by word length than the fine-grained code. Such modulation becomes less evident with increasing proficiency. When proficiency was high (right panel of **Figure 1**), the two opposite effects of word length and word frequency were independent: a frequency effect was observed, but the inhibitory effect of word length was quite similar for all words, irrespective of their lexical frequency. In this case, it can be assumed that both low- and high-frequency words are processed mainly through coarse-grained orthographic representations.

Figure 2 represents the interaction between proficiency and base frequency ($b = 0.0243$, $t = 2.50$, $p = 0.02$; $F = 5.27$, $p = 0.02$): in low-proficiency children (with scores of about 2.92 z, corresponding to quantiles of the factor scores on reading time measure), the higher the base frequency, the longer the gaze duration. This result suggests that base-word activation can lead to time-consuming processing of the derived words in less proficient readers, maybe for the conflict between base- and whole-word representations, which was noticed in the early stages of processing, through the analysis of first-fixation duration. This conflict seems to still affect reading at later processing stages, but only for less proficient readers. Skilled readers did not show such an effect anymore, suggesting that the initial conflict is quickly solved by these children.

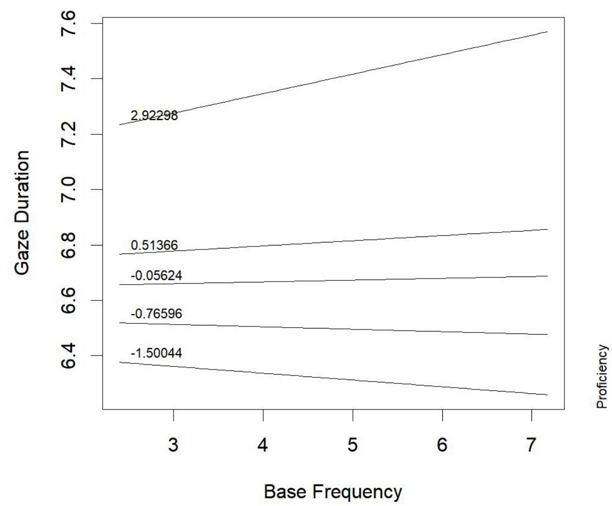

FIGURE 2 | Words derived from noun base: proficiency *by* base-frequency interaction effect on gaze duration.

Also for words derived from verb base (**Table 6**), the main effect of proficiency on gaze duration was very strong ($b = 0.271$, $t = 3.52$, $p < 0.001$; $F = 12.38$, $p < 0.001$): the lower the proficiency, the longer the gaze duration. The three-way interaction within proficiency, word length, and word frequency did not reach a significance level ($b = -0.0135$, $t = -1.40$, $p = 0.16$; $F = 1.95$, $p = 0.16$), but was in the same direction of the effect observed in nouns derived from noun bases. The two-way interactions between proficiency and word length ($b = 0.031$, $t = 0.92$, $p = 0.34$; $F = 0.84$, $p = 0.34$), and between proficiency and word frequency ($b = 0.013$, $t = 1.11$, $p = 0.27$; $F = 1.23$, $p = 0.27$) were not significant. Only the two-way interaction between word length and word frequency emerged, irrespective of children's proficiency ($b = -0.053$, $t = -2.27$, $p = 0.03$; $F = 5.16$, $p = 0.03$; **Figure 3**): for low- to middle-frequency words (until up to about 100 occurrences/million), the inhibitory effect of word length on gaze duration was stronger than the facilitative effect of word frequency.

This result suggests that for words derived from verb base the fine-grained code is the most used, irrespective of reading proficiency. Only for high-frequency words, the role of word length got smaller and changed its direction. The latter result might be explained by the presence, in the ending of high-frequency long words derived from verb base, of

TABLE 6 | Words derived from verb base: mixed-effects on *gaze duration.*

Random effects	Variance	*SD*			
Item (Intercept)	0.0215	0.1468			
Subjects (Intercept)	0.0461	0.2148			
Residual	0.2446	0.4946			
Fixed effects	**Estimate**	***SE***	***t*-Value**	***F*-Value**	***p*-Value**
(Intercept)	6.912	0.1738	39.766		
Proficiency	0.2714	0.0771	3.519	12.38	< 0.001
Word length	0.2234	0.0803	2.781	7.73	0.01
Word frequency	−0.0383	0.0286	−1.341	1.80	0.19
Base frequency	0.0084	0.0278	−0.304	0.09	0.76
Proficiency*Base frequency	−0.0134	0.0117	−1.139	1.30	0.25
Word length*Word frequency	−0.0527	0.0232	−2.271	5.16	0.03
Proficiency*Word length	0.0306	0.0335	0.916	0.84	0.35
Proficiency*Word frequency	0.0130	0.0117	1.109	1.23	0.27
Proficiency*Word length*Word frequency	−0.0135	0.0097	−1.398	1.95	0.16

the longest and most productive suffix used, in Italian, in deriving nouns from verbs, i.e., *-zione* (e.g., *operazione*, operation; *produzione*, production; *costruzione*, construction, etc.). In this case the base+suffix combination is quite predictable. Thus, gaze duration was shorter for such long words than for short high-frequency derived words ending with less productive and short suffixes like *-nza* (e.g., *partenza*, departure; *speranza*, hope).

For this set of stimuli, base-word frequency did not affect gaze duration either as main effect ($b = -0.008$, $t = -0.304$, $p = 0.76$; $F = 0.09$, $p = 0.76$) or in interaction with proficiency ($b = -0.013$, $t = -1.14$, $p = 0.25$; $F = 1.30$, $p = 0.25$).

DISCUSSION

In a previous study on 4th and 5th grade children, participants were asked to read aloud nouns derived from noun base and nouns derived from verb base (Traficante et al., 2014): morpho-lexical effects on RTs emerged for nouns derived from verb base, whereas only length in letters affected latencies for nouns derived from noun base. However, for both types of stimuli, base- and whole-word frequency affected accuracy: the higher the frequency measures, the more accurate the children's performance. Data on latency was interpreted as evidence for the peculiarity of verb bases, which are more likely to be used as a headstart for naming than noun bases, due to the distributional properties of verb paradigms. That evidence came from latency measure and informed us on the time needed by the reader for finding, in the string of letters, some familiar letter chunk to start the stimulus pronunciation. Morpho-lexical effects on accuracy observed in reading not only nouns derived from verb base, but also nouns derived from noun base, suggested that even noun base might be involved in the recognition process. In the present work we presented the same target words selected in the previous study, embedded in sentences, and used eye-movement recording to get clues on the whole processing of derived words, and not only on the pronunciation onset. Data from literature showed that eye-movement recording allows one to reveal the reader's behavior from early processing (first-fixation duration) to the final word recognition (gaze duration). Studies in the field showed that eye-movements are guided by "the big three" (i.e., word frequency, word length, and predictability in the context), and by the morphemic parsing procedure. Moreover, Häikiö et al.'s (2011) study of eye-movements in Finnish children showed that the use of morphemic constituents in that population can be affected by the reading proficiency.

First-Fixation Duration

Data from first-fixation duration showed a different pattern of results for words derived from noun bases and words derived from verb bases, but offers a picture of early processing which is quite different from evidence obtained with latency measure in the previous work. For nouns derived from noun bases, both base-word frequency and whole-word frequency affected children's first-fixation duration, but in the opposite direction. Base-word frequency exerted a facilitative effect, as the higher the frequency, the faster the first-fixation duration: so children seemed to gain advantage from the base activation. However, the higher the whole-word frequency, the longer the first-fixation duration. It seems that children, when the target is a high-frequency word, are faced with two conflicting representations: the base word and the whole word, which, in the case of noun-base targets, are both equally consistent with the grammatical and semantic constraints related to the sentence context. This condition of uncertainty seems to lead to longer first fixation. Erroneous productions by children supported this interpretation, as almost all errors consisted in productions of the base word with the omission of the suffix (e.g., 'mattina,' instead of 'mattin*ata,*'

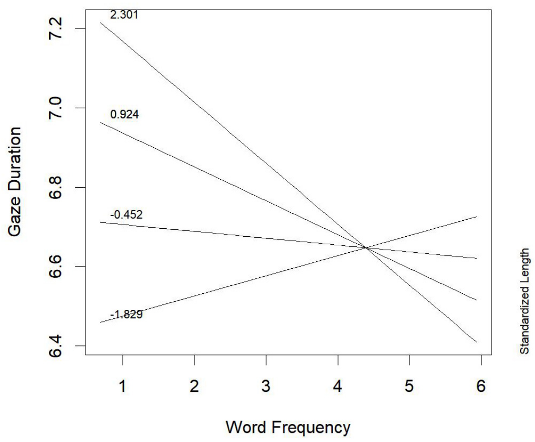

FIGURE 3 | Words derived from verb base: word frequency *by* word length interaction effect on gaze duration.

morning; 'camino,' chimney, instead of 'camin*etto,*' fireplace, etc.).

This result, along with data found by Amenta et al. (2015), suggested that first-fixation duration might be sensitive to possible competition, induced by sentence context, between base-word and whole-word representations. The complex interplay between base- and whole-word frequency observed in first-fixation duration might explain the null effect of morpho-lexical features on latency measure, obtained in the previous study, as the result of a competition between two alternative lexical representations, which leads to a reduction of frequency effects on RTs. However, these results from eye-movement recordings showed that both (base- and whole-word) representations come into play, as accuracy data from the previous study has suggested.

As for words derived from verb base, first fixation was influenced by reader's proficiency, as the lower proficiency, the slower the first fixation, and by base frequency, which exerted an inhibitory effect. Null-effect of whole-word frequency can be interpreted as the readers' difficulty in accessing the base+suffix combination in the very early processing phases, and can be explained in light of the experimental conditions. In fact, it can be assumed that, during first fixation, parafoveal information (see Reichle et al., 2013 for perceptual span in children) concerning word length gives the reader the cue that the target must be a long word, embedding the base word which is situated at the beginning of the letter string. In the case of a noun base, as discussed above, a competition between base word and whole word is likely to occur. In the case of a verb base, the syntactic context seems to determine a condition that is similar to GCST. In fact, all targets were nouns and the sentences were made up with a plain syntactic structure, according to usual word order in the Italian language, which requires a noun in the target position. When the reader detects a verb base at the beginning of the target word, a conflict is likely to occur between expected noun base and actual verb base. The inhibitory effect from this conflict seems stronger for high-frequency bases. In the derivation task used in Silveri and colleagues studies (Di Tella et al., 2018; Silveri et al., 2018), healthy adults and patients with Parkinson's Disease were asked to read a verb base (e.g., 'osservare,' to observe) on a computer screen and to retrieve the noun derived from that base (e.g., 'osservazione,' observation). It was a very difficult task even for adults in a healthy-control group. Those results were consistent with data from the fMRI study by Berlingeri et al. (2008) on healthy undergraduate students, that showed slower RTs for nouns than for verbs in GCST. In all those studies, results were interpreted as evidence that deriving a noun from a verb involves complex selection and inhibition processes, due to the large number of derived and inflected words sharing the same verb base. So, the lack of a significant word frequency effect on first-fixation duration that emerged from the present study can be conceivable for primary school children, who during early phases of processing might not have automatic access to the lexical representations involved in such a difficult computation.

Gaze Duration

Differences between words derived from noun base and words derived from verb base could also be observed in gaze duration. For the first category of stimuli (i.e., derived words with noun base), readers' proficiency played an important role in determining the impact that word length and word frequency exerted on children's eye movements. For low-proficiency children, the inhibitory effect of word length was stronger for low- rather than for high- frequency words. This result suggested that the processing of low-frequency words is carried out through time-consuming fine-grained orthographic representations (Grainger and Ziegler, 2011). On the contrary, for high-frequency words, lexical representations were likely to be accessed through coarse-grained orthographic representations, thus reducing the impact of word length. It is worth noting, however, that the effect of word length on gaze duration was also modulated by proficiency: it was smaller for high-proficiency children than for low-proficiency children. Moreover, for high-proficiency children length effect was independent from word frequency effect. This result suggests that low-frequency words are likely to be recognized by skilled children through the same procedure applied for high-frequency words, i.e., coarse-grained representations. This pattern of results mirrors a different degree of automatization in accessing lexical representations and a different use of sublexical/morpholexical procedure in reading aloud, according to different degrees of reading proficiency (Grainger and Ziegler, 2011). Difficulty of low-proficiency children in word recognition turned out also in the inhibitory effect of the base word, that can be observed as the proficiency decreases. This effect is consistent with Beyersmann et al. (2015) results, as in masked-priming paradigm low-proficiency children (grades 2–5) showed inhibition in finding a real stem in a non-word prime stimulus, whereas high-proficiency children showed facilitation.

Evidence from first fixation duration along with data from gaze duration suggested that, in early processing, when derived nouns are presented in a sentence context, noun-base representation (which is much more frequent than whole-word representation: see **Table 1**) can be a useful headstart for all children. However, its positive effect could be reduced by the competition with whole-word representation. Uncertainty between the two representations seems to be resolved in later stages of processing by skilled readers, whose gaze duration is affected only by whole-word frequency (the higher the word frequency, the faster gaze duration is) and length (the longer the word, the longer the gaze duration). Word length had a strong effect also on gaze duration in children with low proficiency in reading, mainly for low-frequency words. Moreover, for these children, the competition of base representation could be observed still in a late processing phase, as the higher the base frequency, the longer the gaze duration.

As for words derived from verb bases, all children, irrespective of their proficiency in reading, showed an interplay between length and word frequency effects: length effect on gaze duration was much stronger for low-frequency words, suggesting a massive use of fine-grained orthography for these words. However, it is worth noting that the higher the word frequency (i.e., frequency of base+suffix combination), the smaller the length effect was, until an inversion of the effect for highest frequency words was observed. The longest and most frequent words were associated with the shortest gaze duration: this effect can be due to the presence, in these words, of a long and very productive suffix (e.g., *-zione*, -tion; see **Supplementary Material**), which can work as a very useful chunk.

Summing up the results from the two procedures we used to contrast noun and verb bases, i.e., reading words in isolation (Traficante et al., 2014) and reading words in a sentence context (the present study), it seems that the effect of probabilistic features may be modulated by the processing context. As for verb bases, the effects of both base and word frequency on latency and accuracy, when the stimulus is presented in isolation (Traficante et al., 2014), suggest that the onset of pronunciation starts as soon as the base is recognized, and the pronunciation of the whole word can be computed as the base+suffix combination. The inhibitory effect of base frequency on first-fixation duration, observed in the present study, leads to hypothesize that the information acquired with the first fixation does not promote the onset of pronunciation, when the stimulus is embedded in a sentence calling for a noun in the target-word position: on the contrary, the inconsistency between the early detected verb base and the expected noun base is likely to engage the reader in difficult selection and inhibition processes, similar to those investigated in other studies in Italian adults (Marangolo et al., 2006; Berlingeri et al., 2008; Di Tella et al., 2018; Silveri et al., 2018). Only when the whole base+suffix combination has been accessed in later processing (as tapped by gaze duration), the reader can gain advantage from word frequency, with a reduction of inhibitory length effect. The inversion of the length effect for the most frequent words suggests that the long suffix *-zione* is a more useful chunk than the shorter suffix *-nza*, and support the hypothesis of the use of fine-grained codes in recognition of words derived from verb base.

As for words derived from noun bases in isolation (Traficante et al., 2014), the lack of lexical effects on latency in reading aloud was an unexpected result and we interpreted it by assuming that morphemic constituents, in those stimuli, are not informative enough to influence RTs in word processing. However, both base and whole-word frequency affected accuracy in reading these words: so, there was evidence for activation of morpho-lexical representations in processing words derived from noun base. Data from the present study offers a different pattern of results: when the sentence context leads to foreseeing a noun, first-fixation duration shows that noun base is likely to be already activated since early processing steps, but the gain from this activation is reduced by the competition of whole-word representation, as eye-movement analyses proved. The base is shorter and more frequent than the derived word, and shares the core-meaning with it, so the base word may be a good option, that fits with the features of the expected target, and may play the role of competitor of the derived word, in particular when reading proficiency is low. Data from gaze duration shows that in late processing only word length and word frequency affects the eye-movement of skilled readers, whereas base representation seems to be still a competitor of whole-word representation only in low proficiency children.

To conclude, the pattern of results shows a complex picture, in which the relation between base- and whole-word representations may be not only complementary, as in the case of reading aloud single words, but also competitive, as in the case of reading aloud derived words in a sentence context. Moreover, our data, along with results from Finnish and French studies, suggests that processing morphologically complex words is not influenced by grade, i.e., by explicit learning, but by reading skills that have been referred to several individual's features, such as visual perceptual span (Bosse and Valdois, 2009), decoding and lexical access speed (Wolf and Bowers, 1999; Blythe and Joseph, 2011; Zoccolotti et al., 2014), and sensitivity to semantic and distributional properties of language (Marinelli et al., 2017) (implicit learning processes).

Finally, the comparison between results from different experimental procedures, i.e., reading words in isolation (Traficante et al., 2014) vs. reading words in a sentence context (this research), involving the same stimuli, offered an interesting insight on the role of syntactic context in word recognition and, in particular, in recognition of morphemic constituents. Development of new measures on distributional properties of words in different syntactic and semantic contexts might offer useful means to collect new evidence on the development of probabilistic strategies in reading acquisition, and for modeling morphemic parsing in young readers with different proficiency levels.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of the Psychological Research Institutional

Review Board of Catholic University of Milan, with written informed consent from all subjects' parents. All subjects' parents gave written informed consent in accordance with the Declaration of Helsinki. The protocol was approved by the Psychological Research Institutional Review Board – Catholic University of Milan.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2018.02335/full#supplementary-material

TABLE S1 | Target words and stimuli list.

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Orthographic Transparency Enhances Morphological Segmentation in Children Reading Hebrew Words

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Morphological processing of derived words develops simultaneously with reading acquisition. However, the reader's engagement in morphological segmentation may depend on the language morphological richness and orthographic transparency, and the readers' reading skills. The current study tested the common idea that morphological segmentation is enhanced in non-transparent orthographies to compensate for the absence of phonological information. Hebrew's rich morphology and the dual version of the Hebrew script (with and without diacritic marks) provides an opportunity to study the interaction of orthographic transparency and morphological segmentation on the development of reading skills in a within-language design. Hebrew speaking 2nd (N = 27) and 5th (N = 29) grade children read aloud 96 noun words. Half of the words were simple mono-morphemic words and half were bi-morphemic derivations composed of a productive root and a morphemic pattern. In each list half of the words were presented in the transparent version of the script (with diacritic marks), and half in the non-transparent version (without diacritic marks). Our results show that in both groups, derived bi-morphemic words were identified more accurately than mono-morphemic words, but only for the transparent, pointed, script. For the un-pointed script the reverse was found, namely, that bi-morphemic words were read *less* accurately than mono-morphemic words, especially in second grade. Second grade children also read mono-morphemic words faster than bi-morphemic words. Finally, correlations with a standardized measure of morphological awareness were found only for second grade children, and only in bi-morphemic words. These results, showing greater morphological effects in second grade compared to fifth grade children suggest that for children raised in a language with a rich morphology, common and easily segmented morphemic units may be more beneficial for younger compared to older readers. Moreover, in contrast to the common hypothesis, our results show that morphemic segmentation does not compensate for the missing phonological information in a non-transparent orthography, but rather that morphological segmentation is most beneficial in the highly transparent script. These results are consistent with the idea that morphological and phonological segmentation processes occur simultaneously and do not constitute alternative pathways to visual word recognition.

Keywords: morphological segmentation, reading acquisition, orthographic transparency, Hebrew, root, diacritic marks, children, reading

INTRODUCTION

Work in recent years demonstrates the critical contribution of morphological processing abilities to reading and reading acquisition (Treiman and Cassar, 1996; McBride-Chang et al., 2003; Deacon and Kirby, 2004; Kieffer and Lesaux, 2012). Morphological processing ability is the reader's sensitivity to the smallest units of meaning in words, the ability to extract roots and affixes from whole-words and manipulate them to produce grammatically correct words. When these manipulations are performed intentionally, or through conscious reflection, they are referred to as 'morphological awareness' (Carlisle and Nomanbhoy, 1993; Kuo and Anderson, 2006; Bowers et al., 2010; Carlisle, 2010; Nagy et al., 2014).

While there is a growing body of literature on the strong relationships between morphological skills and reading, it is not yet clear how morphological segmentation processes interact with phonological processing during reading and reading development (Carlisle and Nomanbhoy, 1993; Fowler and Liberman, 1995). The effect of morphological skills on reading changes with age and reading experience (Casalis and Louis-Alexandre, 2000; Carlisle and Stone, 2005; Marcolini et al., 2011). Moreover, the degree to which morphological segmentation processes facilitates visual word recognition during reading depends on the morphological properties of the language (Marslen-Wilson et al., 1994; Bertram et al., 1999; Rispens et al., 2008; Duncan et al., 2009; Tolchinsky et al., 2012), on morphological transparency of the orthography (the degree to which derived words perserve the form of the morphemic units; Clahsen et al., 1997; Carlisle and Stone, 2005), and on the phonological consistency of the orthography (Frost, 2012; Casalis et al., 2015). A language with a rich morphology may promote strong reliance on morphological processes already at early stages of reading acquisition. One common hypothesis is that morphological decomposition is especially helpful in deep orthographies, where there is no consistent mapping of graphemes to phonemes, because it compensates for the scarce phonological information (Bar-On and Ravid, 2011; Vaknin-Nusbaum and Miller, 2011). In contrast, in a shallow orthography, where readers can rely on the direct correspondence of letters to sounds, the reliance on morphemes to access meaning is expected to be low (Frost, 2006).

Hebrew has two interesting properties: a rich Semitic morphological system, in which most words are composed of a root and a morphemic pattern, and a dual version of orthography one transparent and one opaque. These characteristics provide an opportunity to examine the interaction between orthographic transparency and morphological complexity on reading processes among developing readers in a within language design. The goal of the current study is to examine the effect of the phonological information present in the script on children' tendency to engage on morphological segmentation in Hebrew speakers. Specifically, we aim to determine (a) The contribution of basic morphological derivation processes to word reading rate and accuracy in Hebrew speaking second and fifth grade children; (b) Whether this contribution differs between transparent and non-transparent scripts; and (c) whether the involvement of morphological processes in reading changes with reading experience and age.

Engagement of Morphological Processing in Word Recognition in Children

As the smallest meaning-bearing linguistic unit, morphemes have the potential to serve as the elementary building blocks of word representations, supporting an economical, non-redundant body of lexical knowledge that facilitates the learning of novel forms and morphological variants of known words (e.g., Rastle and Davis, 2008; Merkx et al., 2011). However, while the role of *phonological* awareness in reading acquisition has been extensively studied for three decades and shown in a variety of orthographies (e.g., Vellutino and Scanlon, 1987; Ben-Dror et al., 1995; Ziegler et al., 2010; Melby-Lervag et al., 2012), the importance of *morphological* segmentation skills to reading development was the focus of researchers' attention mainly in the last decade (Carlisle and Nomanbhoy, 1993; Carlisle, 2000; Deacon and Kirby, 2004). The notion is that children's ability to recognize familiar morphemes embedded in morphologically derived and inflected words facilitates their ability to recognize written words. Although some of the earlier studies (Fowler and Liberman, 1995; Shankweiler et al., 1995) suggested that the role of morphological awareness in reading is attributed to its covariance with phonological awareness, more recent studies showed the unique contribution of morphological awareness to reading achievements in children (Casalis and Louis-Alexandre, 2000; Mahony et al., 2000; Nagy et al., 2003; Deacon and Kirby, 2004).

While there is no question today about the importance of morphological knowledge for reading acquisition, the developmental trajectory of morphological knowledge and its effect on reading acquisition is less clear. Morphological knowledge of spoken language develops over time, through accumulating language experience. Children, as young as 3 years of age are aware of the morphological components of words and how they can be manipulated to create new words (Berman, 1982). Studies in English speaking children show that morphological awareness of inflections and simple derivations might emerge early whereas an understanding of more complex derivational relations may come into place later. For example, while kindergarten and first grade children display some competence with simple derivations that do not involve phonological changes in the morphemes (Clark and Cohen, 1984), older children adeptly tackle more complex derivational relations (such as between electric and electricity), by about the fourth grade (Carlisle, 1988; Tyler and Nagy, 1989). As in spoken language, children's ability to extract morphemes from written words increases simultaneously with the improvement in reading accuracy, fluency and comprehension during elementary school years (Kieffer and Lesaux, 2012; Nagy et al., 2014; Sparks and Deacon, 2015). Children's performance on morphological awareness tasks (e.g., judgment of decomposability and defining the correct usage of complex words) increases from first to third grade (Carlisle and Fleming, 2003). Share (1995) suggests that recognition of morphemic regularities is an indication of a child's consolidation and fluency of print-sound correspondences.

Many studies suggest that in addition to the improvement of morphological awareness and segmentation skills, there is also an increase in the contribution of these abilities to reading in later stages of reading acquisition, mainly due to the increase in the proportion of complex words in the lexicon (Adams, 1990; Anglin, 1993; Mahony et al., 2000; Singson et al., 2000; Kuo and Anderson, 2006; Rispens et al., 2008). A study of French speaking children (Casalis and Louis-Alexandre, 2000) showed that morphological awareness had a significant contribution to the variance in words decoding skills, in second grade but not in first grade. However, readers' reliance on morphological segmentation does not depend only on their morphological knowledge, but also on the complete set of reading skills available to them while trying to identify written words. Hence, morphological segmentation can serve as a compensatory reading strategy for children and adults with low reading skills, who do not fully master whole-word processing, with a decrease in reliance on morphology in more skilled readers. For example, Italian speaking children and adult with dyslexia benefit from the morphological structure of derived words in an oral reading task more than skilled adult readers (Burani et al., 2008; Marcolini et al., 2011). Similarly, a study in French showed that the morphemic status of words had a facilitative effect on spelling only in poor readers but not in skilled readers (Quemart and Casalis, 2017). Other studies, in English and French (Nunes et al., 2003; Carlisle and Stone, 2005; Quemart et al., 2011), show the contribution of morphological knowledge to reading acquisition already at the beginning of elementary school and suggest that some morphological regularities may have very early effects on reading, and some may even have greater effects in early compared to later stages of reading development.

In addition to the individual's reading skills, the reliance on morphemic units during reading also depends on the morphological structures of the language (Marslen-Wilson et al., 1994; Bertram et al., 1999), as well as the transparency of orthography to phonology correspondence (Clahsen et al., 1997; Carlisle and Stone, 2005; Frost, 2012; Casalis et al., 2015). A study that tested the effect of morphological cues on spelling in school-age children (1–6 grade) found a greater reliance on morphological cues in Hebrew compared to Dutch speaking children (Gillis and Ravid, 2006), presumably due to the rich Semitic morphology of the Hebrew language. It has been suggested that morphological decomposition may compensate for incomplete phonological information in opaque orthographies in which the phonological code cannot be easily accessed through mapping of smaller units (Ziegler et al., 1997; Frost, 2006; Bar-On and Ravid, 2011; Vaknin-Nusbaum and Miller, 2011). However, a study that compared French and English speaking children showed stronger morphological effects in French, which has a more transparent orthography (Casalis et al., 2015). The authors suggest that the rich morphological productivity in French has outweighed the effect of the opaque English orthography. The unique properties of the Hebrew orthography provide an opportunity to test the complex interactions between morphological complexity and orthographic transparency in a within language and within subject design.

Hebrew Orthography and Morphology

Hebrew has one script with two versions that differ in their orthographic transparency. The opaque version is the un-pointed "Abjad" orthography that represents mostly consonants, and partially represents vowels using vowel letters. Vowel letters, provide only ambiguous vowel information because they denote both consonants and vowels, and some of them represent more than one vowel, creating extensive phonological under-specification (Bar-On, 2010). The transparent version is pointed, with diacritic marks superimposed under or above the letters, providing full representation of words' phonology. Children learn to read the transparent (pointed) version first, and are only exposed to the un-pointed version around 2nd or 3rd grade, with the transformation to the un-pointed script completed around 4th grade (Bar-On and Ravid, 2011).

The Hebrew language is also characterized by high morphological density in both its inflectional and derivational word formation. In the Hebrew derivational system, as in other Semitic languages, most words are morphologically complex as they are composed of two abstract morphemes: the root and the word pattern (Mishkal/Binyan). All the verbs and most of the nouns and adjectives in Hebrew are derived via non-linear formation in which a consonantal root is interleaved with a vocal pattern which adds the vowels between the root consonants [i.e., "GIDUL", "גידול", (*growth*) root – G.D.L. (*associated with growing*) pattern CiCuC] (Ravid and Malenky, 2001). The root that provides the basic meaning to the word, is not an independent word. It typically consist of three (but sometimes four) consonants. The morphemic pattern consists of the vowels, and can also include consonants, but only at the beginning [e.g., "MIGDAL", "מגדל", (*tower*) root – G.D.L. pattern miCCaC] and/or at the end [e.g., "MAGDELET", "מגדלת", (*magnifying (glass)*) root – G.D.L. pattern maCCeCet] of the word. Thus, the orthographic representation of the root is an almost continuous sequence, which is only interrupted occasionally by narrow vowel letters (vav- "ו", which represents the vowels /o/ and /u/, or yod-"י" which represent the vowel /i/). Other vowels (i.e., /a/ or /e/ which can be represented by the letters he'-"ה" or aleph-"א") are never represented by a vowel letter when they appear amidst the root consonants (Ravid and Malenky, 2001; Vaknin-Nusbaum et al., 2015).

The Effect of Diacritics and Derivational Morphology on Reading in Hebrew

Diacritics facilitate word recognition in early stages of reading acquisition (Navon and Shimron, 1981; Shimron and Sivan, 1994; Ravid, 1996; Harel-Koren, 2007; Shany and Share, 2011). In skilled adult readers diacritics have mixed effects, showing either facilitation (Navon and Shimron, 1981; Shimron and Navon, 1982; Koriat, 1984, 1985) or no effect (Bentin and Frost, 1987; Shimron and Sivan, 1994; Schiff and Ravid, 2004; Harel-Koren, 2007) on speed and accuracy of word recognition. However, both behavioral (Weiss et al., 2015a) and brain imaging (Weiss et al., 2015b) studies, of word reading in Hebrew show that even skilled adult readers who do not benefit from diacritics in terms of accuracy or RT, resort to a more piecemeal segmentation approach of decoding small units when reading pointed words.

Morphological segmentation has a prominent role in reading Hebrew words. Studies in skilled adult readers found long lasting priming effects of both the root and the morphemic pattern, suggesting that these units are activated when skilled Hebrew readers recognize written words (Bentin and Feldman, 1990; Frost et al., 1997). Studies in Hebrew speaking children show that children's awareness of the root morpheme in spoken language is already evident at the age of 3 years (Berman, 1982), however, the awareness of patterns develops later, and only reaches an adult level in 9th grade (Ravid and Malenky, 2001). School children's (2nd–6th grades) performance in morphological analogies of *written* words and pseudowords also shows early robust explicit knowledge of roots and patterns (Ravid and Schiff, 2006). Furthermore, children's morphological awareness in explicit judgment tasks was shown to correlate with their reading skills in 2nd (Vaknin-Nusbaum et al., 2015, 2016a,b) and 5th grade (Cohen-Mimran, 2009; Vaknin-Nusbaum et al., 2015), suggesting that morphological knowledge affects children's ability to read Hebrew already in early stages of reading acquisition. The triplex model of Hebrew reading development (Share and Bar-On, 2017) denotes three phases of development with growing sizes of units: the phonological (*sub-lexical*) sequential spelling-to-sound translation (in Grade 1); the higher-order string-level (*lexical*) lexico-morpho-orthographic processing (in Grade 2) followed by a *supra-lexical* contextual level (in upper elementary grades). According to this model first grade readers practice their decoding skills in reading phonologically transparent script. In second grade, readers gradually begin using their lexico-morpho-orthographic knowledge to cope with the incompletely vocalized Hebrew, a process which promotes their reading fluency. Then, during third grade and the transition to the unpointed script readers must rely on context in order to solve ambiguities, due to the extensive homography (Share and Bar-On, 2017).

While many of the above studies used explicit judgment tasks of morphological awareness, another study examined morphological segmentation skills in an online reading task of unfamiliar words and pseudowords. Hebrew speaking children (2nd to 11th grade) read aloud unfamiliar words and pseudowords containing real morphemic patterns, written in the opaque un-pointed script (Bar-On and Ravid, 2011). The results show a dramatic improvement in children ability to rely on morphosyntactic cues to identify unfamiliar words during 2nd grade, with a more gradual improvement throughout the rest of the school years. This study shows that Hebrew speaking children are able to extract morphological patterns from written words in very early stages of reading acquisition and this knowledge facilitates identification of new words. However, it is not clear to what extent these segmentation skills are also applied when reading real and familiar words. Moreover, the authors note that this ability facilitates reading of the opaque un-pointed script. However, since this study did not compare pointed and un-pointed words, it is not clear whether the reliance on morphological segmentation was indeed enhanced by the opacity of the un-pointed script.

The Current Study

The goal of the current study is to examine the interaction between morphological and phonological segmentation processes during reading development. For this aim we tested the effect of orthographic transparency on children's reliance on morphological segmentation when reading Hebrew derived words. Children (in 2nd and 5th grade) read single words (nouns) presented with or without diacritic marks, and the reliance on morphological segmentation was tested by comparing the speed and accuracy of reading bi-morphemic words (composed of a productive root and pattern) and mono-morphemic words. These two age groups represent lower and higher reading skills and reading experience within elementary school, and specifically 2nd grade children have a very a low level of experience with the unpointed script.

Many of the previous studies that tested the effect of morphological knowledge on reading development in Hebrew (Cohen-Mimran, 2009; Vaknin-Nusbaum et al., 2015) and other languages (Carlisle, 2000; Deacon and Kirby, 2004; Kieffer and Lesaux, 2012) used an explicit measure of morphological awareness. By comparing between oral reading of bi-morphemic and mono-morphemic words the current study tests the reliance on morphological segmentation in an online method. This approach, which was previously used in studies of Italian speakers (Burani et al., 2008; Marcolini et al., 2011) measures the reader's sensitivity to the words morphological structure implicitly and directly, without relying on their meta-linguistic awareness. This approach may be better suited to tapping young children's mental processes.

Based on previous studies, showing the sensitivity of young Hebrew speakers to roots and patterns in spoken and written derived words (Berman, 1982; Bar-On and Ravid, 2011) we expect that: (1) the morphological structure will facilitate word recognition as would be evident in higher accuracy of bi-morphemic compared to mono-morphemic word reading. (2) This effect is expected to be stronger in 2nd grade compared to 5th grade children, because the older children may rely more on whole-word recognition when reading familiar words

(Burani et al., 2008; Marcolini et al., 2011). (3) Finally, based on the notion that reliance on morphological segmentation can compensate for the sparse phonological information in opaque orthographies (Ziegler et al., 1997; Frost, 2006; Bar-On and Ravid, 2011), we predict that the facilitating effect of the morphemic structure would be stronger in un-pointed compared to pointed words.

MATERIALS AND METHODS

Participants

Twenty-nine 2nd grade students (ages 7:01–8:04 years, 16 girls) and 29 5th grade students (ages 10:01–11:04 years, 17 girls) were recruited from a regular elementary school in north Israel. Written informed consent was obtained from the parents of all participants. The study was approved by the ethics committee of the Faculty of Social Welfare and Health Sciences at the University of Haifa, and by the Ministry of Education. All were native Hebrew speakers without learning disabilities as reported by their teachers and confirmed by our assessment. Their reading level was tested using the Word Recognition and the Pseudo Word Decoding Tests, from "*Alef-Taf, Diagnostic test battery for written language disorders*" (Shany et al., 2006) described below. The inclusion criterion was having a score higher than one standard deviation below the norm in both tests and both measures: reading rate and accuracy. No student was excluded based on this criterion. One 2nd grade participant was excluded from the group analysis because their performance on the experimental task was lower than 3 standard deviations below the group average in three of the four experimental conditions, in both accuracy and reaction time. This resulted in 28 participants in 2nd grade and 29 participants in 5th grade who were included in the analysis.

Stimuli

The experimental stimuli consist of 96 concrete Hebrew nouns in two levels of orthographic transparency and two morphological conditions. Morphologically rich (bi-morphemic) words are composed of two morphemes: a root + a morphemic pattern. Examples of the stimuli are shown in **Table 1**. All roots were three consonantal productive roots, which are also used in existing Hebrew verbs, as judged by a linguist. Morphologically simple (mono-morphemic) words cannot be decomposed into smaller morphemes. We did not include words that can be decomposed into base + suffix (e.g., /gagon/: /gag/+/on/ 'small roof') even if they did not include a root.

In each morphological level, half of the words (24) were presented with diacritics and half without diacritics. None of the words in the experiment were homographs even when presented with no diacritics. Word lists were matched across conditions for the number of consonants (3–4), the number of vowel letters (0–2), the number of syllables (2–3), and for written frequency. As there is no available consensus corpus for written Hebrew frequency, we based the frequency ranking on the rating of ten elementary school teachers on a Likert scale of 1–5, that represents a range of low to high frequency for second graders.

TABLE 1 | Example of stimuli.

	Bi-morphemic (root and template)	Mono-morphemic
With Diacritics	מִכְשׁוֹל	סַנְטֵר
	MXSOL	SNTR
	/mixshol/	/santer/
	(obstacle)	(chin)
Without diacritics	תלמיד	סנפיר
	TLMID	SNPIR
	/talmid/	/snapir/
	(student)	(fin)

The frequency of the selected words ranged from 2 to 4.8, and the average frequency was equal in all conditions (between 3.4 and 3.6).

Standardized Tests

All participants underwent three standardized screening tests, in order to assess their reading and decoding abilities, and their vocabulary knowledge. In addition, phonological and morphological abilities were measured in order to assess the correlation of these abilities with performance on the experimental task. The first two screening tests were taken from the "*Alef-Taf*" battery (Shany et al., 2006): (1) *Word recognition*: participants read aloud 38 nouns with diacritics which represent different levels of frequency, length, and phonological structure. Different age-appropriate lists are used for different age groups. The scores indicate the number of accurately read words per minute and the percentage of errors. (2) *Pseudo-word decoding:* participants read aloud 33 pseudo-words with diacritics. 24 of these items represent familiar morpho-phonological structures in Hebrew and nine contained sound structures non-existent in Hebrew. Different age-appropriate lists are used for different age groups. The obtained scores indicate the number of accurately read pseudowords per minute and the percentage of errors. (3) *Vocabulary subtest* (WISC-III) (Wechsler, 1994): participants provided the definition for 25 words presented orally by the examiner. The final score is the total number of correctly defined words.

One phonological awareness and two morphological awareness tests were included in order to test the correlation between performance on the experimental task and these abilities: (1) *Phonological awareness* (from the "Alef-Taf" battery; Shany et al., 2006): includes 16 mono and bi-syllable words read aloud by the examiner. Participants produce pseudo-words obtained by omitting a designated phoneme positioned at the beginning, middle or end of the word. The score reflects the percentage of correctly produced items. (2) *Morpho-syntactic awareness* (from the "Alef-Taf" battery; Shany et al., 2006)*:* the ability to inflect and derive words in a context of a sentence is tested in both identification and production. *Identification*– participants identify the missing word in a sentence from five given options, which are all morphologically related to the target word. The score indicates the error percentage in the task. *Production* –participant s are required to complete a missing word in a sentence by deriving it from a given root. Other items include completing a missing pseudo-word in a sentence by inflecting a given pseudo-root. (3) *Passive production test* (Ravid and Saban, 2008). The examiner reads aloud a sentence and the participant is required to say it in the passive form. The test includes 12 sentences and the score represents the percentage of correct items.

Experimental Procedure

We employed an oral naming task because of its high ecological validity for testing reliance on morphological and phonological representations during word recognition (Koriat, 1984, 1985; Burani et al., 2008). Stimuli were presented on a computer monitor and participants were required to read them aloud, while responses and reaction times were recorded using a voice-activated-key (E-prime, Serial Response Box, PST). The trial began with the presentation of a fixation cross, and the presentation of the word was triggered by the participant. The word appeared on the screen 250 ms after the button press and remained there until 1200 ms after the onset of the vocal response when it was replaced by a fixation cross. Reaction times (RT) were collected starting from the stimulus presentation to the onset of vocalization. The 96 words from the current experiment were presented together with 152 words from another experiment (see Weiss et al., 2015a,b) which were similar in length and frequency and also appeared in both the pointed and un-pointed versions. Hence, the total number of trials for both experiments together was 248. Pointed and un-pointed words were presented in separate blocks of 124 words each, to minimize interference from frequent switching between strategies associated with reading pointed and un-pointed words. Block order was counter balanced across individuals, while morphological complexities were randomly intermixed. Data were collected in two sessions during the second trimester of the school year. In the first session the participants performed the standardized tests individually in a quiet room in the school. Participants who passed the selection criteria were invited for a second session where they performed the experimental task.

Data Analysis

Reaction time was analyzed only for correct responses. Self-corrected responses and words read by sounding each letter separately were coded as correct for the analysis of accuracy but were omitted from the analysis of reaction time. 1% of the responses were excluded from the analysis of RT due to technical recording problems. In order to examine the effects of diacritics and morphological complexity on reading, statistical analysis incorporated a GLM analysis separately on response time and accuracy as dependent variables with morphological complexity (mono-morphemic vs. bi-morphemic) and diacritics (pointed vs. un-pointed) as within subject variables and grade (2nd vs. 5th) as between subject variable. In order to test our specific hypotheses within each age group, we have also conducted separate analyses within each group although the interaction with group was not significant. Finally, in order to examine the linguistic and cognitive bases for the effects of diacritics and morphological complexity found in our experimental manipulation we have included scores of three standardized measure (Passive production test, Morpho-syntactic awareness and Phonological awareness) as covariates in three separate GLM analyses, conducted as above across both groups. Significant effects are reported with $p < 0.05$.

RESULTS

Characteristics of the Sample

Performance of all participants was within one standard deviation from the mean in all screening measures (accuracy and speed of words recognition and pseudo-words decoding, and vocabulary) as computed based on the age-appropriate norms of these standardized tests. These scores are presented in **Table 2**. Raw scores are presented in Supplementary Table S1. The scores of the other tests which were used for the correlation analysis are presented in **Table 3**.

Experimental Task

Accuracy

A GLM repeated measures analysis for accuracy as the dependent variable was conducted with morphological complexity (mono-morphemic vs. bi-morphemic words) and diacritics (with/without diacritics) as within-subject variables and

TABLE 2 | Participants' average *Z* score (and SD) in the screening tests.

	2nd grade (n = 28)	5th grade (n = 29)
Reading pseudo-words (% errors *z* score)	1.01 (0.55)	There are no norms
Reading pseudo-words (number per minute z score)	0.79 (0.56)	0.96 (0.56)
Reading words (% errors *z* score)	0.89 (0.33)	0.56 (0.39)
Reading words (number per minute *z* score)	0.98 (0.67)	0.17 (0.72)
Vocabulary (scaled score)	13.18 (2.80)	12.21 (2.02)

For the vocabulary test the scaled scores are presented (mean = 10, SD = 3).

TABLE 3 | Participants' average scores (and SD) in the Phonological and Morphological awareness tests used in the correlation analysis.

	2^{nd} grade (n = 28)	5^{th} grade (n = 29)
Phoneme omission (% errors)	22.10 (26.92) 47.49 (26.89)	9.70 (14.99) 24.50 (24.35)
Morpho-syntactic awareness (% errors)	12.69 (10.78) There are no norms	6.51 (5.95) 10.51 (11.12)
Passive production (% accuracy)	65.47 (20.38) 61.04	76.72 (12.87) 89.37

The mean and standard deviation of the norm sample appear below.

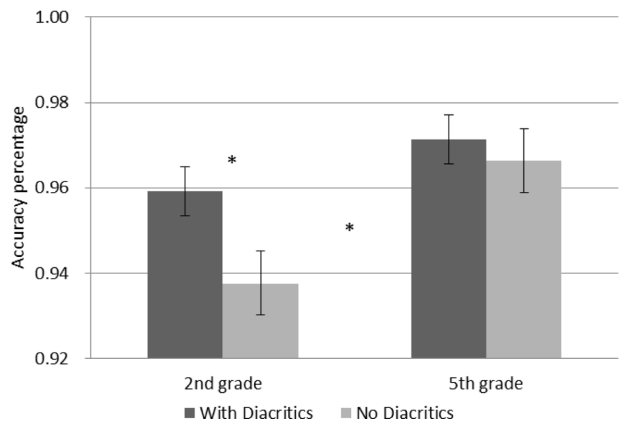

FIGURE 1 | Accuracy in reading words with and without diacritics according to grade. Error bars indicate standard errors. Asterisks represent significant differences at $p < 0.05$.

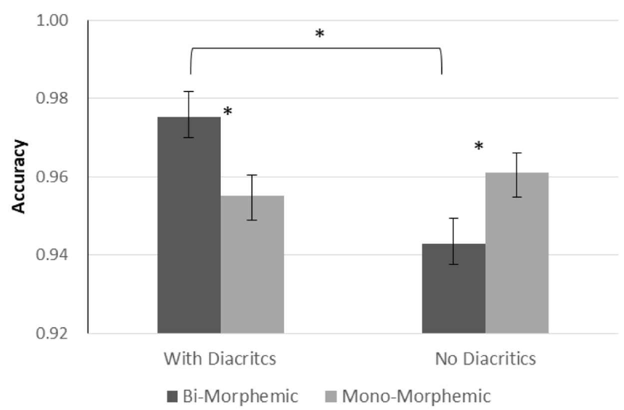

FIGURE 2 | Interaction between Morphological complexity and Diacritics across groups. Error bars indicate standard errors. Asterisks represent significant differences at $p < 0.05$.

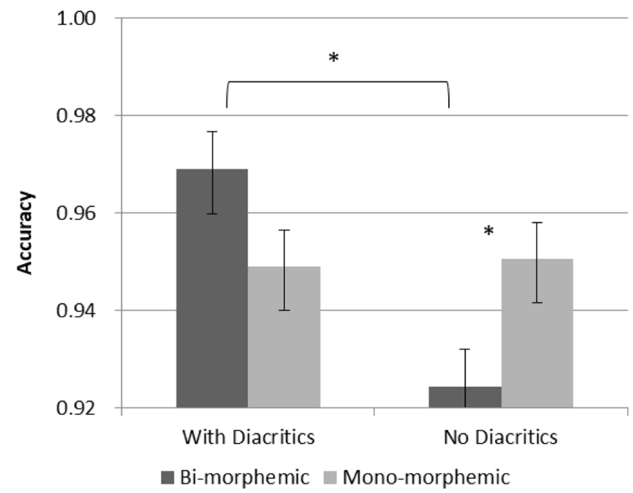

FIGURE 3 | Accuracy in 2nd grade. Error bars indicate standard errors. Asterisks represent significant differences at $p < 0.05$.

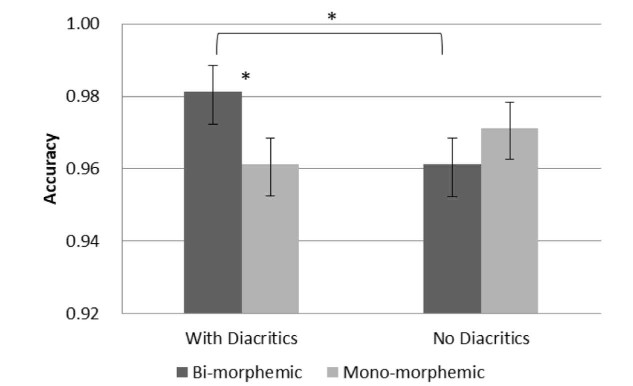

FIGURE 4 | Accuracy in 5th grade. Error bars indicate standard errors. Asterisks represent significant differences at < 0.05.

grade (2nd vs. 5th) as a between subject factor. The analysis showed significantly more accurate performance in 5th grade [$F(1,54) = 6.538$, $p = 0.013$], and a significant effect of diacritics [$F(1,54) = 6.697$, $p = 0.012$] showing that diacritics improved accuracy across groups (see **Figure 1**). The analysis also showed a significant interaction between diacritics and morphological complexity [$F(1,54) = 14.919$, $p < 0.001$], and no interactions with grade. **Figure 2** present follow-up analyses across the two groups showing that for the pointed script bi-morphemic words were read significantly more accurately than mono-morphemic words [$t(55) = 3.154$, $p = 0.003$], while for the un-pointed script the pattern was reversed, with bi-morphemic words read *less* accurately than mono-morphemic words [$t(55) = (-2.569)$, $p = 0.013$]. The results also showed that the pointed script improved accuracy compared to un-pointed script only for bi-morphemic words [$t(55) = 4.139$, $p < 0.001$], with no effect on mono-morphemic words [$t(55) < 1$, NS].

Although no interaction with group was significant, in order to see whether the above effects are evident in both age group and test our specific hypotheses, separate analyses were conducted within each age groups (see **Figures 3**, **4**). The results show that the main effect of diacritics was only significant in 2nd grade [$F(1,26) = 6.041$, $p = 0.021$], however, the interaction between diacritics and morphological complexity was significant in both groups [2nd grade: $F(1,26) = 7.692$, $p = 0.01$; 5th grade: $F(1,28) = 7.368$, $p = 0.011$], with a similar pattern of results across groups (see **Figures 3**, **4**). For the pointed script bi-morphemic words were read more accurately than mono-morphemic words [significant in 5th grade ($t(28) = 2.544$, $p = 0.017$) and marginally significant in 2nd grade ($t(26) = 1.951$, p = 0.062)]. Only 2nd graders showed the opposite pattern for the un-pointed script, with lower accuracy for bi-morphemic compared to mono-morphemic words [$t(26) = -2.185$, $p = 0.038$]. The two groups also showed a similar pattern of effects within each level of morphological complexity: the pointed script improved

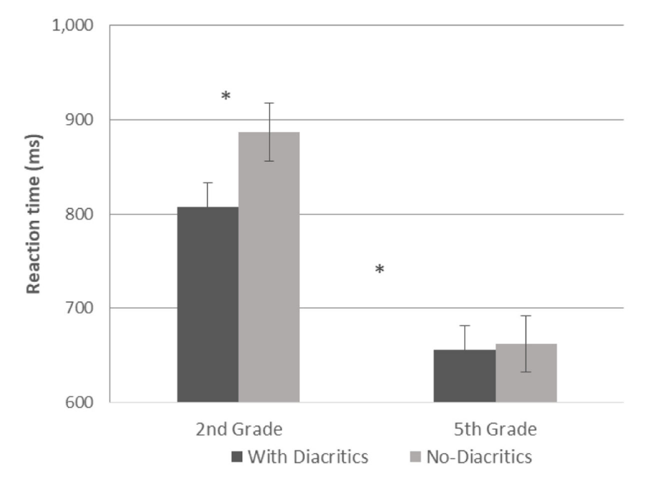

FIGURE 5 | Reaction time in pointed and un-pointed words for both groups.

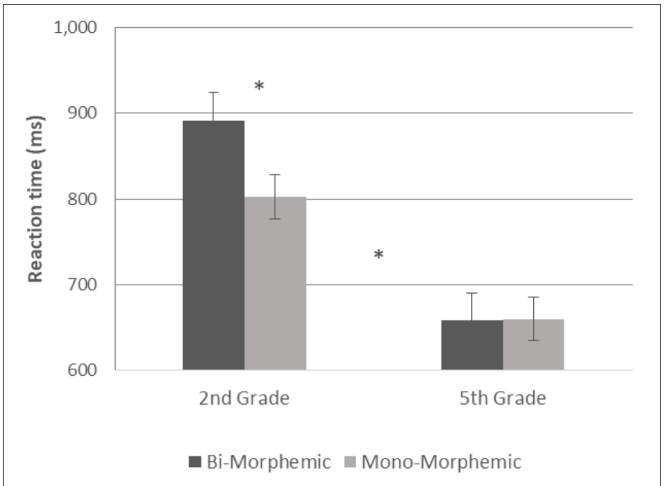

FIGURE 6 | Reaction time in mono-morphemic and bi-morphemic words in both groups.

reading accuracy compared to the un-pointed script only for bi-morphemic words [2nd grade: $t(26) = 3.357$, $p = 0.002$; 5th grade $t(28) = 2.544$, $p = 0.017$], but had no effect on mono-morphemic words in any age group.

Reaction Time

A GLM repeated measures analysis was conducted with reaction time as the dependent variable, morphological complexity and diacritics as within subject variables and with grade as between subject factor. The analysis showed a significant effect for grade [$F(1,54) = 23.394$, $p < 0.001$], with faster responses in 5th grade (see **Figures 5**, **6**). It also showed a significant effect for diacritics [$F(1,54) = 4.963$, $p = 0.03$], with faster responses for the pointed script, and a significant effect for morphological complexity [$F(1,54) = 8.785$, $p = 0.005$] with faster responses for mono-morphemic words. The two-way interaction for grade and morphological complexity was also significant [$F(1,54) = 9.712$, $p = 0.003$] and the interaction between grade and diacritics

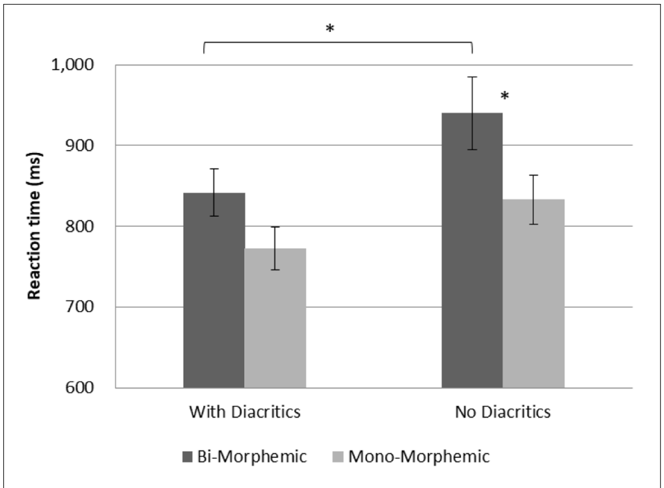

FIGURE 7 | Reaction time in 2nd grade.

was marginally significant [$F(1,54) = 3.693$, $p = 0.06$]. These interactions were followed-up by analyses within each grade level, showing that both of these effects were only significant in the 2nd grade [morphological complexity: $F(1,26) = 8.968$, $p = 0.006$; Diacritics: $F(1,26) = 4.440$, $p = 0.045$]. Hence, for 2nd grade children reaction time was faster for pointed compared to un-pointed words (**Figures 5**, **7**) and for mono-morphemic compared to bi-morphemic words (**Figures 6**, **7**), with no effects in 5th grade.

Correlations with Standardized Tests

Passive Production Test (Ravid and Saban, 2008)

In order to determine the linguistic mechanism underlying the effects in our experimental task, three linguistic measures were included in the GLM repeated measures analyses of accuracy as covariates. The inclusion of the Passive production test as a covariate in the GLM analysis of accuracy across groups showed a main effect for the Passive production test [$F(1,53) = 15.985$, $p < 0.001$], and no interaction with other factors. This was due to positive correlations between performance on the Passive production test and accuracy on the experimental task, which was significant in three of the four conditions (unpointed bi-morphemic words: $r = 0.410$, $p = 0.002$; un-pointed mono-morphemic words $r = 0.442$, $p = 0.001$; pointed bi-morphemic words: $r = 0.399$, $p = 0.002$). None of the other effects were significant (including those which were significant in the original analysis, namely, diacritics, group and morphology × diacritics). These findings indicate that participants with high morphological awareness as measured by the Passive production test, generally read words more accurately.

Morpho-Syntactic Awareness (Shany et al., 2006)

The inclusion of the Morpho-syntactic awareness test scores as a covariate in the GLM analysis of accuracy across groups showed a main effect for the Morpho-syntactic awareness test [$F(1,53) = 5.907$, $p = 0.019$]. There were also significant interactions between the score of the Morpho-syntactic

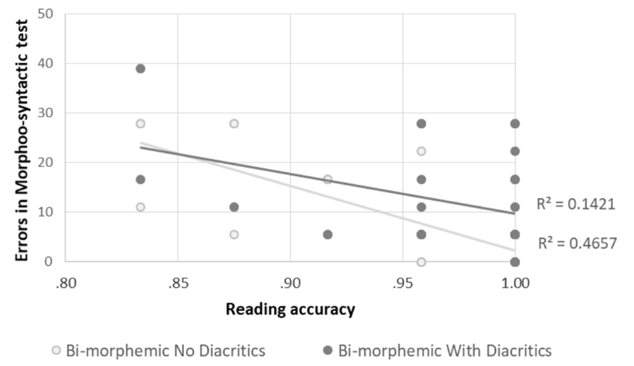

FIGURE 8 | The correlation between scores in the Morpho-syntactic awareness test and reading accuracy in bi-morphemic words in 2nd grade children.

awareness test and the experimental manipulation of morphological complexity [$F(1,53) = 4.231$, $p = 0.045$], as well as between the Morpho-syntactic awareness test and grade [$F(1,53) = 4.298$, $p = 0.043$], indicating that the effect of the morpho-syntactic awareness test is different for the two grade levels. In addition, only the interaction of morphology with diacritics remained significant as in the original analysis [$F(1,53) = 7.735$, $p = 0.007$], while the other effects (diacritics and group) were not. Separate GLM analyses were therefore conducted in each grade level. Only 2nd grade children showed a significant effect of the Morpho-syntactic awareness test [$F(1,25) = 12.229$, $p = 0.002$], and an interaction between the morpho-syntactic awareness test and the experimental task morphological complexity [$F(1,25) = 6.347$, $p = 0.019$]. No effects involving the Morpho-syntactic test were found among 5th graders [$F(1,27) = 0.421$, NS]. Pearson correlation analyses within the 2nd grade group showed negative correlations between the morpho-syntactic test scores (expressed as error percentage) and reading accuracy in bi-morphemic un-pointed words ($r = -0.682$, $p < 0.001$) and marginally significant in bi-morphemic pointed words ($r = -0.377$, $p = 0.053$). The correlations with mono-morphemic words were not significant ($r = -0.179$, $p = 0.372$; $r = -0.269$, $p = 0.175$; for the pointed and un-pointed scripts respectively). Namely, the Morpho-syntactic awareness test predicted reading accuracy only for 2nd grade children and only for bi-morphemic words (see **Figure 8**).

Phonological Awareness

Including the Phoneme omission test scores as a covariate in the GLM analysis of accuracy or RT across groups showed no significant effect of the test [$F(1,53) = 1.068$, 1.125, NS for accuracy and RT respectively].

DISCUSSION

Our study examined the hypothesis that the morphological structure of root and pattern, in derived Hebrew words, would facilitate children's oral reading, as compared to mono-morphemic words. We further expected that this facilitation would be stronger in 2nd grade compared to 5th grade children, and stronger in the opaque, un-pointed compared to the transparent pointed script.

Our results showed faster and more accurate reading in 5th grade compared to 2nd grade children. The transparent, pointed script, was read faster and more accurately compared to the un-pointed script, in 2nd grade children. 2nd grade children also read mono-morphemic words faster than bi-morphemic words. Interestingly we found an interaction between morphology and diacritics across both groups. Specifically, in both groups, derived bi-morphemic words were identified more accurately than mono-morphemic words, but this was only true for the transparent, pointed, script. For the un-pointed script the reverse was found, namely that bi-morphemic words were read *less* accurately than mono-morphemic words, especially in 2nd grade.

Correlation analyses with morphological awareness tests showed a correlation between reading accuracy across conditions and performance on the Passive production test (Ravid and Saban, 2008) across both groups. Interestingly, the Morpho-syntactic awareness test from the Alef-Taf battery (Shany et al., 2006) was specifically associated with reading accuracy of bi-morphemic words and only among 2nd grade children. The following sections will discuss these results and their implications for our understanding of morphological segmentation during reading development in transparent and opaque scripts.

Morphological Segmentation and Its Interaction with Orthographic Transparency

The finding that across both groups, bi-morphemic words were read more accurately than mono-morphemic words, in the pointed script, is partly consistent with our hypothesis. We predicted that the morphological structure of root and pattern would facilitate word identification in general, but more so in unpointed words. The facilitation found in pointed words is consistent with findings in Italian, a transparent orthography, showing higher accuracy in oral reading of bi-morphemic compared to mono-morphemic words (Burani et al., 2008; Marcolini et al., 2011). The authors suggest that morphological segmentation facilitates reading by providing smaller units, which could be identified with a shorter visual span. However, in contrast to our hypothesis that morphological decomposition would be more beneficial for *unpointed* words, because it could compensate for the scarce phonological information (Ziegler et al., 1997; Frost, 2006; Bar-On and Ravid, 2011), our results revealed the opposite pattern. Bi-morphemic words were read *less* accurately than mono-morphemic words in the un-pointed script for 2nd grade children. A possible interpretation of these results is that reading of bi-morphemic words, which contain productive roots, is impeded by the competition from morphologically related words containing the same root. The identification of the target among these morphological competitors depends on identifying the morphemic pattern (Mishkal), which is mostly composed of vowels. Since most of the vowels are not represented in the un-pointed script, there is more interference from the competitors. Thus, the extraction of the root from bi-morphemic words can facilitate identification of the word when the script is transparent, providing information about the morphemic pattern, but when the script is non-transparent, it can create competition, and even impede identification in less skilled readers who have very little experience in reading un-pointed words.

While the specific way in which orthographic transparency interacts with morphological segmentation is unique to the Semitic script and morphology, the general finding is consistent with the results of a study that compared between French and English speaking children in 3rd and 4th grade (Casalis et al., 2015). They showed greater effects of morphology in a lexical decision task in French, which has a richer morphology and a more transparent letter-to-sound correspondence than in English which has a deeper orthography. Moreover, in contrast to French children, English speaking children showed a detrimental effect for the presence of a real root in the word. The authors suggest that this is due to competition between the full word and its components because the form of the root is better preserved in English than French (Casalis et al., 2015). This finding is consistent with our results showing a disadvantage for bi-morphemic compared to mono-morphemic words when presented in the un-pointed script, and support the interpretation that this is due to competition between morphologically related words.

Developmental Changes in the Reliance on Morphological Segmentation

Consistent with our hypothesis, the results show more pervasive morphological effects in 2nd grade compared to 5th grade children. This is reflected in the finding of stronger effect of morphological complexity on reaction time in 2nd grade compared to 5th grade children. Although both age groups were sensitive to the words' morphological structure, as evident by the effect of morphological complextiy on accuracy in both groups, only 2nd grade children showed slower reaction time for bi-morphemic compared to mono-morphemic words, with no effect in 5th grade children. This suggests that while the process of morphological segmentation was faster and automatic in 5th grade children it was more effortful and time consuming for young children, regardless of whether it facilitated (in the pointed script) or impedes (in the un-pointed script) reading accuracy.

Another evidence for the early effect of morphological decomposition on reading is the stronger correlation found in 2nd grade compared to 5th grade children between morpho-syntactic awareness (Shany et al., 2006), and high reading accuracy of bi-morphemic words on the experimental task. The inclusion of these morphological test scores as covariates in the analysis rendered the effect of group insignificant, indicating the important role these skills play in reading acquisition. The specificity of this correlation to bi-morphemic words supports our experimental manipulation and the suggestion that processing of bi-morphemic words relies on morphological segmentation. Importantly, the finding of these correlations only in 2nd grade children suggests that the extraction of roots and morphemic patterns contributes to word identification more in these young unskilled readers compared to the older children. It is consistent with the idea that morphological segmentation in 5th graders is automatic and less demanding, and hence identification of bi-morphemic words depends less on the explicit morpho-syntactic awareness.

Our results are consistent with previous studies in Italian, using the oral naming paradigm, that showed stronger morphological effects in young or poor readers compared to adult skilled readers (Burani et al., 2008; Marcolini et al., 2011). In a similar vein, the morphemic status of French words facilitated spelling in poor but not in skilled readers (Quemart and Casalis, 2017). In Chinese, a morpho-syllabic language, morphological awareness is associated with good reading skills already in kindergarten and 2nd grade children (McBride-Chang et al., 2003). These findings show that when the morphological structure is salient and prevalent in the language, it can compensate for low phonological and decoding skills in young and poor readers.

These findings appear to contradict the claim for a developmental *increase* in the reliance on morphological segmentation skills during the elementary school years (Carlisle, 1988; Tyler and Nagy, 1989; Kieffer and Lesaux, 2012; Nagy et al., 2014; Sparks and Deacon, 2015). Some of the studies showing a developmental increase in reliance on morphological awareness explain it by an increase in the proportion of derivationally complex words children encounter as they mature and become more fluent in reading languages such as Dutch (Rispens et al., 2008) and English (Adams, 1990; Anglin, 1993; Singson et al., 2000). In contrast to this claim, derivationaly complex words are ubiquitous in the Hebrew language, and are thus very common and easily decomposed in the spoken language even in young children (Berman, 1982; Ravid and Malenky, 2001). Moreover, the morphological structure of words in the Hebrew orthography is relatively transparent because the root consonants appear as a continuous string, only interrupted occasionally by a narrow vowel letter (Ravid and Malenky, 2001; Vaknin-Nusbaum et al., 2015). These properties of the Hebrew language may explain the early development of sensitivity to the root in reading Hebrew derived words.

Indeed, our results are consistent with previous studies in Hebrew, showing that 2nd grade children already show explicit awareness of roots and patterns in *written* words (Ravid and Schiff, 2006), and this awareness is correlated with their word recognition skills (Vaknin-Nusbaum et al., 2015). Even in 1st grade Hebrew speaking children show significant contribution of morphological awareness to word reading (Schechter and Katzir, unpublished). When reading unfamiliar pseudo-words 2nd grade children rely on their morphemic structure for correct pronunciation (Shany et al., 2012). Altogether our results are consistent with the claims of the Triplex model for reading Hebrew (Share and Bar-On, 2017), suggesting that by the end of 2nd grade Hebrew speaking children rely less on low-level sub-lexical phonology, and more on higher-order lexical and morpho-orthographic knowledge. Moreover, studies in Hebrew speaking children that showed a continued increase in morphological segmentation from grade 2 to higher school grades used unfamiliar words and pseudowords, rather than real words (Bar-On and Ravid, 2011), or examined the role of morpho-syntactic information when reading sentences (Share and Bar-On, 2017). The current study shows that when reading real familiar single words performance of 5th grade children is less dependent on their morphological segmentation skills compared to 2nd grade Hebrew speaking children.

Limitations

Our study focused on reading of single words in order to control for word characteristics while testing the interaction with orthographic transparency. Nevertheless, the use of sentences which require more reliance on morpho-syntactic cues may show a continued developmental increase in the reliance on morphological segmentation in 5th grade children, and could even reverse the effect of orthographic transparency. Moreover, our study used nouns in order to manipulate the number of morphemes in the word, because the Hebrew nominal system includes both bi-morphemic (derivational) and mono-morphemic words, whereas verbs are all bi-morphemic, and their morphology is more systematic. This raises the possibility that decomposition of verbs may be more beneficial for reading across all groups and conditions.

Finally, our analyses showed no correlations between reading in the experimental task and phonological awareness, as measured by the phoneme-omission task in the Alef-Taf battery (Shany et al., 2006), in any of the groups. This stands in contrast to the ubiquitous evidence for the role of phonological awareness in reading in both Hebrew and other languages (Goswami, 1991; Bentin and Leshem, 1993; Ziegler et al., 2010). One possibility is the high level of performance on the phoneme omission test of even 2nd grade children in our sample. The average no. of errors in our sample was around 1 standard deviation lower than the average in the norms, in both groups (see **Table 2**).

CONCLUSION

The current study shows that children as young as 2nd grade engage in morphological segmentation of Hebrew words composed of a root and a morphemic pattern. This process is effortful and time consuming for 2nd graders and automatic for 5th grade children. Yet, for all children this morphological structure facilitates word identification when the script is transparent. When the script is not transparent, and the vowels that constitute the morphemic pattern are not fully represented, the presence of a root impedes word recognition presumably due to competition from morphologically related words that have the same root and a different morphemic pattern. These results stand in contrast to the idea that morphological segmentation of derived words is applied to compensate for the under-specification of vowels in a non-transparent orthography (Frost, 2006; Bar-On and Ravid, 2011; Vaknin-Nusbaum and Miller, 2011). The current study, which was the first to test this idea empirically in a within-subject experiment, showed an opposite effect of orthographic transparency on morphological segmentation, with greater benefit from morphological segmentation in the transparent orthography. These results are consistent with previous studies showing reliance on morphological segmentation even in transparent orthographies such as Italian and French (Burani et al., 2008; Casalis et al., 2015). Together these findings show that morphological segmentation and decoding of single letters do not constitute alternative-competitive pathways to word recognition. They are consistent with the Grain-Size Hypothesis, suggesting that orthographic units of multiple sizes are mapped simultaneously to their phonological and meaning representations, and together they converge during word identification (Ziegler and Goswami, 2005).

Our results further show that 2nd grade Hebrew speaking children engage in morphological segmentation of derived words and this affects their reading more than for 5th grade children. We suggest that this early peak in the reliance on morphological segmentation is related to the structure of the Hebrew language and orthography that facilitates such decomposition.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of the Ethics committee of the University of Haifa, and the Ethics committee of the Ministry of Education in Israel, with written informed consent from all subjects. All subjects gave written informed consent in accordance with the Declaration of Helsinki.

AUTHOR CONTRIBUTIONS

LH was involved in running the experiment, analyzing data and writing the manuscript. YW was involved in designing the experiment, developing the stimuli, overseeing participant recruitment and administration of the study and writing the manuscript. TK was involved in designing the experiment and writing the manuscript. TB was involved in designing the experiment, developing the stimuli, supervision of LH and YW, analyzing the data and writing the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2017.02369/full#supplementary-material

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Morpheme-Based Reading and Writing in Spanish Children with Dyslexia

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It has been well documented that morphemic structure (roots and affixes) have an impact in reading, but effects seem to depend on the reading experience of readers and lexical characteristics of the stimuli. Specifically, it has been reported that morphemes constitute reading units for developing readers and children with dyslexia when they encounter a new word. In addition, recent studies have stated that the effect of morphology is also present in spelling, as morphological information facilitates spelling accuracy and influences handwriting times. The goal of this study was to investigate the role of morphology in reading and spelling fluency in Spanish children with dyslexia. For that purpose, a group of 24 children with dyslexia was compared with an age-matched group of 24 children without reading disabilities in performing a word naming task and a spelling-to-dictation task of isolated words. Morphological condition (high frequency base, low frequency base, simple) and lexicality (words vs. pseudowords) were manipulated. We considered, for the naming task, reading latencies, reading durations, reading critical segment (three first phonemes) durations and naming accuracy; and, for the spelling task, written latencies, writing durations for the whole word, writing critical segment (three first letters) durations and spelling accuracy. Results showed that Spanish children (with and without dyslexia) benefit from a high frequency base to initiate reading and writing responses, showing that they are familiar with the letter chunks that constitute a morpheme. In addition, base frequency impacts reading critical segment duration only for children with dyslexia, but for both groups in writing. In summary, children with dyslexia benefit from a high frequency base to read and spell unfamiliar stimuli.

Keywords: morphology, reading, spelling, dyslexia, Spanish

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INTRODUCTION

Developmental dyslexia is characterized by specific and pronounced difficulties in learning to read and spell which are unexpected considering the fact that the child's cognitive abilities and educational opportunities are within the normal range in relation to their peers (Lyon et al., 2003). Children with dyslexia are prone to make reading and spelling mistakes and show reading speed deficits (Ziegler et al., 2003); however, these characteristics appear to be determined by the orthographic depth. In transparent orthographies (e.g., Spanish or Italian), in contrast to the opaque ones, the more prominent problem in dyslexia is reading speed rather than reading accuracy (Wimmer, 1993; Suárez-Coalla and Cuetos, 2012). Considerable accuracy in transparent orthographies is explained by consequence of the spelling-sound consistency (Seymour et al., 2003), while slow reading speed is considered a consequence of problems in automating the alphabetic code and in achieving the orthographic representations of words (Manis, 1985; Bergmann and Wimmer, 2008; Suárez-Coalla et al., 2014). As a result, Spanish children with dyslexia have special difficulties with long low frequency words and long pseudowords (Davies et al., 2007, 2013; Suárez-Coalla and Cuetos, 2012), indicating that these children rely on small grain-size units of the words (Davies et al., 2013; Suárez-Coalla et al., 2014). In addition, spelling difficulties have been reported in Spanish children with dyslexia, as they present more mistakes than typically developing children when spelling (Suárez-Coalla et al., 2016). Moreover, like in other consistent orthographies (e.g., in Italian: Angelelli et al., 2004, 2010), children with dyslexia show a specific pattern of errors, as they make a high number of phonologically plausible errors in words with unpredictable spelling, indicating the reliance on a sublexical strategy (Suárez-Coalla et al., 2016).

On the other hand, morphemes constitute an intermediate unit, between the letter and the word, with impact on reading and spelling (Burani et al., 2002; Kandel et al., 2008; Lázaro et al., 2013; Quémart and Casalis, 2016). It is well established that morphology in opaque orthographic systems is very useful for assigning the correct pronunciation and spelling of words (Carlisle and Stone, 2005), but some effects of morphology have also been reported in transparent orthographies, indicating that morphemes are useful intermediate units in every kind of orthographic system (Burani et al., 2002). Nevertheless, morphological effects appear to be determined by task, stimulus characteristics (lexical frequency, length, morpheme type) and literacy experience. Specifically, people with dyslexia are able to recognize and rely on the morphemic structure. Although there are not many studies about this topic in Spanish (and other shallow orthographies), some results support the hypothesis that morphemic units (larger than the grapheme and smaller than the word) could assist reading and spelling processes in this population.

Burani et al. (2002) showed that Italian children (8–10 years old), with and without dyslexia, benefit from morphological structure to read pseudowords (made up of roots: DONN- 'woman' and derivational suffixes: -ISTA, 'ist'), as they were named faster and more accurately than matched pseudowords with no morphological structure (e.g., DENNOSTO); the same benefit happens with adults. When the stimuli were words (e.g., derived: CASSIERE, 'cashier' vs. simple: CAMMELLO, 'camel'), only children with dyslexia and young readers benefited from morphology, so morphological structure did not impact word naming of skilled readers (Burani et al., 2008). On the other hand, it has been confirmed that the impact of morphological structure in word naming is modulated by word frequency and reading skills, as young skilled readers only took advantage of morphology when reading low frequency words, while poor readers benefited in both high and low frequency words, and adults did not benefit in any case (Marcolini et al., 2011). These results suggest that morpheme-based reading in transparent orthographies appears in the absence of well specified orthographic representation (for poor readers, or in low frequency words and pseudowords), which implies that after a complex word has been frequently processed, the orthographic representation for the whole word will have a more important role than its component morphemes.

Additionally, the frequency of morphemes was also found to modulate the use of morphology in Italian children with dyslexia-dysorthography and typically developing children. In a study by Angelelli et al. (2017), third grade children had to read three sets of words (1: derived with high frequency morphemes, 2: derived with low frequency morphemes, 3: non-derived) and two sets of pseudowords (1: combining root + suffix, 2: non-derived). They found that morphology facilitated pseudoword reading accuracy in both groups; in addition, both groups took advantage of high frequency morphemes when reading low frequency words, but, surprisingly, children with dyslexia showed worse results in words with low frequency morphemes than in simple ones.

Regarding the Spanish language, a transparent orthography, only two studies have to our knowledge addressed the role of morphology in reading of children with dyslexia (Lázaro et al., 2013; Suárez-Coalla and Cuetos, 2013). Lázaro et al. (2013) explored the effect of base frequency (i.e., frequency of the target word stem) in a lexical decision task on the supposition that children are able to process morphemic structure, so complex words with a high frequency base could elicit faster responses than low frequency base words. They found that only older skilled children in the study (8 years, age-matched to children with reading problems) showed the facilitation effect of base frequency. In contrast, children with dyslexia did not take advantage of morphology in reaction times. However, Suárez-Coalla and Cuetos (2013) found that children with dyslexia benefited from morphology, since they named complex stimuli (e.g., word: BELL-EZA, 'beaut-y'; pseudoword: PLAT-EZA) better than simple ones (e.g., word: PEREZA, 'laziness'; pseudoword: ASTOZA). These latter results agree with the hypothesis that morphological processing constitutes a compensatory strategy for people with reading difficulties by recognizing units larger than the grapheme. As mentioned before, children with dyslexia show difficulties in developing orthographic representation at the whole word level. Therefore the development of morphological representations (units of multiple grain size) would allow smooth and precise reading, especially with unknown words. In this sense, the morphological processing would be a complementary strategy to grapheme–phoneme conversion and lexical reading. This kind of strategy fits with the recent conceptualization of dual-route models (Grainger and Ziegler, 2011), where lexical route is supposed to include indirect access via letter co-occurrences (e.g., morphemes). In the latter work, words were matched in superficial frequency, but base frequency was not considered, a variable that seems to impact on the visual recognition of words, as suggested by Lázaro et al. (2013). In consequence, it will be possible to find effects of root frequency in word naming.

As in reading, a considerable number of researches in opaque orthographies (French and English) reported benefits of morphology in spelling with accuracy in typically developing children (Treiman et al., 1994; Sénéchal, 2000; Deacon and Bryant, 2006; Kemp, 2006; Pacton and Deacon, 2008; Bourassa and Treiman, 2009; Casalis et al., 2011; Pacton et al., 2013; Quémart and Casalis, 2016) and children with dyslexia (Bourassa et al., 2006; Quémart and Casalis, 2016). Morphological constancy (spelling maintenance of root in family words) helps in spelling words properly despite the phonological changes that may occur (e.g., in English: HEALTH: /hɛlθ/ vs. HEAL: /hiːl/), even from an early age. In more transparent orthographies, morphological effects have also been reported for children with no difficulties (Finnish: Lehtonen and Bryant, 2005; Spanish: Défior et al., 2008; Italian: Angelelli et al., 2014) and with dyslexia (Diamanti et al., 2014; Angelelli et al., 2017). Besides, as for reading, effects look to be modulated by the frequency of the morphological constituents. Benefits were found in low frequency words with high frequency morphemes, while words with low frequency morphemes achieved a similar performance to non-derived words (Angelelli et al., 2017). According to those results, children with dyslexia use some morphological information when spelling, evident in accuracy, by retrieving pre-assembled units.

Recently, new techniques (mainly digitizer tablets) are being used to investigate writing processes, allowing the collection of chronometric measures and providing interesting results about the role of morphology in spelling. In this vein, some data support that morpheme-sized units play a role in handwriting production (Orliaguet and Boë, 1993; Kandel et al., 2008; Kandel et al., 2012). Kandel et al. (2012) observed that movement duration of the root was longer for suffixed words than for pseudo-suffixed words, suggesting that suffix programming is not fully completed when the motor response starts, implying extra time during root production. According to this, a new psycholinguistic model of handwriting was proposed by Kandel et al. (2011), where the orthographic representation of a word could imply a multidimensional structure. This model considers a spelling module (after a linguistic module and before a motor module), where different kinds of abstracts processing levels (words, morphemes, syllables, concurrent letters and letters) exist and could be active in parallel. In this sense, handwriting production would involve the activation of intermediate units (morphemes) between syllables and words (Kandel et al., 2012). The mentioned methodology offers one opportunity to improve knowledge about the role of morphology in children with dyslexia.

Taking into consideration the reviewed literature about morphological effects, we have arguments to hypothesize that morphological structure could play a significant role in reading and writing in transparent orthographic systems, with recognizable effects in accuracy and speed. It could be supposed that morpheme-based reading and spelling will appear for Spanish children with dyslexia, as it has been suggested that the role of morphology is more evident in the absence of orthographic representation. Specifically, we assume greater accuracy and fluency in reading and spelling morphologically complex stimuli than simple ones. However, the facilitation effect could, at the same time, be determined by variables such as lexicality, lexical frequency and base frequency (root frequency), apart from the type of morpheme or the length of the word.

In this framework, the present study addressed the role of morphology in both reading and spelling in Spanish children with dyslexia. We aimed to know if children with dyslexia take advantage of morphology, and whether or not facilitation depends on the root frequency. The facilitation effect of morphology in children with dyslexia would indicate that they are able to use intermediate units when they do not have robust orthographic representation of a word, constituting a compensatory strategy. Children with and without dyslexia completed a word naming task and a spelling-to-dictation task of isolated words and pseudowords, where morphological condition (high frequency base, low frequency base, and simple) was manipulated. The inclusion of pseudowords, made from a real root, constitutes a guarantee that participants do not have orthographic representations of the whole stimuli, and use of morphological processing could be evident. The analysis considered, for the naming task, naming accuracy, reading latencies (RL), reading durations (RD) and reading critical segment durations (RCSD; the first three phonemes, which correspond to the root in morphologically complex words); and for the spelling-to-dictation task, spelling accuracy, written latencies (WL), writing durations (WD) for the whole word and writing critical segment durations (WCSD; the first three letters, corresponding to the root in complex words). We expected that morphological knowledge, particularly base frequency, would have an impact on reading and spelling times, especially in children with dyslexia when they face pseudowords.

MATERIALS AND METHODS

Participants

Twenty-four children with developmental dyslexia (ages 7–12: $M = 9.9$, $SD = 1.5$) and 24 controls (ages 7–12: $M = 9.9$, $SD = 1.45$) participated in this study. Children were recruited from several primary schools in Asturias (Spain) and were matched by age and gender (12 females and 12 males per group). All the participants were native Spanish speakers and had no known motor or perceptual disorders. Participants with dyslexia (DYS) had an IQ of 85 or higher ($M = 103$, $SD = 12$) according to the Wechsler Intelligence Scale for Children (WISC, Wechsler, 2001) and showed persistent reading problems. (It should be noted that, in Spain, children start reading instruction at 4 years old and at around 6 years every child presents a high level of reading accuracy.) Children with dyslexia were given an extended number of tests (e.g., reading process, writing process, phonological awareness, working memory, etc.) and WISC was used to confirm that reading problems were not due to general cognitive problems. Their profile satisfied the criteria of the International Association of Dyslexia (cited in Shaywitz, 2003): (a) reading skills are highly deviant in relation to the control matched by age ($SD = 1.5$–2); (b) persistent reading problem, despite instruction and training; and (c) reading problem more severe than expected based on intellectual capacity and socio-economic status. Control children did not show any type of learning disability according to the assessment of the school psychologist. The reading level of participants was taken from

TABLE 1 | Means and standard deviations (in parenthesis) for reading scores of children with dyslexia and controls.

	Control group mean (*SD*)	Dyslexia group mean (*SD*)	*p*-values
Age (years)	9.9 (1.55)	9.9 (1.58)	$p = 0.78$
Reading words			
Accuracy	39.60 (0.70)	37.21 (9.71)	$p = 0.24$
Speed (s)	33.60 (14.38)	74.83 (34.78)	$p < 0.001$
Pseudowords			
Accuracy	38.9 (1.22)	30.90 (5.40)	$p < 0.001$
Speed (s)	51.46 (34.78)	91.13 (24.75)	$p < 0.001$

the test battery PROLEC-R (Cuetos et al., 2007) in order to confirm the reading problems of children with dyslexia. PROLEC-R gives scores for word and pseudoword reading. The word reading subtest includes 40 Spanish words (high frequency [HF], and low frequency [LF], short and long words). The pseudoword reading section consists of 40 stimuli (short and long). Children included in the group with dyslexia showed accuracy and/or reading speed scores two standard deviations (SD) below the age mean according to norms provided by PROLEC-R. Children in the control group (CON) had a reading level in line with their age in both measures. Means, standard deviations and *p*-values for demographic characteristics and scores obtained in reading assessment tests are provided in **Table 1**.

Materials

Thirty-six stimuli were selected, comprising 18 words and 18 pseudowords. All stimuli had six letters and three syllables, where morphological condition (morphologically complex with HF base, morphologically complex with LF base and simple words) and lexicality were manipulated in order to create six experimental sets with six stimuli in each set. The words (three sets) were matched by superficial lexical frequency according to the LEXESP database (Sebastián-Gallés et al., 2000). Words in the first set (e.g., PELUDO, 'hairy') consisted of an HF root (PEL-), and a derivational suffix, (-UDO); words in the second set (e.g., TEJADO, 'roof'), consisted an LF root (TEJ-), and a derivational suffix, (-ADO); words in the third set were simple LF words (e.g., PAGANA, 'pagan'). The first set of pseudo-morphemic words (e.g., PELERA) were made from a real HF root (e.g., PEL-) and a real suffix (e.g., -ERA); the second set of pseudowords were made from a real LF root (e.g., TEJ-) and a real suffix (e.g., -UDO); and the simple pseudowords were created from real LF words by changing one or two letters (e.g., PEMURA). In addition, 16 fillers were included. All sets of stimuli were matched by initial letter and phoneme, length in letters and syllables, root length in letters (for morphologically complex stimuli), syllable frequency, *N*-size, and imageability (all $p > 0.05$). For *N*-size and imageability variables, the BuscaPalabras database (Davis and Perea, 2005) was used; the dictionary of Alameda and Cuetos (1995) was used for syllable frequency. The values for manipulated and controlled variables are shown in **Table 2** and the experimental stimuli are given in Appendix A.

Procedure

All the participants performed two tasks: a word naming (reading task) and spelling-to-dictation (writing task). We first conducted the word naming task, and 15 days later the spelling-to-dictation was carried out. The procedure of this experiment was approved by the Ethics Committee of the Department of Psychology of the University of Oviedo. Parental written consent was collected for all participants.

Reading Task

Stimuli were written in 22-point Arial font. Firstly, there appeared a blank screen for 500 ms; then, a black asterisk was presented in the center of a gray field screen for 500 ms; the stimulus appeared 500 ms after the asterisk and remained on the screen for 4,000 ms. Experimental stimuli and fillers were presented in two blocks of 26 stimuli each and appeared randomly in each block. The two blocks were separated by a pause, and preceded by four practice trials in order for the child to become familiar with the task. Children were 30 cm from the screen, and at the beginning of the test, it was explained that they had to read. We gave them the following instructions: 'Words and pseudowords will appear on the computer screen. You will have to read them aloud as quickly as possible without making any mistakes.' Participants completed the task during individual sessions that lasted approximately 15 min. The responses were recorded in .WAV files using DMDX (Forster and Forster, 2003). The recordings were subsequently analyzed using Praat software (Boersma and Weenink, 2017) through which we obtained accuracy, RL, RD, and RCSD from the resulting spectrograms.

Spelling-to-Dictation Task

Stimuli presentation and digital recording of the writing responses were controlled by Ductus (Guinet and Kandel, 2010). The experiment was run on an HP Mini laptop. A WACOM Intuos 5 graphic tablet connected to the computer and an Intuos Inking Pen were used to register the participants' responses. Auditory stimuli for presentation were recorded by a female speaker with a Plantronics microphone and edited with Audacity software.

In the spelling-to-dictation task, each trial started with the simultaneous presentation of an auditory signal and a 500-ms fixation point. The auditory stimulus was presented 500 ms after the offset of the fixation point. Participants had to write the stimulus in lower case as quickly and as accurately as possible on a lined sheet of paper placed over the digitizer. When they finished a response, participants were instructed to hold the pen over the next line of the response sheet, but to avoid any contact with the paper. Then the experimenter clicked the left button of the mouse to start a new stimulus. The stimuli were presented in a quasi-randomized order; four lists, including the total number of stimuli, were created after randomizing the stimuli. Twelve participants (six with dyslexia and six controls) performed the same list. The experimental sessions were conducted for each participant individually in a quiet room and lasted around 15 min. Accuracy, WL, WD, and WCSD were considered for the statistical analysis.

TABLE 2 | Psycholinguistic characteristics of stimuli.

	Morph Cond	Lex Freq	Base Freq	Let Leng	Syll Leng	*N*-size	1st Syll Freq	2nd Syll Freq	3th Syll Freq	Imag
Words	HF base	2.7	186**	6	3	2.6	3,325	1,723	7,817	0.84
	LF base	4.00	3.84**	6	3	2.6	2,998	2,312	12,520	1.04
	S	3.16	NA	6	3	1	5,389	2,334	6,013	0.21
Pseudowords	HF base	NA	131**	6	3	2.3	3,793	2,628	10,324	NA
	LF base	NA	5.00**	6	3	1	5,086	3,498	10,512	NA
	S	NA	NA	6	3	1	4,486	1,885	8,133	NA

*Morph Cond, morphological condition; Lex Freq, lexical frequency; Let Leng, letter length; Syll Leng, syllable length; N-size, neighborhood size; Syll Freq, syllable frequency; Imag, imaginability, HF, High frequency, LF, low frequency, S, simple. NA, not applicable. **Significant difference between HF base and LF base.*

TABLE 3 | Reading measures (accuracy, reading latencies, reading durations, and critical segment durations) by condition and group.

		Control group				Dyslexia group			
		Accuracy % (*SD*)	RL ms (*SD*)	RD ms (*SD*)	CSD ms (*SD*)	Accuracy % (*SD*)	RL ms (*SD*)	RD ms (*SD*)	CSD ms (*SD*)
Words	HF base	97.92 (0.30)	753 (215)	598 (141)	244 (59)	81.25 (0.90)	1,263 (413)	811 (242)	341 (130)
	LF base	97.22 (0.40)	789 (247)	593 (143)	303 (51)	75.69 (1.41)	1,331 (459)	770 (235)	476 (122)
	Simple	94.44 (0.50)	856 (297)	604 (153)	285 (55)	70.83 (1.43)	1,315 (438)	794 (253)	434 (147)
Pseudowords	HF base	95.13 (0.45)	844 (269)	608 (171)	287 (69)	67.36 (1.30)	1,299 (441)	763 (226)	406 (88)
	LF base	95.83 (0.52)	861 (313)	635 (176)	304 (78)	68.05 (1.60)	1,351 (421)	831 (246)	444 (134)
	Simple	93.75 (0.50)	902 (284)	615 (150)	314 (80)	66.66 (1.51)	1,356 (429)	902 (311)	528 (156)

TABLE 4 | Writing measures (accuracy, writing latencies, writing durations, and critical segment durations) by condition and group.

		Control group				Dyslexia group			
		Accuracy % (*SD*)	WL ms (*SD*)	WD ms (*SD*)	CSD ms (*SD*)	Accuracy % (*SD*)	WL ms (*SD*)	WD ms (*SD*)	CSD ms (*SD*)
Words	HF base	98.60 (0.10)	1,036 (236)	2,418 (544)	1,150 (293)	92.36 (0.50)	1,280 (402)	2,967 (960)	1,324 (401)
	LF base	95.13 (0.30)	1,040 (233)	2,349 (538)	1,171 (314)	80.55 (1.20)	1,306 (306)	3,023 (1139)	1,367 (420)
	Simple	93.05 (0.22)	1,063 (252)	2,387 (517)	1,269 (445)	87.50 (0.75)	1,357 (358)	3,135 (1175)	1,568 (602)
Pseudowords	HF base	89.58 (0.63)	1,034 (234)	2,258 (505)	1,149 (350)	89.58 (0.60)	1,287 (324)	2,831 (903)	1,326 (394)
	LF base	88.88 (0.67)	1,044 (261)	2,450 (548)	1,178 (297)	79.86 (1.21)	1,316 (287)	3,109 (1164)	1,399 (420)
	Simple	90.27 (0.60)	1,064 (254)	2,397 (508)	1,293 (299)	86.80 (0.79)	1,372 (388)	3,004 (1093)	1,583 (594)

RESULTS

For analyses of latencies and durations, we only included data from correct responses; mistakes (self-corrections, substitutions, regressions, omissions, false responses) and outliers were excluded from analyses. Data were analyzed by using generalized linear mixed-effects modeling with the lme4 package in R (R Core Team, 2012). Mixed-effects models allowed us to estimate both fixed effects—i.e., replicable effects of theoretical interest (group, lexicality, morphological condition)—and random effects—i.e., unexplained effects because of random variation between items or participants (Baayen et al., 2008). We incrementally added the predictor variables (group, lexicality, morphological condition) and interactions to the model to see whether or not the model was improved. Model fit was assessed using chi-squared tests on the log-likelihood values to compare different models. The most complex adjustment but the smallest BIC (Schwarz, 1978) and significant chi-squared test for the log-likelihood were retained. *F*-values from the ANOVAs of type III with Satterthwaite approximation for degrees of freedom are reported for fixed effects. When interactions were significant, *t*-tests were performed and the *p*-values were adjusted via the Bonferroni method.

For the analysis of accuracy, mixed effects logistic regression (used to model binary outcome variables) was performed using the lme4 package in R (R Core Team, 2012).

Table 3 shows data for the reading task (percentage of accuracy, means and standard deviations of reading durations) in each condition for both groups, whilst **Table 4** shows data for the writing task. Following the analyses, the significant results are reported below.

Reading

Excluding practice trials and fillers, a total of 1,728 responses were collected (864 from each group), where 265 (15.33%) of responses were discarded because they were mistakes or non-responses. Children with dyslexia gave rise to 230 discarded responses of 864 collected (26.62%); children without dyslexia executed only 35 (4.05%) discarded responses.

Accuracy in Reading

The mixed effects logistic regression analysis showed group effect ($p = 0.000$; Estimate = 2.359, $SE = 0.323$; $OR = 0.094$, $CI = 0.050–0.180$) and lexicality effect ($p = 0.006$, Estimate = 0.503, $SE = 0.185$; $OR = 0.604$, $CI = 0.420–0.870$), as the number of mistakes was bigger for the DYS group than for the CON group, and for pseudowords than for words. The morphological condition effect was close to significance between HF base stimuli and simple ones ($p = 0.099$; Estimate = 0.370, $SE = 0.224$; $OR = 0.690$, CI = 0.444–1.072), as there was a higher probability of committing mistakes in simple than in HF stimuli. The participants' intercepts vary with an *SD* of 0.846 (participants effect, $p = 0.200$), the items' intercepts with an *SD* of 0.322 (items effect, $p = 0.000$).

Reading Latencies

Reading latency is considered as the time from when the stimulus appears on the screen to when the participant begins to read—i.e., the time a participant takes to initiate the response (see **Table 3**).

We found a statistically significant effect of group [$F(1,45) = 50.26$, $p = 0.000$], as the CON group initiated responses significantly faster than the DYS group (Estimate = 495, $SE = 69$); of lexicality effect [$F(1,32) = 5.38$, $p = 0.026$], as reading latencies were bigger for pseudowords than for words (Estimate = 50, $SE = 21$); and of morphological condition [$F(2,32) = 3.82$, $p = 0.032$]. Pairwise comparisons showed significant differences between HF base and simple words [$t(32) = -2.76$, $p = 0.028$], as RL were higher for simple stimuli than for HF base ones (Estimate = 73, $SE = 26$). The participants' intercepts vary with an *SD* of 236.62 (participants effect, $p = 0.000$); items' intercepts have an *SD* of 47.35 (items effect, $p = 0.000$); the *SD* of error not accounted for was 275.23.

Reading Duration

Reading duration is the time a participant needs to read a word, the articulation time (see **Table 3**). When RD was considered, we found a group effect [$F(1,45) = 19.24$, $p = 0.000$], as the CON group took less time to articulate a response than the DYS group (Estimate = 211, $SE = 48$); lexicality effect [$F(1,30) = 5.85$, $p = 0.021$], where pseudowords took more time than words (Estimate = 34, $SE = 14$); group by morphological condition [$F(2,1359) = 4.11$, $p = 0.016$]; and group by lexicality by morphological condition [$F(2,1358) = 6.857$, $p = 0.001$]. Pairwise comparison indicated a significant difference between HF base pseudowords and simple pseudowords for the DYS group [$t(54) = -3.96$, $p = 0.014$], as they took more time reading simple pseudowords than HF base ones (Estimate = 111, $SE = 28$). The participants' intercepts vary with an *SD* of 165.50 (participants effect, $p = 0.000$); items' intercepts have an *SD* of 36.61 (items effect, $p = 0.000$); the *SD* of error not accounted for was 128.07.

Reading Critical Segment Duration

Critical segment duration in reading was considered as the time needed to read a segment—in this case, the pronunciation of the first three phonemes of the stimuli, which correspond with the root in the morphological complex words (see **Table 3**). The results indicated a significant effect of group [$F(1,45) = 25.42$, $p = 0.000$], where children with dyslexia took more time than controls (Estimate = 111, $ES = 22$); of lexicality [$F(1,30) = 6.40$, $p = 0.019$], where pseudowords took more time than words (Estimate = 24, $ES = 10$); and of group by lexicality by morphological condition interaction [$F(2,1343) = 4.19$, $p = 0.015$]. In addition, group by morphological condition was close to significance [$F(2,1343) = 2.52$, $p = 0.081$]. As in the previous analysis, pairwise comparison indicated a significant difference between HF base pseudowords and simple pseudowords for the DYS group [$t(49) = -3.69$, $p = 0.037$], as they took more time to read simple pseudowords than HF base ones (Estimate = 72, $ES = 19$). The participants' intercepts vary with an *SD* of 77.99 (participants effect, $p = 0.000$); items' intercepts have an *SD* of 27.14 (items effect, $p = 0.000$); the *SD* of error not accounted for was 79.97 (see **Figure 1**).

Spelling

Of 1,728 responses, we found 1,543 correct spellings and a total of 185 mistakes (10.70%), where the DYS group made 120 mistakes in 864 responses (13.89%) and the CON group made 65 (7.52%). Percentage and mean distribution of correct responses for participants in every morphological condition and group appear in **Table 4**.

Spelling Accuracy

After the mixed effects logistic regression analysis, we found a group effect ($p = 0.011$; Estimate = 0.722, $SE = 0.286$; $OR = 0.485$, $CI = 0.276–0.851$) and morphological condition, with significant differences between HF and LF stimuli ($p = 0.012$; Estimate = 0.782, $SE = 0.31$; $OR = 0.457$, $CI = 0.31$). The participants' intercepts vary with an *SD* of 0.779 (participants effect, $p = 0.000$); the items' intercepts have an *SD* of 0.558 (items effect, $p = 0.000$).

Written Latencies

Written latency is defined as the time between the onset of the stimulus and the occurrence of the first contact of the pen with the digitizing tablet (see **Table 4**).

Analyses showed a group effect [$F(1,45) = 27.64$, $p = 0.000$], as WL were higher for children with dyslexia than for children without dyslexia (Estimate = 269, $SE = 51$) and the morphological condition was close to significance [$F(2,33) = 3.02$, $p = 0.06$]. Pairwise comparisons showed that the differences tended to be significant between HF base and simple stimulus [$t(33) = 2.39$, $p = 0.06$; Estimate = 45, $SE = 19$]. The participants' intercepts vary with an *SD* of 171.65 (participants effect, $p = 0.000$); the items' intercepts have an *SD*

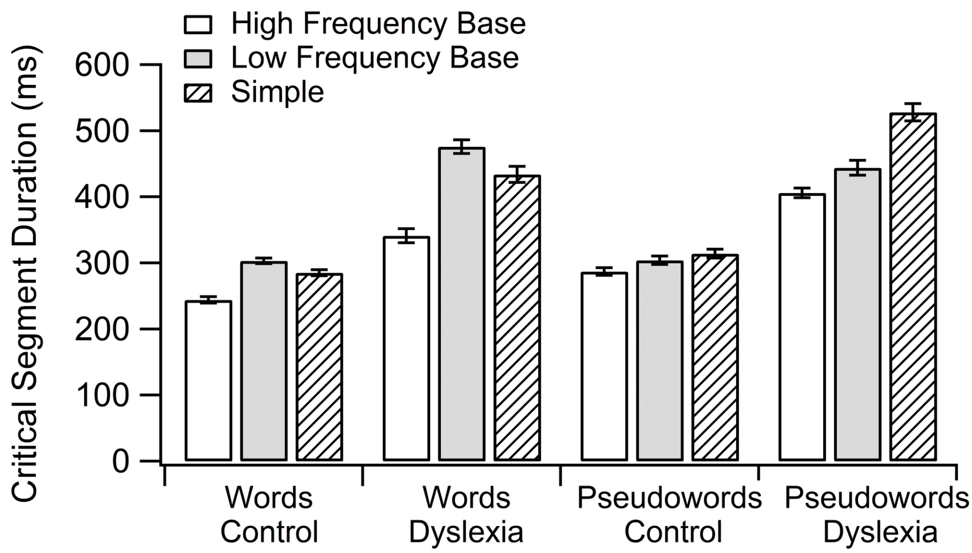

FIGURE 1 | Group by lexicality by morphological condition interaction in reading critical segment duration.

of 25.57 (items effect, $p = 0.09$); the *SD* of error not accounted for was 252.29.

Writing Duration

Writing duration is the time between the first pen contact in producing a word and the last pen lift in the same word (see **Table 4**). After the analysis, we only found a group effect [$F(1,45) = 12.40$, $p = 0.000$], as children with dyslexia spent more time writing one stimulus than children without dyslexia (Estimate = 700, *SE* = 198). The participants' intercepts vary with an *SD* of 682.00 (participants effect, $p = 0.000$); the items' intercepts have an *SD* of 232.80 (items effect, $p = 0.000$); the *SD* of error not accounted for was 504.40.

Writing Critical Segment Duration

In this study, writing critical segment duration refers to the time between the first contact of the pen with the digitizer in a given stimulus and the beginning of the fourth letter of that stimulus (see **Table 4**). The trajectory and tangential velocity were considered to isolate the critical segment using geometric (cuspids and curvature maxima) and kinematic (velocity minima) criteria, as proposed by Kandel and Valdois (2006). We found an effect of group [$F(1,45) = 9.07$, $p = 0.004$; Estimate = 275.64, *SE* = 91.49], as the DYS group took more time than the CON group; of morphological condition [$F(2,32) = 5.75$, $p = 0.007$], with significant differences between HF base and simple stimuli [$t(32) = -3.29$, $p = 0.007$; Estimate = 199.72, *SE* = 60.55]; and LF base and simple stimuli were close to significance [$t(33) = -2.34$, $p = 0.07$; Estimate = 141.86, *SE* = 60.65]. We also found group by morphological condition interaction [$F(2,1396) = 4.31$, $p = 0.013$]. Pairwise comparisons showed significant differences between HF base and simple words in the DYS group [$t(38) = -3.93$, $p = 0.005$; Estimate = 248.00, *SE* = 63.01]. The participants' intercepts vary with an *SD* of 313.00 (participants effect, $p = 0.000$); the items' intercepts have an *SD* of 142.70 (items effect, $p = 0.000$); the *SD* of error not accounted for was 260.50 (see **Figure 2**).

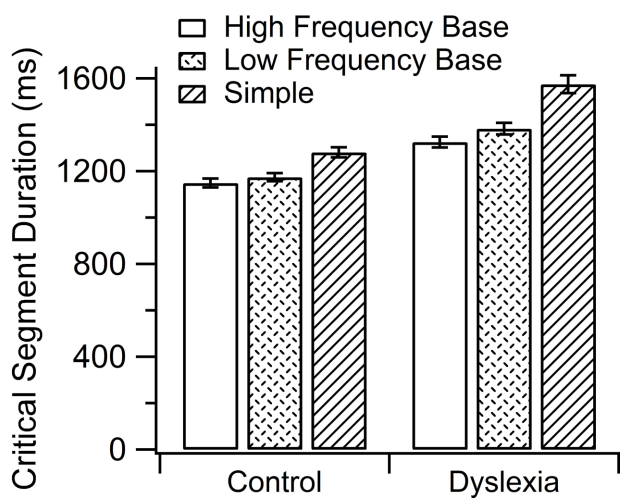

FIGURE 2 | Group by morphological condition interaction in writing critical segment duration.

DISCUSSION

In the present study, we addressed the role of morphology in both reading and spelling in Spanish children with dyslexia. We aimed to know if they access intermediate linguistic units (morphemes), improving their reading and spelling performance (accuracy and speed). In addition, we aimed to know whether facilitation could depend on the base (root) frequency or not. To achieve the objective, participants performed two tasks, word naming and spelling-to-dictation, where lexicality and morphological condition were manipulated. Different measures (accuracy and chronometric measures of the responses) were collected. In Spanish, the consistency of grapheme-to-phoneme mapping is sufficient to achieve the correct pronunciation when reading, and quite sufficient when spelling. Because the main interest was to test the effect of the base frequency of words, in this work we only used consistent phoneme–grapheme correspondences. In this sense, morphology probably would not be as necessary to achieve reading and spelling accuracy, but it would have an impact on spelling and reading speed.

In reading, results indicated that children with dyslexia took advantage of morphology, which is evident in the reading speed scores, as in Spanish reading accuracy is a measure less sensitive than reading speed. All the children initiated an earlier response (RL) when they faced HF base stimuli (words and pseudowords) than when they had to read a simple one. Both DYS and CON groups benefit from the HF base of stimulus to initiate the response of LF words and pseudowords. It is supposed that children, especially children with dyslexia, do not have robust orthographic representation of LF words and, of course, they have no representations of pseudowords, as they do not exist. But they showed longer RL for simple words than for HF base words, indicating that they were relying on shorter reading units (morphemes). We did not find benefits from the LF base of words in RL, so probably they do not have representations of small grain-size units with LF. Effects of morphology in RL in children with dyslexia were previously reported, but modulated by other variables, such as reading skills and lexical frequency (Burani et al., 2002, 2008; Marcolini et al., 2011; Suárez-Coalla and Cuetos, 2013). Regarding base frequency effects, it has been reported that HF base speeds up LF word reading in Italian adults (Colombo and Burani, 2002) and facilitates reading accuracy (pseudowords and LF words) in third grade children, both typically developing children and children with dyslexia (Angelelli et al., 2017). Otherwise, different results were described by Lázaro et al. (2013), where only eight year old skilled readers benefited from base frequency to respond in a lexical decision task. This makes sense, though, considering the nature of the tasks. In a lexical decision task, it is necessary to process both constituents (root and suffix) to make a decision, involving a time cost. In contrast, in a word naming task, RL is the time a participant takes to initiate the response, so children could rely on the initial lexical unit (root) to start pronunciation, without processing the whole stimulus. In this sense, when they are able to recognize the HF base root they start to pronounce the words, even if they do not have the orthographic representation of the whole word.

It should be noted that the most important results concerned RD and RCSD, which were not considered in previous studies about morphology. RD was modulated by readers and lexical-morphological condition, as differences were only found between HF base and simple pseudowords in the DYS group. The same pattern was found when RCSD was considered, as the DYS group spent less time on the articulation of the segment when it was an HF base one in a pseudo-morphemic word. These results suggest that children with dyslexia are able to use morphemic pre-assembled representations, with effects on articulation durations. According to this, morphological information is a useful mechanism to gain reading speed in this population. It probably cannot be said that the advantage is due to the semantic access to the morphological units, taking into account the task performed. However, according to grain-size theory, children could be relying on salient units of different size (Ziegler and Goswami, 2005). It is noteworthy that we did not find the morphological effect in RD in the CON group, nor in word reading in the DYS group, which could signify that children process the whole stimulus before they start to read.

As for spelling, children with dyslexia committed more mistakes and were slower than children without dyslexia. However, both the DYS and CON groups benefited from morphology, as accuracy was higher for HF base stimuli than for LF base ones and they tended to start to spell HF base stimuli faster than simple ones. That implies that morphological information (base frequency) supposes an advantage for them when they have to spell. This is consistent with recent studies, supporting the idea that morphological structure favors spelling accuracy in opaque (Bourassa et al., 2006; Quémart and Casalis, 2016) and transparent orthographies (Angelelli et al., 2017). In the present study, there were no phoneme-to-grapheme inconsistencies, but an advantage of morphology was found. More interestingly, when WCSD was considered, morphological effects were modulated by group, where the DYS group spent less time spelling an HF base critical segment than a simple one. These data seem to indicate that children with dyslexia have representation of chunks of letters (morphemes) that help them to improve speed of handwriting unfamiliar stimuli. Taking together the results of WL and WCSD, we can observe that the morphological effects in WL continue in WCSD, but only for spelling in children with dyslexia. This might suggest that the CON group do not rely on morphology after recovering the orthographic output. In addition, the influence of morphology on the DYS group handwriting reinforces the hypothesis, suggested by Sumner et al. (2014), that their slowness is due to linguistic factors rather than the existence of graphomotor speed problems. Evidence reported here can be easily integrated into the context of the role of morphology in handwriting, a process mediated by linguistic units and spelling ability, independent of the semantic level (Orliaguet and Boë, 1993; Kandel et al., 2008, 2012).

Recently, Quémart and Lambert (2017) explored the influence of morphological structure on French adults' and children's handwriting. They also compared morphologically complex and simple words, and adults exhibited shorter latencies for morphologically complex words than for simples ones. However, children did not show effects of morphological structure in writing latencies, suggesting that morphological effects are modulated by expertise in the written language. In contrast, our data support the effect of morphology in both typically developing children and children with dyslexia, but the differences only tended to be significant between HF base and simple stimulus. The discrepant results could be due to the task, as Quémart and Lambert (2017) used a copy instead of a spelling-to-dictation task. The processes prior to motor execution vary from one task to another, and possibly spelling-to-dictation could benefit more from the morphological structure of words than copying. Another explanation could be related to the orthographic system, as French is more opaque than Spanish, and the orthographic system could determine the influence of the morphological structure according to writing exposure. Additional studies are needed to look more deeply into these aspects.

Furthermore, it is interesting to highlight another important result considering the outcomes of the two tasks (reading and writing). The HF base speeds up RL and WL in both groups, but morphological condition continues to influence RCSD and WCSD only in the group with dyslexia. This result suggests that morphemes could be programmed before writing or reading begins in typically developing children, but the influence continues after the start of reading or writing in children with dyslexia. Additionally, the absence of a lexicality effect in writing suggests that children (in this study) process LF words and pseudowords in a similar way. However, further research is necessary to know differences between reading and writing of morphologically complex stimuli.

In summary, the evidence achieved in the present study suggests that children with dyslexia benefit from morphological structure, especially an HF base, in reading and spelling. Children with dyslexia speed up in their reading and spelling of unfamiliar stimuli when they involve an HF base. That suggests that they are familiarized with letter chunks that constitute an HF morpheme. The results support important implications for teaching and clinical work with children with dyslexia. Taking into consideration difficulties they exhibit in developing orthographic representations of the whole word, it could be interesting to encourage the use of units larger than graphemes and help them to develop morphological processing.

Finally, a limitation of this study was the small number of stimuli for each experimental condition. The reason for such a selection was that children with dyslexia show fatigue after long reading and writing tasks. Consequently, when many stimuli are used, the results may not be reliable. However, it would be useful to confirm the results of this study with new stimuli and new participants.

AUTHOR CONTRIBUTIONS

PS-C and FC developed the study concept and design. CM-G performed testing and data collection. PS-C and FC analyzed data and drafted the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2017.01952/full#supplementary-material

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Reading Derived Words by Italian Children With and Without Dyslexia: The Effect of Root Length

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Children with dyslexia are extremely slow at reading long words but they are faster with stimuli composed of roots and derivational suffixes (e.g., CASSIERE, 'cashier') than stimuli not decomposable in morphemes (e.g., CAMMELLO, 'camel'). The present study assessed whether root length modulates children's morphological processing. For typically developing readers, root activation was expected to be higher for longer than shorter roots because longer roots are more informative access units than shorter ones. By contrast, readers with dyslexia were not expected to be facilitated by longer roots because these roots might exceed dyslexics' processing capacities. Two groups of Italian 6th graders, with and without dyslexia, read aloud low-frequency derived words, with familiar roots and suffixes. Word reaction times (RTs) and mispronunciations were recorded. Linear mixed-effects regression analyses on RTs showed the inhibitory effect of word length and the facilitating effect of root frequency for both children with and without dyslexia. Root length predicted RTs of typically developing readers only, with faster RTs for longer roots, over and above the inhibitory effect of word length. Furthermore, typically developing children had faster RTs on words with more frequent suffixes while children with dyslexia were faster when roots had a small family size. Generalized linear regression analyses on accuracy showed facilitating effects of word frequency and suffix frequency, for both groups. The large word length effect on latencies confirmed laborious whole-word processing in children when reading low-frequency derived words. The absence of a word frequency effect along with the facilitating effect of root frequency indicated morphemic processing in all readers. The reversed root length effect in typically developing readers pointed to a stronger activation for longer roots in keeping with the idea that these represent particularly informative units for word decoding. For readers with dyslexia the facilitating effect of root frequency (not modulated by root length) confirmed a pervasive benefit of root activation while the lack of root length modulation indicated that the longest roots were for them too large units to be processed within a single fixation.

Keywords: word length, reading, orthographic depth, transparent orthography, children, dyslexia, morphology, root length

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INTRODUCTION

In languages with transparent orthography, like Italian, reading through grapheme-to-phoneme conversion rules leads to accuracy levels almost as high as reading through access to lexical representations, but it may be more time consuming. Most Italian children with developmental dyslexia show an extremely slow and analytical reading behavior (Zoccolotti et al., 1999, 2005), which is probably due to a massive use of the extra-lexical route. They typically make several small amplitude saccades accompanied by long-lasting fixations within a word (De Luca et al., 1999, 2002; see also Hutzler and Wimmer, 2004). They usually read rather accurately, but very slowly and serially (Spinelli et al., 2005). Within the psycholinguistic grain size theory proposed by Ziegler and Goswami (2005), this reading behavior can be seen as a failure in developing reading units of a large grain size (i.e., words, Hawelka et al., 2010), possibly because of limitations in their visuo-perceptual processing (e.g., Bosse et al., 2007; Martelli et al., 2009).

As a consequence, children with dyslexia typically experience great difficulties in reading long stimuli. However, long words that contain morphemes (roots and affixes) are read aloud by them faster than matched words not composed of morphemes. In several studies (for a review, see Burani, 2010) we showed that word naming times of children with dyslexia were shorter for stimuli composed of a root and a derivational suffix (e.g., CASS-IERE, 'cashier'), as compared to simple words of the same length and frequency not parsable in root + derivational suffix (e.g., CAMMELLO, 'camel'; Burani et al., 2008). We proposed that children with limited reading ability may find morphemes useful because morphemes are reading units of an intermediate grain size with respect to graphemes on the one side and words on the other: Morphemes are larger reading units than single graphemes (which entail slow analytical sub-lexical processing) but at the same time they are shorter reading units as compared to the word, which is too long for them to be processed in a single fixation as a whole. As a consequence of their formal and lexical characteristics, morphemes can be exploited to increase reading fluency (see also Deacon et al., 2016).

A facilitation on reading times due to the morphological composition of the stimulus was also found in typically developing readers at different ages. However, whereas skilled readers were facilitated by morphemes only when they were present in newly encountered words (i.e., pseudowords; Burani et al., 2002) and in low-frequency words (see also Carlisle and Stone, 2005; Deacon et al., 2011), children with dyslexia were facilitated by the presence of morphemes both in reading new words and words of various frequencies, including high-frequency words (Burani et al., 2008; Marcolini et al., 2011). Overall, the facilitating effect of the word's morphological composition was larger in children with dyslexia as compared to skilled readers of the same age (see also Elbrö and Arnbak, 1996; Carlisle and Stone, 2005; Suárez-Coalla and Cuetos, 2013).

For both children with dyslexia and skilled readers, the facilitating effect on vocal reaction times (RT) to pseudowords was mainly driven by the root, not the suffix (Traficante et al., 2011). This finding was interpreted as the combined effect of the main lexical role of the root which provides a head-start to morphemic decomposition (Bertram and Hyönä, 2003) and the serial reading behavior which is typical of developing readers of a transparent orthography.

Several properties contribute to the leading role of the root in morpheme-based reading. A number of studies reported effects of base frequency on English-speaking children's reading of derived words. Mann and Singson (2003) found that third- and sixth-grade children were more accurate in reading derived words with high- than with low-base frequencies. Similar effects were reported by Carlisle and Stone (2005) on grade 4 and 5 (but not on grade 2 and 3) children. Deacon et al. (2011) replicated these findings and extended them to the reading speed of children in grades 4, 6, and 8. In both the latter studies, morphemic effects were apparent on low frequency derived words. Carlisle and Katz (2006) also showed that grade 4 and 6 English-speaking children read derived words with large and frequent morphological families (i.e., large family size and high family frequency) more accurately than words with small and less frequent morphological families.

While the effect of frequency of the root on the processing of morphological words has been attested, it is much less known which other factors may contribute in modulating the influence of the root. Laudanna and Burani (1995) have proposed that the perceptual salience of morphological constituents within the word may bias reading toward morphological decomposition. In this vein, the focus of the present paper is to examine whether also a formal property of the root, such as its length, influences word processing. To the best of our knowledge, up until now the effect of root length on reading speed and accuracy has been considered only in the study by Hyönä and Pollatsek (1998) who included length of the first morphemic constituent among the predictors of the pattern of adult readers' eye-movements. It is well known from eye-tracking studies that, at least for adult readers, longer morphologically complex words are more subject to morphemic decomposition than shorter ones, with increasing word length enhancing the probability of morphological processing (see, among others, Bertram and Hyönä, 2003; Niswander-Klement and Pollatsek, 2006). Hyönä and Pollatsek (1998) went on and assessed whether also the length of the first component had an influence on the locations of fixations in reading compound words, based on the idea that the morphemes in a word could guide eye movements just as words do (see also, more recently, Hyönä et al., 2018) and that the visual width of the morphemic constituent could control the size of the saccade (see also Kuperman et al., 2010).

In particular, Hyönä and Pollatsek (1998) anticipated a difference in landing position when a word included either a short or a long first morphemic constituent, with eye fixations being farther into a word the longer the initial morpheme. In Hyönä and Pollatsek's (1998) study the length of the initial morpheme influenced the location of the second fixation on the target word and the patterns of re-fixations and fixation durations: The second fixation was farther in the word when first morphemes were longer. There were more intra-word regressions when the first morpheme was short then when it was long. When the first morpheme was long, the first-fixation duration was shorter but the second-fixation duration was longer. Thus, the pattern of eye movements appeared to be at least partly guided by processing of the morphemic components of the word.

However, it also appeared that first-morpheme length was not controlling the subsequent eye-movement when the initial fixation was near the beginning of the word. When the initial fixation landed on the first four letters of the word, there was only marginal control of eye movements by morphemes. By contrast, when the initial fixation landed near the middle of the word, the length of the initial morpheme had an influence on the length of the initial fixation, and there was a greater modulation of the location of the second fixation. This is consistent with data reported for the reading of isolated words by O'Regan et al. (1984) and Vitu et al. (1990), who found that, when the initial fixation occurred in a "bad" location (i.e., far from the optimal viewing position), a corrective eye movement was made to a more advantageous viewing location (presumably nearer the middle of the word). In summary, in the study of Hyönä and Pollatsek (1998) morphemic processing was more complete when the initial fixation was nearer the middle of the word (and in this case, the role of root length emerged). When the initial fixation was near the beginning of the word, guidance of the fixation appeared largely affected by oculomotor factors. According to the authors, these differences indicate that not all eye-movement behavior is guided by morphemic processing, but there is a compromise between visual and morphemic guidance, which is likely to be acquired during reading development.

It is well known that both the effects of visuo-perceptual and linguistic factors on the recognition of words and the viewing-position effects are modulated by print exposure and reading limitations (Ducrot et al., 2013). By fifth-sixth grade, the size of the visual span of typically developing children and most of the indices of their eye movements during reading are already very much like those of adults (Rayner, 1986; Kwon et al., 2007; Häikiö et al., 2009). By contrast, the visuo-attentional span of same age children with dyslexia is smaller than that of skilled readers (Bosse et al., 2007; Bosse and Valdois, 2009). The eye movements of dysfluent readers as old as 16–36 years still reveal a deficiency in the early serial orthographic processing of those words that do not have solid orthographic memory representations (Hautala and Parviainen, 2014).

It can consequently be envisaged that the modulation of the reading behavior induced by morphemic constituents of different sizes requires a flexible reading system, which, however, may be deficient in children with dyslexia. On the basis of the evidence on adult readers (Hyönä and Pollatsek, 1998), we thought that the length of the root could have a differential role in the reading behavior of children with and without dyslexia, respectively. In order to be processed as a unit in a single fixation, longer roots may require a mature level of visuo-perceptual integration, as the one already present in typical readers of sixth grade. For these children, we expected that the wider is the perceptual unit corresponding to the root (i.e., the longer is the root), the higher is the advantage that a reader can gain from the recognition of the root morpheme over the decoding of the long low-frequency word. Take, for example, two Italian suffixed words like 'nasino' (small nose) and 'cavallino' (young horse) that differ in root length ('nas-' and 'cavall-,' three- and six-letter long, respectively). Our prediction is that the recognition of a longer root like 'cavall-' should produce more advantage in reading the long and low-frequency word 'cavallino' than a shorter root like 'nas-' does in reading the word 'nasino.'

We further hypothesized that the visuo-perceptual limitations of children with dyslexia made it more likely that their initial fixation occurred near the beginning of the word (Hawelka et al., 2010).[1] This eye-movement behavior should allow children with dyslexia to fully process shorter roots but might result in frequently missing the middle of longer words, which is required for full processing of longer roots.

Although our main hypothesis assigns a leading role to the root in affecting reading speed, effects of suffix properties cannot be excluded. Indeed, there is evidence of the role of derivational suffix knowledge in decoding morphologically complex words (e.g., see Mann and Singson, 2003). Furthermore, several studies have shown effects of suffix properties in lexical decision tasks and on the eye-movement behavior of children (e.g., Lázaro et al., 2017) and adults (e.g., Ford et al., 2010; Kuperman et al., 2010). In previous studies on Italian children, both with and without dyslexia, although not affecting reading speed, the presence of a suffix in a pseudoword exerted a facilitating effect on reading accuracy (Traficante et al., 2011). However, the relative contributions of root and suffix properties on the reading aloud of words has not yet been assessed.

Overall, the present study assessed the role of root length on the performance of children with and without developmental dyslexia in reading derived words by means of an experimental regression design in which, along with root length, several other predictors related to word, root and suffix properties, were included. We focussed on low frequency derived words given the evidence discussed above for morphemic effects particularly on these forms. We expected that all children would benefit from morphological processing in terms of reading speed, with faster reading times for words embedding higher-frequency roots. The frequency of the suffix was not expected to have a particular role on reading times, at least not on those of children with dyslexia, given their visuo-perceptual limitations and their serial scanning procedure. The length of the root was expected to positively modulate the reading speed of typically developing readers only, with larger facilitating effects driven by longer than shorter roots. However, the length of the root was not expected to influence the reading times of children with dyslexia because of their visuo-perceptual limitations in processing long stimuli.

MATERIALS AND METHODS

Participants

Twenty children with dyslexia participated to the study: eight children were examined at the Centre for Cognitive and Linguistic Disorders (ASL 1) in Rome and 12 children were

[1]Note that perceptual limitations are selective for orthographic materials and children with dyslexia are not generally impaired in oculo-motor mechanisms *per se*; in particular, they show a spared mechanism for correcting fixations in suboptimal landing positions (Gagl et al., 2014).

selected during a screening carried out in 6th grade classes of junior high-schools in Milan. All children showed a marked reading delay in two standardized tests: text reading (*MT Reading test*; Cornoldi and Colpo, 1998), and word list reading (*Word Reading* subtest from the *Developmental Dyslexia and Dysorthography battery*; Sartori et al., 1995). Time (in sec/syllable) and accuracy (number of errors) were measured. Raw scores were converted to *z*-scores according to Italian normative data. All children with dyslexia scored at least 1.65 *z*-scores below the normative values for reading speed and/or below the fifth percentile for accuracy in at least one of the measures.

Readers with dyslexia were compared to 40 typically developing children of the same chronological age, assessed in 6th grade classes of junior high-schools in Milan ($N = 28$) and Rome ($N = 12$). Performances on the *MT Reading test* and on the *Word Reading* subtest were well within normal limits for both reading speed and accuracy. As a group, readers with dyslexia were slower than controls in the *MT Reading test* by 76% and in the *Word Reading* sub-test by 81%, respectively. Summary statistics and mean scores on the screening tests are presented in **Table 1**.

The two groups of readers were matched for gender (5 girls and 15 boys in the group of children with dyslexia; 11 girls and 29 boys in the group of skilled children), age, and non-verbal intelligence (*Raven's Colored Progressive Matrices*; Italian adaptation, Pruneti et al., 1996; see **Table 1**). All children had normal or corrected-to-normal vision.

The study was carried out according to the principles of the 2012–2013 Helsinki Declaration. Written informed consent to participate in the study was obtained from the parents of all children. The study was approved by the IRB of the Department of Psychology of Sapienza University of Rome.

Materials

Sixty low-frequency derived words were selected, composed of a root and a derivational suffix (e.g., PIED-INO, 'little foot'). All words were orthographically, phonologically and semantically transparent with respect to their base word, and included familiar roots and suffixes. Word frequency, root frequency, root family size, and suffix frequency were calculated on a written child frequency count (*Elementary lexicon: Statistical data on written and read Italian language in primary school children*; Marconi et al., 1993). Descriptive statistics for the experimental variables are reported in **Table 2**. The complete list of the experimental stimuli is available in the Supplementary Material.

Sixty simple words, matched to the derived words for length and word frequency were added as fillers to the list of experimental stimuli, for a total of 120 word stimuli. The inclusion of simple word fillers aimed at preventing the induction of a forced parsing strategy, which could be present had the list included only morphologically complex words. All words had the most frequent Italian stress pattern, on the penultimate syllable.

Procedure

The stimuli were presented in black lower case (font Courier New 18pt bold) in the center of the computer screen. Each stimulus was preceded by a fixation point (300 ms), followed by a brief interval (250 ms). Each word remained on the screen until the onset of pronunciation, or for a maximum of 6000 ms. There was an inter-stimulus interval of 1400 ms.

The 120 test items were presented in four blocks of 30 trials each. Order of presentation was randomized both within and between blocks. A short pause followed each block. Before the first experimental block the participants completed a practice block, consisting of 10 items with similar characteristics as the experimental items, presented in random order.

Participants were instructed to read aloud the words that appeared on the computer screen as fast and accurately as possible. The children were tested individually in a quiet room at school or at the clinical center. Responses were recorded by a microphone connected to a voice-key. Performance in terms of RTs was measured in ms using the E-Prime software. The experimenter manually noted mispronunciation errors.

Data Analysis

Invalid trials due to technical failures accounted for 3.9 and 1.6%, in children with dyslexia and in typically developing readers, respectively, and were treated as missing data. Pronunciation errors were excluded from the analyses on RTs.

As expected, children with dyslexia were much slower ($M = 1475$ ms, $SD = 464.6$, range: 850–2342 ms) than typically developing children ($M = 701$ ms, $SD = 130$, range: 468–985). Children with dyslexia also made more reading errors (9.6%,

TABLE 1 | Means (and standard deviations in parentheses) for age, performances on the *Raven Test*, on text passage reading from the *MT Reading Test* and Reading of words sub-test from the *Developmental Dyslexia and Dysorthography Battery*.

	Children with dyslexia		Typically developing children	
Age – in months	**141.50 (4.3)**		**140.57 (4.5)**	
	Raw score	***z* score/ percentile**	**Raw score**	***z* score/percentile**
Raven test – correct responses	29.42 (3.5)	–	30.54 (3.7)	–
Time (Text passage) – sec/syllable	0.44 (0.07)	−1.81 (0.78)	0.26 (0.03)	0.13 (0.38)
Accuracy (Text passage) – no of errors	22.0 (17.3)	−1.95 (2.4)	7.7 (4.1)	0.04 (0.57)
Time (Word Reading) – sec/word	1.18 (0.24)	−1.47 (0.8)	0.65 (0.10)	0.30 (0.3)
Accuracy (Word reading)° – no of errors	8.5 (5–32)	20*	1 0-4	0*

*Data are separately presented for children with dyslexia and typically developing children. °Medians (and ranges) are reported for this parameter. *Number of children with a score at or below the fifth percentile.*

range: 0–30%) than typically developing children (2.2%, range: 0–18%). The two groups of readers were quite different in both RTs ($t = 7.3$, $df = 58$, $p < 0.001$) and accuracy ($t = -4.52$, $df = 58$, $p < 0.001$). Thus, because of the large difference between groups both in mean values and in dispersion measures, the two groups were considered as two separate statistic populations and analyses of data were carried out within each group separately.

Log-transformed RTs and accuracy of responses in binary form (Correct = 1, Error = 0) were considered as dependent variables. Mixed-effects regression models (Baayen, 2008) were carried out, with participants and items as random intercepts, and six fixed effect predictors: word frequency, word length, root frequency, root family size, root length, and suffix frequency. Suffix length was not considered because it was linearly dependent on root length. Pearson's correlations across items were calculated on a by-item basis to determine how word features were related within stimuli (**Table 3**). All correlations between experimental variables except one (see below) were well below the 0.60 threshold (indeed all < 0.30), ensuring that there were no critical multicollinearity concerns (Tabachnick and Fidell, 2007). Root family size was moderately but significantly correlated with both word frequency ($r = 0.27$) and root frequency ($r = 0.28$). Because of the high correlation between word length and root length ($r = 0.79$), a residualization process was applied, in which root length was predicted from word length. The unexplained residuals from this regression analysis were included in the mixed-effects models instead of raw root length. To reduce skewness of the distributions and decrease the influence of atypical outliers, word frequency, root frequency and suffix frequency were logarithmically transformed, whereas word length and root family size were standardized (see Kuperman et al., 2010).

Different mixed-effects regression models with variables referred to whole word (word frequency and word length), root (root frequency, root family size, root length), and suffix frequency, respectively, were refitted through the model criticism procedure (Baayen, 2008). Models were compared using Akaike Information Criterion (AIC): AIC = 2k – 2ln(L), where k = number of parameters and L = maximum likelihood. Each (*N*) model was derived from the previous (*N-1*) model after removing non-significant effects. The model with all variables reaching significance level and associated to the numerically lowest AIC was considered the best model fitting data. Analyses were carried out by means of the statistical software R (R Development Core Team, 2009), using lme4 package (Bates et al., 2015).

For accuracy, generalized mixed-effects regression models with Laplace's approximation for binomial data were carried out.

TABLE 2 | Descriptive statistics for the psycholinguistic features of the experimental stimuli ($N = 60$).

	M	*SD*	Minimum	Maximum
Word frequency	16.55	17.3	0	56
Word length	8.38	1.4	6	11
Root frequency	618.57	714.9	83	3676
Root family size	3.28	2.0	1	11
Root length	4.50	1.1	3	6
Suffix frequency	766.43	462.4	15	2147
Suffix length	3.72	0.6	3	5

Word length, in letters; Root frequency, sum of all word tokens that share the root; Root family size, number of all different word types sharing the root; Root length, in letters; Suffix frequency, sum of all word tokens ending with the suffix; Suffix length, in letters. All the measures of frequency and family size are calculated on 1 million occurrences in a written child frequency count (Marconi et al., 1993).

RESULTS

Typically Developing Children

The AIC index identified Model 6, representing the linear combination of word length, root length, root frequency, and family size, as the best model fitting RT data (**Table 4**). In this model, none of the interactions tested in the other models (indicated by the '*' symbol) reached significance level.

Coefficients of the best mixed-effects regression model selected are presented in **Table 5**. The model showed that word length and root length had opposite effects on latencies. The longer the word, the slower was the response ($b = 0.03$, $t = 3.98$, $p < 0.001$). However, the effect of root length was in the opposite direction ($b = -0.01$, $t = -2.02$, $p = 0.047$), as increases in (the residual values of) root length were associated to faster RTs. The effect of root frequency was significant ($b = -0.02$, $t = -2.71$, $p = 0.008$), indicating that the higher was the frequency of the root, the faster was the response. Suffix frequency had a significant effect ($b = -0.02$, $t = -2.22$, $p = 0.03$): the higher the frequency of the suffix, the faster the response.

TABLE 3 | Pearson's correlation indices among raw variables.

	Word frequency	Word length	Root frequency	Family size	Root length
Word frequency	–				
Word length	0.057	–			
Root frequency	0.184	−0.187	–		
Family Size	0.275*	−0.128	0.279*	–	
Root length	0.073	0.787***	−0.167	−0.134	–
Suffix frequency	0.039	−0.131	0.066	−0.224	−0.010

$^*p < 0.05$, $^{***}p < 0.001$.

TABLE 4 | Typically developing children: Comparison of mixed-effects regression models on RTs (best fitting model in bold).

Model	AIC
Model 1 – Word length * Word frequency + Root length*Root frequency*Root family Size + Suffix frequency + (1| subject) + (1| items)	–403.03
Model 2 – Word length * Word frequency + Root length*Root frequency + Root family Size + Suffix frequency + (1| subject) + (1| items)	–406.05
Model 3 – Word length + Word frequency + Root length*Root frequency + Root family Size + Suffix frequency + (1| subject) + (1| items)	–408.04
Model 4 – Word length + Word frequency + Root length + Root frequency + Root family Size + Suffix frequency + (1| subject) + (1| items)	–408.3
Model 5 – Word length + Word frequency + Root length + Root frequency + Suffix frequency + (1| subject) + (1| items)	–410.2
Model 6 – Word length + Root length + Root frequency + Suffix frequency + (1| subject) + (1| items)	**–410.7**
Model 7 – Word length + Root length + Root frequency + (1| subject) + (1| items)	–408.64
Model 8 – Word length + Root length + Suffix frequency + (1| subject) + (1| items)	–403.37
Model 9 – Word length + Root frequency + Suffix frequency + (1| subject) + (1| items)	–408.46
Model 10 – Root length + Root frequency + Suffix frequency + (1| subject) + (1| items)	–402.84

For accuracy, the AIC index identified Model 4, representing the linear combination of word frequency and suffix frequency, as the best model (**Table 6**).

Both word frequency ($b = 0.22$, $z = 2.03$, $p = 0.043$) and suffix frequency ($b = 0.41$, $z = 2.69$, $p = 0.007$) were significant: accuracy was higher for higher-frequency words and when the word included a frequent suffix.

Children With Dyslexia

The AIC index identified Model 7, representing the linear combination of word length, root frequency, and family size, as the best model fitting RT data (**Table 7**). In this model, none of the interactions tested in the other models (indicated by the '*' symbol) reached significance level.

Table 8 shows the main effects that reached significance level. A word length effect was observed, such that the longer was the word, the slower was the response ($b = 0.05$, $t = 3.62$, $p < 0.001$). Also in children with dyslexia root frequency had a facilitating effect ($b = -0.05$, $t = -3.67$, $p < 0.001$): the higher the frequency of the root, the faster the response. A negative effect of root family size ($b = 0.03$, $t = 2.22$, $p = 0.03$) emerged in children with dyslexia: the larger the root family size, the longer children's RTs. Differently from typically developing readers, children with dyslexia did not show any effect of root length.

For accuracy, the AIC index identified Model 3, representing the linear combination of word frequency and suffix frequency, as the best model (**Table 9**).

Similar to typically developing peers, generalized mixed-effects regression models on accuracy data showed the main effects of word frequency ($b = 0.14$, $z = 1.93$, $p = 0.054$) and of suffix frequency ($b = 0.43$, $z = 3.64$, $p < 0.001$): pronunciation accuracy was higher for more frequent words and when the word included a frequent suffix.

TABLE 5 | Typically developing children: Coefficients of the best mixed-effects model on RTs.

Random effects	***SD***				
Participant	0.1639				
Item	0.0476				
Residual	0.1478				
Fixed effects	***Estimate***	***t*-value**	**Pr (> |*t*|)**	***F*-value**	**Pr (> *F*)**
(Intercept)	6.7478	88.227	<0.001		
Word length	0.0277	3.977	<0.001	9.1023	0.004
Root length	–0.0140	–2.022	0.047	4.0697	0.047
Root frequency	–0.0226	–2.708	0.008	9.9391	0.003
Suffix frequency	–0.0174	–2.220	0.03	3.6881	0.06

DISCUSSION

The reading aloud of children, both with and without dyslexia, is usually facilitated by the possibility of parsing a long word into its constituent morphemes, roots and affixes (Burani, 2010). The present study focussed on the possible effects of a visuo-formal property of the root (i.e., root length) in affecting morphological parsing during children's reading of low-frequency suffixed derived words. The results of the present experiment confirmed the expectation that, in typically developing children attending sixth grade, the presence of a longer root fosters morphemic access with consequent faster reading latencies. Long roots were not expected to result in a greater reading benefit over shorter

TABLE 6 | Typically developing children: Comparison of generalized mixed-effects regression models on accuracy (best fitting model in bold).

Model	AIC
Model 1 – Word length + Word frequency + Root length + Root frequency + Suffix frequency + (1| subject) + (1| items)	493
Model 2 – Word length + Word frequency + Root length + Suffix frequency + (1| subject) + (1| items)	491.5
Model 3 – Word frequency + Root length + Suffix frequency + (1| subject) + (1| items)	489.6
Model 4 – Word frequency + Suffix frequency + (1| subject) + (1| items)	**488.4**
Model 5 – Word frequency + (1| subject) + (1| items)	492.8
Model 6 – Suffix frequency + (1| subject) + (1| items)	490.4

TABLE 7 | Children with dyslexia: Comparison of mixed-effects regression models on RTs (best fitting model in bold).

Model	AIC
Model 1 – Word length * Word frequency + Root length*Root frequency*Root family Size + Suffix frequency + (1| subject) + (1| items)	905.31
Model 2 – Word length * Word frequency + Root length*Root frequency + Root family Size + Suffix frequency + (1| subject) + (1| items)	902.14
Model 3 – Word length * Word frequency + Root length*Root frequency + Root family Size + (1| subject) + (1| items)	902.19
Model 4 – Word length + Word frequency + Root length*Root frequency + Root family Size + (1| subject) + (1| items)	901.18
Model 5 – Word length + Root length*Root frequency + Root family Size + (1| subject) + (1| items)	901.58
Model 6 – Word length + Root length + Root frequency + Root family Size + (1| subject) + (1| items)	902.73
Model 7 – Word length + Root frequency + Root family Size + (1| subject) + (1| items)	**900.9**
Model 8 – Word length + Root frequency + (1| subject) + (1| items)	902.92
Model 9 – Word length + Root family Size + (1| subject) + (1| items)	910.89
Model 10 – Root frequency + Root family Size + (1| subject) + (1| items)	906.19

roots in children with dyslexia because of their limitations in visuo-perceptual processing and in their eye movements' behavior. The experimental data confirmed also this expectation.

Notably, several other predictors also exerted some effects on children's reading latencies to the suffixed derived words. For both typically developing readers and children with dyslexia, the main effect of word length indicated faster RTs for shorter than longer words. A general effect of word length may be expected due to the characteristics of the stimuli used, i.e., long low-frequency words. The main effect of root frequency indicated faster RTs for words including more frequent roots. Neither for skilled readers nor for children with dyslexia, whole-word frequency played a significant role on RTs to low-frequency derived words. The lack of significance for word frequency is in keeping with the idea of a massive use of morphemic parsing in reading aloud low-frequency long words in both groups. At the same time, the large root frequency effect for both groups indicates that the root was accessed as the main reading unit, irrespective of reading ability. The difficulty in using the whole word as an access unit for these long low-frequency words was also suggested by the inhibitory effect of word length for both groups of children.

The effect of root length was different in the two groups. In the case of typically developing children, both word and root length influenced reading times, but in opposite directions: word length negatively affected reading latencies while root length positively affected reading latencies, with longer roots leading to shorter latencies. It is thus confirmed that, for skilled readers, root length positively affects naming times over and above the opposite (and potentially confounding) effect of word length. This advantage may indicate that the longer is the morphemic constituent, the more informative is the reading unit that can be identified in the string of letters, thus favoring reading fluency. Overall, the effectiveness of longer roots on reading latencies could be caused by the combined effects of their perceptual salience within the word, and the fact that they are particularly informative access reading units. This may be because they have less lexical competitors (i.e., fewer competing root neighbors) than shorter roots (Marian et al., 2012). It might be interesting in further research to jointly examine the influence of root length and root neighborhood. For children with dyslexia the selective influence of root length found in typically developing children was absent, suggesting that their visuo-perceptual limitations may limit the possibility of a long root to exert its positive effect on reading. It should be added that the different pattern of results in children with dyslexia and typically developing readers was obtained through separate analyses (due to their basic large differences in speed). Accordingly, it would certainly be important to replicate these findings on separate samples. Possibly, if the two groups of children are not so different in terms of reading skills this might

TABLE 8 | Children with dyslexia: Coefficients of the best mixed-effects model on RTs.

Random effects	***SD***				
Participant	0.2963				
Item	0.0609				
Residual	0.3217				
Fixed effects	***Estimate***	***t*-value**	**Pr (>| *t*|)**	***F*-value**	**Pr (>*F*)**
(Intercept)	7.5393	61.960	<0.001		
Word length	0.0465	3.620	0.0006	7.3208	0.009
Root frequency	–0.0485	–3.675	0.0005	12.3326	0.0009
Root family size	0.0320	2.217	0.03	3.5890	0.06

TABLE 9 | Children with dyslexia: Comparison of generalized mixed-effects regression models on accuracy (best fitting model in bold).

Model	AIC
Model 1 – Word length + Word frequency + Root length + Suffix frequency + (1| subject) + (1| items)	711.5
Model 2 – Word frequency + Root length + Suffix frequency + (1| subject) + (1| items)	710.2
Model 3 – Word frequency + Suffix frequency + (1| subject) + (1| items)	**709**
Model 4 – Word frequency + (1| subject) + (1| items)	718.3
Model 5 – Suffix frequency + (1| subject) + (1| items)	710.6

also allow running a single analysis which would certainly be informative.

The present results indicate that not only the frequency of the root but also its length is an important parameter in modulating morphological processing. It should be noted that the existing computational models of reading aloud in Italian (i.e., Pagliuca and Monaghan, 2010; Perry et al., 2014) both have the potentiality to account for our findings. Both models have been developed for capturing the statistical regularities of the spelling-to-sound mapping in Italian polysyllabic words and both have shown sensitivity to large grain sizes in reading Italian. Both the CDP++ (Perry et al., 2014) and the model of Pagliuca and Monaghan (2010) were successful in simulating morphological effects in reading aloud Italian polysyllabic pseudowords even though they do not have either explicit morphological processing layers or semantics, consistently with the idea that morphological effects in word naming are non-semantic in nature (Burani et al., 1999). Thus, if these models would also prove adequate to capture the effects found in the present study, this would suggest that these effects can be explained by factors correlated with morphemic status, such as frequency or size of the chunks corresponding to morphemes, rather than some sort of explicit morphological status or the semantics associated with particular morphemes. If, by contrast, in simulating our results on word reading the differences between the two models (i.e., the absence of lexical units in the model by Pagliuca and Monaghan (2010), and the presence of these units in the CDP++ model) should result in a better performance of one of the models over the other, this would help adjudicating on the lexical vs. non-lexical status of morphemes as reading units.

Two less expected results were found in typically developing children and in children with dyslexia, respectively. A facilitating effect of suffix frequency was found on typically developing children only: words including more frequent suffixes were read faster than words with less frequent suffixes. A negative effect of root family size was found on dyslexics' reading speed: words that included a root which is present in several different words were read aloud slower than words including a root occurring in fewer different words.

Both these findings may have their source in the different reading scanning procedures adopted by the two populations of readers. The results of the present study confirmed that in the presence of long low-frequency words composed of morphemes, both typically developing children and children with dyslexia rely on the root as the main access unit driving morphemic parsing and latencies. However, skilled readers may extend their processing farther in the word at the extent that their reading latencies are speeded up by the presence of a suffix frequently occurring at the end of a complex word. By contrast, children with dyslexia may not be able to exploit the word ending information to accelerate their vocal RTs. This interpretation is consistent with several findings in the literature that show that less skilled readers use parafoveal information less effectively than do more skilled readers. Unlike faster readers, slower readers focus their attention more on foveal processing during a fixation (e.g., Häikiö et al., 2009) and are delayed in detecting word-end information (Hautala and Parviainen, 2014). Overall, increasing reading proficiency involves the ability to more effectively use partial word information available in parafoveal vision (Rayner, 1986). Thus, our skilled young readers may have started pronunciation on the basis of information coming from both the foveally fixated root and the parafoveally processed suffix.

A similar reasoning may also account for the negative effect of root family size found on the reading times of children with dyslexia. Words with a root that occurs in many different word-types are more easily recognized and have faster lexical access in lexical decision in both adults (e.g., see Schreuder and Baayen, 1997; Bertram et al., 2000) and children (Perdijk et al., 2012). However, similarly to our skilled children, a large morphological family did not affect word reading aloud in adults (Baayen et al., 2006, 2007). According to the latter authors, the family size facilitating effect is driven by the property that different words sharing the root also share their semantics, i.e., they share part of their meanings. For this reason, family size effects would occur in a task that implies access to semantics, like lexical decision, but would not be found in a task like fast reading aloud that is largely impermeable to the semantic properties of the words (Burani et al., 1999; Baayen et al., 2007).

The reversed family size effect found in children with dyslexia might be due to a different reason, namely to their characteristic serial processing in reading. Let us consider two examples of words differing in root family size that were presented to our participants: the first word, 'autista' (driver) has a root ('aut-') with a large family size ('auto' - car, 'autobus' - bus, 'autocarro' - van, 'automobile' - car, 'automobilista' - driver, 'autoscontro' - dodgem, 'autostrada' - highway), whereas the second word, 'durezza' (hardness) has a root ('dur-') which only occurs in another word in the child corpus ('duro,' hard). For readers whose reading limitations make it unlikely that the suffix is taken into account when starting pronunciation, a word like 'durezza,' whose root is present only in two words, might lead to less uncertainty in planning pronunciation of the whole word, while a word like 'autista,' which includes a root compatible with several possible different words, may delay the start of pronunciation. A similar effect has been reported by Traficante et al. (2014), who observed that children had higher error rates when the root of a derived word was compatible with several alternatives. The pattern of effects we found for root family size may appear in contrast to the effects reported by Carlisle and Katz (2006), cited in the Section "Introduction," who found that fourth and sixth English speaking graders read derived words with large morphological families more accurately than words with small families. However, the word sets used by Carlisle and Katz (2006) also differed in base word frequency, which was higher for words with a large family size than for words with a small family size. Crucially, Carlisle and Katz did not use a regression design that allowed to evaluate whether the effect of family size on derived word reading survived controls for correlated properties such as base frequency or cumulative frequency of the words present in the family (our root frequency). Therefore, the facilitating family size effect they found could be driven by the high root frequency of words with a large family size (see also Deacon and Francis, 2017, for empirical demonstration that only base frequency made an independent contribution to reading accuracy of English-speaking children in Grades 3 and 5 beyond the influence of the control variables base family size and family frequency).

Although not being the focus of the present research, our results concerning reading accuracy deserve some comment. For both typically developing readers and children with dyslexia pronunciation accuracy was positively affected by word and suffix frequency. In order to interpret these effects, it should be considered that pronunciation accuracy reflects the part of reading processing that takes place after the onset of pronunciation. In order to start pronunciation, articulatory planning of the whole word is not necessary, but the reader can start reading aloud on the basis of a sub-part of the whole word (Rastle et al., 2000; Sulpizio et al., 2015), i.e., in the present case, on the basis of the initial morpheme (i.e., the root; Bertram and Hyönä, 2003). Then, after starting pronunciation, the pronunciation of the whole stimulus must be correctly completed. To this end, several properties of the word and its constituent parts may play a role. The frequency of occurrence of the whole stimulus, which reflects repeated exposures to a given word, is one of these properties. However, as Baayen (2010) has shown, in addition to the amount of exposure to the word, part of the word frequency effect in a morphologically complex word also reflects the probability that a given root is followed by a given suffix: thus, the higher this probability (i.e., the higher the probability of the combination of that root with that specific suffix), the more accurate its production can be. Both sources of information (i.e., the total amount of exposure to the whole word, and the word's local morphological micro-context or co-occurrence) affect the probability that a given word is assigned a correct pronunciation.

The second variable that affected correctness of pronunciation of both groups of children was suffix frequency, with higher accuracy driven by higher-frequency suffixes. This finding can be seen as the complementary effect of the root frequency effect on latencies: for all children, the frequency of the first constituent affects the pronunciation onset, but the correctness of the pronunciation of the whole string depends on the recognition of the ending perceptual chunk, i.e., the suffix. The effect of suffix frequency on the reading accuracy of children, and of children with dyslexia in particular, must have its source on some properties of suffixes in driving pronunciation after starting the pronunciation process. It has been often shown in developmental reading studies that suffixes act as stress attractors (e.g., Jarmulowicz et al., 2007, 2008) and more generally provide a cue to stress position, i.e., to where stress should be placed when pronouncing a word (Grimani and Protopapas, 2017). This is crucial in pronouncing polysyllabic words like Italian derived words, which are usually 3-to-5 syllables long. The role of suffixes in cueing stress position is particularly important if we consider that children start pronunciation of morphologically complex words by planning pronunciation of the root alone. For most derived words (and for all the words we considered in our study), following root parsing, the root's lexical stress must be shifted forward in the word. For example, for a word like 'gattino' (kitten) pronunciation may start by planning the root ('gatt-,' cat) pronunciation, whose stress is 'gAtt-'. However, assembling the pronunciation of the root with that of the suffix after parsing entails re-assigning stress to the complex word, so that the correct stress (i.e., 'gattIno') is finally assigned. In such a complex process, the more frequent the suffix, the easier is stress assignment and the consequent co-articulation of the root-suffix combination. The present findings confirm those of Traficante et al. (2011) who showed that the presence of a suffix in a pseudoword did not influence the onset of children's pronunciation but had a role in enhancing pronunciation accuracy.

In summary, the results of the present experiment confirm that, when reading low-frequency suffixed derived words, both typically developing children and children with dyslexia largely rely on morphemes as reading units, and especially on the root as providing a head-start to pronunciation. The novel finding of this study is that, for skilled 6th grade readers, the longer is the root, i.e., the wider is the chunk that can be recognized at the beginning of the word, the more it can speed up the onset of stimulus pronunciation. By contrast, readers with dyslexia show a benefit from accessing the root, that is not modulated by its length. Longer roots do not result in particular benefits for readers with dyslexia as compared to shorter roots, probably because they are more likely to exceed the width of their visual scanning. These findings need to be accommodated within a model of morphological processing which accounts for the respective roles of visuo-perceptual properties of morphemes, such as root length, and differing reading abilities.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2018.00647/full#supplementary-material

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The Impact of Morphological Awareness on Word Reading and Dictation in Chinese Early Adolescent Readers With and Without Dyslexia

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This study investigated the role of morphological awareness in understanding Chinese word reading and dictation among Chinese-speaking adolescent readers in Hong Kong as well as the cognitive-linguistic profile of early adolescent readers with dyslexia. Fifty-four readers with dyslexia in Grades 5 and 6 were compared with 54 chronological age-matched (CA) typical readers on the following measures of cognitive-linguistic and literacy skills: morphological awareness, phonological awareness, visual-orthographic knowledge, rapid naming, vocabulary knowledge, verbal short-term memory (STM), Chinese word reading, and dictation (or spelling). The results indicated that early adolescent readers with dyslexia performed less well than the typical readers on all cognitive-linguistic and literacy measures except the phonological measures. Both groups' scores showed substantial correlations between morphological awareness and Chinese word reading and dictation. Visual-orthographic knowledge and rapid naming were also associated with dictation in early adolescent readers with and without dyslexia, respectively. Moderated multiple regression analyses further revealed that morphological awareness and rapid naming explained unique variance in word reading and dictation for the readers with dyslexia and typical readers separately after controlling readers' age and group effect. These results highlight the potential importance of morphological awareness and rapid naming in Chinese word reading and writing in Chinese early adolescents' literacy development and impairment.

Keywords: morphological awareness, cognitive-linguistic skills, word reading, word spelling, Chinese language, dyslexia, early adolescence

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INTRODUCTION

Developmental dyslexia, also referred to as reading disability, is a disorder characterized by severe and often pervasive difficulty in learning to read and spell despite normal intelligence and in the absence of sensory and neurological impairment or environmental deprivation (Lyon et al., 2003; Rose, 2009). Widely accepted as a life-span disorder, dyslexia has been well-studied in young children across languages (e.g., Snowling, 2000; McBride, 2015), although few studies document the progress of readers with dyslexia in adolescence (e.g., Wolf and Katzir-Cohen, 2001; Snowling et al., 2007), particularly for non-alphabetic languages. While several cognitive-linguistic skills are recognized to be important for reading development, it appears that the role of morphology in relation to other cognitive-linguistic skills could be of particular importance in enhancing the understanding of reading development and impairment in Chinese (e.g., McBride-Chang et al., 2003; Shu et al., 2006). Although not discounting the role of phonological awareness in Chinese literacy development (e.g., Ho and Bryant, 1997), it is worth highlighting why morphological awareness could be of particular importance for literacy development in Chinese. The present study seeks to extend this work by investigating the development of cognitive-linguistic skills associated with both reading and spelling abilities during the transition from childhood to early adolescence among Chinese students with dyslexia. We drew on previous work to look at six cognitive-linguistic skills associated with both reading and writing ability in dyslexia across alphabetic and non-alphabetic languages, namely, morphological awareness, rapid naming, visual orthographic knowledge, verbal short-term memory (STM), phonological awareness and vocabulary skills (e.g., Ho et al., 2002; de Jong and van der Leij, 2003; Shu et al., 2006). The goal of this study is to investigate the potential importance of morphological awareness in relation to word reading and dictation among Chinese-speaking students with and without dyslexia in Hong Kong senior primary schools. Also to be examined, are the cognitive-linguistic skills that might distinguish Chinese early adolescent readers with and without dyslexia in Grades 5 and 6, as well as the relations among the six cognitive-linguistic skills, word reading and dictation in readers with and without dyslexia.

Below, we highlight literature regarding the cognitive-linguistic deficits of readers with dyslexia across alphabetic languages and the features of Chinese language. Later, we zero-in on why morphological awareness in relation to other cognitive-linguistic skills could be of particular importance in enhancing word reading and dictation among Chinese adolescent readers.

Dyslexia in Alphabetic Languages

Although reading impairments can be found in all languages, the differences in languages, including their structure, indicate that dyslexia manifests itself differently (e.g., McBride, 2015). Extensive studies on dyslexia in alphabetic languages such as English indicate that dyslexia is primarily due to phonological processing deficits that affect the processing of speech sounds in a word, and it disturbs the learning of letter knowledge, resulting in failure to acquire adequate word recognition skills (e.g., Snowling, 2000; Spafford and Grosser, 2005). Catts and Kamhi (2005) further noted that those with dyslexia often have difficulty acquiring letter-sound correspondences and using such knowledge to "decode" unfamiliar words in a text once they begin learning to read. This difficulty with phonological sensitivity highlights how a lack of understanding of the close link between script and sound may interfere with the children's ability to read text accurately, eventually impacting reading comprehension. The second core deficit in dyslexia is deficient speeded processing (Bowers and Wolf, 1993; McBride-Chang and Manis, 1996). Measured via rapid automatized naming, deficits in rapid naming may interfere with the automatic processing that encompasses orthographic pattern extraction in a language (e.g., Bowers and Wolf, 1993). The lack of fluency tends to be more prominent among students with dyslexia acquiring literacy skills in a transparent orthography such as Finnish, where readers have an intact phonological decoding ability but with slow reading speed. On the other hand, readers with dyslexia acquiring literacy skills with a deep orthography, such as English, could exhibit difficulties in both phonological decoding and speed of reading (Aro and Wimmer, 2003). Besides these two deficits, readers with dyslexia may also exhibit difficulties in visual-orthographic knowledge (Corcos and Willows, 1993), including complications with morphological awareness, i.e., the sensitivity to morphemes in words (Carlisle, 1995; Leong, 1999). These problems generally impact the learners' ability to manipulate the structure of words, encode printed words, and analyze the meaning of words that could be morphologically complex. In fact, literacy learning in senior primary grades (e.g., 4th–6th grade) tends to be much more difficult for children because of the need to read and comprehend complex text as well as literature that demands more-challenging comprehension and critical thinking skills than merely grasping the alphabetic principle to enhance the decoding of words and familiar text. Most countries consider 4th grade to be a vital transition point into senior primary school because of pedagogical changes such as the shift from focusing on word decoding to reading comprehension (e.g., Chall, 1983). While this phase could be problematic for all students, it is likely that those with dyslexia could have an even more devastating experience. This brief overview of dyslexia in alphabetic languages suggests that multiple cognitive-linguistic causes are at play in students with dyslexia. Yet despite the distinctive features of writing systems such as Chinese, relatively few studies have shown interest in ascertaining what underlies dyslexia in these non-alphabetic orthographies.

Characteristics of the Chinese Language

Here, we shall describe certain features of Chinese, focusing on how language- and orthography-related aspects of Chinese could be different from alphabetic languages such as English. Highlighting these features is cardinal in terms of providing a basis for the importance of morphological knowledge in Chinese readers, especially those with dyslexia.

First, Chinese has sometimes been regarded as a morpho-syllabic writing system, because in Chinese, each basic graphic unit, referred to as a character, is connected with a morpheme (meaning unit) and signifies a spoken Chinese syllable (Mattingly, 1984; DeFrancis, 1989). A character is composed of strokes that are combined to form stroke-patterns, radicals, which are then used to make whole characters. As Guo (1995) notes, a whole character can have as many as 32 individual strokes. A character typically consists of two different parts, a semantic radical and a phonetic radical (Shu and Anderson, 1997). The phonetic radical provides clues to the sound of a character, although this information is unreliable when compared to the phonetic cues found in alphabetic orthographies, where each graphic unit, the letter, is directly linked to the sound (McBride, 2015). Alphabetic languages such as English are considered relatively transparent with regard to mappings between phonology and orthography, making phonological awareness critical for reading acquisition in alphabetic orthographies (Wimmer and Goswami, 1994; Aro and Wimmer, 2003). For Chinese, however, the relatively arbitrary associations between sound and print indicate that the orthography is not phonologically reliable but further requires that numerous characters and phonological units be stored in the lexicon. Thus, phonological awareness may not be as important to promote word reading in this script (Ho et al., 2004; Chung et al., 2010).

As alluded to earlier, the semantic radical is another constituent of a Chinese character, which unlike the phonetic radical, provides more-dependable cues that directly connect with the meaning of a character (Chung and Ho, 2010). Considering that in 80% of Chinese characters, semantic radicals are directly connected to meaning (Shu et al., 2006), some researchers argue that the structure of a Chinese character by itself likely points to the significance of morphological skills in Chinese reading (e.g., Lee et al., 2006). However, as indicated by McBride (2016), this is still an issue of debate. In any case, the direct association between the semantic radical and a character's meaning distinguishes morphological from phonological information in ways that are specific only to Chinese.

In addition to the above-highlighted functional regularity, the positional regularity of radicals is at the center of a character's orthographic structure and plays an important orthographic processing role (Shu and Anderson, 1997). Radicals typically occupy certain positions within a character. For example, the semantic radical mostly occupies the top or left portion within the top-bottom or left-right structure (for details, refer to: Chung and Ho, 2010; Kalindi et al., 2018). Thus, sensitivity to orthographic structures and radicals is a crucial factor influencing reading acquisition and failure in Chinese (Ho et al., 2003; Chung et al., 2011). In fact, aspects of inconsistency in the positional regularity of radicals, as highlighted by Ho et al. (2003), imply a likely complication for typical learners' literacy acquisition process (e.g., Tong et al., 2009) and a further heightened difficulty for those with reading difficulty in achieving competent reading levels (e.g., Chung et al., 2011). It is worth contrasting here that while Chinese learners have to acquire numerous characters and be conversant with the positional regularity of the radicals in order to develop literacy skills, learners in alphabetic languages simply have to learn a limited number of alphabet letters (for details, see McBride, 2016) that are always presented in a linear fashion. This, however, also presents considerable difficulty for those with reading difficulties (e.g., Bowers and Wolf, 1993).

Besides the orthographic features highlighted above, Chinese has some structural language features that affect typical and dyslexic readers differently, further highlighting the importance of morphological knowledge. Lexical compounding is one structural feature of the Chinese language that actually highlights the importance of morphological awareness in literacy acquisition (Shu et al., 2006). Typically, word formation in Chinese occurs by way of compounding two or more morphemes, and thus, many words share the same morpheme and are semantically related. Based on the language structure, Chinese can be said to be relatively semantically transparent because complex vocabulary can be built by combining morphemes via compounds. Although some level of lexical compounding is evidently common in alphabetic languages, it is worth noting that there is considerable variability among the alphabetic languages. For example, while lexical compounding is very common in Finnish, with some words ending up with as many as 50 letters, the English language does not allow for such compounding (for details see: McBride, 2016).

Closely linked to the feature of lexical compounding in relation to morphological awareness and literacy development in Chinese is homophone knowledge (Liu et al., 2013). In Chinese, the majority of words are multi-syllabic, with a further two-thirds of the words being bisyllabic (Taylor and Taylor, 1995). Thus, Chinese has largely been recognized as have a large number of homophones, a feature that is key for word recognition. To read competently, it is important for one to be sensitized to the different homographic and homophonic morphemes and to find the means to determine a character by considering it in context. Although this feature is evidently present in alphabetic orthographies such as English (for details see, McBride, 2016), the presence of homographs and homophones in Chinese is much more pronounced, thus highlighting the need for such skills. As Carlisle (1995) notes, the more children read, the more they understand about how morphemes are related to one another (Carlisle, 1995), and this further facilitates vocabulary development. In Chinese, learning to orally distinguish the many homophones may be bidirectionally associated with character recognition in typical readers (McBride-Chang et al., 2003). Chinese readers with dyslexia generally tend to perform poorly in morphological awareness tasks (e.g., Chung et al., 2010).

Given these features of Chinese, examining the cognitive-linguistic profile of dyslexia in Chinese is essential, while bearing in mind the highlighted features of Chinese that make our first goal worth exploring.

Cognitive-Linguistic Profile of Dyslexia in Chinese

Compared to research on dyslexia in alphabetic languages, research on Chinese literacy development, including impairment, is still in its infancy, and there is generally a paucity of studies on dyslexia. Moreover, similar to the trend in alphabetic languages, very few studies have looked at dyslexia in senior primary grades. Nonetheless, existing studies indicate that Chinese children with dyslexia present various underlying multiple deficits in cognitive-linguistic skills such as rapid naming, morphological awareness, phonological awareness, visual-orthographic knowledge, vocabulary knowledge, and verbal short-term memory (STM) (e.g., Shu and Anderson, 1997; Ho and Lai, 1999; McBride-Chang et al., 2003; Ho et al., 2004; Shu et al., 2006; Chung et al., 2010). Although some recent studies have identified rapid naming, visual-orthographic skills and morphological awareness as the most dominant types of cognitive-linguistic deficits in Chinese children with dyslexia (Ho et al., 2002, 2004; Shu et al., 2006), we present below why these cognitive-linguistic deficits, including those that may not be so "dominant," could be of particular importance among readers with dyslexia in senior primary grades. Senior primary school is when learners transition to early adolescence and become more accustomed to "reading to learn" as opposed to "learning to read" (for details, see Chall, 1983). As such, our focus on readers in the 5th and 6th grades could reveal some developmental differences in the associations between cognitive-linguistic skills and literacy performance.

Given the various aspects of morphological awareness that are of practical importance to Chinese literacy acquisition, we measured the morphological awareness skills of early adolescents in the present study. Research in alphabetic languages indicates that morphological awareness significantly contributes to reading processes, especially with regard to reading problems (e.g., Casalis and Louis-Alexandre, 2000; Lyytinen and Lyytinen, 2004). Although recent studies conducted in Mainland China (e.g., Shu et al., 2006) have indicated the importance of morphological awareness in distinguishing children with reading difficulties from those without any such impairments, we felt it is important to still determine whether this measure would distinguish between poor and good adolescent readers in a different Chinese society, such as Hong Kong. Although the study by Shu and colleagues also focused on pupils from senior primary schools, it was conducted in Mainland China, and owing to some literacy-related differences between Hong Kong and Mainland China, we were curious whether our study would reveal any novel findings. It is worth pointing out here that while Mainland China uses a modified Chinese script, Hong Kong uses the traditional script, which is likely influence the reading process (for details, see Kalindi et al., 2018) and may be a critical issue when learners are now expected to read in order to learn. Morphological awareness—conceptualized in Chinese as the capacity to distinguish meanings among morpheme homophones or the skill of manipulating and accessing morphemes in words with at least two morphemes—could still be key in distinguishing between poor and good readers in Hong Kong because of both the structural nature of the Chinese characters and the structure of the language itself, as earlier indicated. Note that while in early literacy studies of alphabetic languages, measures of morphological awareness substantially focus on the derivational and inflectional morphology (e.g., Deacon et al., 2007), in Chinese, measures of morphological awareness that have been identified as important for word recognition in early childhood (e.g., Tong et al., 2009) and early adolescence (e.g., Liu and Zhu, 2016) typically focus on lexical compounding and homophone/homonym awareness due to the nature of the Chinese script. Chung (2018) further illustrates that in Chinese, morpheme awareness is commonly measured via tasks of morpheme discrimination, morpheme construction and morpheme production. Considering the naturally enormous presence of lexical compounding and homophones in the Chinese language, it is likely that deficits in morphological awareness in relation to other cognitive-linguistic skills may be much more conspicuous. Although the very nature of Chinese words as having two or more characters, as well as the generally morphological nature of the Chinese language, could aid in performing literacy tasks such as dictation, constituent characters in Chinese words tend to actually be cued in a specific context (Tong et al., 2009). Therefore, insensitivity to the morphemic structures may well have devastating effects in the literacy acquisition of both young and adolescent readers (e.g., Chung et al., 2011). Besides the likely importance of morphological awareness in Chinese literacy acquisition being imbedded deeply, in an operational definition of Chinese, that is, "a meaning-centralized writing system" (Tong et al., 2009, p. 429), it is possible that the underlying connection between Chinese morphological awareness and literacy skills in Chinese could also be explained using the metalinguistic processing model (Bialystok and Ryan, 1985). In that model, the key component skills underlying metalinguistic and literacy development include knowledge analysis and control of cognitive linguistic processing. Since literacy development enhances the learner's ability to manipulate and analyze language (Chomsky, 1979), it is possible that this skill of accessing or manipulating language (e.g., morphemic structures) "fits" Carlisle's (1995) basic definition of morphological awareness and, as such, somewhat parallels Bialystok and Ryan's (1985) broader concept of analyzed knowledge and its associations with literacy skills. In any case, previous studies show that morphological production and discrimination tasks reliably predict Chinese word reading in both typical readers (e.g., McBride-Chang et al., 2003; Liu and Zhu, 2016) and readers with dyslexia (e.g., Shu et al., 2006; Chung et al., 2011), although in dictation tasks, less-consistent prediction in typical readers has been observed (e.g., Tong et al., 2009; Liu and Zhu, 2016).

In addition to morphological awareness, we included phonological awareness measures. Phonological awareness is important for reading acquisition across languages because of its focus on accessing and manipulating speech sounds. Measured at the syllable, onset-rime and phoneme unit level, phonological awareness has been demonstrated to be highly correlated with English and Chinese word reading (e.g., McBride-Chang and Kail, 2002). Phonological awareness in Chinese literacy development has revealed mixed results (e.g., Chow et al., 2005; Chung et al., 2010), partly due to the location of study participants and the type of script they need to learn, which influences the early literacy instruction method adopted by the teachers (for details, see Kalindi et al., 2018). In any case, we included measures of phonological awareness in this study because of previous demonstrations of the key role it plays in Chinese word reading and spelling among typical readers (e.g., Tong et al., 2009; Liu and Zhu, 2016) and those with dyslexia (Shu et al., 2006).

Another construct we considered important for distinguishing individual variability among Hong Kong children was rapid naming. Across orthographies, there is consensus on the significance of rapid naming as a core cognitive-linguistic skill for reading acquisition (e.g., Wagner et al., 1997; Ho and Lai, 1999). Profiling studies among Hong Kong children indicate the presence of multiple deficits in individual children, of which rapid naming and orthographic processing are the most dominant profile deficits, including visual and phonological processing (Ho et al., 2002, 2004). Considering that Chinese character recognition is a relatively "arbitrary" process (Manis et al., 1999), including a rapid naming measure may tap into the capability of learning arbitrary links between print and sound.

Thus, based on previous profiling studies (e.g., Ho et al., 2002) and the observed unique associations with Chinese literacy in typical readers (e.g., Liu and Zhu, 2016), we added a measure of rapid naming to determine whether it would predict literacy skills in Chinese early adolescents and distinguish between typical readers and those with dyslexia.

Visual-orthographic knowledge is another construct we included in this study, as it is said to distinguish between children with and without dyslexia in various alphabetic and non-alphabetic orthographies (e.g., Wolf, 1999; Ho et al., 2002). Known to tap the processing of orthographic information that alters the unit of perception, visual-orthographic knowledge enables the reader to move from processing, e.g., particular letters to particular sequences of letters (Chung et al., 2010). In Chinese, visual-orthographic knowledge refers to the learners' sensitivity to conventional rules when structuring Chinese characters, including their competency in distinguishing a set of non-characters, visual symbols and pseudocharacters from real Chinese characters. Previous studies show that visual-orthographic knowledge uniquely predicts Chinese literacy skills in both typical readers (e.g., Tong et al., 2009) and those with dyslexia (e.g., Chung et al., 2011). Cognitive profiling studies also show that visual-orthographic knowledge tasks distinguish students with dyslexia from those without dyslexia during primary grades (e.g., Ho et al., 2002, 2004; Chung et al., 2010). Thus, we included this measure in our study.

We also included the measure verbal short-term memory (STM) because of its demonstrated importance for reading acquisition in both alphabetic and non-alphabetic languages (e.g., Savage and Frederickson, 2006; Kormos and Sáfár, 2008). Research in alphabetic scripts further indicates that poor readers tend to struggle when rehearsing, storing, encoding, and recovering speech stimuli from memory (e.g., Siegel and Ryan, 1988). Studies done in Chinese children and early adolescents with and without dyslexia (e.g., Ho et al., 2000; Chung et al., 2010) indicate that those with dyslexia performed worse on verbal STM measures of digit memory as well as other intricate memory tasks than did typically developing children. We included the verbal STM measure in the current study due to observed associations between this construct and Chinese literacy skills (e.g., Shu et al., 2006; Chung et al., 2011) and to ascertain its capacity to discriminate between good and poor readers in Hong Kong.

The last measure we included involves oral vocabulary. Some studies have suggested that because of the breadth of oral language deficits associated with dyslexia, the explanation offered by the phonological deficit hypothesis for reading failure is incomplete (e.g., Gallagher et al., 2000). Dyslexia is often viewed as a "general verbal limitation" that, over time, presents varying expressions and is on a continuum with multi-componential language deficits. Indeed, children identified as having dyslexia have exhibited an early history of rather inferior vocabulary skills, including other verbal deficits such as verbal comprehension (Scaborough, 1991; Gallagher et al., 2000). In Chinese, however, the role of oral language skills in reading development has not been extensively examined, except in a few studies where vocabulary knowledge predicted Chinese character recognition (e.g., Wang et al., 2006; Liu and McBride-Chang, 2010). Additionally, vocabulary knowledge distinguished readers with and without dyslexia and explained literacy skills in a study by Shu et al. (2006) in Mainland China. Thus, we included the oral vocabulary measure in our study to see whether it would be associated with Chinese literacy skills and to distinguish between good and poor readers in early adolescence.

The Present Study

The research we have highlighted above shows that there are various cognitive-linguistic skills that distinguish readers with dyslexia in many languages. It is, however, important to investigate how deficits in morphological awareness in relation to the other five cognitive-linguistic skills are associated with reading difficulties as children with dyslexia graduate to senior primary grades and the extent to which such deficits persist. Questions then arise in view of the morphological nature of the Chinese language to determine the extent to which morphological awareness, among other cognitive-linguistic skills, is key in predicting Chinese word reading and dictation as readers with and without dyslexia transition into early adolescence. Also important is to establish the cognitive-linguistic deficits that persist into early adolescence for Chinese students with dyslexia.

The present study, therefore, sought to understand literacy development and impairment among Hong Kong Chinese early adolescent readers by investigating the potential importance of morphological awareness in explaining Chinese word reading and writing skills in readers with and without dyslexia from senior primary grades. We examined the extent to which six cognitive-linguistic skills—morphological awareness, phonological awareness, visual-orthographic knowledge, rapid naming, verbal STM, and oral vocabulary knowledge—would distinguish early adolescent readers with dyslexia from their peers with the same chronological age (CA). We also examined the relationships among the cognitive-linguistic skills, word reading and dictation and whether these relationships were the same for readers of dyslexia and typical readers.

METHODS

Participants

One hundred and eight Hong Kong Chinese senior primary school students in Grades 5 and 6 were recruited for 2 groups, i.e., the group for adolescents with dyslexia and the CA control group. All participants were native Cantonese speakers and enrolled in local primary schools where the main medium of instruction was Cantonese. For literacy acquisition instruction, Hong Kong public schools do not provide phonics instruction. Thus, Cantonese reading instruction employs the "look and say" method, where learners typically memorize the characters (Holm and Dodd, 1996). The dyslexia group consisted of 54 students from Grade 5 to 6 [mean age = 130.70 months, standard deviation (*SD*) = 6.55], with 31 boys and 23 girls. The students who participated in this study had been assessed on Hong Kong standardized intelligence tests by qualified psychologists. These tests include the Hong Kong Test of

Specific Learning Difficulties in Reading and Writing for Primary School Students [HKT-P(II)] (2nd ed.) (Ho et al., 2007) and the Hong Kong Wechsler Intelligence Scale for Children (HK-WISC) (Hong Kong Psychological Corporation, 1981). This test battery involved literacy tasks, phonological awareness, rapid naming, orthographic skills and phonological memory. The HKT-P(II) is a standardized test with local norms and is used to diagnose developmental dyslexia among students in Hong Kong primary schools. Participants with dyslexia had to meet the criterion that the literacy composite score, including one or more of the cognitive-linguistic composite scores in the HKT-P(II), was at least 1 standard deviation below their respective age. In line with the Hong Kong diagnostic criteria of developmental dyslexia, those with dyslexia also needed to have normal intelligence, with an IQ of 85 or above. Further screening of all participants was performed to ensure each had been accorded sufficient learning opportunities and without serious behavioral or emotional problems, suspected brain damage or uncorrected sensory impairment. Also excluded from our study were new immigrants.

In the control group, we recruited 54 typically developing readers from two Hong Kong primary schools. Based on age, 26 boys and 28 girls (mean age = 129.46 months, *SD* = 5.57) from the control group were matched to the dyslexic students (see **Table 1**). The control group members were all average performers, and based on the previous grade average, they were nominated to the group by their class teachers. The grade point average was within the 50–75 percentile for Chinese language/literature. None of the students had a childhood history of learning difficulty or psychopathology.

Materials and Procedures

Participants were administered 9 measures, including the standardized vocabulary test from the HK-WISC, two morphological awareness tasks, two literacy tests, one test of visual-orthographic knowledge, one test of rapid naming, one test of phonological awareness, and a verbal STM task. The measures were all individually administered. Before formal testing, the participants were given two practice trials for each task. Written and informed consent from the parents/legal guardians of all participants was obtained prior to testing, and the Education University of Hong Kong's Human Research Ethics Committee approved the study. All measures were administered by trained experimenters.

Assessment Measures

Literacy

Chinese word reading

This measure was modeled on a test employed in previous studies (Chung et al., 2010, 2014). A total of 124 Chinese two-character words were selected as sample items from popular Chinese language textbooks recommended for use in upper primary school by the Hong Kong Education Bureau. These words were cross checked with the list of graphemes of commonly used Chinese characters (常用字字形表) that comprise 4762 commonly used words recommended by the Hong Kong Education Bureau (Curriculum Development Institute, 2007) for teaching at junior and senior primary school levels. These word items were presented in order of increasing difficulty, and students were asked to read the words aloud one-by-one. One point was awarded when the two characters in presented words were correctly read. The maximum score for this test was 124.

Chinese word dictation

This measure was modeled after tests from previous studies (e.g., Chung et al., 2010). Students were orally presented with 96 two-character words and then requested to write them down. Again, the target items were selected from three sets of Chinese language textbooks commonly used in upper primary schools. These words were also cross-checked with the list of graphemes of commonly-used Chinese characters (常用字字形表) used in primary school grades. For each correctly written character, one point was awarded. The maximum score for this test was 96.

Morphological Awareness

Morpheme discrimination

The students' comprehension of a morpheme having different meanings in two morphemic words was measured using this task. This measure, which was constructed based on the test used in Chung et al. (2014) study, involved 19 items, each comprising four two-character words presented orally and visually. Each set had a character sharing the same word and written form but did not share the same meaning when joined with the other characters. For example, the character 信,/seon3/ was the common character in the words 信任 /seon3 jam6/, trust; 信封, /seon3 fung1/, envelope; 信件, /seon3 gin6/, letter; and 信箱, /seon3 soeng1/, mailbox. For every presented set, participants were asked to identify the "odd" word. Thus, the correct answer was 信任, /seon3 jam6/, trust because the character /seon3/ in the word /seon3 jam6/ signified a dissimilar morpheme. One point was awarded for each correct answer, and 19 was the maximum score.

Morpheme production

This task, also used in the previous study (Chung et al., 2014), examined the participants' competence in applying and integrating the contextual and morphological information in particular settings. Participants were orally presented with 18 sentences with missing words. They were told to listen carefully as incomplete sentences would be read out to them and they would then be asked to fill the "blank" with a suitable word. An example sentence is "因爲工作需要, 我在昨天購買了一台新的電____來處理文件", *Due to my work, I brought a _______ home yesterday to process documents. One* of the possible correct responses for this was 電腦, *computer*, because 電, *electricity,* was joined to the word 腦, *brain*. When students provided a word response that satisfied the semantic constraints of the position and was sensible given the sentence context, a correct answer was awarded. The maximum score for the task was 18.

Rapid Naming

Rapid Digit Naming. When presented with a paper having five stimulus items, i.e., digits (2, 4, 6, 7, 9) in different orders across five rows, the students were asked to name the numbers presented on the list as fast as they possibly could. Every participant

TABLE 1 | Means, standard deviations, and *t*-tests of all variables for adolescent readers with dyslexia and typical readers.

	Reliability	Dyslexics *N* = *54*		Typical readers *N* = *54*		*t* tests	Effect size (*d*)
		Mean	*SD*	Mean	*SD*	*t* values	
Age in months		130.70	6.55	129.46	5.57	−1.06	−0.01
LITERACY SKILLS							
Chinese Word Reading	0.97	60.37	16.72	106.20	12.85	15.97***	0.53
Chinese Word Dictation	0.96	37.43	6.04	62.20	11.52	14.00***	0.48
COGNITIVE-LINGUISTIC SKILLS							
Rapid digit naming	0.93	39.08	7.33	26.91	4.99	−10.08***	−0.36
Verbal STM	0.79	59.87	12.46	72.43	13.38	5.05***	0.19
Morpheme discrimination	0.78	9.52	2.79	12.35	2.33	5.73***	0.26
Morpheme production	0.88	9.33	2.19	12.52	1.42	8.96***	0.29
Visual-orthographic knowledge	0.82	12.85	2.32	15.28	1.68	6.23***	0.17
Vocabulary knowledge	0.79	9.78	3.56	12.09	3.67	3.33***	0.21
Phonological awareness	0.87	13.48	3.04	14.00	2.69	0.94	0.04

*Test-retest reliability was computed for the rapid digit naming measure. Non-Dyslexics were matched on chronological age. ***p < 0.001.*

performed this task twice, and the score was the average time to name the digits across the two trials.

Phonological Awareness

A syllable and onset deletion task was used (McBride-Chang et al., 2003). In the syllable deletion task, the participants were orally presented with nine meaningless three-syllable items and were asked to say aloud what was left if one syllable was removed for each item. An example item was "say /fu1 on3 baan2/ without /baan2/," and the correct answer was "/fu1 on3/." In the onset deletion task, 10 real and four pseudo one-syllable words as well as four two-syllable and four three-syllable pseudo words (i.e., 22 items altogether) were used. Again, children were orally presented with each item and asked to remove the onset from each syllable. An example item was "say /tau1/ without /t/," and the correct answer was "/au1/." One point was allotted for each correct answer. A phonological awareness score was computed by summing the scores from the two tests.

Visual-Orthographic Knowledge

Character Matching

Constructed in line with Chung et al. (2010), this task assessed the learners' knowledge about the structures of Chinese characters. After looking at a target character, participants were asked to identify the same character from given options of nine stimuli comprising similar visual forms and orthographic units as the target characters. Made up of a combination of five error types, the stimuli involved inverted components, illegal positions, incorrect number of strokes, incorrect orientation and one component combining different components. For example, the target character 媒 was simultaneously presented together with options such as [illegible] (one component merging with a dissimilar component), [illegible] (one component with inappropriate strokes), [illegible] (the components in wrong positions), [illegible] (a component with mirror orientation), and [illegible] (components with reversed left/right positions). The maximum score was 18, and one point was awarded for correct answer.

Verbal STM Test

Non-word repetition. Adopted from previous studies (Chung et al., 2010, 2014), this measure tested the participants' phonological working memory. This memory test had 20 trials of three to eight Chinese syllables altogether. Although the particular presented syllables were legal phonetic syllables in Cantonese, they were also monosyllabic non-words (e.g., /bei5/, /tan5/, and /daai5/). A CD player was used to present stimuli, and the participants were asked to orally repeat the syllables, maintaining their order of presentation. A point was awarded for each correctly reproduced syllable.

Vocabulary Knowledge

Oral Vocabulary

Adapted from Chik et al. (2012), this vocabulary test measured participants' ability to use vocabularies in a given context as well as the depth of their vocabulary knowledge. Participants were orally presented with nine Chinese two-character words (e.g., adjectives, verbs, and nouns) familiar to students in junior secondary school and were then requested to explain or define the given target words. Students were also asked to construct sentences using the target word to help illustrate what the word entails. For instance, given the target word (miracle), the likely words to define this would be (extraordinary), (unimaginable), (mysterious), and (very surprising and unexpected event). An example of a sentence would be (I was so sure my dog would never make it to the finish line in this event. Considering his ill health, just him coming this far is a pure miracle!). Three points were used to award a score: a point for clearly stating what the target word means, another for expounding on the meaning of the target word and one last point for using the target word in a suitable context. The maximum score was 18.

RESULTS

Three types of analyses are presented. First, the means, standard deviations (*SD*) and *t*-values of all tests are presented for both the

TABLE 2 | Correlations among all measures in readers with dyslexia (lower left) and typical readers (upper right) after statistically controlling for age in months.

Measures	1	2	3	4	5	6	7	8	9
1. Chinese word reading	–	0.33*	−0.22	0.17	0.39**	0.32*	0.15	0.05	−0.05
2. Chinese word dictation	0.27*	–	−0.38**	0.07	0.31*	0.32*	0.11	0.12	0.15
3. Rapid digit naming	−0.25	−0.13	–	0.07	−0.02	−0.11	0.06	−0.02	0.08
4. Verbal STM	0.20	0.04	−0.27*	–	0.11	0.19	0.08	0.05	0.25
5. Morpheme discrimination	0.36**	0.36**	0.09	−0.24	–	0.13	−0.01	0.02	0.06
6. Morpheme production	0.31*	0.33*	−0.22	0.16	−0.03	–	0.09	0.06	0.04
7. Visual-orthographic knowledge	0.26	0.37**	−0.25	−0.12	0.19	0.26	–	−0.15	0.02
8. Vocabulary knowledge	0.10	0.22	−0.02	−0.26	0.24	0.19	0.16	–	0.00
9. Phonological awareness	0.05	−0.08	−0.09	−0.05	0.19	−0.14	0.10	0.11	–

*$p < 0.05$; **$p < 0.01$.

group with dyslexia and the CA control group. Second, separate correlational associations for the two groups on their Chinese word reading and dictation are presented. Finally, associations of independent cognitive-linguistic measures with Chinese word reading and dictation for the two groups are explored using four-stage hierarchical regressions.

Coefficient alphas were calculated for each measure used in the present study. The reliability estimates for the rapid naming task involved test-retest reliabilities. The internal consistency reliabilities for all other tasks are presented in **Table 1**.

Group Comparisons of Literacy and Cognitive-Linguistic Measures

The means, standard deviations and effect sizes for all tasks are presented in **Table 1**. The reliability of the tasks was generally acceptable (all 0.70 and above). Independent *t*-tests were conducted to examine group differences on the measures of word reading and dictation. Although no significant mean difference was observed for the phonological awareness task, the observed mean differences for both literacy tasks and for morphological awareness, rapid naming, visual-orthographic knowledge, verbal STM, and vocabulary knowledge were all significant. The group with dyslexia performed worse than the CA across all these tasks except for the phonological awareness task [($m = 13.48$, $sd = 3.04$), $t_{(106)} = 94$, $p > 0.05$], where no group differences were observed.

Correlations Between the Literacy and Cognitive-Linguistic Measures

As shown in **Table 2**, separate correlational analyses were conducted for early adolescent readers with and without dyslexia regarding their literacy and cognitive-linguistic skills. For both groups, after controlling for the effect of age, the early adolescent readers' Chinese word reading and dictation was significantly associated, that is, $r = 0.27$, $p < 0.05$ for the group with dyslexia and $r = 0.33$, $p < 0.05$ for the control group. In the two groups, the measures of morphological awareness were significantly associated with word reading and dictation skills. Further examination of the associations of the key cognitive-linguistic skills as regards Chinese word dictation showed different patterns in the two groups. For the group with dyslexia, the dictation task was significantly associated with visual-orthographic knowledge ($r = 0.37$, $p < 0.01$; see **Table 2**). However, for the control group, the Chinese dictation task was significantly associated with rapid naming ($r = -0.38$, $p < 0.01$).

Relations Among Cognitive-Linguistic Skills, Word Reading, and Dictation

To examine the cognitive-linguistic skills that would explain Chinese word reading and dictation for early adolescent readers in the group with dyslexia and the typical readers, separate four-stage hierarchical regression analyses were conducted. Cognitive-linguistic tasks, including rapid naming, vocabulary knowledge, visual-orthographic knowledge, phonological awareness, and morphological awareness, were entered as independent variables at step 3 after controlling for age and the group interaction effect in steps 1 and 2, respectively. To differentiate group properties when explaining the associations between the variables in the regression models, dummy variables were created with the group with dyslexia as the reference group (typical readers = 0, dyslexic readers = 1). Thus, the interaction of the group and the cognitive-linguistic measure was entered at stage 4. Unfortunately, after this, the group interaction effect ceased to be significant, and the key skills known to explain Chinese literacy skills predicted neither of the assessed literacy measures in the group of adolescents with dyslexia (see **Tables 3**, **4**). The results of step 3 of the regression analyses (refer to **Tables 3**, **4**), therefore, indicated that after controlling for age and group interaction effects, only the constructs rapid naming and morphological awareness could significantly explain Chinese word reading and dictation in the two groups. The verbal STM, vocabulary, visual orthographic knowledge and phonological awareness measures were not associated with word reading and dictation.

Worth highlighting is that both measures of morphological awareness uniquely predicted Chinese word reading and dictation after controlling for age and group membership. As shown in **Table 3**, morpheme discrimination ($\beta = 0.24$, $p < 0.001$) and morpheme production ($\beta = 0.61$, $p < 0.05$) uniquely explained Chinese word reading. Similarly, morpheme discrimination ($\beta = 0.19$, $p < 0.01$) and morpheme production ($\beta = 0.15$, $p < 0.05$) uniquely predicted dictation skill. Overall,

TABLE 3 | Hierarchical regression analyses explaining Chinese word reading.

	R^2	ΔR^2	*F* Change	β	*t*
Step 1	−0.01	0.00	0.11		
Age in months				−0.03	−0.33
Step 2	0.70	0.71	255.96***		
Age in months				0.05	1.03
Typical readers vs. Dyslexics				−0.85	−16.00***
Step 3	0.78	0.09	6.19***		
Age in months				0.03	0.58
Typical readers vs. Dyslexics				−0.45	−5.70***
Rapid digit naming				−0.14	−2.14*
Verbal STM				0.10	1.86
Morpheme discrimination				0.24	4.42***
Morpheme production				0.16	2.39*
Visual-orthographic knowledge				0.07	1.20
Vocabulary knowledge				0.01	0.10
Phonological awareness				−0.03	−0.70
Step 4	0.77	0.00	0.28		
Age in months				0.02	0.43
Typical readers vs. Dyslexics				−0.57	−0.80
Rapid digit naming				−0.10	−1.26
Verbal STM				0.06	0.82
Morpheme discrimination				0.21	2.50*
Morpheme production				0.15	1.28
Visual-orthographic knowledge				0.09	0.92
Vocabulary knowledge				0.02	0.30
Phonological awareness				−0.06	−0.76
Dummy_VSTM				0.17	0.65
Dummy_MP				0.03	0.10
Dummy_MD				0.11	0.55
Dummy_RDN				−0.14	−0.63
Dummy_V-OK				−0.14	−0.39
Dummy_PA				0.10	0.43
Dummy_VK				−0.06	−0.38

VSTM, Verbal STM; MP, Morphological production; MD, Morphological discrimination; RDN, Rapid digit naming; V-OK, Visual-orthographic Knowledge; PA, Phonological Awareness; VK, Vocabulary Knowledge. $^*p < 0.05$; $^{***}p < 0.001$.

TABLE 4 | Hierarchical regression analyses explaining Chinese word dictation.

	R^2	ΔR^2	*F* Change	β	*t*
Step 1	−0.01	0.00	0.00		
Age in months				0.00	0.00
Step 2	0.65	0.66	200.04***		
Age in months				0.08	1.45
Typical readers vs. Dyslexics				−0.81	−14.14***
Step 3	0.71	0.08	4.02***		
Age in months				0.06	1.06
Typical readers vs. Dyslexics				−0.44	−4.85***
Rapid digit naming				−0.16	−2.11*
Verbal STM				0.02	0.34
Morpheme discrimination				0.19	3.13**
Morpheme production				0.15	2.04*
Visual-orthographic knowledge				0.08	1.20
Vocabulary knowledge				0.04	0.74
Phonological awareness				0.02	0.27
Step 4	0.71	0.02	1.16		
Age in months				0.05	0.93
Typical readers vs. Dyslexics				0.79	1.00
Rapid digit naming				−0.19	−2.13*
Verbal STM				−0.04	−0.48
Morpheme discrimination				0.25	2.69**
Morpheme production				0.33	2.52*
Visual-orthographic knowledge				0.14	1.27
Vocabulary knowledge				0.08	1.09
Phonological awareness				0.12	1.46
Dummy_VSTM				0.18	0.63
Dummy_MP				−0.56	−1.68
Dummy_MD				−0.17	−0.78
Dummy_RDN				0.09	0.37
Dummy_V-OK				−0.13	−0.34
Dummy_PA				−0.45	−1.66
Dummy_VK				−0.05	−0.31

VSTM, Verbal STM; MP, Morphological production; MD, Morphological discrimination; RDN, Rapid digit naming; V-OK, Visual-orthographic Knowledge; PA, Phonological Awareness; VK, Vocabulary Knowledge. $^*p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

the model explaining Chinese word reading had a total variance of 78%, while that explaining dictation accounted for 71%.

DISCUSSION

The present study investigated the potential key role of morphological awareness in enhancing literacy development and impairment in early adolescent Chinese readers, as well as the extent to which the cognitive-linguistic profile of readers with dyslexia differed from typically developing readers in Hong Kong. We were also interested in establishing the link between cognitive-linguistic skills and literacy measures that may distinguish early adolescent readers with and without dyslexia. Our results provide data that add to the body of research evidence highlighting the potential importance of morphological awareness in literacy development and impairment (e.g., Carlisle, 1995), especially in early adolescent Chinese readers (Shu et al., 2006). Hierarchical regression analyses demonstrated that both morphological awareness tasks, including the rapid naming measure, uniquely predicted Chinese word reading and dictation even after controlling for age and group membership. In line with our second goal, we observed that the group with dyslexia was significantly weaker than the control group in the two literacy tasks, including the six cognitive-linguistic tasks: morphological awareness, visual-orthographic knowledge, rapid naming, phonological awareness, verbal STM, and vocabulary knowledge. Confirming existing work on the multiple cognitive-linguistic deficits (e.g., Shaywitz et al., 1999; Wolf and Katzir-Cohen, 2001) that may influence reading and dictation mechanisms in Chinese readers, our findings further indicate that even in early adolescence, there are still cognitive-linguistic and literacy differences between typical readers and those with dyslexia, indicating that certain cognitive deficits of dyslexia could persist through early adolescence (e.g., Shaywitz et al., 1999). Below, we highlight the potential importance of morphological awareness in literacy development and impairment among Chinese learners, and we shed light on the other cognitive-linguistic differences that distinguish readers with and without dyslexia in early adolescence.

The Role of Morphological Awareness

It is important to mention yet again that both of our measures of morphological awareness significantly differentiated between adolescent readers with and without dyslexia. The morphological awareness tasks were also significantly associated with Chinese word reading and dictation. There are a number of reasons why morphological processing in Chinese literacy development is important. First, as noted earlier, Chinese, by nature, has morphological characteristics (e.g., Packard, 2000) that can easily be associated with the practical aspects of reading impairment and development. Mastery in Chinese literacy is dependent on the salient semantic transparency of the compounding morphological structure in many words. This distinct compounding morphological structure coupled with the large number of Chinese homophones together suggest approaches and impairments that may tend to be more pronounced in Chinese readers.

Chinese has many homophones, in sharp contrast to the relatively few homophones in alphabetic languages. This makes phonological or sound information unreliable in identifying or decoding Chinese words. In fact, several studies have noted that this feature of morphological awareness is critical for Chinese word recognition at the word level (Shu et al., 2006; Tong et al., 2009). This is considering the fact that as readers become more competent, they tend to see more clearly how the morphemes are related to one another. By quickly grasping the homophonic nature of Chinese, that is, basically figuring out the fact that identical sounds may actually imply different meanings in varying word contexts, this realization is an advantage that not only enhances the competent reader's accuracy in Chinese word reading and dictation but also facilitates educated guesses (e.g., McBride-Chang et al., 2003; Shu et al., 2003). This is an important issue to highlight concerning Chinese literacy acquisition because, as would be expected, early readers search and desire to employ the obvious systematic and regular associations in their spoken and written language in order to facilitate proximal learning (Shu et al., 2006). For Chinese, this would clearly be the morphemic structure of the language.

Considering that the readers in our sample were from senior primary schools, this further highlights the key role of morphological awareness in literacy development across the primary grades. Bearing in mind also that our study was interested in identifying cognitive-linguistic skills that distinguish adolescent readers with dyslexia from the control group, it is possible that morphological awareness deficits impair reading development by slowing down the process of word reading, including dictation ability. This further highlights the likely difficulty Chinese readers with dyslexia may have in identifying and discriminating morphemes during literacy acquisition (e.g., McBride-Chang et al., 2003). Clearly, the immense quantity of homophones here presents a challenge that calls for extended hours of adult support and supervision (e.g., Li and Rao, 2000) compared with what would be necessary for acquiring literacy skills in an alphabetic orthography. This study shows that for early adolescent readers with dyslexia, attaining the acceptable levels of sensitivity to different homographs and the many homophonic morphemes for the purposes of skilled reading continues to be a great burden affecting both their reading and dictation skills (e.g., Shu et al., 2006; Chung et al., 2010). Even though literacy instruction in Hong Kong begins much earlier than in most other Chinese societies, difficulty in attaining levels of competence in reading could further be compounded by the fact that the traditional script the pre-readers are expected to learn is generally more complicated and contains much more visual information than the simplified script used in Mainland China (for details, see Wong et al., 2013; Kalindi et al., 2018). In general, the findings from this study indicate that the difficulty experienced by readers with dyslexia in morphological discrimination persists through the senior primary grades, as they still seem to have difficulty identifying and discriminating morphemes and in generalizing morpheme meaning. Together with findings from other studies (e.g., Shu et al., 2006; Liu and Zhu, 2016), the present findings indicate that persistent deficits in morphological awareness may largely affect the quality of semantic representations of morphemes, which, in turn, cause a vast number of homophonic and semantic errors in early adolescent readers with dyslexia. This is in line with what has been demonstrated in previous research (e.g., Xue et al., 2013; Liu and Zhu, 2016), that morphological awareness plays an important role in enhancing reading development not just for the early stages of acquiring reading skills (e.g., McBride-Chang et al., 2008) but more so across the grades.

Although our findings, in line with the study by Shu et al. (2006), highlight the critical role of morphological awareness with regard to literacy development and impairment among Chinese adolescents, it is worth noting differences such as the location of the study, methods of literacy instruction and the type of language and nature of the script to be learned (Cheung and Ng, 2003). These findings of the potential importance of morphological awareness in adolescence thus transcend script and literacy instruction method differences and call for further investigations into the likely importance of morphological awareness in other Chinese societies. The analyses of the current study demonstrated that morphological awareness uniquely explained literacy performance, and worth highlighting is that the two measures of morphological awareness both predicted Chinese word reading and dictation. This information might be useful in confirming the core cognitive-linguistic skills tapped into separately by the two morphological awareness tasks, i.e., morpheme discrimination and morpheme production.

Other Cognitive-Linguistic Skills Differentiating Between Early Adolescent Readers With Dyslexia and Typical Readers

We also observed some differences between those with dyslexia and the control group in other cognitive-linguistic skills. Besides the constructs of morphological awareness, our construct of rapid naming was strongly associated with both literacy tasks. Additionally, in line with previous studies (e.g., Chung et al., 2010, 2011), we observed that most adolescent readers with dyslexia were slower than the control group in rapid naming. The relatively arbitrary associations between print and sound in the Chinese script play a crucial role in Chinese reading development and impairment, thus making rapid naming important (e.g., McBride-Chang and Ho, 2000). Studies performed on Chinese children with dyslexia (e.g., Ho et al., 2002, 2004) indicate that rapid naming deficits are the most prominent of difficulties faced by Chinese readers with dyslexia. Consistent with the current findings, Chung and Ho (2010), Chung et al. (2010) found that rapid naming deficits continued to be among the dominant cognitive-linguistic deficits and a major difficulty experienced by adolescent Chinese readers with dyslexia. Additionally, the fact that rapid naming was uniquely associated with both word reading and dictation, even after controlling group membership and age, is noteworthy. This finding underscores, yet again, the importance of rapid naming in understanding the development of a wide range of reading-related skills in Chinese readers with and without dyslexia (Shu et al., 2006; Tong et al., 2009; Chung et al., 2011).

There were also substantial differences in the visual-orthographic knowledge of students with dyslexia and the control group. This construct of orthographic processing was moderately associated with Chinese character dictation in the group of adolescents with dyslexia. It is possible that adolescents with dyslexia could still be having difficulty with mastering knowledge of the Chinese orthographic structure as well as the radical positions. Indeed, considering that even typically developing children in Hong Kong have considerable challenges in acquiring comprehensive visual-orthographic knowledge of Chinese (e.g., Ho et al., 2004), it is likely that the problem could be even more pronounced for those with dyslexia. The generally complex traditional Chinese script used in Hong Kong likely compounds the visual-orthographic deficit problem among students with dyslexia. In line with previous research, the current data demonstrate that the visual-orthographic processing ability of early adolescents with dyslexia does not improve over time (e.g., Bruck, 1998). While a number of studies have also observed associations between visual-orthographic knowledge and literacy skills (e.g., Tong et al., 2009; Chung et al., 2011), the failure of visual-orthographic knowledge to predict literacy tasks has equally been reported in isolated cases (e.g., Liu and Zhu, 2016). In any case, the evidence of association calls attention to the importance of visual-orthographic knowledge in Chinese literacy development.

Although the constructs of vocabulary knowledge and verbal STM both significantly distinguished between the early Chinese adolescent readers with and without dyslexia, these constructs were not associated with the literacy measures for the control group or the group with dyslexia. The failure by the Verbal STM and vocabulary knowledge measures to be associated with literacy tasks is rather unexpected, considering the established importance of verbal STM (e.g., Zhang et al., 1998; Gathercole et al., 2004) and vocabulary knowledge (e.g., Shu et al., 2006) among Chinese readers. Considering that the observed effect sizes were relatively small and considering the lack of association between these constructs and the literacy measures, future studies should preclude this unexpected finding, perhaps by using a large sample size and including other measures, such as a backward digit span, for the verbal STM.

As for the measure of phonological awareness, it is unsurprising that it could neither differentiate between the two groups nor be associated with the literacy tasks (e.g., Ho et al., 2004; Chung et al., 2010) in the control group and the group with dyslexia. This is partly because a phonological awareness deficit has less frequently been reported compared to other cognitive-linguistic deficits, particularly for Hong Kong students with dyslexia. Also, considering the way that Hong Kong readers learn to read the characters using the whole word approach as opposed to the phonetic coding system used in Mainland China (reflecting the importance of phonological awareness, e.g., Shu et al., 2006), it is likely that phonemic awareness skills may not be well developed even for readers in upper primary school (Chung et al., 2010). Despite this finding among Hong Kong learners, previous studies have indicated the likely importance of phonological awareness in Chinese reading development among early learners (e.g., Ho and Bryant, 1997; McBride-Chang and Ho, 2000). Thus, more studies need to be conducted in order to shed more light on the nature of the association between phonological awareness and literacy skills in Chinese as well as the role of phonological awareness in the reading acquisition process of adolescent readers with and without dyslexia.

Limitations and Future Directions

There are a number of limitations to the present study. First, the tasks presented in this study only measured accuracy and did not limit the response time for the tasks. Since readers with dyslexia generally show poorer performance on tasks measuring speed of processing, it is likely data on their reaction time would have helped reveal cognitive-linguistic processing at the lexical level. Second, the data were limited to readers from Hong Kong. Considering the differences obtaining in various Chinese societies concerning the nature of the script used, i.e., traditional vs. simplified, as well as the different modes of literacy instruction adopted with Chinese learners in Hong Kong, Mainland China, and Taiwan, the extent to which our results are generalizable across Chinese societies remains unclear. Third, the present study showed that verbal STM, vocabulary knowledge, and phonological awareness appeared to be a less important feature in Hong Kong adolescent readers with dyslexia. This calls for further investigation where additional measures of a particular construct could be added, especially for verbal STM, as this would enhance understanding of the impairments of verbal working memory in relation to language skills. As regards phonological awareness, a further examination of the nature of phonological problems experienced by Chinese readers using a phonemic coding system may be worth exploring. Fourth, the current study had limited and specific sets of cognitive-linguistic skills that may not be comprehensive enough to enhance understanding of reading and writing problems in Chinese. Other cognitive-linguistic skills, such as syntactic skills, could be examined in future studies. Fifth, only students in relatively higher grades were included as participants, with all measures administered at a single time point. Inasmuch as our study established strong associations between morphological awareness and literacy skills, no causal links can be determined, hence the need for future studies to turn to the causal nature of this association through longitudinal studies.

Despite these limitations, the present study is valuable firstly because the findings are linked to the aims of this special issue. More importantly, it is among the few studies that have considered the potentially unique role of morphological awareness, among other cognitive-linguistic correlates, in distinguishing early adolescent Chinese readers with and without dyslexia. For Chinese early adolescent readers, with or without dyslexia, it appears that there is a somewhat natural reliance on morphological awareness for the acquisition of Chinese literacy skills. In addition to studies on younger (e.g., McBride-Chang et al., 2003) and older (e.g., Shu and Anderson, 1997) developing Chinese readers, the current findings demonstrate the need to further explore the concept of morphological awareness in understanding reading development and impairment for Chinese adolescent readers. Although studies of cognitive profiles distinguishing between Chinese readers with and without dyslexia have mostly been performed with children (e.g., Ho et al., 2002, 2004), the present study has revealed that readers with dyslexia in Chinese continue to display problems in reading and writing even when in upper primary school, indicating that dyslexia is a difficulty that persists chronically across all ages and scripts.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of Education Guidelines on Ethics Research, by the University's Institutional Review Board i.e., Human Research Ethics Committee of the Education University of Hong Kong, with written informed consent from all subjects. All subjects gave written informed consent in accordance with the Declaration of Helsinki. The protocol was approved by the Human Research Ethics Committee.

AUTHOR CONTRIBUTIONS

KC and SK both made substantial contributions to the design of the work, acquisition of the data, analysis, as well as the write-up of the manuscript.

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Spelling and Meaning of Compounds in the Early School Years through Classroom Games: An Intervention Study

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The study aimed to evaluate the intervention effects on spelling and meaning of compounds by Greek students via group board games in classroom settings. The sample consisted of 60 pupils, who were attending the first and second grade of two primary schools in Greece. Each grade-class was divided into an intervention ($N = 29$ children) and a control group ($N = 31$ children). Before intervention, groups were evaluated by standardized tests of reading words/pseudowords, spelling words, and vocabulary. Students were also assessed on compound knowledge by a word analogy task, a meaning task and a spelling task. The experimental design of the intervention included a pre-test, a training program, and a post-test. The pre- and post-assessments consisted of the spelling and the meaning tasks entailing equally morphologically transparent and opaque compounds. The training program was based on word families ($N = 10$ word families, 56 trained items, 5 sessions) and aimed to offer instruction of morphological decomposition and meaning of words. The findings showed that training was effective in enhancing the spelling and most notably the meaning of compounds. A closer inspection of intervention data in terms of morphological transparency, revealed that training group of first graders improved significantly both on transparent and opaque compounds, while the degree of gains was larger on opaque items for the second graders. These findings are consistent with the experimental literature and particularly optimistic for the literacy enhancement of typically developing children in regular classrooms.

Keywords: intervention, spelling, morphology, compounds, classroom games

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INTRODUCTION

Over the last decades, morphology has been receiving increasing attention among studies concerning children's literacy acquisition (Carlisle, 2003; Nunes and Bryant, 2006; Sénéchal and Kearnan, 2007; Berninger et al., 2010; Bowers et al., 2010; Kirby et al., 2012; Nagy et al., 2014). Various aspects of morphological processing has started to be an important aspect of linguistic enquiry. Morphological awareness has been acknowledged as an essential skill in language development for both typical and non-typical readers, while morphological instruction is recognized to be beneficial for the enhancement of reading, spelling, vocabulary, and reading comprehension of students, especially those with literacy difficulties (Deacon et al., 2006; Bowers et al., 2010; Goodwin and Ahn, 2010, 2013; Gilbert et al., 2013; McCutchen et al., 2014).

Compounding is one of the richest sources of word formation in everyday language and scientific terminology (Ralli, 2005; Scalise and Vogel, 2010). Longitudinal studies have demonstrated that children with typical development acquire simple compounds very early and in a fairly consistent developmental sequence (Nicoladis, 2006). In fact, children primarily begin to treat compound words as single units, and then gradually to understand that a compound may consist of two parts with a meaningful relation between them. However, as soon as literacy is well established and children are progressing to later stages of development, they start out to enrich their language via the compounding process (Berman, 2009).

Beyond these aspects, another significant factor that is thought to influence literacy performance is the level of morphological transparency of compounds. In particular, morphologically transparent words are considered those whose morphemic constituents remain intact during the transformation process (e.g., *blackboard*), thus they are usually visible to an inexperienced reader. Conversely, non-transparent or opaque words entail constituents which undergo a variety of phonological, orthographic or morpho-phonological changes during the word-formation process (e.g., *comprehend, agriculture*), resulting in an obscured internal structure that is not easily discernable by a novice reader. Research findings indicate that transparency affects literacy skills considerably, especially of those who are young children or students with literacy difficulties. In particular, transparent items evoke higher scores than opaque items in spelling and meaning of words, including morphologically complex items (Kuo and Anderson, 2006; Goodwin and Ahn, 2013; Goodwin et al., 2014).

Moreover, semantic transparency of compounds, where the meaning could not be conveyed directly by the two separate lexical bases (e.g., *roadside* vs. *butterfly*, see Brooks and Cid de Garcia, 2015) also affects the individual's word recognition. In addition, semantic transparency appears to be influenced by ambiguity in morpheme boundaries of a compound and modulated by word length. Recently, Lemhöfer et al. (2011) demonstrated that adult native speakers of Dutch showed a parsing sensitivity when reading long compounds containing a parsing cue, that is a bigram of consonants at the constituent boundary that would be illegal within a morpheme (e.g., *fiet**sb**el* [bicycle bell]), and not in the presence of a legal but ambiguous bigram (e.g., *fiet**sp**omp* [bicycle pump] can be read either as **fie**t**-**s**pomp*). On the contrary, bilingual adults of German-Dutch showed this sensitivity on both short and long compounds, a fact that was taken as an indication of a broader use of sub-lexical strategies in compound processing than that of native speakers (p. 365). Similarly, in a relevant study by Bertram et al. (2004) (also in Hyönä et al., 2012, p. 92), the same effect of the ambiguity on legal consonants within a morpheme boundary was found (i.e., when the consonant can either be the last letter of the first constituent or the first letter of the second constituent), but not in the unambiguous condition, where the initial consonant of the second constituent, cannot be the last one of the first constituent. It was also shown that gaze duration was longer when the two vowels at the constituent boundary of long compounds were of the same quality (e.g., *ryöst**öy**ritys* [robbery attempt]) rather than when they were of different quality (e.g., *selk**äo**ngelma* [back problem]), a fact which was regarded as an indication of parsing effects on long compounds (pp. 88–89).

However, these findings do not seem directly relevant for the Greek language, since morpheme boundaries of Greek compounds are rarely ambiguous, given that consonant bigrams that may follow the linking vowel /o/ should be phonologically legal. This process might be better understood by the fact that the most usual type of structure of Greek compounds are mainly stem-based, requiring the first constituent "*to be superficially bare, that is, an item without any suffixal material*" (Ralli, 2013, p. 134), which is mostly followed by the linking vowel /o/. This is true either for morphologically transparent or opaque items (e.g., ζωοτροφή [*zootrofi*/animal-food], αυγότσουφλο [*avɤotsuflo*–eggshell], see Appendix II in Supplementary Material), while the majority of compounds are typically long (more than eight letters) (see, Appendix II in Supplementary Material), since the majority of the constituents are at least of two syllables. Thus, although, Greek data is sparse on these aspects (Kehayia et al., 1999), it can be hypothesized that parsing may facilitate recognition of compounds, since segmentation cues are already available to readers. In any case, further research is needed on these important aspects of compound processing in Greek.

The focal point of this study is the investigation of compounds during the early school years. Although, Greek is acknowledged to be a regular orthography in terms of reading (Seymour et al., 2003), in terms of spelling is less transparent, since there are a few occasions with one-to-many phoneme–grapheme mappings, which are mainly rule governed. Since these spelling patterns are made comprehensible via the etymological and grammatical word features, spelling can be supported by a progressive acquisition of the rules based on morphology and lexical information (Porpodas, 2006). Moreover, Greek is a language with a rich morphology with lots of polysyllabic and morphologically complex words, while compounding is one of the central ways of word-formation (Ralli, 2005). More than 60,000 compounds are present in the language, usually forming multi-member word-families (Babiniotis, 2016). Compound acquisition, therefore, seems to be of major significance for the spelling and vocabulary development in Greek, even from the early school years, where children encounter an increased number of compounds in their school books (for instance, about 500 compounds are encountered in Grade 1 school books, and 800 compounds in Grade 2 school books).

Greek compounds are normally formed by placing a linking vowel (-o-) between the first and second constituent and are mostly right-headed. In terms of word structure, they are allocated into four main categories (Ralli, 2005, 2013): (i) Stem–Stem, where two lexical stems, along with a linking vowel (-o-) between them and an inflection in the end, form a compound (e.g., χρυσ+ό+ψαρ+ο */chris+o+psar+o/ gold fish*), (ii) Stem–Word, where a lexical stem and a word with the linking vowel (-o-) between them, form the compound (e.g., μελαν+ο+δοχείο/ *melan+o+ðocheio/ inkpot*), (iii) Word–Stem, where a word and a lexical stem with the compound's inflection are united together to form a compound (e.g., κατω+σέντον+ο/ *kato+senton+o/ undersheet*), and finally, (iv) Word–Word, where two words are united together without a linking vowel between them (e.g., ξανα+δουλεύω/ *xana+ðoulevo/ work again*). According to Ralli (2005, 2013), the majority of compounds in Greek fall in the first two categories, usually forming large word-families, while the other categories are minor and usually non-productive, especially the last one. Since both of the first categories are non-transparent compounds, it can be concluded that the majority of compounds in Greek are morphologically opaque compounds, where the main constituents of the compound are not easily visible to a novice reader, while the last category entailed compounds that are morphologically transparent, thus easily analyzed even by a novice native reader. Greek data in terms of transparency showed that children are also affected by transparency effects, causing noteworthy difficulties to those with impoverished spelling abilities (Rousoulioti, 2011). Given the effects of morphological knowledge to spelling, current research suggests that systematic and sequential instruction of morphology is necessary in the elementary school, even from the earliest years of schooling (Sénéchal and Kearnan, 2007; Reed, 2008).

According to recent theoretical accounts of literacy acquisition (Seymour and Duncan, 2001; Seymour et al., 2003; Duncan et al., 2013) acquisition of morphology in regular orthographies, such as Greek, typically occur earlier than in deep orthographies, such as English, after the grasp of grapheme–phoneme correspondences and the syllabic system of the language. Relevant evidence from other rather regular orthographies, such as French, suggests also an early development of morphological awareness in comparison with English (Casalis and Colé, 2009). According to Seymour and Duncan (2001, p. 296), Greek children can progress rapidly through the foundation and alphabetic phase and approach the morphographic phase, in which morphological structure of words is emphasized, with an inventory of well-defined syllabic units in place, whereas English children require up to 2 years of instruction in order to progress through the above phases. This is empirically true since Greek children typically are able to read and write by the end of their first year of schooling, while acquisition of the morphology is accelerated via the systematic instruction in Greek schools, which involves at least instruction on the inflectional system of the language. Thus, morphological training appears to be important even in the initial phase of literacy acquisition, since young children have to face a large amount of complex words, and learn from very early the complexities of the rich morphological system in Greek. Certainly, this varies in different orthographic systems depending on the nature and characteristics of the morphological system of each alphabetic language, beyond the differences in terms of their phonological system.

On the other hand, it could be argued that children as young as first graders may be too young to grasp the morphological principles. However, relevant data (Casalis and Colé, 2009; Lyster et al., 2016) shows that children are able to use these principles, providing that they are taught in a comprehensible way via multi-sensory methods and not by abstract rules. Besides, data from children with impoverished phonological skills appears to be benefitted from morphological instruction, even in their first grades. For instance, Casalis and Colé (2009) found that morphological awareness training may increase preschoolers' sensitivity to sounds, a finding which is also reported earlier on older children with phonological difficulties, such as dyslexic teenagers (Arnbak and Elbro, 2000; Tsesmeli, 2002). These findings give further support to morphological training studies with children, even at very early grades of schooling.

Intervention studies on morphological awareness carried out on early readers, even preschoolers, illustrate that young learners are responsive to morphological instruction. A recent study by Ramirez et al. (2014) investigated training effects on a sample of 108 kindergartners with different ability levels taken from six classes from schools of low socio-economical status. The intervention focused only on compounds with semantic and morpho-phonological transparency (i.e., *teapot*). Before training, children were assessed by a standardized vocabulary test, and also by another task where they were asked to produce 10 compounds in a story context, e.g., *"We call a house that is built in a tree, a tree house. What should we call a house that is built on a mountain?"* (p. 58). The intervention took place in classrooms within a 3 months period and included 24 sessions of 30 min each, where children were asked mostly orally to analyze compounds into their morphological constituents and to produce new ones from already known morphemes. The material based on 10 illustrated story-books entailed 10–15 compounds or pseudo-compounds per book (e.g., *Dino-Soccer*). Children were asked to analyze them into morphemes and think how to derive the words' meaning, or to produce new words (e.g., *Dinohouse*) via assorting pictures which illustrated concrete words (e.g., *house*) with already knows morphemes (e.g., *Dino*). Results showed that children significantly improved their morphological skills and vocabulary over a period of 3 months, with the greatest gains made by children with the lowest performance before the intervention. However, students of medium performance also improved and reached the levels of students of high performance. Moreover, the distance between those with low vocabulary skills and those with higher skills diminished, and it is possible that the intervention assisted in their enhanced performance on the vocabulary assessment. Authors concluded that morphological awareness and vocabulary skills were reciprocally related, which was indicated by the fact that morphological awareness made an independent contribution to the development of vocabulary and that vocabulary made an independent contribution to the development of morphological awareness (Ramirez et al., 2014). However, in this study there were no control groups, and no association with factors of emergent literacy skills.

In another recent study by Apel and Diehm (2014), the effectiveness of intervention on the morphological awareness and literacy skills on a group of 75 students who followed kindergarten ($n = 27$), Grade 1 ($n = 22$), Grade 2 ($n = 26$) was investigated, which compared with a control group of 76 students (kindergarteners = 27, Grade 1 = 21, Grade 2 = 28). The intervention included 32 sessions of 25 min for a period of 8 weeks and focused on awareness of affixes and the relations between base words and their inflected or derived forms. Students from experimental groups were taught in small groups at the school library. Intervention included the teaching of 11 inflectional (e.g., *-ing*) and derivational affixes (e.g., *-ness*) through a variety of educational activities. For instance, students should be able to identify the taught morphemes on target words and produce new words from the already taught morphemes. Findings showed that experimental groups across grades produced statistically significant gains in morphological awareness skills but non-significant gains in literacy skills (reading and reading comprehension), while the control groups did not show any increase in any of these skills. In particular, explicit morphological instruction benefited students with weak morphological awareness abilities at the beginning of the study, who reached their levels of their peers of typical morphological awareness abilities after the intervention.

In another study by Wolter and Dilworth (2014), there were investigated morphological training effects on 20 second grade children with spelling deficits allocated into two intervention groups: (i) a group trained in phonological and orthographic awareness activities, and (ii) a group trained in phonological, orthographic and morphological awareness activities. Morphological activities included mainly inflectional and derivational affixes. Findings of this study indicated that the morphological awareness intervention group increased its performance on standardized spelling, spelling of morphological patterns and a measure of reading comprehension, while there were no differences between the groups on spelling of orthographic patterns.

However, morphological facilitation is feasible not only on deep orthographies, as described above, but also to rather phonologically transparent orthographies, such as Norwegian or French. A recent study by Lyster et al. (2016) on Norwegian-speaking children suggest that early training in morphological awareness can have long-term effects on children's literacy skills. In particular, preschoolers divided into a phonology group ($N = 106$), a morphology group ($N = 127$), and a control group ($N = 36$) which participated in ordinary pre-school activities. Training for the two experimental groups lasted over 17 weeks' time. The phonology group participated in activities involving syllable and sound blending or matching words based on alliteration and rhyming. The morphology group received training on suffix and prefix identification on derivations as well as recognition of constituents of compounds (e.g., *'skoeske'/ shoe box*). Activities also entailed segmenting, deleting or changing the order of compound constituents to create new compounds. Findings showed that children who received morpheme training in preschool improved both reading comprehension and word reading at the end of Grade 1 in comparison with their control group. Most notably, the morpheme trained group exhibited better reading comprehension skills 6 years later, at Grade 6, than the control group, despite the fact that the children in this group had lower phonological skills compared with the control group children before intervention. Relevant findings on French pre-school children are coming from a training study by Casalis and Colé (2009). They found that morphological awareness can be successfully trained before formal schooling, although the training at a pre-school age did not produce significant transfer of learning results on first years' reading skills, possibly because, as authors stated, children were not involved in print exposure activities.

The above studies conducted mainly in English presented the experimental evidence that morphological training could be of an essential advantage to students of typical and non-typical development, even from the very early grades of schooling. While the main corpus of evidence is less extended to other alphabetical systems (Casalis and Colé, 2009; Tsesmeli, 2010; Lyster et al., 2016), apart from English, intervention studies in this field are still lacking, especially in phonologically regular languages, such as Greek.

The present study aims to examine the efficiency of training in the spelling and meaning of compound words by two experimental groups of young students of first and second grade, who are in the early stages of literacy acquisition. The study extends earlier intervention case-studies in Greek by Tsesmeli (2010) and Tsesmeli and Tsirozi (2015), since it would be important to see how training effects from individuals would be transferred to students of typical development in regular school classes (i.e., Nunes and Bryant, 2006). Moreover, an essential educational aim is to assist "*all children achieve their optimal levels*" (Ramirez et al., 2014, p. 54) in terms of literacy, and help children who are at risk of developing such difficulties to start from very early, due to the accumulative nature of these types of deficiencies (Ramirez et al., 2014). Also, research outcomes would be suggested for educational and school policy to evoke the wider transfer of learning effects.

The training was systematic and sequential and implemented via a variety of board games in small groups in the whole classroom, as being the most appropriate way to teach early learners at their first years of schooling (Brock et al., 2009). Main benefits were the multisensory learning via real objects, the promotion of visual coding strategies and the active participation of the students through recreational and learning targets of their content. The advantages of these multi-modal programs are that they can capture the student's interest, creating strong motivations for learning and knowledge acquisition (Kast et al., 2011). In the last decades, there have developed a variety of intervention programs for early readers aiming to train early literacy abilities, focusing mainly on the phonological processing of words (McCandliss et al., 2003; Brooks et al., 2007; Kast et al., 2011), and to a lesser extent to other linguistic abilities.

Main Hypotheses of the Study

The main hypotheses for the training study can be formulated as the following: (i) Each experimental group would enhance considerably the spelling performance of compounds after training, as an effect of the intervention (Tsesmeli, 2002; Nunes and Bryant, 2006; Tsesmeli and Seymour, 2009; Wolter and Dilworth, 2014); (ii) Transparent compounds are assumed to be spelled more successfully than opaque items (Carlisle, 1987; Kuo and Anderson, 2006; Goodwin et al., 2014; To et al., 2014) before the intervention, however, it is anticipated that the training would increase performance on compounds by each compound category (Tsesmeli and Seymour, 2009); (iii) Each experimental group would increase substantially the meaning performance of compounds after training, due to intervention (Bowers and Kirby, 2010; Ramirez et al., 2014); (iv) It will be investigated whether experimental groups would recognize the internal structure of the compounds to a greater extent after the intervention than the control groups (Anglin, 1993; Tsesmeli and Koutselaki, 2013); (v) Differences of training effects between spelling and meaning of compounds will also be assessed in order to be identified particular profiles for each experimental group (Tsesmeli and Koutselaki, 2013); (vi) Generalization effects will be finally evaluated based on the hypothesis that untrained pseudo-compounds of similar structure would induce transfer-of-learning effects (Wysocki and Jenkins, 1987; Nunes and Bryant, 2006) after intervention, since they include common stems with the trained items (Bowers and Kirby, 2010).

MATERIALS AND METHODS

Participants

Participants for the study were 60 students (34 males and 26 females) who were attending the first and the second grades of two primary schools in the prefecture of Achaia in Peloponnese, Greece. Students in each grade were already allocated to their regular classrooms situated in two different schools. A possible variation within classrooms in terms of cognitive/academic abilities is usual, since public schools in Greece accept children based mainly on chronological criteria. Since the basic aim of the study was to evaluate the possible efficiency of an intervention program to regular classes within the schools, no other selection criteria were applied to the groups. The choice in relation to which class of each grade would be the experimental group was based on the standardized measures of reading and spelling abilities (see the section The Preliminary Assessment) and teachers' motivation to participate in the training program. Thus, teachers who had in their classes more cases with lower performance than the mean, appear to be more willing to give their consent to the program. However, there were no students with a z-score above 1.50 SD on these skills, apart from two cases equally belonging to the experimental and control groups of Grade 1. These characteristics are presented in terms of groups in more detail[1] as follows:

(i) Grade 1-Experimental group ($N = 14$): They were students who participated in the training program with a mean chronological age of 6.48 years (sd: 0.47). Children's variation in terms of reading words (mean: −0.31, range: 1.72 to −1.45, sd: 1.07) and non-words (mean: −0.54, range: 1.21 to −1.60, sd: 0.77) based on z-scores on standardized measures of reading ability was within the normal range, while three children were at the lower normal limit (−1.45 SD) on both abilities, and only one child had a z-score of −1.60 SD on reading non-words.

(ii) Grade 1-Control group ($N = 15$): They were students who did not take part in any intervention study, apart from the regular classroom teaching, and had a mean chronological age of 6.40 years (sd: 0.46). Children's variation in terms of reading words (mean: 0.29, range: 1.72 to −1.84, sd: 0.85) and non-words (mean: 0.50, range: 1.56 to −1.07, sd: 0.93) based on z-scores on standardized measures of reading ability was within the normal range, while only one child had a z-score of −1.84 SD on reading words.

(iii) Grade 2-Experimental group ($N = 15$) entailed students who took part in the intervention and had a mean chronological age of 7.34 years (sd: 0.42). Children's variation in terms of spelling words (mean: −0.53, range: 0.61 to −1.40, sd: 0.63) and vocabulary acquisition (mean: −0.64, range: 0.60 to −1.40, sd: 0.63) based on z-scores on standardized measures of these skills was within the normal range, while three children were at the lower normal limit (−1.40 SD) on both abilities.

(iv) Grade 2-Control group ($N = 16$) consisted of students who did not participate in any intervention study, apart from the regular classroom teaching and had a mean chronological age of 7.32 years (sd: 0.42). Children's variation in terms of spelling words (mean: 0.50, range: 1.77 to −1.12, sd: 1.03) and vocabulary acquisition (mean: 0.60, range: 1.80 to −0.75, sd: 0.90) based on z-scores on standardized measures of these skills was within the normal range.

All students were Greek monolinguals of average socioeconomic background and they had no mental, hearing, visual, or serious health problems. Their participation was secured after parents' written consent in the study.

The Preliminary Assessment

All students, before initiation of the intervention, were given a series of standardized psychometric tests so as to evaluate their reading, spelling, and written vocabulary abilities. Grade 1 students were given only the standardized measures of reading ability, since there are no standardized tests in spelling and written vocabulary in Greek for this grade. Also, the standardized test of reading ability was not given to Grade 2 students, due to the possible ceiling effects for this age. These tests are exhibited as follows:

(a) *Reading ability of words/non-words* was evaluated by the Test of Reading Performance (TORP; Padeliadu and Sideridis, 2000) which is an untimed comprehensive test of reading ability in Greek. Each student had to read 40 single words derived from school reading books and structured by word frequency and ascending phonological difficulty. Next, every pupil had to decode 19 pseudowords of ascending phonological difficulty. Both reading tests were instructed individually to Grade 1 students at a quiet room within the school. Scoring was based on reading

[1] Both experimental and control groups entailed students of a wide range of scores in terms of reading, spelling and vocabulary skills. Variation in terms of centiles for reading words (RW): Experimental group: 8/14: 100°–50°, 6/14: 40°, Control group: 14/15: 100°–50°, 1/14: 30°. For reading non-words (RNW): Experimental group: 4/14: 70°–40°, 5/14: 30°, 5/14: 20°–10°. Control group: 10/15: 70°–40°, 3/15: 30°, 2/15: 20°. For spelling words (SW): Experimental group: 11/15: 90°–70°, 4/15: 25°, Control group: 15/16: 95°–70°, 1/15: 25°. For written vocabulary: Experimental group: 8/15: 75°–40°, 7/15: < 25°, Control group: 12/16: 98°–60°, 4/6: 40°. RW/RNW/SW centiles are based on a sample of about 600 children (Padeliadu and Sideridis, 2000; Mouzaki et al., 2007). Vocabulary centiles are based on a sample of about 2.500 children (Tafa, 1995).

accuracy in terms of target decoding and stress, without time constraints.

(b) *Spelling skills of words* was estimated by the Test of Spelling Ability by Mouzaki et al. (2007), which consists of 60 single words taken also from school books and ordered in terms of word length and increasing phonographic difficulty. Words were dictated in sentences to students of Grade 2 by their classroom teachers.

(c) *Understanding of written vocabulary* in written speech was assessed by the test of Tafa (1995) where each student had to complete 42 open-ended sentences by choosing the suitable word from a multiple choice scheme that fits in the sentence syntactically and semantically. Items were instructed to students of Grade 2 by their teachers in the classroom.

Table 1 presents the results of psychometric evaluation for the participants based on mean accuracy rates. The one-way analysis of variance between the experimental and control group of Grade 1 showed that their mean performance on reading single words [$F(1,28) = 2.885$, ns] did not differ with each other, while in terms of reading non-words, the experimental group had significantly lower performance than the control group [$F(1,28) = 10.896$, $p < 0.01$]. Similarly, analysis of variance between the two groups of Grade 2 showed that their mean performance on spelling single words [$F(1,30) = 11.368$, $p < 0.01$] and acquisition of written vocabulary [$F(1,30) = 19.231$, $p < 0.001$] differed significantly in favor of the control group.

Experimental Assessments

For the purpose of the study, three experimental tasks were developed. Experimental stimuli were chosen from Grades 1 and 2 school books after being selected from a large pool of compounds regarded to represent a wide range of morphological patterns found in school texts. Word analogy and the meaning tasks were delivered individually to students, while the spelling task was dictated to them by their teachers in classrooms. These are described in detail as follows:

(1) Word Analogy Task (*N* = 24/40 Items)

The task aimed to evaluate via word analogies the explicit awareness of oral production of compounds. The task entailed 24 items for Grade 1 and 40 items for Grade 2. All items in this task were equally divided in pairs of compounds. Participants had to discriminate compound transformations in the first word-pair and apply the same transformation to the second pair. Items involved morphologically transparent words ($n = 6$), morphologically opaque words ($n = 6$), compound words including bound stems of ancient Greek origin ($n = 4$), and prefixed compounds ($n = 4$). Examples of these items in the above categories are shown in Appendix I in Supplementary Material. The task was delivered orally via lap-top recordings by a native speaker and instructed to every student by the investigator. Every accurate response was given 1 point and every inaccurate was given 0 points.

(2) Spelling of Pair of Compounds (*N* = 60 Items)

Spelling of compounds was evaluated by a list of 60 items, equally divided in pairs of compounds. The items were also allocated to three categories in terms of transparency and lexicality of compounds, as follows: (i) pairs of transparent compounds ($n = 10$ pairs), where no change on the morphological constituents was apparent during the formation of compounds, (ii) pairs of opaque compounds ($n = 10$ pairs), where phonological, orthographic or both changes were present on the compound constituents during the word-formation process, (iii) pairs of legal pseudo-compounds ($n = 10$ pairs). which were formed by two real words, but their combination was a non-word. Pairs of compounds across the three above categories shared a common stem for helping generalization of learning within members of the same word-family. The teacher dictated to students the pairs of compounds. Students had to write down one compound to one column and the other compound to the other column of an A4 sheet. Every accurate spelling of compound was assigned 1 point and every wrong one was given 0 points. The items are given in Appendix II in Supplementary Material along with their word frequencies.

(3) Meaning of Compounds (*N* = 16 Items)

The experiment aimed to examine the semantic understanding of compounds. The task entailed 16 single compounds. Children were asked individually by the investigator about the meaning of each item, as follows: "*Could you, please, tell me what the word 'πιατοθήκη' /piatothiki/ dish-rack means*?" Every accurate response in terms of word meaning was assigned 1 point and every inaccurate response was given 0 points. The items are given along with their frequencies in Appendix III in Supplementary Material.

Children's responses were categorized in terms of their ability to explain etymologically—from a synchronic perspective—the meaning of the compound words as follows (Tsesmeli and Koutselaki, 2013):

(1) (Etymology+): Every answer entailing the morphological constituents of the target word and had an accurate meaning; (2) (Semantics+): Every answer without entailing the morphological

TABLE 1 | Psychometric data.

	Grade 1 Experimental	Grade 1 Control	Grade 2 Experimental	Grade 2 Control
Reading words	87.14 (6.78)	91.00 (5.41)		
Reading non-words	36.84 (23.17)	68.42 (27.92)		
Spelling words			28.97 (7.30)	40.38 (11.94)
Meaning words			39.95 (11.30)	62.00 (16.10)

Accuracy means (%) (standard deviations in parentheses).

constituents of the target word and had an accurate meaning; (3) (Etymology−): Every answer entailing the morphological constituents of the target word and had a wrong meaning; (4) (Semantics−): Every answer without entailing the morphological constituents of the target word and had a wrong meaning. An example of pupils' responses per each category is given in Appendix IV in Supplementary Material.

The Intervention Study

The experimental design of the study extends earlier studies by Tsesmeli and Seymour (2009) on English-speaking students and by Tsesmeli (2010) (see also, Tsesmeli and Tsirozi, 2015) on Greek-speaking children. These studies assessed acquisition of spelling either on derivations or on both inflections and derivations by typical and non-typical students who followed advanced stages of schooling. The experimental stimuli of this study are described in detail in the next section.

Experimental Stimuli

The study was based on the word-pair paradigm which was first introduced by Derwing (1976) as a way of evaluating the word relatedness in terms of meaning. In this study, each pair consisted of two compounds sharing a common stem and was used as an index of the application of morphological strategies in spelling. The items included in the Spelling task ($N = 60$ items) and the Meaning task ($N = 16$ items) were relevant with children's developmental stage of literacy and vocabulary acquisition in each case (see for the full description of items in section "Experimental tasks, 2 and 3"). For this reason, only semantically transparent compounds of two-constituents were included in the study, and the two constituents were words of Modern Greek. The mean word length of the compounds used in the Spelling task was 10.66 (compounds A: 10.33, compounds B: 11, see Appendix II in Supplementary Material), while the mean word length of the compounds in the Meaning task was 11.37.

For the purposes of the training study, the Spelling task was divided into two subsets of items: (i) Trained items ($n = 40$ items) entailed all the items used in the training program. Items were equally divided into pairs of compounds. Trained items were equally allocated to transparent and opaque items (ii) Untrained items ($n = 20$ items) consisted of pseudo-compounds which did not receive any instruction during the intervention study. These items, however, bear common stems with the relevant compounds, in order to facilitate transfer of learning effects from trained to untrained items.

The Meaning task entailed only compounds, which were a part of the lexical items of the Spelling task used for the training study. Generalization effects could not be evaluated as in Spelling, due to pseudo-compounds, since it is not always possible to define with precision the meaning of pseudo-compounds.

General Procedure of the Intervention Study

Table 2 presents the general procedure of the intervention study. Each study included two pre-tests (Spelling task and Meaning task), a training program and two post-tests (Spelling task and Meaning task). The procedure of the study lasted nine sessions for every grade, and was implemented by the investigator in the spring semester of the school year over a period of 3 months.

Assessments before and after the Teaching Program

All the items for each task (Spelling task and Meaning task) of the study were randomized to form the pre- and post-tests. The Spelling task was given to experimental and control groups by their teachers to the whole classrooms and lasted two sessions of about 40 min. Both compound words were instructed to dictation as a pair. The students had to write down the spellings on two A4 sheets marked with two separate columns, placing the one compound in the left column and the other compound in the right column.

The Meaning tasks were given individually to the student from each group (except the post-tests for the control groups, due to practical circumstances in terms of school access) by the investigator and lasted two sessions of about 40 min. Each child had to say the meaning of the word and the investigator wrote down their responses on a piece of paper. Children's definitions of compounds were scholastically written down by the investigator on a paper.

Training Program

The training program was implemented by the investigator in five sessions of about 2 h for each experimental group (10 h × 2 experimental groups). These separate teaching units involved instruction on five or six compounds which were assigned to a particular word-family (10 word-families). These families were present in children's school books. Each base word of the family was a phonologically opaque word, so as to permit spelling via the use of a morphological strategy, e.g., φύλλο */filo/ leaf.* This word if spelled phonetically should be written as φίλο */filo/ friend.* In addition, word-families were chosen as the most appropriate items, in order to allow young students to gain insight to every word-family through getting knowledge on the hierarchical relations among its members, and thus, understanding more deeply the way of word-formation and production process (Nunes and Bryant, 2006). Moreover, the training program was based on a systematic progression from transparent items, where the morphemic constituents of the compounds are easily visible to the early readers' eyes and then to non-transparent items,

TABLE 2 | General procedure of the intervention study.

Pre-tests	
1. Spelling compounds ($N = 60$ items)	G1, G2 experimental/ control
2. Meaning compounds ($N = 16$ items)	G1, G2 experimental
Intervention	
1. Training program (5 sessions × 2 h) ($N = 56$ compounds, 10 word families)	G1, G2 experimental
Post-tests	
1. Spelling compounds ($N = 60$ items)	G1, G2 experimental/ control
2. Meaning compounds ($N = 16$ pairs)	G1, G2 experimental

which are more difficult to be decomposed due to their obscure internal nature. In that way, children could move smoothly from transparent to opaque items, internalizing by practicing the internal structure of compounds using board games.

Hence, the program aimed to teach the students in a step by step way the internal structure of the compounds and how this is related to their spelling and meaning. Each session had a structural and sequential nature and was based on the active participation of the individuals in the classroom settings. More specifically, instruction was targeted toward two main principles: (i) word structure – every compound word is composed of two stems and a suffix; (ii) stem consistency – similar stems of the compounds are spelled identically and carry the same meaning. The sessions were divided into phases, referred to as the Segmentation, the Synthesis, the Spelling practice, the Meaning, and the Oral/Written production of compounds. The Segmentation phase included activities where the children had to analyze the compound word into its constituents, while in the Synthesis phase children were asked to blend two free or bound stems to form a compound word. During the Spelling practice, children should write down the stems of a compound word or the compounds themselves, and at the Meaning phase, children should explain the meaning of the compounds. Finally, during the Oral/Written production, children would produce orally or by writing as many compounds as they could, using the same base word as its main stem.

The control groups did not participate in any of the intervention activities of the training program. However, they attended the formal instructional program followed in schools. This involves a broad variety of activities for enhancing literacy (e.g., reading passages, learning to write small passages, exercises on grammar, vocabulary, etc.), but was not focused on compounds like the training study.

Materials and Procedure

All sessions of the training program were delivered through group work in the classroom. Each experimental group was divided in three to four smaller groups of three to four students each, depending on the class size. Each group was trained in compounding via 34 educational activities which were constructed by the investigator. The children would have to play as a group via a variety of educational activities such as playing with cards, plastic bricks, puzzles, dices, clock indicators, small boxes, or board games. The first sessions involved mostly segmentation and blending activities using real objects (e.g., bricks, cards, etc.), while the rest sessions included activities in spelling, meaning and oral/written production of compounds. In that way, each child could easily identify, via touching, the appropriate morphological constituents of the words, while the color and size of the objects enhanced the salience and clarity of the constituents of the compounds. Moreover, teaching sessions were analyzed with precision after intervention, giving in this way the appropriate feedback to the experimenter to reflect on the investigator's training and students' learning behavior. Students seemed to enjoy learning through the variety of board games used in the classroom.

RESULTS

Every accurate answer on spelling, meaning, and analogy tasks was assigned 1 point and every inaccurate answer 0 points. Mean percentage accuracy rates are used in every statistical analysis described in the following section.

Performance on Morphological Awareness, Spelling, and Meaning of Compounds

Table 3 shows accuracy rates for Morphological Awareness ($N = 24$ for Grade 1, $N = 40$ for Grade 2), Spelling ($N = 60$), and Meaning ($N = 16$) of compounds for the experimental and control groups of Grades 1 and 2. The significance of the difference of the means among the groups on analogy, spelling, and meaning tasks was tested by a 2 × 2 × 3 analysis of variance in which Grade (G1 and G2) and Group (Experimental and Control) were between-participants factors and Task (Analogy, Spelling, and Meaning) was a within-participants factor. This verified significant effects for Task [$F(2,112) = 24.177$, $p < 0.001$, $\eta^2_p = 0.302$] and Grade [$F(1,56) = 15.469$, $p < 0.001$, $\eta^2_p = 0.216$] but not for Group [$F(1,56) = 2.537$, $p = 0.117$, ns, $\eta^2_p = 0.043$]. Following a similar ANOVA between the spelling and meaning tasks showed that spelling accuracy scores were significantly lower than the meaning ones (Task: [$F(1,56) = 30.883$, $p < 0.001$, $\eta^2_p = 0.355$]), however, the significant interaction Task × Grade [$F(1,56) = 18.360$, $p < 0.001$, $\eta^2_p = 0.247$] indicated that this was the case only for the Grade 1. Grade effects were significant [$F(1,56) = 37.508$, $p < 0.001$, $\eta^2_p = 0.401$] but not Group effects [$F(1,56) = 0.563$, $p = 0.456$, $\eta^2_p = 0.010$]. Correspondingly, a comparable ANOVA between the spelling and analogy tasks showed significant effects for Task [$F(1,56) = 45.811$, $p < 0.001$, $\eta^2_p = 0.450$], revealing that spelling scores were significantly lower than the scores on the morphological awareness task, however, the significant interaction Task × Grade [$F(1,56) = 54.894$, $p < 0.001$, $\eta^2_p = 0.495$] indicated again that this result was valid only for the first grade students. Grade but not Group effects were significant (Grade: [$F(1,56) = 15.925$, $p < 0.001$, $\eta^2_p = 0.221$], Group: [$F(1,56) = 0.931$, $p = 0.339$, $\eta^2_p = 0.016$]). Finally, the ANOVA on the meaning and analogy tasks showed non-significant effects for Task [$F(1,56) = 0.083$, $p = 0.775$, $\eta^2_p = 0.001$] and Grade [$F(1,56) = 0.772$, $p = 0.383$, $\eta^2_p = 0.014$], suggesting comparable performance on the morphological awareness and meaning of compounds by two grades. Group effects were significant [$F(1,56) = 6.672$, $p < 0.05$, $\eta^2_p = 0.106$],

TABLE 3 | Spelling, Meaning, and Analogy tasks.

	Spelling	Meaning	Word Analogy
G1- Experimental group	40.57 (11.34)	57.10 (27.54)	66.03 (17.73)
G1- Control group	34.18 (16.11)	72.18 (13.61)	73.85 (16.91)
G2- Experimental group	69.18 (18.70)	70.54 (13.00)	61.00 (18.34)
G2- Control group	68.81 (15.94)	74.23 (09.59)	74.06 (17.24)

Accuracy means (%) (standard deviations in parentheses).

indicating better analogy scores on behalf of the control groups from both grades.

Training Effects for Spelling Compounds

Table 4 shows accuracy rates for pre- and post-tests of the intervention study for the groups along with their gain scores on lexical compounds ($N = 40$). The significance of the difference of the means among the groups was tested by a repeated measures 2 × 2 × 2 analysis of variance in which Grade (G1 and G2) and Group (Experimental and Control) were between-participants factors and Time (Pre-test and Post-test) was a within-participants factor. This verified significant effects for Time [$F(1,56) = 17.711$, $p < 0.001$, $\eta_p^2 = 0.240$], Grade [$F(1,56) = 36.710$, $p < 0.001$, $\eta_p^2 = 0.396$], and Group [$F(1,56) = 6.158$, $p < 0.05$, $\eta_p^2 = 0.099$]. Since the interactions Time × Grade [$F(1,56) = 15.914$, $p < 0.001$, $\eta_p^2 = 0.221$] and Time × Group [$F(1,56) = 20.163$, $p < 0.001$, $\eta_p^2 = 0.265$] were significant, further analyses were followed to disentangle these effects. In particular, to evaluate differences between the experimental and control group of Grade 1, a 2 (G1-Experimental and G1-Control) × 2 (Pre- and Post-) ANOVA showed significant effects for Time [$F(1,27) = 23.483$, $p < 0.001$, $\eta_p^2 = 0.465$] and the interaction Time × Group [$F(1,27) = 5.191$, $p < 0.05$, $\eta_p^2 = 0.161$]. Further pairwise t-tests per each group showed that the experimental group of Grade 1 enhanced significantly its spelling of compounds [$t(13) = -5.472$, $p < 0.001$], as an effect of the intervention, while the control group of the same grade did not present any significant change [$t(14) = -1.710$, $p = 0.109$]. On the other hand, a 2 (G2-Experimental and G2-Control) × 2 (Pre- and Post-) ANOVA between the experimental and control group of the Grade 2 showed non-significant effects for Time [$F(1,29) = 039$, $p = 0.845$, $\eta_p^2 = 0.001$], while the interaction Time × Group [$F(1,29) = 21.178$, $p < 0.001$, $\eta_p^2 = 0.422$] was significant. Pairwise t-tests per each group showed that the experimental group of Grade 2 presented a significant improvement [$t(14) = -3.942$, $p < 0.01$], due to the intervention, while the control group of the same grade presented a significant fall of its performance [$t(15) = 2.817$, $p < 0.05$]. Finally, developmental differences were also significant between experimental groups of Grades 1 and 2 [$F(1,27) = 13.077$, $p < 0.01$, $\eta_p^2 = 0.326$] and between control groups of the same grades [$F(1,29) = 25.073$, $p < 0.001$, $\eta_p^2 = 0.464$]. To summarize, these results showed that the two experimental groups improved significantly their spelling performance on trained compounds due to their participation in the training program, while the two control groups did not improve significantly their performance on these items.

TABLE 4 | Spelling lexical compounds.

	Pre-test	Post-test	Gains
G1- Experimental group	40.89 (12.92)	58.92 (17.61)	18.03
G1- Control group	33.00 (15.21)	39.50 (17.40)	6.50
G2- Experimental group	68.83 (20.52)	76.83 (18.95)	8.00
G2- Control group	68. 90 (17.02)	61.56 (19.23)	−7.34

Accuracy means (%) (standard deviations in parentheses).

Training Effects for Spelling Compounds in Terms of Transparency

Figure 1 shows accuracy rates for pre- and post-tests of the intervention study for the groups on transparent ($N = 20$) and opaque lexical compounds ($N = 20$). The significance of the difference of the means among the groups was tested by a 2 × 2 × 4 analysis of variance in which Grade (G1 and G2) and Group (Experimental and Control) were between-participants factors and Transparency (Transparent pre-, Transparent post-, Opaque pre-, and Opaque post-) was a within-participants factor. This revealed significant effects for Transparency [$F(3,168) = 9.341$, $p < 0.001$, $\eta_p^2 = 0.143$], Group [$F(1,56) = 6.158$, $p < 0.05$, $\eta_p^2 = 0.099$], and Grade [$F(1,56) = 36.710$, $p < 0.001$, $\eta_p^2 = 0.396$]. The interactions Transparency × Group [$F(3,168) = 10.684$, $p < 0.001$, $\eta_p^2 = 0.160$] and Transparency × Grade [$F(3,168) = 10.634$, $p < 0.001$, $\eta_p^2 = 0.160$] were also significant, hence further analyses were followed to reveal these differences.

In particular, for Group effects, first a 2 (G1-Experimental and G1-Control) × 4 (Transparent pre-, Transparent post-, Opaque pre-, and Opaque post-) ANOVA between the experimental and control groups of Grade 1 was pursued. The analysis showed significant training effects for Transparency [$F(3,81) = 14.469$, $p < 0.001$, $\eta_p^2 = 0.349$], Transparency × Group [$F(3,81) = 3.993$, $p < 0.05$, $\eta_p^2 = 0.129$], and Group [$F(1,27) = 6.528$, $p < 0.05$, $\eta_p^2 = 0.195$]. A separate ANOVA only between pre- and post-test scores on transparent items, it was found that training effects was significant [$F(1,27) = 24.316$, $p < 0.001$, $\eta_p^2 = 0.474$] as well as the interaction Transparency × Group [$F(1,27) = 8.298$, $p < 0.01$, $\eta_p^2 = 0.235$], while the pairwise t-tests per each group showed

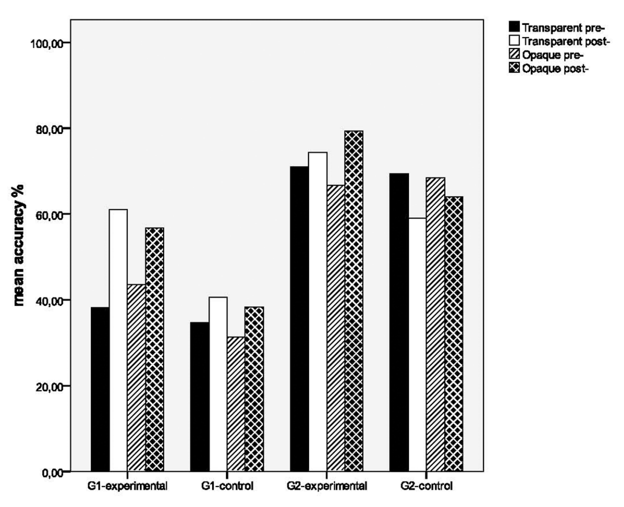

FIGURE 1 | Transparency effects on lexical compounds for the experimental and control groups.

that the experimental group of Grade 1 enhanced significantly its spelling performance on transparent items, as an effect of training [$t(13) = -5.223$, $p < 0.001$], while the control group did not present any significant change between the two testing points [$t(14) = -1.535$, $p = 0.147$]. Accordingly, a similar ANOVA between pre- and post-test scores on opaque items revealed significant training effects [$F(1,27) = 12.640$, $p < 0.01$, $\eta_p^2 = 0.312$], while the interaction Transparency × Group [$F(1,27) = 1.195$, $p = 0.284$, $\eta_p^2 = 0.042$] was not significant. The pairwise t-tests per each group showed that experimental group of Grade 1 improved significantly its spelling scores on opaque items, due to training [$t(13) = -3.509$, $p < 0.01$], while the control group did not present any significant change [$t(14) = -1.659$, $p = 0.119$].

Secondly, a 2 (G2-Experimental and G2-Control) × 4 (Transparent pre-, Transparent post-, Opaque pre-, and Opaque post-) ANOVA between the experimental and control groups of Grade 2 was conducted. This showed non-significant effects for Transparency [$F(3,87) = 2.398$, $p = 0.073$, $\eta_p^2 = 0.076$] and Group [$F(1,29) = 1.324$, $p = 0.259$, $\eta_p^2 = 0.044$], but not for Transparency × Group [$F(3,87) = 8.991$, $p < 0.001$, $\eta_p^2 = 0.237$]. A separate ANOVA only between pre- and post-test scores on transparent items, it was found that training effects was not significant [$F(1,29) = 1.916$, $p = 0.177$, $\eta_p^2 = 0.062$], while the interaction Transparency × Group [$F(1,29) = 7.326$, $p < 0.05$, $\eta_p^2 = 0.202$] was significant. The pairwise t-tests per each group showed that the experimental group of Grade 2 presented a small non-significant change [$t(14) = -1.214$, $p = 0.245$] on transparent items, while the control group exhibited a significant fall between the two testing points [$t(15) = 2.488$, $p < 0.05$]. Accordingly, a similar ANOVA between pre- and post-test scores on opaque items revealed significant training effects [$F(1,29) = 4.696$, $p < 0.05$, $\eta_p^2 = 0.139$], while the interaction Transparency × Group [$F(1,29) = 19.836$, $p < 0.001$, $\eta_p^2 = 0.406$] was also significant. The pairwise t-tests per each group showed that the experimental group of Grade 2 improved significantly its spelling scores on opaque items, due to training [$t(14) = -4.750$, $p < 0.001$], while the control group did not present any significant change [$t(15) = 1.600$, $p = 0.130$]. Developmental differences were apparent between the experimental groups of Grades 1 and 2 [$F(1,27) = 13.077$, $p < 0.01$, $\eta_p^2 = 0.326$] and between the control groups of the same grades [$F(1,29) = 25.073$, $p < 0.001$, $\eta_p^2 = 0.464$]. To conclude, the above results showed that the experimental group of Grade 1 improved significantly its spelling performance on transparent and opaque compounds due to the intervention, while the experimental group of Grade 2 enhanced significantly its performance only on spelling opaque items. By contrast, the two control groups did not improve their performance on spelling these items.

Training Effects for Meaning Lexical Compounds

Table 5 shows accuracy rates for pre- and post-tests of the intervention study for the two experimental groups along with their gain scores on total items ($N = 16$ items). The significance of the difference of the means between the two experimental groups was tested by a 2 × 2 ANOVA in which Grade (G1-Experimental and G2-Experimental) was a between-participants factor and Time (Pre-test and Post-test) was a within-participants factor. This verified significant effects for Time [$F(1,27) = 46.209$, $p < 0.001$, $\eta_p^2 = 0.631$], while the interaction Time × Grade [$F(1,27) = 0.724$, $p = 0.402$, $\eta_p^2 = 0.026$] was not significant. In particular, pairwise t-tests per each group showed that the experimental group of Grade 1 [$t(13) = -3.998$, $p < 0.01$], as well as the experimental group of Grade 2 [$t(14) = -8.008$, $p < 0.001$] enhanced significantly their meaning performance, as an effect of the intervention. Group effects [$F(1,27) = 4.888$, $p < 0.05$, $\eta_p^2 = 0.153$] were significant, verifying that Grade 2 had higher accuracy scores at both testing points than Grade 1.

Qualitative Analysis of Meaning Scores

In the next section, in order to explore further how far the experimental groups would understand the compound structure, children's data from the meaning task were categorized across four categories in terms of whether they use etymological information at their definitions of these words (see "Meaning of Compounds"). **Table 6** shows this performance of the two groups on the semantic categories in terms of etymology. The significance of the difference of the means among the meaning categories on the accurate responses of the two groups was tested by an ANOVA in which the Meaning category on positive answers (Pre-Etymology+, Post-Etymology+, Pre-Semantics+, and Post-Semantics+) was a within-participants factor and Grade (G1-experimental and G2-experimental) was a between-participants factor. The analysis showed significant effects for the Meaning categories [$F(3,81) = 97.829$, $p < 0.001$,

TABLE 5 | Meaning of lexical compounds.

	Pre-test	Post-test	Gains
G1- Experimental group	57.10 (27.52)	84.80 (8.73)	27.70
G2- Experimental group	70.54 (13.00)	92.05 (6.01)	21.51

Accuracy means (%) (standard deviations in parentheses).

TABLE 6 | Meaning categories (%).

		G1- Experimental	G2- Experimental
Etymology+	pre-	27.07 (12.89)	34.32 (11.66)
	post-	74.55 (14.80)	78.33 (11.29)
	gains	47.48	44.01
Semantics+	pre-	03.17 (3.20)	38.51 (7.11)
	post-	12.05 (13.07)	15.83 (10.59)
	gains	8.88	−22.68
Etymology−	pre-	12.16 (12.44)	11.11 (8.51)
	post-	11.60 (8.44)	5.41 (3.99)
	gains	−0.56	−5.7
Semantics−	pre-	5.02 (7.35)	16.04 (7.62)
	post-	1.78 (3.82)	0.00 (0.000)
	gains	−3.24	−16.04

(Standard deviations in parentheses).

$\eta_p^2 = 0.784$], while the interaction Categories × Grade [$F(3,81) = 13.881$, $p < 0.001$, $\eta_p^2 = 0.340$] and Grade [$F(1,27) = 4.340$, $p < 0.05$, $\eta_p^2 = 0.138$] were also significant, indicating that the two grades improved significantly their performance on the Etymology and Semantics category, as an effect of the intervention. Accordingly, the significance of the difference of the means among the categories on the inaccurate responses of the same groups was also tested by a similar analysis of variance in which the Meaning category on negative answers (Pre-Etymology-, Post-Etymology-, Pre-Semantics-, and Post-Semantics-) was a within-participants factor. The analysis showed significant training effects for the Meaning categories [$F(3,81) = 11.062$, $p < 0.001$, $\eta_p^2 = 0.291$], while the interaction Categories × Grade [$F(3,81) = 3.534$, $p < 0.05$, $\eta_p^2 = 0.116$] and Grade [$F(1,27) = 4.340$, $p < 0.05$, $\eta_p^2 = 0.138$] were also significant, indicating that the two grades decreased significantly their meaning errors due to the intervention. The above results verified that both experimental grades increased substantially their accurate etymological responses after intervention, with a parallel decrease of the relevant errors, thus suggesting a considerable improvement at their understanding of the morphological structure of the compounds.

Training Effects on Spelling and Meaning Lexical Compounds

Figure 2 illustrates the spelling and meaning performance of the two experimental groups on the lexical compounds for the pre- and post-tests of the intervention study, since the two tasks share partly identical items (e.g., πιατοθήκη [*piatothiki*-dishrack]) and partly items with a common morpheme (λαχανό<u>φυλλο</u> [*lachano<u>filo</u>*-cabbage-leaf] for spelling, μαρουλό<u>φυλλο</u> [*marulo<u>filo</u>*-lettuce-leaf] for meaning) (see, Appendices II and III in Supplementary Material). The significance of the difference of the means between the spelling and meaning of the compounds was tested by a 2 × 2 × 2 ANOVA in which Grade (G1-experimental and G2-experimental) was a between-participants factor and the Time (Pre- and Post-) and the Task (Spelling and Meaning) were the two within-participants factors. This verified significant effects for Time [$F(1,27) = 84.956$, $p < 0.001$, $\eta_p^2 = 0.759$], while the interaction Time × Grade was marginally non-significant [$F(1,27) = 3.935$, $p = 0.058$, $\eta_p^2 = 0.127$], indicating significant training effects for the two tasks. Significant effects were revealed also for the Task [$F(1,27) = 17.777$, $p < 0.001$, $\eta_p^2 = 0.397$], while the interaction Task × Grade [$F(1,27) = 14.727$, $p < 0.01$, $\eta_p^2 = 0.353$] was not significant, indicating that meaning performance was significantly higher than spelling for both experimental groups. The interaction Time × Task was also significant [$F(1,27) = 7.997$, $p < 0.01$, $\eta_p^2 = 0.229$], suggesting that training effects were stronger for meaning than for spelling for both experimental groups as indexed by the non-significant interaction Time × Task × Group [$F(1,27) = 0.223$, $p = 0.641$, $\eta_p^2 = 0.008$]. Developmental effects in favor of Grade 2 were present as shown by the significant Group effect [$F(1,27) = 14.727$, $p < 0.01$, $\eta_p^2 = 0.353$].

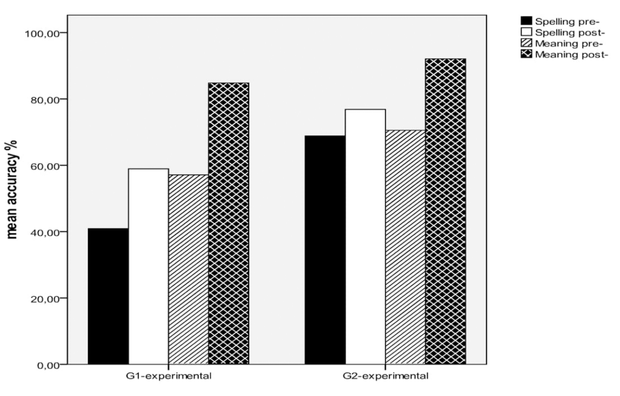

FIGURE 2 | Spelling and Meaning training effects on lexical compounds for the experimental groups.

Generalization Effects for Spelling Pseudo-Compounds

The generalization of learning was tested by comparing pre- and post-test results for the untrained pseudo-compounds who bear, however, similar bound stems with the trained ones, to facilitate transfer of learning from trained to untrained items. **Table 7** shows accuracy rates for pre- and post-tests of the intervention study for the groups along with their gain scores on untrained pseudo-compounds ($N = 20$). The significance of the difference among the groups was tested by a 2 × 2 × 2 analysis of variance in which Grade (G1 and G2) and Group (Experimental and Control) were between-participants factors and Time (Pre-test and Post-test) was a within-participants factor. This verified significant effects for Time [$F(1,56) = 4.154$, $p < 0.05$, $\eta_p^2 = 0.069$] and Grade [$F(1,56) = 40.990$, $p < 0.001$, $\eta_p^2 = 0.423$], but not for Group [$F(1,56) = 1.786$, $p = 0.187$, $\eta_p^2 = 0.031$]. The interaction Time × Group [$F(1,56) = 3.045$, $p = 0.086$, $\eta_p^2 = 0.052$] was not significant. Since only the interaction Time × Grade was significant [$F(1,56) = 4.378$, $p < 0.05$, $\eta_p^2 = 0.073$], two separate 2 (G1-experimental and G2-experimental) × 2 (Pre- and Post-) and 2 (G1-control and G2-Control) × 2 (Pre- and Post-) ANOVAs were performed. The first one between the two experimental groups showed significant effects for Time [$F(1,27) = 10.660$, $p < 0.01$, $\eta_p^2 = 0.283$] and the interaction Time × Group [$F(1,27) = 6.328$, $p < 0.05$, $\eta_p^2 = 0.190$] indicating significant generalization

TABLE 7 | Spelling pseudo-compounds.

	Pre-test	Post-test	Gains
G1- Experimental group	40.00 (12.55)	52.85 (17.39)	12.85
G1- Control group	36.66 (20.32)	39.66 (21.16)	3.00
G2- Experimental group	70.00 (17.11)	71.66 (17.79)	1.66
G2- Control group	68. 75 (17.17)	66.87 (18.33)	−1.88

Accuracy means (%) (standard deviations in parentheses).

effects which differed between the two experimental groups. Hence, the pairwise t-tests on these two groups showed that the experimental Grade 1 generalized significantly to untrained pseudo-compounds [$t(13) = -3.229$, $p < 0.01$], while the experimental Grade 2 did not achieve to generalize to the non-lexical items [$t(14) = -0.770$, $p = 0.454$]. Accordingly, the second analysis between the two control groups showed non-significant generalization effects [$F(1,29) = 0.033$, $p = 0.856$, $\eta_p^2 = 0.001$] for both groups as indexed by the non-significant interaction Time × Grade [$F(1,29) = 0.629$, $p = 0.434$, $\eta_p^2 = 0.021$]. Developmental effects in terms of spelling pseudo-compounds were significant for both experimental [$F(1,27) = 18.507$, $p < 0.001$, $\eta_p^2 = 0.407$] and control groups [$F(1,29) = 22.833$, $p < 0.001$, $\eta_p^2 = 0.441$], suggesting that first graders spelled better these items than the second graders. As a conclusion, the main outcome is that only the experimental group of Grade 1 generalized significantly its spelling performance on untrained pseudo-compounds due to the intervention, while the experimental group of Grade 2 and the two control groups did not improve their performance on spelling these items.

Generalization Effects for Spelling Pseudo-Compounds in Terms of Transparency

Figure 3 shows accuracy rates for pre- and post-tests of the intervention study for the groups on transparent ($N = 10$) and opaque ($N = 10$) pseudo-compounds. The significance of the means difference among the groups was tested by a 2 × 2 × 4 analysis of variance in which Grade (G1 and G2) and Group (Experimental and Control) were between-participants factors and Transparency (Transparent pre-, Transparent post-, Opaque pre-, and Opaque post-) was a within-participants factor. This verified significant effects for Transparency [$F(3,168) = 5.682$, $p < 0.01$, $\eta_p^2 = 0.092$] and Grade [$F(1,56) = 40.990$, $p < 0.001$,

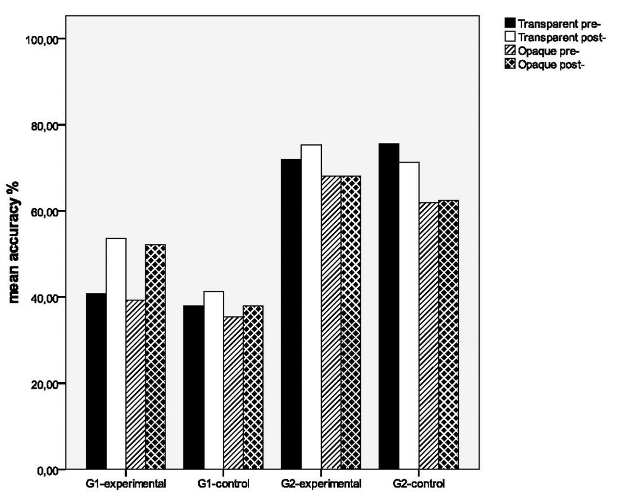

FIGURE 3 | Transparency effects on pseudo-compounds for the experimental and control groups.

$\eta_p^2 = 0.423$], while Group effects [$F(1,56) = 1.786$, $p = 0.187$, $\eta_p^2 = 0.031$], as well as the interaction Transparency × Group [$F(3,168) = 1.990$, $p = 0.117$, $\eta_p^2 = 0.034$] were not significant. Since the interaction Transparency × Grade [$F(3,168) = 3.369$, $p < 0.05$, $\eta_p^2 = 0.057$] was significant, further separate for each grade 2 × 4 ANOVAs were performed. In detail, the first one between the two experimental groups of Grades 1 and 2 showed significant generalization effects for Transparency [$F(3,81) = 4.665$, $p < 0.01$, $\eta_p^2 = 0.147$], while the interaction Transparency × Grade [$F(3,81) = 2.579$, $p = 0.059$, $\eta_p^2 = 0.087$] was marginally significant. An exploration of these differences via the pairwise t-tests per each group showed that the experimental group of Grade 1 generalized significantly its spelling performance to transparent [$t(13) = -2.857$, $p < 0.05$] and opaque pseudo-compounds [$t(13) = -2.482$, $p < 0.05$], while the experimental group of Grade 2 did not present any generalization effects neither to transparent [$t(14) = -1.160$, $p = 0.265$] nor to opaque items [$t(14) = 0.000$, $p = 1.000$]. Besides, the second ANOVA between the two control groups of Grades 1 and 2 showed significant generalization effects for Transparency [$F(3,87) = 3.177$, $p < 0.05$, $\eta_p^2 = 0.099$], while the interaction Transparency × Grade [$F(3,87) = 1.518$, $p = 0.216$, $\eta_p^2 = 0.050$] was not significant. This was also verified by the pairwise t-tests that showed that both control groups did not generalize neither to transparent [G1, $t(14) = -0.564$, $p = 0.582$, G2, $t(15) = 1.000$, $p = 0.333$], nor to opaque items [G1, $t(14) = -0.541$, $p = 0.597$, G2, $t(15) = -0.115$, $p = 0.910$]. Grade effects were significant for both experimental [$F(1,27) = 18.507$, $p < 0.001$, $\eta_p^2 = 0.407$] and control groups [$F(1,29) = 22.833$, $p < 0.001$, $\eta_p^2 = 0.441$], indicating developmental differences in the accuracy spelling scores on pseudo-compounds between the groups. To finalize, these results showed that the experimental group of Grade 1 generalized significantly its spelling on transparent and opaque pseudo-compounds due to the intervention, but the experimental group of Grade 2 and the two control groups did not show generalization effects to any of these items.

DISCUSSION

The study aimed to evaluate the intervention effects on spelling and semantic understanding of compounds by Greek students in their first years of schooling via a rich variety of educational activities in classroom settings. The intervention study extends earlier case-studies by Tsesmeli and Seymour (2009) on English-speaking students and Tsesmeli (2010; Tsesmeli and Tsirozi, 2015) on Greek-speaking students who followed advanced grades of schooling on inflectional and derivational items, and confirmed the main hypotheses and aims of the study.

Before the commencement of the study, findings from the experimental tasks on spelling, meaning and morphological awareness showed that first grade students exhibited lower performance on spelling compounds than on their semantic understanding, while their ability to produce new compounds based on given ones via analogy was at the same level with their meaning scores. The three tasks did not differ significantly for the second graders. Developmental differences on experimental groups were evident between first and second graders only for spelling (40.57% vs. 69.18%), while for meaning (57.10% vs. 70.54%) and morphological awareness of compounds (both over 60%), differences between the grades were not significant. These results are in line with another study's findings in relation to compounds by Tsesmeli and Koutselaki (2013) on typically developing Greek students throughout schooling, that showed that semantic understanding of words significantly precedes spelling of words.

Findings from the intervention study on spelling lexical compounds showed that the two experimental groups following the first and second grades was enhanced their spelling performance considerably after the intervention, due to their participation in the training program. In particular, students of the experimental group of Grade 1 improved their mean spelling scores on morphologically complex words up to 58.92% (gains: 18.03) during a short program of 10 h over 2 week's via enjoyable classroom activities. The main training effect was significant, indicating that the change of the experimental group of Grade 1 due to training was significantly higher, if compared with their control group of the same grade. On the other hand, the experimental group of Grade 2 students presented a change, which was much smaller than the relevant group of Grade 1 students (up to 76.83%, gains: 8.00), possibly due to ceiling effects. Change of Grade 2 was also a significant one in comparison with their control group, which exhibited an opposing pattern, since it decreased significantly its performance, possibly due to lack of motivation at the re-test session. Developmental effects on spelling accuracy levels were significant for both the experimental and the control groups, as expected. These results are in line with experimental literature (Nunes and Bryant, 2006; Tsesmeli and Seymour, 2009; Bowers et al., 2010) extending findings from children at later stages of literacy but on other types of morphologically complex words, i.e., inflections and derivations. Moreover, they corroborate relevant data from other intervention studies on early readers, such as kindergarteners and first and second graders (Casalis and Colé, 2009; Apel and Diehm, 2014; Ramirez et al., 2014; Wolter and Dilworth, 2014; Lyster et al., 2016) and lead to a confident conclusion that it is feasible to train children at a very early age in such complex and demanding vocabulary, as the compounds, in the natural environment of a common school class.

A notable query here is how spelling performance is varied among different types of items in terms of morphological transparency. The data from lexical compounds showed that, before the beginning of the study, first grade students from the experimental group had about the same performance on transparent (38.21%) and opaque (43.57%) compounds, however, after intervention, they attempted to increase significantly both types of items, with the increase being more profound on transparent items (gains: 22.86 vs. 13.21 for opaque items). The contrasting profile was shown for second grade students from the experimental group. In particular, before the beginning of the study, while they had, as first graders, comparable performance on transparent (71%) and opaque (66.66%) compounds, they attempted to present a significant change only on opaque items (gains: 12.67 vs. 3.33, transparent items) after training. On the contrary, neither control groups showed any significant improvement either on transparent or on opaque compounds. These unexpected findings indicate weak transparency effects prior intervention, contrary to experimental evidence (Kuo and Anderson, 2006; Goodwin and Ahn, 2013; Goodwin et al., 2014), however, first and second grade young readers attempted to make significant gains either on transparent or opaque items accordingly, after internalizing word-formation rules during training.

These results are not easily interpretable, however, it can be hypothesized that the choice of task stimuli might affected spelling performance. In particular, both transparent and opaque compounds were chosen to belong to the same word family, which means that they had a common constituent (the base word of the family), in order to facilitate progressive learning from transparent to non-transparent items by young readers. This might resulted to comparable spellings (e.g., transparent: 'λαχανόφυλλο' [*lachanofilo*–cabbage-leaf] vs. opaque: αμπελόφυλλο [*abelofilo*–vine-leaf], see Appendix II in Supplementary Material for their constituents) that evoked comparable spelling scores. In addition, the degree of transparency in these sets of compounds is much smaller in comparison with compounds entailing bound morphemes from Ancient Greek (see, Appendix I in Supplementary Material) where its internal structure is really obscured and it is not easily discernable by a young reader. These words were not chosen to be stimuli of an early intervention as not at all appropriate for very young readers. However, in the later case, the transparency effects on spelling would be expected to be strong, as indicated by Greek data on older students (Tsesmeli, 2008; Rousoulioti, 2011). In any case, further research is needed for this important aspect of compounding, along with other psycholinguistic features such as semantic transparency, compound frequency and prosody, as shown in recent literature (Lemhöfer et al., 2011; Koester, 2014).

Another important issue that should be addressed at this point, is training effects in relation to semantic understanding of morphologically complex items. In particular, although both experimental groups had a different starting point before intervention (57% vs. 70%), they attempted to present significant gains of important size (27.50 vs. 21.51), and this effect was stronger for the early beginners of the first grade. Further comparisons between spelling and meaning scores showed that training effects for meaning were significantly stronger than relevant effects for spelling, and this was the case for both first and second graders. This finding is particularly important, indicating that morphological awareness training on very young readers even from their first years of schooling can lead to significant increments not only to literacy skills, such as spelling (Nunes and Bryant, 2006; Tsesmeli and Seymour, 2009; Tsesmeli, 2010), but also to vocabulary improvement, forming the basis for later improvements on reading comprehension and academic success (Ramirez et al., 2014).

The above results are enlightened by the qualitative categorization of students' responses on meaning. In particular, a careful examination of pre-test responses in relation to compounds' explanations indicated that the correct etymological answers were multiplied rather than the correct non-etymological ones for both experimental groups. Most considerably, experimental groups attempted to increase substantially their etymological positive responses after the intervention (gains: 47.48 vs. 44.01), and at the same time to decrease noticeably their etymological and semantic errors, indicating strongly that children participating in the program were able to use considerably more often the etymological information to convey the meaning of the compounds, and the way they are spelled. Namely, it was shown for both experimental groups that children recognized the morphological constituents of the target word prior intervention to a larger extent and this effect was highly accelerated as a means of intervention. This may suggest that this type of awareness exists in children's brains and regardless of its small size it can be used as a morphological strategy to improve their vocabulary and spelling performance (Tsesmeli and Koutselaki, 2013). Also, according to Ramirez et al. (2014), morphological awareness is "generative," thus children can use it independently to analyze thousands of words and derive meanings for new items.

The postulation at this point is that children who developed better skills of morphological awareness may have a benefit in attaining a complex vocabulary, as suggested by Bowers and Kirby (2010), who showed that students' skill to recognize bases in complex words contributed an important amount of variance to their comprehension, and hence predicted their general vocabulary knowledge. This can lead to better reading comprehension skills, as shown by the remarkable study by Lyster et al. (2016), where children who received morphological training at the pre-school exhibited better skills in this aspect 6 years later, at Grade 6, than the control group. These results may be broadened by recent evidence in the context of morphological processing by Feldman et al. (2015) who demonstrated that meaning influences even the very early stages of visual recognition of morphemes, suggesting an early and dynamic interaction of meaning and form. This was based on the data tracking the earliest possible time course of processing, where the facilitation based on the form of a shared morpheme (*sneaker-sneak*) is weaker than facilitation based on semantic similarity along with its form (*sneaky-sneak*) (p. 167), although this topic is still controversial, since models of visual word recognition, as well as current studies, suppose that the form of a word is accessed before its meaning (Pylkkänen et al., 2004; Goucha and Friederici, 2015).

According to Seymour (1998), an important issue in the assessment of the intervention studies relates to whether children would be able to generalize learning from instructed items to uninstructed ones. Generalization is further assisted via homologous items of common word structure and identical lexical units, as in this study. In particular, findings showed that first grade students, who took part in the program, attempted to generalize the pseudo-compounds to a considerable degree (gains: 12.85), while the relevant control group did not show any significant generalization change, confirming that generalization effects by early readers was due to training. Unfortunately, this was not the case, for the experimental group of second grade whose change was small and did not reach significance, while there was not any significant change for its relevant control group. Findings in terms of generalization effects in relation to transparency indicated different profiles for the two experimental groups. In particular, early beginners of first grade showed significant generalization effects of equal size both on transparent and opaque pseudo-compounds (gains: 12.86), while they had a similar performance on these items before intervention. Late beginners of second grade showed small and non-significant generalization effects only on transparent pseudo-compounds, while none of the controls presented any significant generalization effects on transparent or opaque items. However, the results are positive, at least for the first graders, suggesting that even very young readers of this age are able to make use of their instructed knowledge to spell new items and in consistency with related studies, as by Nunes and Bryant (2006) and Tsesmeli and Seymour (2009) (see also, Tsesmeli, 2010; Tsesmeli and Tsirozi, 2015) where older children transferred principle learning to derivational items of similar word structure.

Therefore, the results of this study have a number of substantial implications for educational practice. The main suggestion is that morphological awareness is of importance and that instruction of the morphological structure of the words would be valuable to students in regular classroom settings (Nunes and Bryant, 2006), even from their first years of schooling. Students may need to apply in a specific and concrete way the most abstract ideas of internal word structure (Tsesmeli and Tsirozi, 2015). This process could be further assisted via a variety of appropriate educational materials, as used in the present study, such as color-coding techniques, real objects, board-games in small groups, in order to increase active involvement of the learner to the task. Moreover, comparable interventions should improve the training of the morphemic structure of the words in an explicit and sequential way from the simplest to the most complex structures (i.e., transparent vs. opaque items). Also, spelling should be complemented with the understanding of these forms, since it has been shown that morphological training increases student's vocabulary development (Bowers and Kirby, 2010; Ramirez et al., 2014; Lyster et al., 2016).

Some of the limitations of this study would be the lack of control group's data in the meaning study, due to practical circumstances in terms of school access, to facilitate comparison with experimental groups, as in the spelling study. However, significant results from the meaning study suggest that the improvement in meaning scores was due to training. Moreover, the investigation of the variability of the students in terms of ability levels would add important aspects to the present findings, since there is a number of individuals that might differ in their cognitive ability and degree of improvement, as in the study by Ramirez et al. (2014). Besides, one significant query for research in the future would be the examination of the acquisition of morphologically complex forms and their response to more extensive treatment in larger samples for the experimental and control groups, along with other cognitive and psycholinguistic factors (i.e., general intelligence, reading comprehension, standardized measures of reading/spelling, etc.) in order to enhance the generalization of the results for the relevant populations (Apel and Diehm, 2014; Wolter and Dilworth, 2014). Finally, an important factor that should be taken into account is the duration of the intervention which was short (five sessions, 10 h) in order to produce stronger training and generalization effects for the experimental groups.

However, this study is among the first attempts at morphographic training in compounding in Greek, which is a phonologically transparent orthography (Seymour et al., 2003) but with a rich morphology (Ralli, 2013; Babiniotis, 2016). The outcome indicated that intervention was efficient in improving the spelling and semantic understanding of morphologically complex words for early readers of the first years of schooling. These results are consistent with experimental literature (Nunes and Bryant, 2006; Bowers et al., 2010; Apel and Diehm, 2014; Ramirez et al., 2014; Wolter and Dilworth, 2014; Lyster et al., 2016) and are especially valuable for the development of complementary approaches to the educational interventions of typically developing children in regular classroom settings.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of ethical guidelines of Greek Psychological Society with written informed consent from all subjects. All subjects gave written informed consent in accordance with the Declaration of Helsinki. The protocol was approved by the regional educational authority of schools.

AUTHOR CONTRIBUTIONS

ST conceptualized the research project, supervised the data-collection, run the statistics, conducted the writing of the paper and the interpretation of the findings.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2017.02071/full#supplementary-material

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The Training of Morphological Decomposition in Word Processing and Its Effects on Literacy Skills

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This study set out to examine the effects of a morpheme-based training on reading and spelling in fifth and sixth graders ($N = 47$), who present poor literacy skills and speak German as a second language. A computerized training, consisting of a visual lexical decision task (comprising 2,880 items, presented in 12 sessions), was designed to encourage fast morphological analysis in word processing. The children were divided between two groups: the one underwent a morpheme-based training, in which word-stems of inflections and derivations were presented for a limited duration, while their pre- and suffixes remained on screen until response. Another group received a control training consisting of the same task, except that the duration of presentation of a non-morphological unit was restricted. In a Word Disruption Task, participants read words under three conditions: morphological separation (with symbols separating between the words' morphemes), non-morphological separation (with symbols separating between non-morphological units of words), and no-separation (with symbols presented at the beginning and end of each word). The group receiving the morpheme-based program improved more than the control group in terms of word reading fluency in the morphological condition. The former group also presented similar word reading fluency after training in the morphological condition and in the no-separation condition, thereby suggesting that the morpheme-based training contributed to the integration of morphological decomposition into the process of word recognition. At the same time, both groups similarly improved in other measures of word reading fluency. With regard to spelling, the morpheme-based training group showed a larger improvement than the control group in spelling of trained items, and a unique improvement in spelling of untrained items (untrained word-stems integrated into trained pre- and suffixes). The results further suggest some contribution of the morpheme-based training to performance in a standardized spelling task. The morpheme-based training did not, however, show any unique effect on comprehension. These results suggest that the morpheme-based training is effective in enhancing some basic literacy skill in the population examined, i.e., morphological analysis in word processing and the access to orthographic representations in spelling, with no specific effects on reading fluency and comprehension.

Keywords: morphology, reading, spelling, literacy, intervention study, second language learners

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INTRODUCTION

The role of morphological processing in lexical access has been repeatedly shown in studies of different languages and orthographies (e.g., Drews and Zwitserlood, 1995; Clahsen, 1999; Diependaele et al., 2005; Frost et al., 2005; Penke, 2006; Smolka et al., 2007; Beyersmann et al., 2012). Morphemes are the smallest linguistic unit to convey a semantic meaning in a word. Morphologically related words share phonemes, graphemes and often also semantics, and therefore provide consistencies of recurring connections between spelling, sound, and meaning. Consequently, morphological decomposition of words should allow benefiting from these consistencies in reading and writing.

And indeed, studies of skilled readers indicate that morphological decomposition is an integral part of word processing. Methods addressing this aspect usually apply different morphological manipulations on the presentation of printed material. Sonnleitner (2013), for example, examined the role of morphological processing in reading of German by comparing the reading efficiency of pseudowords composed of real morphemes and of pseudowords composed of pseudo-morphemes. Children read the pseudo-words, which were built out of real morphemes faster than the pseudo-words built out of pseudo-morphemes. Another task used in this study was the Word Disruption Task, in which words were presented under three conditions: (1) the morphemes of each word were separated by a symbol (e.g., fang#en). (2) The syllables of each word were separated by a symbol (e.g., fan#gen). (3) The sequence of letters of each word was not violated by the symbol (e.g., #fangen). Children read the words separated by their morphemes significantly faster than the words separated by their syllables, and reading of the first was only marginally slower than reading under the no-separation condition. While taking into account that the separation of the syllables violated the sequence of letters of the words' morphemes, and that this condition produced the largest disruption in reading rate, these results were taken to suggest that the processing of morphemes plays a role in word recognition.

One more widely used method in the study of morphological processing in word recognition is the priming task, in which visually (e.g., Smolka et al., 2007) or acoustically (e.g., Sonnenstuhl et al., 1999) presented prime words precede a visual presentation of target words in a computerized lexical decision task. In these studies, morphological relations between the primes and targets were found to accelerate the response to the targets. The extraction of the shared morpheme between the prime and the target was suggested to explain this effect. This was found even when primes were presented for a very brief duration (40–60 ms), which usually does not allow their conscious processing. In these studies, readers were found to extract the main morphological units, which carry the core meaning of words (word-stems or roots) from morphologically complex words (e.g., Frost et al., 2005; Marslen-Wilson et al., 2008). As the brief presentation duration of the primes is thought to capture initial processes of lexical processing (e.g., Rastle et al., 2000; Frost et al., 2005 see review by Rueckl, 2010), these results were taken to suggest that morphological analysis occurs at a very early stage of visual word recognition (Rastle et al., 2000; Frost et al., 2005; Marslen-Wilson et al., 2008; Rueckl, 2010). Consequently, morphological analysis was suggested to constitute a first priority in word processing (Marslen-Wilson et al., 2008).

However, findings are less consistent in studies of reading disabled participants (e.g., Elbro and Arnbak, 1996; Leikin and Hagit, 2006; Verhoeven and Schreuder, 2011; Quemart and Casalis, 2013; but see Deacon et al., 2006; Schiff and Raveh, 2007). While some studies suggest that these do not apply morphological analysis in visual word recognition (Raveh and Schiff, 2008), others suggest that poor readers even rely on morphological information as a strategy compensating for their word reading difficulties (Elbro and Arnbak, 1996; Burani et al., 2008). Nonetheless, the fact that morphological decomposition in visual word recognition was more consistently found in typical readers than in reading disabled participants may suggest that morphological analysis is not carried out as effectively or to the same extent by reading disabled participants as it is carried out by typical readers. Other studies further indicate that children with reading and language disabilities show deficient morphological awareness compared to age-matched typical readers (Carlisle, 1987; Fowler and Liberman, 1995; Casalis et al., 2004; Siegel, 2008). As previously suggested, interventions focusing on morphological skills may be particularly important for students struggling with literacy acquisition, as despite difficulty with some aspects of morphological processing, they may have the potential of addressing the morphological skills they do possess as a supporting strategy of reading (Goodwin and Ahn, 2010). With this in mind, morphological training might be regarded as an effective component of interventions aimed at enhancing literacy skills.

Studies on morphological instruction have indeed shown positive effects on literacy skills, and in speakers of different languages (Elbro and Arnbak, 1996; Nunes et al., 2003; Reed, 2008; Tsesmeli and Seymour, 2009; Bowers et al., 2010; Tsesmeli et al., 2011; Goodwin and Ahn, 2013). A meta-analysis of morphological intervention studies carried out in English-speaking school-aged children, who represent a general population of students, indicated a medium overall effect of morphological instruction on measures of literacy achievement (Goodwin and Ahn, 2013). Intervention effects were, however, moderated by the type of literacy skill tested, with significant and medium effects on morphological knowledge, phonological awareness, vocabulary, decoding and spelling, but not on reading fluency and comprehension. In another meta-analysis of these researchers, which focused on morphological instruction in students with difficulties in acquiring literacy skills, significant medium mean effect sizes were found for morphological interventions on phonological awareness, morphological awareness and vocabulary, and more modest effects on spelling and comprehension (Goodwin and Ahn, 2010). Morphological instruction was particularly effective for children with speech and language delay followed by English language learners, struggling readers, children with learning disabilities, and children with a reading disability.

The purpose of the present study was to examine the effect of a morpheme-based training on literacy performance, while adding to previous studies on morphological interventions in three respects: in the type of intervention provided, in the language and orthography examined, and in the characteristics of the population in focus. As far as the first respect is concerned, previously studied interventions focused on teaching participants explicit morphological rules and strategies. These provided, for example, instruction on morphological components and rules for combining them into words, instruction on linking morphemes to their grammatical functions, and introduction of word families and of strategies for identifying words by analogies (Goodwin and Ahn, 2010). While such explicit morphological knowledge is expected to contribute to various conscious processes involved in literacy skills (e.g., inferring the meaning of unfamiliar words in reading based on familiarity with morphologically related words), it may not necessarily influence implicit morphological processing involved in reading and writing. Fast morphological decomposition in word processing was, however, suggested to be an implicit process, which readers carry out automatically and without being able to report on it (e.g., Frost et al., 2005). Considering the important role suggested for this procedure in lexical access (e.g., Rueckl, 2010), the present study was designed to directly train it. This was done by developing a morpheme-based training program, which imposes a demand of quickly extracting the core morphological units from visually presented morphologically complex words. The program consisted of a lexical decision task, in which inflections and derivations were presented one after the other. In order to encourage the fast extraction of the core morphological unit of each word, the duration of presentation of the word-stems was restricted, while the pre- and suffixes remained on screen until response. The participants were tested for different literacy skills before training, right after training, and 1 month following training. The morpheme-based training was contrasted with a control training, which was designed to isolate the possible effect of the morphological manipulation. As the morpheme-based training included not only a morphological manipulation but also the imposing of time constraints on word processing –which in themselves were found to have positive effects on reading (Breznitz, 2006), the control training consisted of the same training program, except that the duration of presentation of a non-morphological unit was restricted.

An additional aspect referring to the type of intervention provided is that many of the previous studies applied several strategies of morphological instruction (Goodwin and Ahn, 2010, 2013). Consequently, the effect of each training technique is difficult to disentangle, which may be one reason for the great variability in the reported effects of morphological interventions. In contrast, the training examined in the current study focused on a single procedure of fast morphological decomposition in word processing. Finally, it may also be noted that morphological interventions are usually provided using explicit teaching, which necessitate the presence of a tutor. The training program examined here, however, was designed as a computer task, which allows independent work of the trainees.

The second addition of the current study refers to the language and orthography tested. In the present study, the effect of the morpheme-based training was examined in the German language. A Hebrew version of the same morpheme-based training was recently tested in the framework of a pilot examination among Hebrew speakers with a reading disability (Bar-Kochva, 2016). The results suggested an improvement in some basic literacy measures (spelling and accuracy in reading) of the morpheme-based training compared to a control intervention. However, the Hebrew language (with its Semitic origin), differs from the German one (with its Indo-European origin) in many aspects. One major difference lies in the morphological structure of the two languages, which may influence the salience and role of morphological processes in lexical access (Frost et al., 2005). Consequently, the effect of the suggested morpheme-based training on readers and spellers of the German language deserves a separate examination. Notably, the implications of differences between languages and orthographies on effects of training have received little attention in studies on literacy skills. Although the present investigation does not offer a direct comparison between languages and orthographies, it may provide some indication on whether a morphological training found to be relevant to the Hebrew language is also relevant to the German language.

Finally, the current study adds to previous intervention studies by focusing on a group of children struggling with literacy skills, who also have a migration background. The vast majority of studies on reading and writing addressed participants with a reading disability or readers with other developmental disabilities (e.g., language deficits), who usually speak the language of instruction as their first language. Until recently, reading disability was diagnosed when significant difficulties in accuracy and fluency in word recognition, decoding and/or spelling, were identified (DSM IV; American Psychiatric Association, 1994). Most recently, however, reading disability has been regarded as one aspect of a more general learning disability, while difficulties in reading comprehension and performance in other academic fields (e.g., mathematics) are also diagnostic criteria (DSM V; American Psychiatric Association, 2013). However, having a migration background, defined when a student or his or her parents were born outside the country of residence, has also been related to difficulties in acquiring literacy skills, and to difficulties in reading comprehension in particular (OECD, 2001, 2003, also see Aarts and Verhoeven, 1999; Verhoeven, 2000; but see Lesaux et al., 2007). It is important to note, that a migration background in itself may not necessarily be a source of difficulties in acquiring literacy skills, with the context of learning possibly having a mediating impact. For instance, the Programme for International Student Assessment [PISA] (OECD, 2001, 2003) indicated that in some countries (e.g., Germany and Belgium) adolescents with migration background reached literacy levels (defined in terms of reading comprehension) well below those of native students, and that these differences were more moderate in others countries (e.g., France, Sweden, United States, while having a migration background had very little effects in Australia and Canada). Lesaux et al. (2007) even found similar literacy skills in children with and without migration background in a longitudinal study of younger students (kindergarten to grade 4) in Canada. Therefore, the exact source of difficulty of the group in focus in the current study is difficult to trace. Their literacy deficits may lie in a developmental learning disability, and/or be related to their migration background, to the context of learning as well as to other possible factors [such as public policies relating to the filtering of immigrants by economic or educational background, see the Programme for International Student Assessment [PISA] (OECD, 2001, 2003)]. Despite the possible heterogeneity of this group, there is a practical need to search for intervention tools addressing the difficulties of these students, with their growing representation in different countries in the world. From a theoretical perspective, extending the examination of morphological training to these students may further contribute to the understanding of the role of morphology in acquiring literacy skills in various population.

Notably, of the various aspects involved in having a migration background (e.g., socio-economic status, parents' level of education) an exposure to a language at home, which is not the language of instruction in school, appears to be a critical factor. In most countries surveyed in the Programme for International Student Assessment [PISA] (OECD, 2001, 2003), speaking another language at home raised by two to two and a half times the likelihood to be among the 25% of lowest achievers in reading literacy measures. In further analyses of the Programme for International Student Assessment [PISA] (OECD, 2003), it was found that when controlling for the language spoken at home, the performance gaps between students with and without migration background were substantially reduced in both mathematics and reading (also see Marx and Stanat, 2012). As previously formulated, while bilingualism in itself is not suggested to be a source of difficulty in acquiring literacy skills, students with migration background might be at a disadvantage if they lack opportunities to learn basic literacy skills in both of their languages (Marx and Stanat, 2012). Interventions approaching literacy through training of basic language skills were therefore suggested to address the needs of this population (Verhoeven, 1990; OECD, 2001, 2003; Marx and Stanat, 2012). Notably, the group in focus in this study may vary from certain groups of bilinguals who, for example speak the language of instruction with at least one of their parents. Nevertheless, previous findings indicating some disadvantage of bi-lingual children in language skills related to literacy acquisition, such as in vocabulary, lexical access and morpho-syntactic knowledge in their L2 (da Fontoura and Siegel, 1995; Hutchinson et al., 2003; Lesaux et al., 2006; Bialystok et al., 2008) may further support a linguistic approach to literacy intervention in children with poor literacy skills, who speak the language of instruction as their second language.

RESEARCH QUESTION AND HYPOTHESES

The following research question was examined: what are the effects of a morpheme-based training, designed to train fast morphological analysis in word processing, on different literacy skills in a group of children struggling with literacy acquisition, and to whom the language of instruction is not their mother tongue. The hypotheses were as follows: (1) considering the important role found for morphological analysis in word processing, a general positive effect of the morpheme-based training was expected on literacy performance. (2) At the same time, in line with previous studies on morphological interventions (Goodwin and Ahn, 2010, 2013), including the study of the same morpheme-based training in Hebrew readers (Bar-Kochva, 2016), we expected to find effects of the program on basic literacy skills (on morphological analysis in word recognition and on spelling) more than on reading fluency and comprehension.

MATERIALS AND METHODS

Participants

Children in the fifth and sixth grades ($N = 47$, mean age = 11.24 years, $SD = 0.931$) with migration background were tested. The children were recruited from two schools situated in middle-low to middle class neighborhoods in the area of Frankfurt am Main, Germany. All participants had a word reading efficiency score at the lowest 30th percentile in a standardized reading test (Salzburger Lese- und Rechtschreibtest, SLRT II; Moll and Landerl, 2010), and a non-verbal IQ score of above 75 (Zahlen-Verbindungs-Test, ZVT; Oswald and Roth, 1997). Considering that efficient word recognition is the building block of skilled reading (Lyon et al., 2003; Fletcher, 2009), the measure of word reading fluency was taken as a defining criterion. As general ability has a wide influence on various cognitive tasks, variance in the literacy skills resulting from differences in general ability was controlled by excluding from analysis students who performed below the average range in the non-verbal IQ task (ZVT; Oswald and Roth, 1997).

In line with the definition applied at the PISA surveys (e.g., OECD, 2001), the inclusion criterion for having a migration background was that the children were either born in Germany into families where both caregivers grew up in another country, or the children came themselves to Germany. In order to avoid possible effects of limited knowledge of German, participants who were not born in Germany were included in analysis only if they came to Germany as infants and were involved in a German speaking educational system from the age of 3 at the latest. Countries of origin were Turkey, Greece, Poland, Russia, Croatia, Portugal, Ethiopia, Ghana, Morocco, Afghanistan, and Iran. In addition, all children were exposed to a language other than German at home. This information was collected using a questionnaire referring to the following aspects: country of origin of the child and of each of his or her parents, the language first acquired by the child, age of acquisition of the German language and the dominant language spoken with each caregiver. All participants were exposed to a mother tongue other than German from birth on. Most children from all origins were exposed to German between birth and their first year of life, while eight children (whose origin was either from Turkey, Morocco, Ethiopia, or

Afghanistan) started to learn German between the ages of two and three.

Participants were divided between two training groups: the one received the morpheme-based training ($n = 24$, 14 boys), and the other received a control training ($n = 23$, 11 boys). The assignment of participants into one of the two training groups was random. The study was approved by the local ethic committee of the German Institute for International Educational Research (DIPF), and participants provided written informed consent from their parent to take part in the study.

Materials

Background Measures

Considering that, general ability has an influence on almost any cognitive task, and in order to verify similar general ability of the two groups, two tests were administered as approximations for non-verbal and verbal general abilities. The first was the "ZVT" (a number-connecting test. Oswald and Roth, 1997), which is a standardized test of cognitive processing speed, in which participants are required to link as fast as they can between visually presented numbers according to their order. The test is administered individually in a pencil and paper form. The test norms allow converting the mean cognitive processing speed into an IQ estimation. Internal consistency and 6-month test–retest reliability are between 0.84 and 0.98. The second test was the Vocabulary subtest from the German version of the WISC-IV (HAWIK IV; Petermann and Petermann, 2010), in which children are first presented with pictures and required to name them, and then asked to define words of various semantic categories (e.g., nouns, verbs, and adjectives). The test was administered individually.

Another background measure, which was administered in order to verify similar skills of the two groups, was the SLRT II decoding test (Moll and Landerl, 2010). The test is administered individually, while the items are presented on a printed page. The test comprises a list of 156 pseudowords, preceded by eight example items. The pseudowords were constructed based on legal structures in the language. The items in the test are arranged in columns, increasing in length and complexity. The children were instructed to read as fast and as accurately as they could and were stopped after one minute. Each correct reading of a pseudoword earned one point. Parallel test reliability coefficients of this test is above 0.90.

Morphological Analysis in Word Recognition

A Word Disruption Task was administered, which was a variation of the task previously used by Sonnleitner (2013). Three word lists were compiled. There were 29 morphologically transparent past participles of regularly inflected verbs in each list (German participles including the *ge-* prefix, the *-t* suffix and a base form in between, e.g., *getanzt*, meaning "danced"). The items were words previously used by Smolka et al. (2007) in their study (see Appendix B in their article). The mean participle frequency of each list was 4.10, 5.55, and 6 (as indicated by the CELEX database, Baayen et al., 1993, see Smolka et al., 2007), and the mean word length was 8.03, 8.24, and 8.34 letters. It should be noted, that there is no consensus on whether all German complex words are morphologically decomposed in reading (Clahsen, 1999; Penke, 2006; Smolka et al., 2007). Consequently, the words included in the lists were only of a class of words, which were repeatedly found to be analyzed into morphological units in reading of typical readers of German.

The task was administered individually. In each session, participants were presented with three word lists printed on three separate pages, which they were asked to read out aloud. Each list was presented under one of the following three conditions: (1) A no-separation condition. Words were presented with two identical non-orthographic symbols attached to their beginning and end (i.e., the symbols did not disrupt the sequence of letters in the words, e.g., #getanzt#, meaning "danced"). (2) A morphological separation condition. The pre- and suffix were separated by the non-orthographic symbols from the word-stem (ge#kauf#t, meaning "bought"). (3) A non-morphological separation condition. The symbols separated the words into three orthographic units, which did not convey a meaning (get#räu#mt, meaning "dreamt"), thereby violating the sequence of the morphemes' letters. In trying to isolate the morphological factor in this task, and in order to reduce possible effects of visual differences between the morphological separation condition and this condition, the two symbols were integrated into the words in a location, which was as close as possible to their location in the morphological separation condition. Notably, integrating the symbols according to a different linguistic principle (such as between phonemes or syllables) would have created a visual difference between the morphological condition and the non-morphological condition (as more than two symbols would have been integrated into at least some of the words). Therefore, the segmentation of the non-morphological condition was guided by the location of the symbols, which created a random segmentation as far as the linguistic structure of the words is concerned.

Reading performance in the first condition was taken as a base-line measure of word reading fluency, to which reading under the two other conditions was compared. Similar reading proficiency in the no-separation condition and the morphological-condition would suggest that morphological analysis is integrated into the reading routine. Reduced word reading fluency in the morphological condition compared to the no-separation condition would suggest that morphological analysis is not carried out as part of the reader's word recognition routine. The non-morphological separation condition was taken as a control condition, in order to examine whether the violation of the sequence of letters of the morphemes in each word created a disruption in word reading rate.

Each of the three word-lists appeared in all of these conditions across three testing times (administered before and after training, see **Table 1**). For example, in one session with a child, a specific word appeared in the no-separation condition, #getanzt#; in the second session, the same word appeared under the morphological-separation condition, ge#tanz#t; and in the third session it appeared under the non-morphological condition, get#an#zt. This procedure created nine versions of presentation

TABLE 1 | An example of words presented in the Word Disruption Task in the three testing times.

	No-separation	Morphological-separation	Non-morphological separation (disruption of the words' morphemes)
Time 1	#getanzt#	ge#kauf#t	get#räu#mt
Time 2	#geträumt#	ge#tanz#t	gek#au#ft
Time 3	#gekauft#	ge#träum#t	get#an#zt

altogether (three word lists × three presentation conditions). In order to avoid effects of order of administration, the lists were presented in a counterbalanced manner across participants, conditions and testing times. Participants were instructed to read as fast and as accurately as they can, and to ignore the symbols they see on the page. A measure of word reading fluency, which was based on the number of words correctly read within one minute, was calculated for each condition. In addition, the difference between the word reading fluency score in the no-separation condition and the morphological condition, and between the no-separation condition and the non-morphological condition was calculated. This measure served to estimate whether the location of the symbols violating the sequence of letters interfered in the process of word recognition (i.e., large differences would indicate a large disruption).

Word Reading Fluency

Fluency in reading of words was measured in three tests, which examined different levels of possible generalization effects of the trainings. These included the reading of trained words, the reading of untrained words which share morphological structures with the words appearing in training, and the reading of words in a standardized word reading fluency test.

Reading of trained words

Three parallel lists of words were created by sampling 291 items from the total items appearing in training. Due to time constraints, not all items presented in training could be included in this task. Therefore, randomly selected items were included from each morphological form which appeared in training (regularly inflected forms, *-s* plurals and *-t* participles; plural marker *-n* for feminine nouns; *-ung* nominalizations and -chen diminutives with and without umlauted stems). Examples of the items presented appear in Table 2 of the Supplemental Material. One list was presented at each testing time and in a counterbalanced manner across participants. Considerations for using different lists at each testing time appear under the "Procedure" section. This task was administered individually, by presenting the participants each list on a separate printed page. The lists were matched in terms of number of items (97), mean word-length (all lists had a mean length of 7.4 letters) and frequency (mean appearances in each of the three lists was: 549.25, 551.68, and 549.6, according to dlexDB, Heister et al., 2011). The lists were also matched in terms of number of items from each of the morphological forms included in training. Participants were instructed to read the words aloud as accurately and as fast as they can, and a score representing the words correctly read within one minute was calculated.

Reading of untrained words

The test was created by compiling three parallel word lists, comprising 97 words each (see examples in Table 2 of the Supplemental Material). One form was administered at each testing session, and in a counterbalanced manner across participants. As in the case of the reading task of trained items, this task was administered individually, by presenting the participants each list on a separate printed page, which they were required to read out aloud. The lists were matched in terms of mean word length (7.44, 7.52, and 7.63 letters in a word) and frequency (532.91, 539.37, and 538.82 appearances, according to dlexDB, Heister et al., 2011). The words in these lists comprised word-stems which did not appear in training, and pre- or suffixes which did appear in training (regularly inflected forms, *-s* plurals and *-t* participles; plural marker *-n* for feminine nouns; *-ung* nominalizations and -chen diminutives with and without umlauted stems). The number of appearances of each pre- and suffix was also matched between the lists. The instructions given to participants and the scoring procedure were the same as in the reading test of trained words.

Word reading in a standardized test

The subtest of word reading efficiency from the SLRT II (Moll and Landerl, 2010) was used. The test is administered individually, with its items presented on a printed page. A list of 156 items (nouns and verbs), preceded by eight example items appear on this page. The items are arranged in eight columns, ordered in an increasing level of difficulty as far as word length, frequency, and complexity (in terms of syllable structure) are concerned. The children are instructed to read as fast and as accurately as they can and are stopped after one minute. Each correct reading of a word earns one point. Parallel test reliability coefficients of this test are above 0.90. The test has two parallel forms (A and B), which allowed the use of different forms in the three session of testing. These were administered in a counterbalanced manner across participants (A, B, A or B, A, B). The results of the first testing-time were taken as a background measure, and participants achieving a score at the 30th percentile or lower were included in training.

Reading Fluency and Comprehension

The standardized "Leseverständnistest für Erst- bis Sechstklässler" (ELFE 1–6; Lenhard and Schneider, 2006) was administered. As this test examines reading comprehension under time constraints, this measure represents both fluency in reading and comprehension. The test comprises three subtests: (a) word comprehension, (b) sentence comprehension, and (c) text comprehension. In the first subtest children have to choose the name of an object presented as a picture out of four written words (72 words altogether). In the second subtest, including 28 items, the children are required to choose a word matching the context of a written sentence out of four written words. In the third subtest, children are required to read short paragraphs and to answer multiple-choice comprehension questions (20 paragraphs altogether). The test is administered in groups in a paper and pencil form. The children are stopped after two minutes in the word and sentence subtests and after six minutes in the text subtest. Two examples precede each subtest. The children are required to read silently. Each item correctly answered earns one point. A sum score of the three parts is calculated. Cronbach's alpha reliability coefficients of the subtests are between $\alpha = 0.92$ and $\alpha = 0.97$. This test offers two parallel forms (A and B). These were administered in the three sessions of testing in a counterbalanced manner across participants (A, B, A or B, A, B).

Spelling

As in the case of the word reading tests, three spelling tests were administered in each testing session, in order to examine the extent of possible effects of generalization. The tests included: spelling of trained words, spelling of untrained words which shared morphological structures with trained items, and a standardized spelling test. The tests were administered individually in a pencil and paper form.

Spelling of trained words

Three parallel lists of words were created by sampling 126 items from the total items included in training (none of the items were shared with the items presented in the word reading tasks, see examples in Table 2 of the Supplemental Material). One list was dictated in each testing session (presented in a counterbalanced manner across participants). All words imposed ambiguity in spelling of the word stems (i.e., phoneme–grapheme conversion did not suffice in order to produce their correct spelling). The lists were matched in terms of number of items (42), mean word length (7.76, 7.76, and 7.85), and frequency (612.73, 614.80, and 621.78 appearances, according to dlexDB, Heister et al., 2011). The lists included a sample of all morphological forms appearing in training, and these were equally represented across the three lists. The test was administered individually, while the experimenter read each word out aloud, and the child was asked to write the words down in a list. Each correct spelling of a word earned one point.

Spelling of untrained words

Three parallel word lists were compiled, including 42 items each (none of the items were shared with the items presented in the word reading tasks, see examples in Table 2 of the Supplemental Material). One list was dictated in each testing time (administered in a counterbalanced manner across participants). The lists were matched in terms of mean word length (7.56, 7.85, and 8.00) and frequency (515.56, 516.98 to 518.34 appearances, according to dlexDB, Heister et al., 2011). The words were composed of word-stems, which did not appear in training and of pre- or suffixes which did appear in training. In this test too, all items involved ambiguity in spelling of the word stems. The morphological forms were equally represented across the three lists. The procedure of administration and scoring was the same as in the spelling test comprising the trained words.

Spelling in a standardized test

As there was no available standardized spelling test with norms for both fifth and sixth graders at the time of administration, different aged-matched standardized tests were used for participants in the two grade levels. The two tests were administered in groups in a pencil and paper form. The "Diagnostischer Rechtschreibtest für fünfte Klassen," DRT 5 (diagnostic of spelling for fifth graders, Grund et al., 2004) was administered to the fifth graders. According to the instructions of this test, a form is presented to the children which includes 51 written sentences, with one missing word per sentence. The experimenter reads each sentence out aloud, including the missing word, which the child is required to write on a blank line in the form. The test focuses on basic vocabulary (nouns, adjectives, and verbs) representing the most important spelling cases in the language. Split-half reliability of this test is $r = 0.93$. The sixth graders were presented with the second part of the "Rechtschreibtest für 6. und 7. Klassen" (RST, Rieder, 1992). Similarly to the DRT-5, a text which contains 29 missing words is presented to participants. An experimenter reads out aloud the text, including the missing words, and the children are asked to write down these words in the appropriate blank lines. As in the case of the spelling tests of trained and untrained items, the spelling of the target words in this test require orthographic knowledge (i.e., decoding of phonemes into graphemes is insufficient for correct spelling of these words). Internal reliability is between Cronbach's $\alpha = 0.87$ and $\alpha = 0.93$. Both tests, DRT-5 and RST 6-7, have parallel forms (A and B). These were used in each testing time in a counterbalanced manner across participants (A, B, A or B, A, B). As each group tested included both fifth and sixth graders, the scores from the two tests had to be combined. This was done by converting the raw scores into percentile (PR) according to the tests' norms.

Training

Two training programs were developed, in a form of a computerized visual lexical decision task, in which words and pseudoword were presented at the center of a computer screen, one after the other. The training was programed using the E-Prime software (Schneider et al., 2002). Participants were asked to decide as quickly and as accurately as they can, whether each item presented is a real word or a pseudoword (by pressing two different keys on the keyboard). Presentation of each item was terminated by response. A blank screen (appearing for 1000 ms) and a visual mask (a line of asterisks presented for 500 ms) appeared between the stimuli, in order to separate their processing. The difference between the two programs lied in the orthographic unit manipulated within each item presented (**Figure 1**):

(1) Morpheme-based training: The duration of presentation of the word-stem of each stimulus was restricted. The rest of the letters (pre- and suffixes) and small dashes replacing the letters of the word-stems, remained on screen until response (e.g., the word *gelernt*, meaning "learned," appeared on screen, while the unit *lern* appeared for a

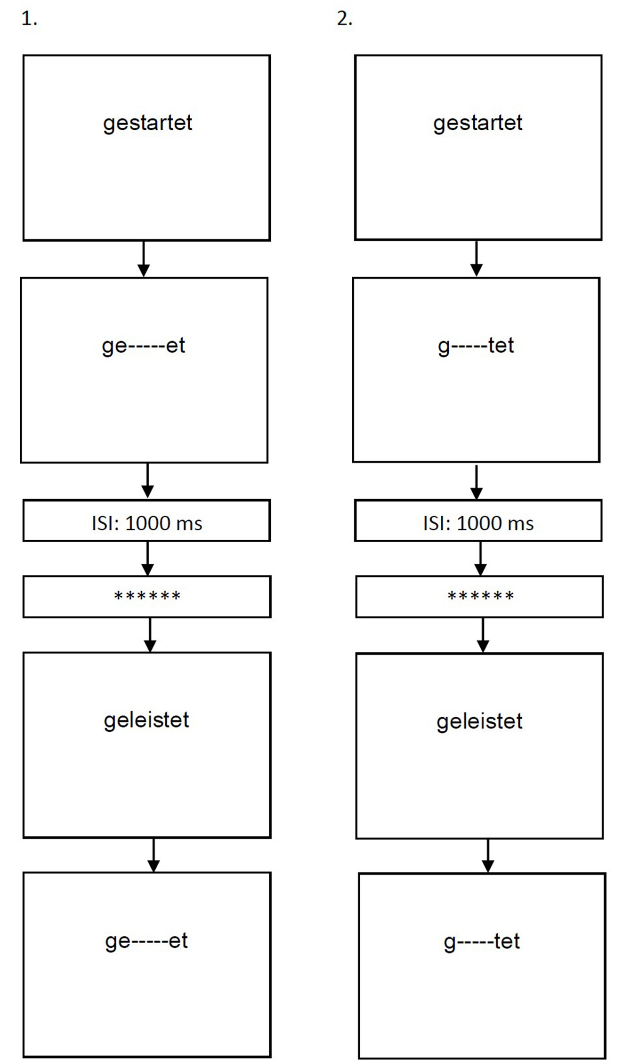

FIGURE 1 | Examples of the two training programs: (1) morpheme-based training. (2) Control training. The two programs consisted of a lexical decision task, in which the presentation of an orthographic unit within a word was restricted in time- the word-stem in the morpheme-based training and a non-morphological unit in the control training. The rest of the letters in each word remained on screen until response. Each stimulus (word/pseudoword) was followed by a blank screen appearing for 1000 ms (inter-stimulus interval, ISI) and by a screen with a forward mask consisting of 6 asterisk marks appearing for 500 ms.

limited time, and *ge- - - -t* remained on screen until response).

(2) Control training: As time-constraints in themselves were found to enhance reading performance (Breznitz, 2006), a control training was designed to allow isolating the possible effect of the morphological manipulation provided in the morpheme-based training. The procedure of the control training was the same as in the morpheme-based training, except that the letters manipulated did not constitute a meaningful lexical unit (e.g., the word *gelernt*, meaning "learned," appeared on screen, while the unit *eler* appeared for a limited time, and *g- - - -nt* remained on screen until response). The non-morphological unit manipulated was equivalent in length and similar as much as possible in its position in the word to the word-stems manipulated in the morpheme-based training.

The two training programs included the same items: verbal inflections and noun derivations of various frequencies (ranging from rare to highly frequent according to the dlexDB, Heister et al., 2011). As aforementioned, there is no consensus on whether all German complex words are morphologically decomposed in reading (Clahsen, 1999; Penke, 2006; Smolka et al., 2007). Consequently, only certain classes of words were included, for which an agreement appears to exist: regularly inflected forms, *-s* plurals and *-t* participles; plural marker *-n* for feminine nouns; *-ung* nominalizations and -chen diminutives. Pseudowords were created on the basis of the real words, by changing 1–3 letters from the words' stems. The same manipulation applied on real words in the two training conditions was also applied on pseudowords (e.g., in the case of the morpheme-based training, the pseudoword *geschernt* was presented, while the unit *schern* appeared for a limited time, and *ge- - - -t* remained on screen until response. In the control training, the duration of presentation of the unit *escher* was manipulated, while *g- - - - - -nt* remained on screen until response).

In order to take into account variation between participants in reading rate, the duration of presentation of the units manipulated in the two programs was set individually using a similar method to the one previously applied by Breznitz (2006): a lexical decision task comprising the same word classes and morphological forms presented in training was administered prior to the training. The task did not include any manipulation involving time constraints. Each stimulus was presented on screen, one after the other, while its presentation was terminated when participants decided whether the stimulus was a word or a pseudoword (by pressing one of two keys on the keyboard). Based on performance in this task, the individual per-letter reading rate was calculated. The initial duration of presentation of the manipulated units in training was set by multiplying the number of letters in the unit by the individual per-letter reading rate (e.g., the duration of presentation of the unit *Heiz* in *Heizung*, meaning "heating," was the individual per-letter reading rate times 4). This duration was further restricted by 5% per training block, provided accuracy stayed beyond 80%. A block included 20 stimuli, half words and half pseudowords, sharing the same morphological form (see Table 3 of the Supplemental Material). Each training program included 144 blocks altogether, divided between 12 training sessions. In other words, in each training session participants responded to 240 items, 120 words and 120 pseudowords (20 items in a block × 12 blocks in a session). In order to reduce effects of re-exposure to the same items, each item appeared only once throughout the training.

As a repeated lexical decision task was expected to have an exhaustive effect on participants, other very short tasks were added between blocks, with the purpose of

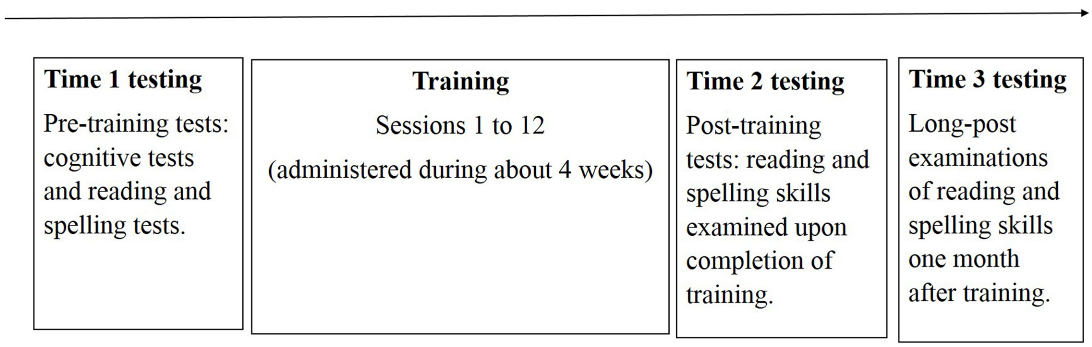

FIGURE 2 | Description of the experimental procedure.

keeping participants interested and involved in the training sessions. The tasks included one to two questions presented after each block, such as different trivia questions, inquiry on personal views on school and learning, and questions concerning the items presented in previous blocks (e.g., did you notice any kind of animal name in the previous block?). The same questions were presented in the two training programs.

Procedure

Training was carried out in small groups, while each child worked individually on a computer. Experimenters supervised the training, and verified that the tasks were understood and followed by the children. The background tests and the pre-training reading and spelling tests were administered in one meeting, which ended with the first training session. Eleven additional sessions of training followed thereafter (administered within about 4 weeks). The individually administered post-training reading and spelling tests were presented right after the last training session. The post-training tests administered in groups (ELFE 1-6, DRT 5, and RST 6-7) were presented to the children 1–2 days after the last training session. These group tests were also administered in separate days. An additional series of post-tests were administered one month after training, in order to examine whether effects were maintained (**Figure 2**). Each testing session lasted 0.75–2 hours, and a training session lasted 15–25 minutes. Participants were asked to work quickly and accurately in all tasks.

It should be noted, that as three testing sessions were planned, and within a rather short time frame, the use of the same test forms in all testing sessions, may have resulted in effects of retesting, including possible ceiling effects. In order to avoid this possibility, three parallel versions of tests were created for the tasks developed in the present study, and one of the criteria for choosing a standardized task was that it would have parallel forms. Although parallel forms may reduce effects of retesting, some influence of the different items presented in each testing time (and even when items are carefully matched) cannot be ruled out. In an attempt to reduce this possibility, the three versions of each test were presented in a counterbalanced manner across participants and testing points (for example, one participants was tested with version 1 at Time 1, with version 2 at Time 2 and with version 3 at Time 3. The next participant was tested with version 3 at Time 1, with version 1 at Time 2 and with version 2 at Time 3. Another participant was then tested with version 2 at Time 1, version 3 at Time 2, and with version 1 at Time 3).

RESULTS

Performance of the Two Groups Prior to Training

It was first examined whether the two groups differed in any of the measures prior to the intervention. Performance in the background measures is presented in **Table 2**. *T*-tests for independent samples confirmed that the two groups did not differ significantly in terms of estimated IQ, vocabulary and decoding skills, as well as in age. It was further examined whether the two groups differed prior to training in performance in any of the other tasks, which were administered as pre- and post-training tests. To this end, *t*-tests for independent samples were carried out on the Time 1 measures, and these confirmed that there were no significant differences between the groups (**Table 3**, while the means and standard deviations of these tests are presented in **Tables 4–6**).

Effects of the Manipulation Applied in the Word Disruption Task Prior to Training

In order to examine whether the manipulation applied in the Word Disruption Task had its expected effect (disruption in word reading fluency) regardless of training, we compared performance in the three conditions of presentation (morphological, non-morphological, and no-separation) prior to the interventions. A repeated measure ANOVA was carried out with performance in the three conditions of presentation at Time 1 as a within-participant factor, and group (morpheme-based training and control training) as a between participant factor. A main effect for condition of presentation was obtained [$F(2,90) = 58.30$, $p = 0.000$,

TABLE 2 | Background information on the two groups of participants (mean age, non-verbal and verbal IQ, and decoding scores, standard deviations in parentheses).

	Morpheme-based training	Control training	*t*(45)	*P*
Age in years	11.24 (0.93)	11.25 (0.94)	−0.030	0.976
ZVT IQ score	98.67 (11.07)	98.04 (14.14)	0.169	0.867
Vocabulary standardized score	8.67 (2.14)	8.52 (2.64)	0.207	0.837
Decoding (items decoded correctly in 1 minute)	39.83 (11.00)	41.70 (10.66)	−0.589	0.559

TABLE 3 | Comparison of performance in the reading and spelling tests at Time 1 testing between the two groups.

	t (43)	*p*
Word Disruption: no-separation condition	−3.67	0.715
Word Disruption: Morphological separation	−0.913	0.367
Word Disruption: Non-morphological separation	−0.644	0.523
Word Disruption: Difference between the no-separation condition and the morphological condition	0.803	0.426
Word Disruption: Difference between the no-separation condition and the non-morphological condition	−0.073	0.942
Spelling of trained words	−1.180	0.245
Spelling of untrained words	−1.014	0.316
Spelling in a standardized test	−0.594	0.556
Reading of trained words	−1.248	0.219
Reading of untrained words	−1.005	0.320
Reading of words in a standardized test	−0.716	0.478
Reading fluency and comprehension	−1.175	0.246

The mean scores and standard deviations are presented in ***Tables 4–6****.*

$\eta_p^2 = 0.593$]. Bonferroni pair-wise comparisons indicated significant differences between the no-separation condition and the morphological condition ($p = 0.011$), between the no-separation condition and the non-morphological condition ($p = 0.000$), as well as between the morphological and the non-morphological conditions ($p = 0.000$). The means in **Table 4** confirm that the symbols created a disruption in word reading fluency when violating the sequence of letters within words (i.e., in both the non-morphological and the morphological conditions), and suggest that this effect was more pronounced in the non-morphological condition than in the morphological condition.

Effects of the Training Programs

Next the main question of this study was addressed, i.e., what are the effects of the training programs on the different literacy skills tested. To this end, 3 × 2 repeated measure ANOVA analyses were carried out, with testing time as a within-participant factor (with three levels: Time 1, Time 2, and Time 3), and group as a between-participant factor (with two levels: morpheme-based training and control training). The results of these analyses appear in Table 1 of the Supplemental Material. Bonferroni pair-wise comparisons were applied as *post hoc* comparisons in order to test differences between the three testing times. In case a significant interaction was obtained between testing time and group, additional repeated measure ANOVA analyses were carried out separately for each group (with three levels of testing times as a within-participant factor), and Bonferroni pair-wise comparisons were, once again applied as *post hoc* comparisons. This was done in order to better understand the differences between the groups.

Morphological Analysis in Reading

First, it was examined whether the participants improved in terms of word reading fluency within each condition of presentation in the Word Disruption Task. The 3 × 2 repeated measure ANOVAs indicated main effects for testing time in all conditions [no-separation: $F(2,90) = 31.32$, $p = 0.000$, $\eta_p^2 = 0.416$; morphological separation: $F(2,90) = 44.65$, $p = 0.000$, $\eta_p^2 = 0.534$; non-morphological separation: $F(2,90) = 27.84$, $p = 0.000$, $\eta_p^2 = 0.388$]. Bonferroni pair-wise comparisons indicated significant differences between T1 and T2 and between T1 and T3 ($p = 0.000$ in both comparisons) in all conditions of presentation. A difference between T2 and T3 was found only in the non-morphological condition ($p = 0.026$). The means

TABLE 4 | Mean performance (words per minute, standard deviations in parentheses) of the two groups in the Word Disruption Task across the three testing times (T1, T2, T3).

	Morpheme-based training			Control training		
	T1	T2	T3	T1	T2	T3
No-separation	33.46 (11.20)	45.22 (16.68)	41.88 (12.21)	33.93 (15.20)	42.65 (15.00)	43.34 (15.03)
Morphological separation	27.99 (8.58)	41.19 (11.50)	43.69 (11.91)	30.05 (10.44)	37.01 (12.09)	39.46 (10.67)
Non-morphological separation	19.35 (5.23)	23.13 (7.38)	26.81 (7.20)	20.16 (8.05)	26.25 (7.34)	28.45 (8.34)
Difference no- separation and morphological separation	5.99 (9.67)	2.68 (8.70)	−1.83 (8.71)	2.95 (7.10)	4.10 (7.09)	3.17 (5.73)
Difference no- separation and non-morphological separation	13.75 (9.98)	21.14 (16.62)	15.49 (9.95)	13.38 (8.76)	15.21 (9.97)	15.41 (9.35)

Time = T (1–3).

TABLE 5 | Mean performance of the two groups (standard deviations in parentheses) in the spelling tests across the three testing times (T1, T2, T3).

	Morpheme-based training			Control training		
	T1	T2	T3	T1	T2	T3
Spelling of trained words (accuracy)	16.06 (4.08)	21.17 (4.82)	20.52 (4.77)	18.02 (5.61)	20.59 (6.51)	19.61 (6.04)
Spelling of untrained words (accuracy)	19.33 (3.99)	22.17 (5.31)	24.38 (4.45)	21.09 (6.57)	22.25 (6.85)	22.77 (6.83)
Spelling in a standardized test (PR scores)	25.50 (22.79)	38.65 (26.05)	40.15 (26.21)	30.89 (27.27)	38.97 (21.50)	35.42 (26.53)

Time = T (1–3), PR = Percentile.

TABLE 6 | Mean performance of the two groups (standard deviations in parentheses) in the reading tests across the three testing times (T1, T2, T3).

	Morpheme-based training			Control training		
	T1	T2	T3	T1	T2	T3
Reading of trained words (words per minute)	34.89 (14.57)	42.75 (17.15)	39.95 (16.85)	36.78 (13.01)	43.33 (16.01)	43.86 (19.04)
Reading of untrained words (words per minute)	35.66 (15.14)	42.60 (17.20)	39.16 (16.38)	36.46 (12.96)	43.09 (16.24)	43.11 (19.38)
Reading of words in a standardized test (words per minute)	64.88 (15.40)	71.42 (16.48)	70.08 (14.45)	66.78 (17.42)	71.83 (17.71)	73.57 (19.41)
Reading fluency and comprehension (Z scores)	−1.18 (0.42)	−0.48 (0.55)	−0.26 (0.55)	−0.98 (0.74)	−0.21 (0.81)	0.08 (0.87)

Time = T (1–3), PR = Percentile.

in **Table 4** indicate that the two groups increased their word reading fluency in all conditions, at least from T1 to T2 and from T1 to T3. An interaction between testing time and group was obtained in the morphological condition only: $F(2,90) = 3.29$, $p = 0.042$, $\eta_p^2 = 0.078$. Further ANOVA analyses carried out separately on each group indicated that both groups improved their word reading fluency in this condition [morpheme-based training: $F(2,46) = 35.42$, $p = 0.000$, $\eta_p^2 = 0.651$, with significant differences between T1 and T2, $p = 0.000$, and T1 and T3, $p = 0.000$; control training: $F(2,46) = 12.22$, $p = 0.000$, $\eta_p^2 = 0.379$, with significant differences between T1 and T2, $p = 0.020$, and T1 and T3, $p = 0.000$). The means in **Table 4**, however, suggest a larger improvement in the group receiving the morpheme-based training.

In order to examine whether the symbols in the morphological and the non-morphological conditions interfered with word reading fluency across the three testing times, two mean difference measures of word reading fluency were calculated: the one between the no-separation condition and the morphological condition, and the other between the no-separation condition and the non-morphological condition. These were separately calculated for each testing time. Repeated measure ANOVAs with testing time as a within-participant factor and group as a between-participant factor were carried out on these measure. A main effect was found for the difference between the no-separation condition and the non-morphological condition [$F(2,90) = 3.26$, $p = 0.044$, $\eta_p^2 = 0.077$]. Bonferroni pair-wise comparisons indicated a near significant difference between T1 and T2 ($p = 0.072$). The analysis of the difference between the no-separation condition and the morphological condition indicated a main effect [$F(2,90) = 3.31$, $p = 0.041$, $\eta_p^2 = 0.073$], in addition to an interaction between testing time and group [$F(2,90) = 3.51$, $p = 0.034$, $\eta_p^2 = 0.077$]. The means in **Table 4** suggest that the morphological disruption was reduced only in the group receiving the morpheme-based training across the testing times, with no disruption at T3. Additional ANOVA analyses carried out separately on each group confirmed a significant effect of testing time only in the group receiving the morpheme-based training [$F(2,46) = 5.47$, $p = 0.008$, $\eta_p^2 = 0.199$], with Bonferroni pair-wise comparisons indicating a significant difference between T1 and T3 ($p = 0.018$).

Access to Orthographic Representations

Spelling of Trained Words

The 3 × 2 repeated measure ANOVA analysis indicated a main effect for testing time [$F(2,90) = 21.98$, $p = 0.000$, $\eta_p^2 = 0.323$], together with an interaction between testing time and group [$F(2,90) = 3.32$, $p = 0.041$, $\eta_p^2 = 0.067$]. The means in **Table 5** suggest a larger improvement in the group receiving the morpheme-based training compared to the group receiving the control training. Additional ANOVA analyses carried out on the results of each group separately indicated an improvement in both groups, with possible larger effects for the group receiving the morpheme-based training. The results of the morpheme-based training were: $F(2,90) = 22.45$, $p = 0.000$, $\eta_p^2 = 0.473$, and the pair-wise comparisons indicated an improvement from T1 to T2 ($p = 0.000$) and from T1 to T3 ($p = 0.000$). The results of the group receiving the control training were: $F(2,44) = 4.21$, $p = 0.021$, $\eta_p^2 = 0.167$, and the pair-wise comparisons indicated an improvement from T1 to T2 ($p = 0.036$).

Spelling of Untrained Words

The 3 × 2 repeated measure ANOVA analysis indicated a main effect for testing time [$F(2,90) = 15.17$, $p = 0.000$, $\eta_p^2 = 0.256$], together with an interaction between testing time and group [$F(2,90) = 3.74$, $p = 0.028$, $\eta_p^2 = 0.078$]. The means in **Table 5** suggest an improvement in the group receiving the morpheme-based training. Additional ANOVA analyses carried out for each group separately confirmed that a significant improvement was obtained only in this group [$F(2,46) = 24.27$, $p = 0.000$, $\eta_p^2 = 0.513$], and the pair-wise comparisons indicated an improvement from T1 to T2 ($p = 0.003$), from T1 to T3 ($p = 0.000$), as well as from T2 to T3 ($p = 0.022$).

Spelling in a Standardize Test

The 3 × 2 repeated measure ANOVA analysis indicated a main effect for testing time [$F(2,90) = 16.12$, $p = 0.000$, $\eta_p^2 = 0.287$], together with a near significant interaction between testing time and group [$F(2,90) = 3.01$, $p = 0.055$, $\eta_p^2 = 0.070$]. The means in **Table 5** suggest an improvement in both groups, with a larger improvement in the group receiving the morpheme based training. ANOVA analyses carried out separately on the results of each group support this possibility. The results of the morpheme based training were: $F(2,46) = 17.86$, $p = 0.000$, $\eta_p^2 = 0.448$, and the pair-wise comparisons indicated an improvement from T1 to T2, $p = 0.000$, and from T1 to T3, $p = 0.000$. The results of the control training were: $F(2,44) = 3.30$, $p = 0.048$, $\eta_p^2 = 0.155$. The pair-wise comparisons did not suggest, however, any significant differences between the testing times (comparison between T1 and T2, $p = 0.112$; comparison between T1 and T3, $p = 0.167$; comparison between T2 and T3, $p = 0.955$).

Word Reading Fluency

Reading of Trained Words

The 3 × 2 repeated measure ANOVA analysis indicated a main effect for testing time [$F(2,90) = 27.66$, $p = 0.000$, $\eta_p^2 = 0.370$]. The pair-wise comparisons and the means in **Table 6** suggest an improvement from T1 to T2 ($p = 0.000$) and from T1 to T3 ($p = 0.000$).

Reading of Untrained Words

The 3 × 2 repeated measure ANOVA analysis indicated a main effect for testing time [$F(2,90) = 24.82$, $p = 0.000$, $\eta_p^2 = 0.350$]. The pair-wise comparisons and the means in **Table 6** show an improvement from T1 to T2 ($p = 0.000$) and from T1 to T3 ($p = 0.000$).

SLRT II Word Reading

The 3 × 2 repeated measure ANOVA analysis indicated a main effect for testing time [$F(2,90) = 17.30$, $p = 0.000$, $\eta_p^2 = 0.278$]. The pair-wise comparisons and the means in **Table 6** point to an improvement from T1 to T2 ($p = 0.000$) and from T1 to T3 ($p = 0.000$).

Reading Fluency and Comprehension

The 3 × 2 repeated measure ANOVA analysis indicated a main effect for testing time [$F(2,90) = 96.81$, $p = 0.000$, $\eta_p^2 = 0.688$]. The pair-wise comparisons and the means in **Table 6** suggest an improvement from T1 to T2 ($p = 0.000$), from T1 to T3 ($p = 0.000$), as well as from T2 to T3 ($p = 0.001$).

DISCUSSION

This study set out to examine the effects of a computerized morpheme-based training on reading and writing skills in fifth and sixth graders, who struggle with literacy skills and speak a language other than the language of instruction (German) at home. In line with the study's predictions, the morpheme-based training contributed beyond the control training to a number of basic literacy skills (morphological analysis in word recognition and access to orthographic representations in spelling), but not to reading fluency and comprehension.

First the results of the Word Disruption Task are discussed – a task designed to examine whether morphological analysis is carried out as a process of word recognition. The comparison between the three conditions of this task at Time 1 (i.e., prior to training) confirmed that the non-orthographic symbols integrated in between the words' letters created an interference in word reading fluency (compared to the no-separation condition). Furthermore, the results indicate that the interference was the largest when the sequence of the morphemes' letters within words was violated (i.e., in the non-morphological condition). The present results converge with the results reported by Sonnleitner (2013), who examined younger children (second graders) to whom German was a first language. Notably, although Sonnleitner (2013) compared the violation of the morphemes' letters in a word to the violation of another linguistic unit – syllables (in addition to a no-separation condition), the former still created the largest disruption. Together, these results confirm the role of morphological analysis in reading of German. While this role was previously demonstrated mainly in studies of adults with typical reading skills (e.g., Clahsen et al., 2003; Smolka et al., 2007), the current results suggest that regardless of training, fifth and sixth graders with poor literacy skills (and to whom German is a second language) also carry out morphological analysis of words in reading – at least to a certain extent.

The analysis examining the effects of the training programs on performance in the Word Disruption Task indicated that both groups improved in word reading fluency across the three testing times in all conditions (no-separation, morphological separation, and non-morphological separation). However, an interaction between testing time and group was found only in the morphological condition, and the results suggest a larger improvement in word reading fluency in the group receiving the morpheme-based training. This may indicate that following training, this group benefited more than the control group from the separation between words' morphemes. An interaction between testing time and group was also obtained in the measure representing the difference in word reading fluency between the no-separation condition and the morphological condition. Further analysis suggests that the disruption caused by the symbols separating the words into their morphemes was reduced (between T1 and T3) only in the group receiving the morpheme-based training. As there was practically no disruption in word reading fluency in this group by the third testing time, morphological analysis may have been integrated into the process of word recognition (at least in the case of reading the morphological structures included in this task). These findings are in line with previous studies examining the effects of different strategies of morphological instruction on morphological knowledge and awareness (Goodwin and Ahn, 2010, 2013). However, while previous studies examined tasks involving explicit processing of morphological units (such as circling the main morpheme in morphologically complex words or specifying the meaning of word parts, see Bowers and Kirby, 2010; Lesaux et al., 2010; Harris et al., 2011), here we applied a task, which may indicate that morphological processing improved as an implicit procedure of word processing.

A main effect for testing time was also found in the measure representing the difference between the no-separation condition and the non-morphological condition, while the Bonferroni pair-wise comparisons indicated that the interference in word reading fluency tended to increase from T1 to T2. These results suggest that as word reading fluency improved in both groups, the non-morphological separation condition interfered with fluency in reading to a larger extent. Although there was no significant interaction between testing time and group in this difference measure, the means suggest that the interference increased mainly in the group receiving the morpheme-based training (from T1 to T2). As this group was trained to quickly locate the core morphological units of words, the violation of the sequence of letters within morphemes in the non-morphological condition may have interfered with the process of word recognition of this group in particular.

Next spelling is discussed. The ANOVA analysis of spelling of trained items showed an interaction between testing time and group. The means in **Table 5** and the ANOVAs carried out on each group separately indicate that both groups improved in spelling of trained item, and suggest a larger improvement, which also extended to the third testing time, in the group receiving the morpheme-based training. As each target-word was presented only once in training, a single presentation may have sufficed in order to induce some improvement in the two groups, while the morphological manipulation used in the morpheme-based training appeared to have had an added value.

Two levels of effects of generalization were further tested: generalization to spelling of untrained word-stems (integrated into trained pre- and suffixes) and generalization to spelling in a standardized test. The analysis of the spelling test of untrained word-stems showed an interaction between testing time and group, while the analysis carried out separately on each group indicated a significant improvement only in the group receiving the morpheme-based training and that this effect was maintained in T3. Hence, a partial effect of generalization can be concluded. The examination whether the effects of the morpheme-based training extend to the spelling of untrained morphological structures resulted in a marginal significant interaction between testing time and group in the standardized spelling test. Although the subsequent ANOVA analyses, carried out separately on each group, indicated a main effect for testing time in both groups, the *post hoc* comparisons were significant only in the group receiving the morpheme-based training (between T1 and T2 and between T1 and T3). Together, these results confirm the role of morphology in spelling development in the German language, as was recently put forward by Bowers and Bowers (2017) for the case of English (also see Bangs and Binder, 2016; Fracasso et al., 2016). The question arises, however, how participants receiving the morpheme-based training improved in spelling of items they were not exposed to in training. As morphological analysis was suggested to have an important role in lexical access (Rastle et al., 2000; Marslen-Wilson et al., 2008), the training of this process may have led to a successful search for orthographic representations in the mental lexicon, which in turn reduced arbitrariness in spelling. Another possibility is that the repeated deletion of the word-stems directed the attention of the trainees to the modularity of morphologically complex words. Being aware that words are composed of morphemes shared by other words, which may have been familiar to the trainees in their written form, could have helped them in producing correct spellings using analogies (Elbro and Arnbak, 1996). Good et al. (2015) also recently demonstrated positive effects of an explicit morphological awareness training on spelling and vocabulary, and these effects extended to untrained words.

The improvement in spelling following the morpheme-based training is in line with the results of the pilot study, which examined the same training technique in readers of Hebrew (Bar-Kochva, 2016). In this examination, a very short termed training was provided (~50 minutes of training divided between two sessions), and the results suggested some advantage of the morpheme-based training over the control training in spelling of untrained items (while both groups improved in spelling of trained items). These results imply that a morpheme-based training, which imposes a demand of morphological analysis in word recognition, contributes to spelling skills in languages with distinctively different characteristics. The role of morphology in improving spelling skills in various languages and orthographies gets further support from studies examining the effects of explicit morphological instruction in additional languages (e.g., see Elbro and Arnbak, 1996 for Danish; Tsesmeli and Seymour, 2009 for English; and Taha and Saiegh-Haddad, 2016 for Arabic).

The ANOVA analyses of the measures of reading fluency and comprehension indicated a main effect for testing time, with no interaction between testing time and group. The means in **Table 6** further indicate that both groups improved across the testing times in these measures. The morpheme-based training did not then have any unique effect on performance in the reading tasks. At least as far as fluency in single word reading is concerned, the findings were surprising, as the training of morphological analysis in reading was expected to enhance lexical access, thereby leading to quicker word recognition skills. At the same time, the pilot study of the same morpheme-based training examined in Hebrew readers also did not result in any unique effect on measures of reading fluency and comprehension (Bar-Kochva, 2016). Similar findings referring to reading fluency and comprehension were reported in the meta-analysis examining the effects of other morphological interventions (Goodwin and Ahn, 2013). Fluency in reading was suggested to be based on accuracy and automaticity in the various aspects contributing to it, including integration of phonological, orthographic, semantic, syntactic, and morphological processes (Wolf and Katzir-Cohen, 2001). With this definition in mind, training morphological skills alone may not suffice in order to produce noticeable gains in such a complex process –even not in the case of fluency in single word recognition, and all the more so in the most complex process of reading –i.e., comprehension.

Yet the lack of effect of the morphological training on reading comprehension requires further consideration, in view of correlations reported between morphological skills and reading comprehension (e.g., Deacon et al., 2014, 2017). In addition, some positive effects of morphological interventions on comprehension were previously reported, although these reports are inconsistent (Bowers et al., 2010; Goodwin and Ahn, 2010, 2013; Lyster et al., 2016). Variance in the type of trainings provided in different studies may explain, at least in part the conflicting results. Some of the studies reported interventions focusing on morphological training alone, while others provided morphological training as part of a more comprehensive program, which addressed also other aspects of literacy skills, such as vocabulary (see Goodwin and Ahn, 2013 for a review). As would be expected, Goodwin and Ahn (2010) found that morphological interventions provided as a part of comprehensive instruction programs were more effective at improving children's reading achievement than interventions with an exclusive focus on morphology. In their analysis, Goodwin and Ahn (2013) also found that one of the factors moderating the effect of morphological interventions on comprehension was the length of the training, with trainings including above 20 hours producing significant gains. In the present study, however, a considerable shorter training was provided.

Three possible factors, which were shared by the two groups (and cannot be disentangled in this study), may then explain the gains obtained in reading fluency and comprehension. These are re-testing, involvement in reading tasks and the imposing of time constraints on reading. Of these factors, the involvement of time constraints in the two trainings deserves further attention. This factor has been repeatedly shown to have a positive impact on fluency in reading and under certain conditions –on comprehension (Breznitz, 2006; Breznitz et al., 2013; Nagler et al., 2014). It may further be mentioned that a recent study suggests that time constraints have a positive effect on fluency in reading, regardless of whether morphemes were manipulated in the presentation of texts or not (Bar-Kochva and Hasselhorn, 2015). In this study, texts were presented on a computer screen, while the duration of presentation of different orthographic units was restricted by deleting the texts from screen in the direction of reading. There were four experimental conditions of text deletion: the texts were deleted one letters after the other, morpheme by morpheme, word by word, or arbitrary orthographic units were erased one after the other. All these conditions of presentation produced positive and similar effects on reading fluency (compared to a reading condition which did not include any manipulation on the presentation of texts). This study, in addition to the present one, converge to suggest that morphological manipulations applied on the presentation of words or texts may not have an effect on measures of reading fluency and comprehension beyond the effect of time constraints.

Practical implications of the current results are further considered. The analysis of the Word Disruption Task at Time 1 suggests that the skill of morphological analysis in reading was available to the children prior to training, at least to some extent. Nonetheless, the further training of the same skill produced positive effects on spelling. These results stand well in line with studies of other populations, which indicate that morphological skills are both available to participants who struggle with literacy skills, and should be further addressed as a means of promoting literacy acquisition. Quémart and Casalis (2017), for example, have shown that French speaking children (ages 10–15) with dyslexia benefited from certain morphological structures of words in spelling. Results by Cavalli et al. (2017) who examined university students with dyslexia, also suggested that morphological skills may serve as a compensating skill in dyslexia. As far as morphological training is concerned, Taha and Saiegh-Haddad (2016) showed that poor readers of Arabic responded more strongly to a morphological intervention than skilled readers. Together, these results highlight the educational relevance of this type of intervention in enhancing literacy skills of students of various populations. At the same time, the current results also point out that morphological training should be integrated in a more comprehensive program addressing additional literacy-related skills in trying to promote fluency in reading and comprehension. An additional practical aspect of the present study lies in the type of intervention provided. The results indicate that a computerized program, which addresses implicit morphological analysis in reading is an effective training method. Considering that explicit teaching of morphological knowledge often requires more resources (e.g., a tutor), this method may offer a more economical intervention.

This study has several limitations. First, the Word Disruption Task included only words sharing the same morphological structures (pre-and suffixes) as the words appearing in training. Therefore, this task does not allow concluding whether the improvement found in morphological decomposition following the morpheme-based training extends to untrained morphological structures. Second, the trainings were designed in the form of an experimental task, with the aim of isolating as much as possible the effect of the morphological manipulation. Consequently, the trainings did not include elements expected to enhance motivation, as this factor in itself may have an influence on performance. When considering the application of the training procedure offered here in field work, methods enhancing students' involvement in the tasks should be considered (e.g., integrating the morphological manipulation as part of a game). Third, the current study examined a group of children struggling with literacy skills, who also have a migration background. The question whether the program tested here is also relevant to children with a developmental reading disability (and who do not have a migration background) remains open. Fourth, the study included several tasks, which were designed for this study, and these were examined in a rather small sample. A larger sample, in addition to the examination of these tasks in a group of typical readers (with or without a migration background) would have provided stronger results. Fifth, in the present study we referred to the aspect of the language spoken at home as an inclusion criterion, as this aspect of migration background was suggested to be related to poor literacy skills (OECD, 2001, 2003). It should be kept in mind, however, that having a migration background involves many other aspects, which may also have an influence on literacy performance, such as different socio-economic factors which were not monitored in this study. The fact that the current sample also included children speaking different languages at home, and that they or their parents immigrated to Germany at different ages, should also be taken into account in considering the generalization of the current results. Finally, although the morphological training presented here offers the practical benefit over explicit instruction methods of not depending on the mediation of a tutor, the question whether different methods of morphological intervention also have different effects on literacy performance requires direct comparisons between such methods.

CONCLUSION

The results indicate that participants receiving the morpheme-based training improved the ability to analyze words into their constituting morphemes, and suggest that they integrated this process into their word recognition routine (at least in reading the morphological structures trained). The results also indicate an improvement in the ability to access word representations in spelling, and these effects extended to untrained material. At the same time, there was no benefit of the morpheme-based training over the control training in measures of reading fluency and comprehension.

AUTHOR CONTRIBUTIONS

IB-K planned and carried out the study, analyzed the data and wrote the manuscript. MH supervised the study.

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SUPPLEMENTARY MATERIAL

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