Morphological Knowledge Assessment Features and their Relations to Reading: A Meta-Analytic Structural Equation Modeling Study

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A Meta-Analytic Structural Equation Modeling Study

by

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ABSTRACT

Morphemes are the smallest meaningful unit of language (e.g., affixes, root words, base words) that express grammatical and semantic information. Theoretical models of reading suggest that morphological knowledge is multidimensional in its support of literacy skills (Levesque et al., 2020). However, few studies have used large morphological assessment batteries to investigate the differential effects of various morphological knowledge dimensions (i.e., assessment features, such as oral versus written and context clues versus no context clues) to reading outcomes. The current study used systematic review, meta-analytic structural equation modeling (MASEM), and univariate meta-analysis techniques to elucidate whether 1) previous studies containing morphology and reading assessments have used more than one morphological task feature/dimension 2) various morphological task features differentially predict word reading and reading comprehension skills 3) the relations between different morphological assessments to reading comprehension vary by age (younger children, older children, adults) and reading ability (individuals who either do or do not struggle with reading). Results from the systematic review revealed that few studies used multiple morphological knowledge dimensions/task features. MASEM results suggested that morphology tasks differentially predicted reading outcomes. In particular, tasks requiring literacy skills (e.g., spelling, decoding) were more uniquely predictive of reading outcomes than tasks that did not demand literacy skills. Univariate meta-analysis results suggested that the relation of morphological knowledge to reading comprehension was moderated by processing tasks in the group of adult readers who struggled with reading. Specifically, the relation between morphological processing tasks and reading comprehension was weaker than the relation between awareness tasks and reading comprehension The results of this study have implications for future correlational studies as well as intervention studies that aim to enhance morphological knowledge to improve reading outcomes.

INDEX WORDS: Morphological knowledge, Assessment, Reading comprehension, Word reading, Vocabulary, Adults, Children

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DEDICATION

To my mother, father, and brother.

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1 INTRODUCTION

A morpheme is the smallest unit of language that represents meaning. Morphemes are either free (i.e., free bases and roots) or bound (i.e., affixes [prefixes and suffixes], bound bases, bound roots) and can be combined to form words that express different types of grammatical and semantic information. *Morphological knowledge* is a general term that is often used to refer to either awareness of morphological meaning and/or structure or sensitivity to morpho-syntactic information. Previous research has found that morphological knowledge shares a strong relation with word reading (Deacon & Kirby, 2004; Mahony et al., 2000; Nagy et al., 2006; Roman et al., 2009; Singson et al., 2000) and uniquely contributes to reading comprehension of children and adults above and beyond other important reading-related skills, such as decoding, listening comprehension, and vocabulary (e.g., Cunningham & Carroll, 2013; Guo et al., 2011; Singson et al., 2000; Tighe & Schatschneider, 2016b; Tong et al., 2011; Wilson-Fowler & Apel, 2015) .

Researchers have broadly defined morphological knowledge by framing the construct in different ways with a wide range of tasks and stimuli (Apel, 2014). Different types of morphological measures may reflect multiple dimensions of morphological knowledge that depend on an array of skills, such as decoding, structural knowledge of morphemes, and semantic information (Levesque et al., 2020). Furthermore, there are specific task features that could impose limitations on individuals who struggle with reading (Deacon et al., 2009). For example, some participants may struggle with tasks that require decoding or spelling if they already demonstrate literacy challenges.

Varied approaches to measuring morphological knowledge may also influence the interpretation of the relation between morphological knowledge and reading outcomes, such as word reading and reading comprehension. For example, Apel et al. (2013) discovered that elementary school children's performance on some morphological tasks were more closely related to word reading ability than others. Evidence from large morphological knowledge assessment batteries with older, adolescent grade-school children also suggests that different dimensions/task features of morphological knowledge share unique relations with reading comprehension outcomes (e.g., Goodwin et al., 2017, 2020). A deeper understanding of which types of morphological tasks uniquely predict reading may guide future intervention studies to focus on specific dimensions of morphological knowledge to improve reading outcomes.

Unfortunately, few studies have used large morphological assessment batteries to examine the relations of different morphology dimensions or task features to reading outcomes, such as word reading and reading comprehension (e.g., Goodwin et al., 2017, 2020; Tighe et al., 2016b). The current study aimed to fill a gap in the literature by using systematic review and meta-analytic structural equation modeling (MASEM), and univariate meta-analysis approaches to investigate 1) the number of studies containing morphology and reading measures that include multiple task features/dimensions of morphology 2) the differential relations of various morphological task features/dimensions to word reading and reading comprehension outcomes and 3) the moderating effects of various morphological task features/dimensions across different age (younger children, older children, adults) and reading ability groups.

The following review of the literature discusses the role of morphology in a theoretical framework of literacy and emphasizes important dimensions, or distinctions amongst morphological knowledge tasks. Next, this review discusses findings from previous research exploring the unique contribution of different types of morphological tasks to word reading and reading comprehension outcomes. Finally, this review discusses evidence that points to the significant relation of morphological knowledge to reading and individual differences across typical and atypical readers as well as children and adults. A review of the current study's research questions and hypotheses are discussed within context of the topics emphasized in the literature review.

1.1 The Role of Morphology in Literacy Development

Researchers have focused on children's (e.g., Carlisle & Fleming, 2003; Cunningham & Carroll, 2013; Singson et al., 2000; Tong et al., 2011) and adults' (Deacon et al., 2006; Guo et al., 2011; Wilson-Fowler & Apel, 2015) morphological knowledge due to its complexity, (e.g., wide range of affixes), theoretical relevance, and critical role in reading and linguistic processing. In particular, morphology is included in the Reading Systems Framework (RSF), which differentiates among lower-level reading (e.g., decoding, oral language), higher-level reading (e.g., comprehension monitoring), and cognitive processes (e.g., long-term and working memory) that are needed to adequately support word reading and reading comprehension (Perfetti & Stafura, 2014). The RSF posits that the lexicon serves as the link between word reading and reading comprehension (Perfetti & Stafura, 2014). Additionally, The Lexical Quality Hypothesis, subsumed under the broader RSF, theoretically supports the role of morphology because it states that the individual draws upon linguistic (syntactic, phonological, and morphological) and orthographic knowledge bases to facilitate word reading and reading comprehension (Perfetti 2007; Perfetti & Stafura, 2014).

Levesque et al. (2020) proposed a *Morphological Pathways Framework*, scaffolded from the RSF, which provides a more explicit role for morphology in a model of literacy (see Figure 1). The *Morphological Pathways Framework* specifically delineates the mechanisms between morphology and literacy skills. According to this framework, morphology interacts with various knowledge bases and processes that contribute to reading outcomes. These interactions explain the multidimensional nature of the morphological knowledge construct (e.g., Goodwin et al, 2017; Tighe & Schatschneider, 2015, 2016b). In other words, morphological knowledge is comprised of different abilities, each with unique contributions to word reading, spelling, and reading comprehension. For example, evidence suggests that children use *morphological decoding*, or use knowledge of morphemes, to master word reading skills (Deacon et al., 2017; Nagy et al., 2006). Another, separate dimension of morphological knowledge that facilitates word reading is *morphological analysis*. Morphological analysis involves comprehension of morphemes, which is an important mechanism for understanding multi-morphemic words (Baumann et al., 2002; Carlisle, 2007; Pacheco & Goodwin, 2013). *Morphological awareness* is an important dimension of morphological knowledge that supports both word meaning and word identification processes. Morphological awareness refers to the consciousness of and ability to manipulate morphemes, which are the smallest units of meaning such as bases, roots, and affixes (Deacon et al., 2014; Deacon et al., 2009). Increased awareness of morphologically complex words helps readers to become attuned to morphological regularities, which in turn allows individuals to pay more attention to form and meaning when reading morphologically complex words. Familiarity with morphological regularities also facilitates spelling development, and the use of these regularities in spelling increases as children age (Deacon & Dhooge, 2010).

The Morphological Pathways Framework also considers multiple roles for morphology in reading comprehension. For example, morphological awareness directly influences reading comprehension, but also indirectly predicts reading comprehension through morphological decoding and morphological analysis (Levesque et al., 2017). Previous studies suggest that morphological awareness is critical to the reading comprehension of children (Carlisle & Fleming, 2003; Cunningham & Carroll, 2013; Singson et al., 2000; Tong et al., 2011) and adults

(Deacon et al., 2006; Guo et al., 2011; Wilson-Fowler & Apel, 2015) over and above other reading-related skills (e.g., phonological awareness, decoding). For example, Cunningham and Carrol (2013) found that morphological awareness uniquely predicted reading comprehension in both second and third-grade students after controlling for phonological awareness and decoding. Tong et al. (2011) discovered that third-grade students with strong derivational morphological awareness performed better on a reading comprehension task than those with poor derivational morphological awareness, even though both groups demonstrated proficiency with other reading-related skills (phonological awareness, orthographic awareness, decoding, and word-naming). In a study with skilled college students, Wilson-Fowler and Apel (2015) reported a moderate, significant relation between morphological awareness and reading comprehension after controlling for spelling and word reading.

1.2 Assessment of Morphological Knowledge

The multidimensional nature of morphological knowledge is not only grounded within multiple pathways that contribute to the reading system, but also in different ways researchers have assessed the construct (Apel, 2014; Deacon et al., 2009). It is critical to consider the various types of measures used to assess morphological knowledge, as some assessments impose more tasks constraints for lower-skilled readers (e.g., individuals who may struggle with phonological awareness or timed-tasks; Deacon, et al., 2009). Overall, different types of measures may tap into other reading-related competencies, such as decoding, linguistic processing, semantic knowledge, phonological awareness, and/or orthographic knowledge. For these reasons, Deacon et al. (2009) delineated a taxonomy of morphological tasks. The three relevant task dimensions included in the taxonomy are *input and output modality*, *content*, and *task or process*.

1.2.1 Input and Output Modality

The input and output modality dimension encompasses both the presentation of assessment items and the collection of answers from respondents, which can involve both oral and written formats. Some evidence suggests that modality influences performance on morphological knowledge tasks. For example, children with learning disabilities appear to demonstrate a disproportionate amount of difficulty on written compared to oral tasks (Carlisle, 1988; Champion, 1997; Windsor & Hwang, 1997).

Different types of modalities may present with their own unique challenges. Older and younger elementary children struggle with oral production of derivational affixes (i.e., morphemes that modify the verbal or written form) due to modifications in sound patterns in some of the assessment items (e.g., *music*→ *musician*; Carlisle, 2000). Additionally, oral assessments may cause difficulties for children who struggle with articulation and verbal short-term memory (Avons & Hannah, 1995; Catts, 1989).

Written assessments may challenge readers because they contain affixes that exhibit modifications in spelling. Evidence suggests that these modifications influence the performance of skilled adults and adults with dyslexia when processing multimorphemic words during timed word reading tasks (Deacon et al., 2006). Deacon et al. (2006) administered a written, computer-based morphological processing task with skilled adult readers and found that they spent more time reading words with modified spellings (e.g., *happy*→*happiness*) than words that did not exhibit changes in spelling (e.g., *write*→*writer*). The adults with dyslexia spent the same amount of time processing multimorphemic words with and without modified spellings, which suggested that they did not notice the orthographic complexities in morphologically complex words. These findings suggest that poor readers and individuals with dyslexia tend to demonstrate weaknesses in orthographic knowledge (Deacon et al., 2009). Thus, it’s important to consider whether poor performance during word reading tasks reflect weaknesses in both orthographic and morphological knowledge as opposed to only morphological knowledge. It’s also important to note the speeded assessment format of Deacon and colleagues’ (2006) morphological measure, as speeded response formats tend to pose a unique challenge for individuals with reading difficulties (Deacon et al., 2009). Moreover, individuals who struggle with literacy skills may exhibit difficulties with providing written answers in response to questions. Written responses put more strain on processes such phonological working memory, a well-known area of weakness for individuals with dyslexia (Deacon et al., 2009).

1.2.2 Content

Several important variations in content have been used in experimenter-designed morphological assessments with both children and adults. Experimenter-designed tasks have included different types of morphemes, specifically derivational and inflectional affixes (e.g., Berninger et al., 2010; Kirby et al., 2012; Nagy et al., 2003, 2006; Roman et al., 2009). Derivational affixes modify the meaning or semantic category of a word (e.g., noun, verb, adjective) The transformation of *teach* to *teacher* changes the word from a verb to a noun. Inflectional morphemes are relatively fewer in number compared to derivational morphemes and add grammatical information to a word without changing the word’s core meaning (e.g., *dog*→*dogs*; *go*→*going*). Children master inflectional affixes in early elementary school (Kuo & Anderson, 2006). In contrast, students begin to show mastery of derivational morphemes in the later elementary school and adolescent years (Berko, 1958; Berninger et al., 2010; Carlisle, 1988; Carlisle & Fleming, 2003). Transformation of derivational affixes is typically more challenging than inflectional affixes because many derivational transformations include modifications in sound or spelling. Carlisle and Nomanbhoy (1993), for example, found that first graders could append derivational affixes to base words that do not change phonologically (*sing* →*singer*) but were not yet able to derive words with phonological changes (*magic*→*magician*).

Task content may also vary according to whether the answers require real words or pseudowords. *The Derivational Suffix Choice Test of Pseudowords* (Mahony, 1994; Singson et al., 2000) is a judgment task that prompts students to complete a sentence with a blank (e.g., *The __ baby cried all night*) by choosing the correct answer from a field of four (*nittery*, *nitterness*, *nitterment*, *nittertion).* In contrast, some tasks are better suited for real word stimuli than pseudowords. Decomposition tasks with a multimorphemic word and accompanying sentence typically use real words (e.g., *Driver; Children are too young to* ___; Answer: *Drive*). One problem attributed to real word morphological tasks is that they rely on knowledge of multimorphemic words that exhibit semantic connections with other words in the same family (e.g., the word *lovely* belongs to the same family as *loveable* and *loving*; Nagy & Townsend, 2012). Therefore, it is difficult to determine whether the reader is applying morphological rules or is mainly relying on prior knowledge related to the word. Pseudoword tasks address this problem by forcing the participant to completely rely on knowledge of morphological rules rather than word meanings.

Additionally, morphology assessments either do or do not provide contextual information. Fill-in-the-blank tasks, such as the *Morphological Structure Task* (Carlisle, 1988, 2000; Leong, 1999), provide additional semantic and syntactic cues to help participants complete the sentence. In contrast, tasks that instruct participants to break down multimorphemic words into their smaller morphological constituents require participants to demonstrate morphology skills with no additional contextual cues (e.g., *tap out the number of parts you hear in the word* *recyclable*; Casalis et al., 2004). Participants may perform better on tasks with contextual cues than without contextual cues because they can rely on linguistic information from the sentence to arrive at the correct answer choice. In tasks that do not provide contextual clues, participants must demonstrate increased reliance on morphology to respond correctly. Previous research has found that context helps both children and adults to decode novel words (Binder & Borecki, 2008; Nagy & Anderson, 1984; Read & Ruyter, 1985). Tighe and Binder (2015), for example, found that struggling adult readers were more likely to demonstrate increased accuracy and response times on morphologically complex words presented in context than in isolation.

1.2.3 Task or Process

Types of Task Response Formats. In a review of the literature on morphology assessment, Apel (2014) identified 4 predominant types of experimenter-designed morphology tasks: *productive*, *judgement*, *blending or segmenting*, and *analogy*. Productive morphology assessments broadly assess the participants' ability to demonstrate knowledge of affixes and their connection to base forms. Productive tasks with a cloze procedure require participants to complete a sentence with a missing blank. For example, the *Morphological Structure Task* prompts participants to complete a sentence with a blank (e.g., *My uncle is a* ___) with the appropriate form of the target word (e.g., *farm*→*farmer*; Carlisle, 2000). Additionally, productive morphology assessments may use fluency (e.g., *Name as many words you can think of that come from the word music*), pronunciation, or spelling tasks (Apel, 2014).

Judgment assessments typically use a multiple-choice response format. For example, Berninger et al. (2010) and Nagy et al. (2006) tasked grade-school students with yes/no questions to evaluate the semantic relation between two words (e.g., *Does fire come from firefighter?*) In another study, Nagy et al. (2003) used the *Suffix Choice Test* to assess 2nd and 4th graders' semantic and/or syntactic accuracy of multimorphemic words. The students listened to an experimenter read a sentence with corresponding answer choices (e.g., *Matthew was not known for being overly* ___; *friendly*, *friendship*, *friendliness*, *friends*). The experimenter instructed the students to orally give the correct answer from the four choices.

Blending and segmenting tasks require the participant to either create or decompose morphologically complex words. Tighe and Schatschneider (2015, 2016b) used a decomposition task with struggling adult readers. The examiners read aloud a target word, followed by a sentence with a blank (e.g., *Firefighter. The house was engulfed in the* ____.) To complete the sentence, participants transformed the target words into their base forms (e.g., *firefighter* to *fire)*. Casalis et al. (2004) prompted 8 to 12-year-old French students to blend French root words (e.g., *nettoie*) and affixes (e.g., *age*) into a single word (e.g., *nettoyage*). The students also decomposed morphologically complex words into their base forms (e.g., *jour* from the French word *journe´ee*).

Analogy tasks assess knowledge of affixes and their relation to base forms by using the format: A is to B as C is to D (Deacon & Kirby, 2004; Kirby et al., 2012; Roman et al., 2009). Some analogy tasks provide three single words and prompt the participant to complete the analogy with a fourth word (e.g., *talking: talked::walking*:___). Other tasks provide three sentences and prompt participants to supply the fourth sentence (e.g., *The girl hugs the teddy bear: the girl hugged the teddy bear::The boy swims fast:*_________).

Awareness Versus Processing. Morphology tasks also differentiate in terms of assessing participants' implicit and explicit morphological knowledge. Assessments that evaluate morphological processing skills examine the participants' implicit knowledge of morphology. Processing tasks require participants to pick between two sentences that 'sound best' (e.g., '*I* *goes to the store*' versus '*I go to the store*'), provide correct pronunciations of a list of multimorphemic words, or correctly spell a list of morphologically complex words. Additionally, processing tasks often use response time data to examine the reader's sensitivity and speed of access to morphological information in words. Evidence from previous studies suggests that children continue to master morphological processing skills throughout grade-school, and that older high school children process multimorphemic words of various complexity faster than middle-schoolers (Carlisle & Stone, 2005).

In contrast, morphological awareness tasks require the specific identification and manipulation of morphemes. These tasks assess the participants' ability to apply a conscious, analytic approach to understanding and using words. Deliberate analysis of morphological information occurs when students engage in settings that teach reflection on both the meaning and structure of language (Anglin et al., 1993; Van Kleeck, 1982). As elementary school students age, they increasingly participate in activities that involve analysis and mastery of the internal structure of words, individual units within words, grammatical roles of affixes, and using words in context (Goodwin et al., 2017). Thus, older grade-school students tend to perform better on morphological awareness tasks than younger grade-school students. For example, Berninger et al. (2010) found that middle school students were more proficient than elementary school students in terms of making judgments about the association between two words (e.g., does *corner* come from *corn*?) and choosing pseudowords with correct suffixes to complete a sentence.

Morphological Analysis. Morphological analysis refers to the person's ability to infer the meaning of a multimorphemic word from its morphological constituents (e.g., Carlisle, 2000; McCutchen & Logan, 2011; Nagy, 2007). Morphological analysis and morphological structure awareness are similar because they both involve the manipulation of morphemes; however, the key difference between the two constructs stems from the use of word meaning (Deacon et al., 2017). Specifically, morphological analysis relies on the use of morphological structure to build word meaning and morphological structure awareness targets the participants' ability to identify and manipulate word structure without necessarily relying on word meaning.

Morphological analysis tasks often use a production or judgment (i.e., multiple choice) format. For example, Carlisle (2000) tested 3rd and 5th grade students' morphological analysis ability by asking them to define a small set of multimorphemic words (e.g., *treelet*). The author found that morphological analysis was correlated with children's reading comprehension skills. In a different study, McCutchen and Logan (2011) examined 5th and 8th grade students' ability to define morphologically accessible (i.e., multimorphemic words, such as *horrific*) and inaccessible (i.e., words that were not composed of more than one morpheme, such as *vile*) words. Both 5th and 8th grade children were better at defining the accessible compared to the inaccessible words, suggesting that children use morphological analysis to determine the meanings of words.

In a recent study, Deacon et al. (2017) examined the unique contribution of morphological analysis skills to reading comprehension in 3rd and 5th grade children over and above measures of morphological decoding, morphological structure awareness, phonological awareness, and word reading. The authors used a multiple-choice morphology task that provided the participant with the target word along with a set of four possible answer choices with the correct definition and three distractor definitions. Morphological analysis uniquely contributed to reading comprehension, supporting previous evidence that using meaning to understand multimorphemic words is an important aspect of grade-school children's reading comprehension.

1.3 Relations of Morphology to Reading Outcomes

Evidence from previous studies suggests that the concurrent validity of participants' morphological knowledge to reading outcomes differentiates as a function of the type of morphological assessment. Apel et al. (2013) used multiple morphology tasks with different types of response formats (e.g., production, judgment) and modalities (oral versus written responses) to predict the reading outcomes of kindergarteners, first, and second graders. The authors found that a fill-in-the-blank production task was a unique predictor of kindergarten students' real word reading skills, over and above the other morphology tasks and a measure of phonological awareness. The fill-in-the-blank task also uniquely predicted the real word reading and reading comprehension skills of second graders over and above the other morphological awareness skills. In a study that examined the influence of implicit morphological knowledge on reading outcomes, Goodwin et al. (2013, 2014) found that morphological processing uniquely contributed to word reading skills.

Previous studies that have used latent variable modeling suggest that specific factors of morphological knowledge uniquely predict reading performance. Tighe and Schatschneider (2016) found that latent factors of real word and psuedoword morphemes each demonstrated a significant, unique relation with reading comprehension in a sample of adult basic education (ABE) students. Goodwin et al. (2017) tested the relation of specific morphological knowledge factors to reading comprehension over and above a general factor of morphological knowledge in a sample of adolescent readers. A specific factor related to defining words with derivational affixes emerged as significant to reading comprehension over and above the general factor, suggesting that this skill was uniquely important beyond a general knowledge of core morphological principles.

Broadly, most studies that have examined the concurrent validity of various morphology measures have included tasks with assessment features from most, if not all, categories of Deacon et al.'s (2009) taxonomy of morphological tasks. However, few studies to date have purposefully aimed to disentangle the unique relations of these assessment features to reading outcomes. Additional research is needed in this area to guide the focus of morphology intervention studies that aim to improve reading outcomes. Elucidating the types of morphological processes that are most predictive of reading outcomes can inspire future interventions to implement designs that focus on those processes.

1.3.1 Individual Differences in the Relation of Morphological Knowledge to Reading

Typical and Atypical Readers. Previous literature suggests that morphological knowledge is important to the reading skills of children with typical development (Carlisle & Fleming, 2003; Roman et al., 2009; Singson et al., 2000; Tong et al., 2011) and adult readers (Guo et al., 2011; Mahony, 1994; Wade-Woolley & Heggie, 2015; Wilson-Fowler & Apel, 2015). Some adults and children with atypical reading abilities (i.e., a wide range of individuals including those with intellectual/developmental disabilities, language impairments, reading disorders, and/or low reading skills) also appear to demonstrate a positive relation between morphological knowledge and reading (Deacon et al., 2006; Elbro & Arnbak, 1996; Tighe et al., 2019; Tighe & Schatschneider, 2015, 2016a, 2016b). For example, morphological awareness exhibits a strong effect on the reading comprehension of struggling adult readers after controlling for other reading components skills such as vocabulary (Tighe & Schatschneider, 2015, 2016b), orthographic, and phonological awareness (Tighe et al., 2019). Previous studies also point to a relation between morphological processing and reading comprehension in adults with dyslexia (Deacon et al., 2006; Law et al., 2018).

It is unclear whether the effects of morphological knowledge on reading varies between individuals with typical and atypical reading skills. Studies have found that individuals with atypical reading skills have diminished morphological knowledge ability in comparison to typical readers (Carlisle, 1987; Casalis et al., 2004; Fowler & Liberman, 1995; Rubin et al., 1991; Siegel, 2008). Therefore, morphological knowledge may have a less significant role in predicting the reading skills of atypical readers compared to typical readers. In a study with first-grade students with and without speech-sound disorders (SSD), Apel and Lawrence (2011) found that MA significantly predicted the word reading skills of children without SSD. However, the children with SSD predominantly relied on phonemic awareness and letter knowledge in lieu of morphological knowledge. Further research is needed to compare the relation of morphological knowledge to reading amongst typical and atypical readers. Uncovering differences amongst these groups may help clarify why morphological intervention is more beneficial to the reading skills of atypical compared to typical readers (e.g., Bowers et al., 2010).

Children and Adults. Morphological knowledge tends to become essential to the reading comprehension skills of more mature learners (Nagy et al., 2006; Singson et al., 2000). Moreover, knowledge of certain morphological features tends to emerge in the later stages of development. Evidence suggests that older grade-school children demonstrate higher levels of accuracy with derivational morphology tasks than younger grade-school children (Berninger et al., 2010; Carlisle & Stone, 2005).

Although previous studies have compared the contribution of morphological knowledge to reading in younger (kindergarten through third grade) and older (fifth grade through high school) children, little is known about whether this relation varies across children and adults. Adults can recognize and manipulate most affixes in morphologically complex words (Kuo &

Anderson, 2006). Skilled adult readers who have no definable disabilities also show sensitivity to processing multimorphemic words (Nagy et al., 1989) and words containing complex morphological spellings (Deacon et al., 2006). In contrast, children only begin to show proficiency with reading morphologically complex words during the high school years (Carlisle & Stone, 2005). Thus, it is important to consider developmental influences on the relations between morphological knowledge and reading outcomes and how those relations may vary depending on assessment features.

1.4 Current Study

The purpose of the current study is to elucidate differences in the relations between various types of morphological assessments to reading outcomes within nine feature categories that varied according to 1) *Modality* (Decoding versus No Decoding, Spelling versus no Spelling), 2) *Task/Process* (Production versus Judgment versus Blending/Segmenting, Awareness versus Processing, Definition versus No Definition and 3) *Content* (Real Words versus Pseudowords, Context versus No Context, Inflectional versus Derivational). This study also investigated whether these relations vary amongst individuals in different age (older children, younger children, adults) and ability groups (typical and atypical readers). Few studies have administered large assessment batteries to large samples of participants to examine the influence of different types of morphological task features on reading outcomes (e.g., Goodwin et al., 2017; Goodwin et al., 2020; Tighe & Schatschneider 2016b;). Thus, additional research is needed to understand the concurrent validity of different types of morphological measures that span various modalities, content, and task/process features. This will help disentangle the types of morphological skills that are most important to reading outcomes and inform future intervention studies that aim to teach morphology to improve reading skills. Additionally, examining the effects of reading ability (atypical versus typical readers) and age (younger children, older children, adults) on the relations between different morphology assessments to reading comprehension can help elucidate the unique morphology needs of different age and ability groups.

1.4.1 Research Questions and Hypothesis

The current study asked the following research questions:

Research Question 1: How many eligible studies contained correlations between the different morphology measures within each assessment feature category (e.g., number of studies with correlations between oral and written measures) and how was this frequency distributed across the age and ability demographic categories?

It is anticipated that some of the feature categories will not be further explored in Research Questions 2 and 3 due to lack of correlations between the measures in those categories. This is because most studies that examined the relations between morphology and reading outcomes appear to include a maximum of only one or two measures (Apel, 2014). This leaves little opportunity to locate studies that include correlations between measures representing different task features. Additionally, it is anticipated that most of these studies would represent samples of children who are typically developing because fewer studies examine the morphological skills of adults and atypical readers.

Research Question 2: What is the relation of the different morphological knowledge tasks in each feature category to reading outcomes (word reading, reading comprehension) after controlling for vocabulary knowledge?

Vocabulary was controlled for in the models because theoretical models of reading posit that lexical knowledge is the driving force behind both word reading and reading comprehension

(Perfetti 2007; Perfetti & Stafura, 2014). It was hypothesized that morphology tasks requiring higher reliance on morphological knowledge (e.g., tasks with pseudowords and no contextual information) would demonstrate stronger relations to reading outcomes than tasks that provided syntactic and semantic cues (e.g., tasks with real words and contextual cues). It was also anticipated that tasks requiring literacy skills would have stronger unique relations with reading outcomes than tasks that did not demand literacy skills because assessments requiring decoding or written responses rely on orthographic knowledge bases that are important to word reading and reading comprehension processes (Deacon et al., 2009; Levesque et al., 2017). Additionally, it was anticipated that tasks requiring awareness of and/or manipulation of morphological information (e.g., morphological analysis and morphological) would demonstrate stronger unique relations to reading outcomes than tasks that did not demand this skill. These types of tasks require explicit understanding of morphological meaning and structure, which is critical to reading comprehension outcomes (Deacon et al., 2017). Finally, it was anticipated that tasks with open-ended responses would demonstrate stronger relations to reading outcomes than multiple choice response formats (e.g., judgment versus production or analogy) because these tasks may provide a truer account of the participants' competency of morphology than identifying the correct answer from a field of two or more.

Research Question 3: What is the relation between morphological knowledge and reading comprehension in younger children, older children, and adults who are represent typical and atypical readers? How do different types of morphological tasks moderate the relations between morphological knowledge and reading comprehension in children and adults, after controlling for the type of reading comprehension task (sentence- and paragraph-level reading comprehension)?

The literature suggests that atypical readers demonstrate poor morphological knowledge skills compared to typical readers (Carlisle, 1987; Casalis et al., 2004; Fowler & Liberman, 1995; Rubin et al., 1991; Siegel, 2008) and that adults broadly have more proficient morphological knowledge skills than children (Kuo & Anderson, 2006). Thus, it is hypothesized that the relations between morphological knowledge and reading may vary across these groups.

2 METHOD

The purpose of the current study was to use a meta-analysis structural equation modeling (MASEM) approach to build regression path models that elucidate differences in the relations between various types of morphological assessments to reading outcomes. The current study employed a two-stage MASEM approach (Cheung, 2015), which allows researchers to estimate multivariate models with existing correlational data across multiple studies. The benefit of two-stage MASEM models is that they can be estimated without requiring every study to include correlational data between all the measures that are hypothesized in the model (Cheung, 2015).

The second part of the meta-analytic study investigated whether the relations between morphology and reading comprehension measures varied for different types of assessment features across children and adults who were typical or atypical readers. To investigate this question, a univariate approach was used in leu of two-stage MASEM. One critical limitation of two-stage MASEM is that the correlational data must be divided into separate groups to examine moderators of age or reading ability. This may cause issues with model convergence, as there may not be enough correlational data across all the hypothesized measures at each age and/or reading ability group (e.g., Quinn & Wagner, 2018). Therefore, the current study did not use two-stage MASEM to examine the complex relations between multiple morphology assessment features to reading outcomes across different age and reading ability groups.

The method of the current systematic review and meta-analysis consists of three phases: 1) Screening studies for inclusion, 2) coding studies and 3) meta-analysis.

2.1 Phase 1: Screening Studies for Inclusion

2.1.1 Framework of Inclusion and Eligibility Criteria

The systematic review for the current study used Cronbach's UTOS (i.e., Units/Subjects, Treatment/Interventions, Outcomes, and Settings; Cronbach, 1982) as a framework to guide study inclusion. *Units/Subjects* consisted of a broad range of individuals, including typical readers, atypical readers, grade-school children, and adults. Data that were included from *Treatments/Interventions* consisted of pretest data that was collected before the interventions were implemented. *Outcomes* consisted of assessments of morphological knowledge and reading measures, specifically, word reading and/or reading comprehension. *Setting* was broadly specified to all countries; however, studies that were published in foreign languages were not eligible due to no resources to translate and evaluate articles in other languages.

2.1.2 Literature Search and Screening Procedures

For the literature search, computerized searches were conducted on February 3, 2021. These searches included three databases, two of which contained mostly published, peer-reviewed articles (Education Resources Information Center [ERIC] and PsycINFO) and one database of unpublished dissertations (Proquest Dissertations and Thesis). Additionally, searches of various preprint databases, including PsyArXiv, MindRxiv, osf, easychair, and EdArXiv, were conducted in Google Scholar using Publish or Perish (Harzing, 2007). The search terms used for the ERIC, PsychiNFO, and Proquest databases included the roots *morph** and *read** to populate results that contained words or phrases with variations of the terms *morpheme* (e.g., morphology, morphological, morphological awareness, morphological processing) and *read* (e.g., reading, reader, word reading, reading comprehension). Publish or Perish did not include an option for entering roots followed by an asterisk (*) into the search field. Thus, all possible variations of the terms *morpheme* and *read* were entered into the Publish or Perish search. With broad search terms, it was anticipated that the search engines would produce an exhaustive list of thousands of articles. Therefore, search results from ERIC, PsycINFO, and Proquest were limited to only titles and/or abstracts that contained *morph** and *read**. The same procedure was not used for Publish or Perish because there was no option to limit search results to titles and abstracts. Results from the literature searches were exported into an .ris file, which included item's citation information and abstract.

The screening procedure was completed using Covidence (Babineau, 2014). Screening consisted of two stages: 1) screening titles and abstracts and 2) screening full articles. During the first stage, titles and abstracts were screened according to the following criteria: 1) Published or unpublished work was not a literature review, case study, or single-case study design; 2) the study included least one morphological knowledge task <u>and</u> either a word reading and/or reading comprehension task and 3) the study included correlations between the morphological knowledge and reading tasks. During the second stage of screening, the full texts of the abstracts that were flagged during the first stage were considered for eligibility according to multiple different criteria. see Figure 3 for additional information regarding eligibility criteria during the second screening stage.

A second reviewer was taught to use the two-stage screening process to determine eligibility. The second reviewer followed the same eligibility concurrent that was created and used by the primary investigator for both stages of screening. The reviewer randomly screened 20% of the abstracts and the full texts, and the results were compared to the results of the primary investigator. A Cohen's kappa of 0.85 and 0.82 was calculated for the abstracts and the full texts, respectively, indicating sufficient inter-rater reliability (0.80 to 1 for acceptable inter-rater agreement).

2.2 Phase 2: Coding

2.2.1 Coding Scheme

General Study Information. General information pertaining to the study was coded, including the study identification number, the effect size identification number, the full study citation, the authors, the year of publication, whether the study was published (yes or no), and the type of manuscript (e.g., journal article, thesis, dissertation, etc.)

Demographic Information. Demographic information extracted and coded for each effect size included age/grade information (mean age, age range, grade-level), and ability status (typical versus atypical reader [e.g., dyslexia, poor reader, struggling adult reader, developmental delay, etc.]) Demographic information was coded for the analyses in Research Question 3, which examined moderators of age and ability status on the relation between morphological knowledge and reading comprehension skills.

Age/Grade. Age/grade information that was extracted from the full texts was used to create additional age categories. There were four categories: *younger child* (approximately 11 years old and younger and/or 5th grade level and below), *older child* (approximately 12-17 years old and/or 6th to 12th), *adults* (18 years of age and above) and *combined*. The combined category consisted of effect sizes that were collapsed across the younger and older child age groups and/or older children and adult age groups. The effect sizes in the combined category were not used for Research Question 3; however, they were included in the analyses for Research Question 2.

Ability status. Information for the ability status category was used to create four categories: *Typical*, *Atypical*, *Combined*, and *No Information Provided*. The combined category consisted of effect sizes that either collapsed information across the typical and atypical groups or represented a sample that contained a broad range of ability levels. The No Information Provided category consisted of effect sizes from studies that did not give any information related to the sample's reading ability level or whether there were learning disabilities, and/or a developmental or cognitive delay/deficit. Data in the Combined and No Information Provided categories were not used for Research Question 3; however, the data were included in the analyses for Research Question 2.

Effect Size and Measures Information. The effect size, Pearson's correlation *r*, and number of participants were coded. The names of the morphology and reading components measures were coded as well as whether the morphology measures were experimental, or norm-referenced.

Reading Component Skills and Morphology Measures. As previously discussed, the effect sizes extracted for this meta-analytic study were Pearson's *r* correlations. Thus, each effect size was given a code that represented the relation between two different types of measures. Before coding the effect sizes, each individual measure was categorized. The reading components skills measures were categorized as either real word reading, pseudoword reading, sentence-level reading comprehension, paragraph-level reading comprehension, receptive vocabulary, and expressive vocabulary. Table 1 contains additional information and examples pertaining to the reading components skills categories.

A coding scheme for the morphology measures was designed based on key morphology assessment features described in Deacon et al.'s (2009) taxonomy of morphological tasks. The morphology measures were coded using nine mutually exclusive categories: 1) *Response format (judgment, analogy, production, blending or segmenting)*, 2) *awareness versus processing*, 3) *definition versus no definition* 4) *oral versus written*, 5) *spelling versus no spelling*, 6) *decoding versus no decoding*, 7) *inflectional versus derivational* 8) *real versus pseudowords*, and 9) *context versus no context*. For each category, there was also an option for *No information provided/Not applicable* if the study did not provide an adequate description of the measure or could not be coded for that category. Table 2 contains additional information and examples pertaining to the categories in the morphology coding scheme.

After the individual measures were categorized, codes were given for each effect size. The types of codes for the effect sizes were different across the two research questions that used meta-analysis, specifically Research Questions 2 and 3. For Research Question 2, each effect size included a code that represented the correlation between either 1) two specific morphology tasks (e.g., *Oral_ Written*) 2) a morphology task and a reading components assessment (e.g., *Oral_ExpressiveVocab*), or 3) two specific reading components skills tasks (e.g., *ReceptiveVocab_ExpressiveVocab*). Research Question 3 only examined correlations between the morphological knowledge and reading comprehension components skills assessments. The morphological task features and type of reading comprehension task (sentence-level versus paragraph-level) were all coded as moderators.

2.2.2 Procedures and Coding Reliability

A coding form was developed, and a digital version of the coding form was uploaded into Qualtrics (2021). The coding form was organized into four sections. The first section required entering general information pertaining to the study. The second section included codes related to effect size demographic information. The third section included codes related to general information pertaining to the measures and effect sizes. The fourth section included codes to categorize the reading component skills and morphology measures. See the coding form in Appendix A for more details.

A second coder provided agreement for the coding process by being taught to use all four sections of the coding form to code the effect sizes. The coder completed a random 20% of the studies that were initially coded by the primary investigator. A Cohen's kappa of 0.85, 0.85, 0.87, and 0.82 was calculated for section 1, section 2, section 3, and section 4, indicating sufficient inter-rater reliability (0.80 to 1 for acceptable inter-rater agreement).

2.3 Phase 3: Summary of Study Characteristics and Meta-Analysis

2.3.1 Research Question 1

Research Question 1. How many eligible studies contained effect sizes that represented the correlations between the different morphology measures within each assessment feature category (e.g., number of studies with correlations between oral and written measures) and how was this frequency distributed across the age and ability demographic categories?

Frequency data were calculated for the first and second part of Research Question 1. The purpose of the frequency data was not only to describe the prevalence of studies that provided correlations between different features of morphology tasks, but to also determine whether there would be sufficient effect size data to fit models for Research Questions 2 and 3. If a feature category contained less than ten studies, the category was not included in further analyses.

2.3.2 Research Questions 2 and 3

For Research Questions 2 and 3, meta-analyses were conducted using Pearson's r correlations to investigate the relations between morphology and reading components assessments. The R statistical software (R Development Core Team, 2014) was used to conduct the analyses.

Effect sizes calculations. Pearson product-moment correlation coefficients (*r*) were coded across the studies and transformed using the Fisher's *Z* transformation. The Fisher's *Z* transformation allowed for interpretation of the Pearson's correlations on a normally distributed scale.

Robust variance estimation (RVE). Many of the eligible studies reported multiple effect sizes. For example, some studies reported more than one effect size containing assessments that measured the same construct (e.g., more than one word reading or reading comprehension assessment). Some studies included multiple samples (e.g., children with and without dyslexia) and reported a separate correlation matrix for each sample. This meta-analytic study incorporated all the relevant effect sizes, which violated the assumption of independence. Dependency in the data was handled using robust variance estimation (RVE) with the clubSandwich package (Pustejovsky, 2020) in R. It was also anticipated that the true effect sizes for this study would demonstrate between- and within-study heterogeneity. To handle data with both a correlated (between-study heterogeneity) and a hierarchical (within-study heterogeneity) structure, a correlated hierarchical effects (CHE) model was used (Pustejovsky & Tipton, 2021).

Research Question 2. What was the relation of the different morphological knowledge tasks to reading outcomes (word reading, reading comprehension), controlling for vocabulary knowledge? Did the concurrent validity of morphological knowledge vary across morphological tasks with different features?

A two-stage approach (Cheung, 2014) was used to fit path models using the metafor (Viechtbauer, 2010) and metaSEM (Cheung, 2015) packages in R. The first stage consisted of combining the correlation matrices using multivariate meta-analysis in the metafor package. The correlation matrix between the morphology and reading variables was estimated with all the variables included in a no-intercept, multivariate meta-regression model. The pooled correlation matrices contained correlations between distinct groups of morphology assessment categories (e.g., oral versus written, context versus no context, real versus pseudo, etc.) and reading components skills measures (word reading, reading comprehension, and vocabulary). A separate matrix was computed for each group of morphology assessment categories, which resulted in eight different correlation matrices. The RVE estimates of the correlations were computed using the clubSandwich package.

The second stage consisted of fitting eight RVE variance-covariance matrices with the metaSEM and clubSandwich packages. Next, eight sets of correlations and variance-covariance matrices were used to fit eight different path models for each of the eight feature categories. The path models included morphological knowledge tasks with different features separately predicting the word reading (real word and pseudoword) and reading comprehension outcomes (sentence-level and paragraph-level), after controlling for vocabulary. see Figure 2 for an example of a path model.

Model fit was evaluated using root-mean square error of approximation (RMSEA), comparative fit index (CFI), and Tucker-Lewis index (TLI). RMSEA below 0.10 and CFI and TLI above .9 are considered good indicators of good model fit (Kline, 2016). Akaike Information Criteria (AIC) and Bayesian Information Concurrent (BIC) values were also used to evaluate model fit. Lower AIC and BIC values represent better-fitting models (Burnham & Anderson, 2004).

Research Question 3. What is the relation between morphological knowledge and reading comprehension in younger children, older children, and adults who represent typical and atypical readers? Do different types of morphological tasks moderate the relation between morphological knowledge and reading comprehension in children and adults, after controlling for the type of reading comprehension task (sentence and paragraph-level reading comprehension)?

Univariate models, including average effect sizes and meta-regression models, were calculated using the metafor package to examine the relations between morphological knowledge and reading comprehension. These models were calculated for each age group (younger children, older children, adults) and across the typical and atypical readers within each age group; however, they were not calculated for groups containing fewer than five studies. Random effects models were used because it was anticipated that there would be variability in the effect sizes due to measurement and/or sampling characteristics. Additionally, RVE estimates were calculated and interpreted for all models, including average effect sizes and meta-regressions. Restricted Maximum Likelihood (REML) was used to estimate the heterogeneity variance.

3 RESULTS

3.1 Systematic Review

Figure 3 depicts a PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses; Moher et al., 2009) flow diagram of the literature search results. The search terms that were entered into the ERIC, PsychInfo, Proquest, and Publish or Perish search engines yielded a total of 6,113 items. One of the authors whose studies appeared in the search results contributed data from two unpublished sources: a preprint and raw, unpublished data. When these unpublished sources were added, the search results yielded a total of 6,115 items. After duplicate records were removed, a total of 5,989 titles and abstracts were screened during the first phase. Of the titles and abstracts screened in the first phase, 748 full texts (12%) were identified and screened in the second phase. The final number of items available for data extraction after consulting the full texts and contacting authors for information was 126 studies (17% of the 12%).

Table 3 contains a summary of the study characteristics and demographics. Out of the 126 studies, 87 were coded as younger children (ages 11 and younger or 5th grade and under), 22 were coded as older children (ages 12 through 17 or 6th through 12th grade), and 27 were coded as adults (18 and over). There were 8, 1, and 9 studies that reported data with atypical readers (that did combine atypical and typical samples) in the younger children, older children, and adult groups, respectively. In the younger children group, there were studies with children who had dyslexia, (*n*=2), low-literacy acquisition (*n*=1), reading disabilities (*n*=1), specific-language impairment (*n* =1) and speech-sound disorders (*n* =1). In the older children group, there was one study with children who had dyslexia. In the adult group, there were studies with individuals who had dyslexia (*n*=2) and studies with struggling adult readers (*n*=7).

Overall, the studies did not administer norm-referenced morphology assessments. Out of the 125 studies, only one study used a norm-referenced morphology assessment. Ninety-nine percent of the studies administered experimental assessments.

3.2 Research Question 1

The purpose of Research Question 1 was to identify the frequency of eligible studies that reported correlations between morphological knowledge assessments containing different task features. The number of studies containing effect sizes in each of the following categories was counted: studies with effect sizes between oral versus written, real words versus pseudowords, processing versus awareness, context versus no context, spell versus no spell, definition versus no definition, derivational versus inflectional, decoding versus no decoding, and effect sizes with correlations between the four different assessment response formats (production, judgment, analogy, blending and segmenting). In total, 46 out of the 126 studies contained at least one correlation in at least one of the feature categories.

Table 4 includes the frequency of studies containing correlations across each of the feature categories, in total and split between the demographic variables (age and reading ability). Most of the categories contained at least ten studies, except for the derivational versus inflectional category. This category only contained 7 studies, and thus was not included in the analyses for Research Questions 2 and 3. Additionally, fewer than ten studies contained effect sizes between analogy and each of the other response format tasks (e.g., analogy with production, analogy with judgment, analogy with blending/segmenting). Therefore, correlations with analogy tasks were not used in Research Questions 2 and 3. The context versus no context category demonstrated the highest frequency, with 37 studies containing at least one effect size in this category, followed by oral versus written (35), and awareness versus processing (29). Studies with younger, atypical children demonstrated the highest total frequency of correlations across the feature categories (56), followed by studies with young children that contained no information about the children’s reading ability (46), atypical younger children (29), and typical older children (29).

3.3 Research Question 2

The purpose of Research Question 2 was to examine whether the concurrent validity of morphological knowledge assessments containing different features varied when predicting multiple reading outcomes after controlling for vocabulary knowledge. Specifically, eight regression path models that varied on 1) *Modality* (oral versus written, decoding versus no decoding, spelling versus no spelling), 2) *Task/Process* (production versus judgment, awareness versus processing, definition versus no definition) and 3) *Content* (real words versus pseudowords, context versus no context).

3.3.1 Preparation of Correlation and Variance-Covariance Matrices

Before specifying the regression path models, a correlation and variance-covariance matrix was calculated for each path model using the metafor (Viechtbauer, 2010) and metaSEM (Cheung, 2015) packages in R. All eight sets of correlation and variance-covariance matrices were non-positive definite due to high correlations between the word reading (real words and pseudowords) and vocabulary (expressive and receptive) measures that either met or surpassed a correlation of one. Therefore, correlations containing real words and pseudowords were collapsed into one category labeled “word reading” and correlations with expressive and receptive vocabulary measures were collapsed into one category labeled “vocabulary”.

RVE correlations below five degrees of freedom were removed from the pooled correlation matrices, due to difficulties with model convergence. This removal influenced the number of studies, effect sizes, and total sample sizes (*N*) across the eight models (see Table 5). Specifically, sentence-level reading comprehension was removed from six out of the eight correlation matrices because the RVE correlations in those matrices exhibited five or fewer degrees of freedom. As a result, only two models contained sentence-level reading comprehension as an outcome: models testing the concurrent validity of oral versus written task features and context versus no context task features to reading outcomes.

The matrix containing correlations between production, blending/segmenting, and judgment tasks was reduced to just production and judgment assessments because RVE correlations containing blending/segmenting assessments were below five degrees of freedom. Consequently, the relations between blending/segmenting tasks to reading outcomes were not tested in Research Question 2. For additional information regarding the variables included in each correlation matrix and the estimates, see Tables 6 through 13.

3.3.2 Regression Path Models

One regression path model was specified for each of the eight sets of correlations and variance-covariance matrices (see Figures 5, 6, and 7 for the modality path models, the task/process path models, and the content models, respectively). Table 14 contains the model fit indices for all eight models. Tables 15 through 22 contain standardized estimates for each of the eight models.

Modality. The modality models consisted of the oral versus written, decoding versus no decoding, and spelling versus no spelling path models.

Oral versus Written. The oral versus written path model was a good fit to the data $\chi 2(3) = 15.22$, p=0.002, RMSEA= 0.017 (95% CI= [.009, 0.027]), CFI= 0.99, TLI= 0.94 (see Figure 5a). The oral morphological measures were significantly predictive of the paragraph-level reading comprehension (p<0.001), sentence-level reading comprehension (p<0.001), and word reading (p<0.001) outcomes. The written morphological measures were significantly predictive of the paragraph-level reading comprehension (p<0.001), sentence-level reading comprehension (p<0.001), and the word reading (p<.001) outcomes. The estimates suggest that the written measures predicted paragraph-level reading comprehension (0.35), sentence-level reading comprehension (0.64), and word reading (0.48), more strongly than the oral measures (0.29, 0.26, and 0.26 for paragraph-level comprehension, sentence-level comprehension, and word-reading respectively). There was a moderate to low correlation between the oral morphological measures and the written morphological measures (*r*=0.48). Table 15 contains standardized estimates for all predictors in the oral versus written model.

Decoding versus No Decoding. The decoding versus no decoding model was a good fit to the data $\chi2(1) = 8.93$, p=0.002, RMSEA= 0.025 (95% CI= [0.012, 0.044]), CFI= 0.99, TLI= 0.92 (see Figure 5b). The decoding morphological measures were significantly predictive of the paragraph level reading comprehension (p<0.001) and word reading (p<0.001) outcomes. The morphological measures that did not require decoding were significantly predictive of the paragraph-level comprehension (p=0.02) and word reading (p=0.004) outcomes. The estimates suggest the decoding measures predicted paragraph-level reading comprehension (0.32) and word reading (0.45), more strongly than the measures that did not require decoding (0.23 and 0.25 for paragraph-level comprehension and word-reading, respectively). There was a moderate to low correlation between the oral morphological measures and the written morphological measures (0.50). Table 16 contains standardized estimates for all predictors in the decoding versus no decoding model.

Spell versus No Spell. The spell versus no spell model was a good fit to the data $\chi2(1) = 1.97$, p=0.159, RMSEA= 0.008 (95% CI= [0.000, 0.026]), CFI= 0.998, TLI= 0.986 (see Figure 5c). The morphological measures that required spelling significantly predicted passage-level comprehension (p<0.001) and word reading (p<0.001). The morphological measures that did not require spelling also significantly predicted passage-level comprehension (p=0.008) and word reading (p=0.044). The estimates suggest the spelling measures predicted paragraph-level comprehension (0.51) and word reading (0.68), more strongly than the measures that did not require spelling (0.15 and 0.14 for paragraph-level comprehension and word-reading, respectively). There was a moderate correlation between measures that did and did not require spelling (0.52). Table 17 contains standardized estimates for all predictors in the spell versus no spell model.

Task/Process. The task/process models consisted of judgment versus production, processing versus awareness, and definition versus no definition path models.

***Judgment versus Production*.** The judgment versus production model was a good fit to the data $\chi2(1) = 10.16$, $p=0.001$, RMSEA= 0.027 (95% CI= [0.014, 0.042]), CFI= 0.99, TLI= 0.88 (see Figure 6a). The judgment morphological measures significantly predicted passage-level comprehension ($p<0.001$) and word reading ($p<0.001$). The productive morphological measures were also uniquely predictive of passage-level comprehension ($p<.001$) and word reading ($p<.001$). The estimates suggest that the judgment measures predicted paragraph-level comprehension (0.59) and word reading (0.69) more strongly than the productive measures (0.22 and 0.28 for passage-level comprehension and word reading, respectively). There was a moderate to low correlation between the judgment and production morphological measures (0.42). Table 18 contains standardized estimates for the predictors in the judgment versus production model.

***Processing versus Awareness*.** The processing versus awareness path model was a good fit to the data $\chi2(1) = 9.59$, $p=0.002$, RMSEA= 0.025 (95% CI= [0.024, 0.040]), CFI= 0.99, TLI= 0.91 (see Figure 6b). The awareness measures were not significantly predictive of either passage-level comprehension (estimate=0.21, $p=0.10$) or word reading (estimate=0.06, p=0.768). The processing measures were predictive of both passage-level comprehension (estimate=0.32, $p<0.001$) and word reading (estimate=0.77, $p<0.001$). There was a moderate correlation between processing and awareness morphological measures (0.61). Table 19 contains standardized estimates for all predictors in the processing versus awareness model.

Definition versus No Definition. The definition versus no definition model was a good fit to the data χ2(1) = 20.69, *p*<0.001, RMSEA= 0.034 (95% CI= [0.025, 0.053]), CFI= 0.98, TLI= 0.78 (see Figure 6c). The morphological measures that did not require providing a definition were significantly predictive of both passage-level comprehension (*p*<0.001) and word reading (*p*<0.001). The morphological measures that did require providing definitions were predictive of word reading (*p*=.002); however, they did not predict paragraph-level comprehension (estimate=0.07, *p*=0.387). The estimates suggest that the measures that did not require providing a definition were more predictive of word reading (0.37) than the estimates that did require providing a definition (0.19). There was a moderate correlation between measures that did and did not require providing a definition (0.55). Table 20 contains standardized estimates for all predictors in the definition versus no definition model.

Content. The content models consisted of the real words versus pseudowords and the context versus no context path models.

Real Words versus Pseudowords. The real words versus pseudowords path model was a good fit to the data χ2(1) = 6.49, *p*=0.011, RMSEA= 0.021 (95% CI= [0.008, 0.037]), CFI= 0.99, TLI= 0.92 (see Figure 7a). The morphological measures containing pseudo words were significantly predictive of the paragraph-level reading comprehension (estimate=0.52, *p*<.001) and word reading (estimate=0.67, *p*<.001) outcomes. The real morphological measures were not predictive of the paragraph-level comprehension (estimate= 0.11, *p*=) and word reading (estimate=0.11, *p*=) outcomes. There was a moderate correlation between the real and pseudoword morphological measures (0.56). Table 21 contains standardized estimates for all predictors in the real words versus pseudowords path model.

Context versus no Context. The context versus no context path model was a good fit to the data $\chi2(3) = 25.43$, $p<0.001$, RMSEA= 0.023 (95% CI= [0.015, 0.031]), CFI= 0.99, TLI= 0.89 (see Figure 7b). The morphological measures with contextual information were significantly predictive of paragraph-level comprehension ($p<0.01$) and word reading ($p=0.01$). Morphological measures with contextual information were not predictive of sentence-level reading comprehension (estimate=0.03, p=0.824). The morphological measures with no contextual information were significantly predictive of the paragraph level reading comprehension ($p<0.001$), sentence-level reading comprehension ($p<0.001$), and word reading ($p<0.001$) outcomes. The estimates suggest that the morphological measures with no contextual information were more strongly predictive of paragraph-level comprehension (0.73) and word reading (0.42) than the morphological measures with contextual information (0.28 and 0.23 for passage comprehension and word reading, respectively. There was a moderate correlation between the context and no context morphological measures (0.52). Table 22 contains standardized estimates for all predictors in the real words versus pseudowords model.

3.4 Research Question 3

The purpose of Research Question three was to first examine the relation of morphological knowledge to reading comprehension in younger children, older children, and adults across typical and atypical readers. Second, the moderating effects of different types of morphological tasks on the relation between morphological knowledge to reading comprehension was examined in both children and adults, after controlling for type of reading comprehension assessment (sentence- and paragraph-level).

3.4.1 Mean Effects Across Age and Ability Level

The average RVE effect sizes of the correlations between morphological knowledge and reading comprehension were calculated for the younger children, older children, and adults. There were no studies with effect sizes for atypical older children and there were only three studies with effects sizes for atypical younger children. Therefore, the average effects sizes were not calculated separately for those two groups. Additionally, mean effect sizes were not separately calculated for correlations that collapsed information across both typical and atypical groups (n=5, 3 and 2, in the younger child, older child, and adult groups, respectively). Mean effect sizes also were not separately calculated for correlations that did not provide enough information about the participants' ability status (n=12, 4, and 1, in the younger child, older child, and adult groups, respectively).

The average effect size was highest for the adults (0.58, p<0.001), followed by the older children (0.46, p<0.001) and the younger children (0.41, p<0.001). The effect size for the typical adults (0.68, p<0.05) was slightly higher than the atypical adults (0.59, p<0.001). The amount of heterogeneity (I^2) in the younger children, older children, and adults was 91.25%, 95.47% , and 90.73%, respectively. Table 23 contains additional information on the frequency of studies and average effect sizes per age and ability group.

3.4.2 Meta-regressions

Children. The data were subset separately into older and younger groups children. There were few studies with atypical children (n=3), and thus moderators were not examined separately for these children. The older and younger groups contained children of all reading abilities, including typical children, atypical children, samples with both types of readers, and samples that did not identify the children as either typical or atypical. There were 161 effect sizes and 39 studies in the younger children group and there were 12 studies and 39 effect sizes in the older children group. The average effect sizes for the younger children and the older children were 0.41 and 046, respectively. Meta-regressions were tested to examine if moderators of morphological features (contextual features, pseudowords, oral responses, processing tasks, decoding, judgment) and reading comprehension type (sentence- versus paragraph-level) accounted for heterogeneity in the overall effect sizes. For both groups, the meta-regression model revealed that none of the moderators were significant (p>0.05). The total R^2 was 2.33% and 0% for the younger and older child models, respectively, suggesting that the moderators accounted for zero to very little percent of the heterogeneity. The degrees of freedom for the moderators in the younger child meta-regression were above 9; however, the degrees of freedom for the moderators in the older child meta-regression were below 5. This suggests that the lack of significant effects in the older child meta-regression model could be due to a power issue.

Adults. The data were subset separately into groups of typical and atypical adult readers. In the atypical adult group, there were 9 studies and 39 effect sizes. The average effect size between morphological knowledge and reading comprehension for this group was 0.59. A meta-regression model with moderators of morphological features (contextual features, pseudowords, oral responses, processing tasks, decoding, judgment) and reading comprehension type (sentence- versus paragraph-level) revealed a significant effect for processing assessments (-0.47, p=0.027), such that the relation between morphological knowledge and reading comprehension was weaker for the morphological processing assessments. The R^2 value was 65.59%, indicating that the moderators accounted for a large portion of the heterogeneity. Additionally, the degrees of freedom for the moderators in were below 5, which suggests that the model was under-powered. Table 24 contains additional information regarding model parameters. Figure 7 presents a forest plot of the effect sizes for the atypical adult readers.

In the typical adult group, there were 6 studies and 17 effect sizes. The average effect size between morphological knowledge and reading comprehension for this group was 0.68. A meta-regression with moderators of morphological features (contextual features, pseudowords, oral responses, processing tasks, decoding, judgment) exhibited no significant effects; however, the R^2 value was 40.64%, indicating that the moderators accounted for a substantial portion of the heterogeneity. Additionally, the degrees of freedom for the moderators were below 5, which suggests that there were no significant effects because it was under-powered. Table 25 contains additional information regarding model parameters. Figure 8 presents a forest plot of the effect sizes for the typical adult readers.

4 DISCUSSION

This systematic review and meta-analysis elucidated important patterns in the literature on the relations between morphological knowledge and reading outcomes. First, Research Question 1 examined the number of eligible studies that investigated multiple dimensions of morphological knowledge. Results reviewed found that few studies in the literature have considered multiple dimensions of morphology (e.g., oral versus written, production versus judgment, real words versus pseudowords) when examining the relations between morphological knowledge and reading outcomes. The systematic review revealed that there is a lack of information regarding the relation between different dimensions of morphology to reading outcomes in specific groups, including children with atypical reading abilities (e.g., poor comprehension, speech-language deficits, reading disabilities), older children, and adults.

Second, Research Question 2 focused on disentangling differences in the relations between multiple types of morphological knowledge task features to word reading and reading comprehension outcomes after controlling for vocabulary knowledge. Eight path models were tested that examined differences in the concurrent validity of morphology tasks across three categories: 1) *Modality* (oral versus written, decoding versus no decoding, spelling versus no spelling), 2) *Task/Process* (production versus judgment, awareness versus processing, definition versus no definition) and 3) *Content* (real words versus pseudowords, context versus no context). Results revealed that morphology tasks that required literacy skills (e.g., decoding and spelling) demonstrated stronger unique relations to reading outcomes than measures that do not require literacy skills. Similarly, higher performance on measures that required participants to rely on syntactic and semantic information without linguistic cues was more predictive of reading outcomes (e.g., pseudowords and no contextual information) than performance on measures that did provide linguistic cues. Higher performance on processing tasks, tasks that did not require definitions, and judgment tasks were also more predictive of reading outcomes than awareness tasks, tasks that required definitions, and tasks that contained production task formats.

Third, Research Question 3 examined whether the relations of different morphological tasks to reading comprehension varied by age and/or reading ability. There were not enough studies to examine whether reading ability moderated the relations between different morphological task formats and reading comprehension in the groups of older and younger children. The morphological task features did not moderate the relation between morphological knowledge and reading in younger children, older children, or typical adult readers. Atypical adult readers tended to rely less on morphological processing tasks than morphological awareness tasks.

4.1 Dimensions of Morphological Knowledge in the Reading Literature

Research Question 1 identified the number of studies in the literature that reported correlations between multiple assessments features, or dimensions, of morphological knowledge, as defined by Deacon and colleagues' (2009) taxonomy of morphology tasks. It also examined the frequency of studies that reported correlations within each morphological knowledge category (e.g., oral versus written, production versus judgment) and the distribution of the frequencies across age groups and reading ability. Studies that provided correlations between different task features did not group the various tasks into one composite morphological knowledge measure when examining the relations between morphology and reading outcomes. Therefore, these studies were considered successful in terms of distinguishing amongst different types, or dimensions, of morphological knowledge assessments.

In general, 37% of the studies included at least one correlation in at least one assessment category. Broken down by category, correlations mostly represented the context versus no context (37 studies) and the oral versus written (35 studies) categories. Correlations were least represented in the blending/segmenting versus productive, blending/segmenting versus judgment, and inflectional versus derivational categories with 13, 8, and 7 studies, respectively. Broadly, this evidence suggests that few studies in the literature have considered the dimensional nature of morphological knowledge. Apel (2014) argued that researchers have used different types of experimenter-designed morphology tasks; however, most studies have reported only one or two measures. Thus, the literature currently seems to favor a general conceptualization of morphological knowledge rather than a nuanced view of morphology that spans a range of different skills.

One explanation for this trend in the literature may be engrained in how researchers have applied reading theories to study the relations between morphological knowledge and reading. For example, the Simple View of Reading (SVR), is a components-based model which argues that reading is a product of decoding and language comprehension abilities (Gough & Tunmer, 1986). Several studies have investigated the unique effects of morphological knowledge over and above SVR correlates without considering different dimensions of morphology that may manifest through interactions between morphological knowledge, language processing (e.g., lexical knowledge), and word reading skills (e.g., Gottardo et al., 2018; Kim et al., 2020; Oliveira et al., 2020; Verhoeven et al., 2019). Additionally, using the SVR may encourage researchers to choose one or two morphological measures without providing an adequate theoretical rationale for the specific type of morphological knowledge measure used.

The Morphological Pathways Framework (Levesque et al., 2020) explicitly delineates important dimensions of morphological knowledge as a function of different processes and knowledge bases, such as decoding and linguistic processing, that have been proposed in the Reading Systems Framework (Perfetti & Stafura, 2014). Therefore, the Morphological Pathways Framework may function as a rationale for the inclusion of various morphological tasks in a model of reading comprehension. Most of the eligible studies in this systematic review that distinguished between different types of morphological measures reported correlations between oral and written morphological measures as well as contextual and non-contextual measures. These feature categories map on to some of the processes and knowledge bases in the Morphological Pathways Framework. Specifically, oral measures were distinguished from written measures because the written measures required participants to spell or decode, which involves the application of knowledge related to orthographic units. The contextual measures contained lexical and syntactic cues, which may have provided additional support to participants who lacked adequate lexical representations and/or linguistic knowledge. There was low representation in the productive versus blending/segmenting and blending/segmenting versus productive feature categories. Thus, eligible studies in this systematic review focused less on different task format dimensions than modality or content dimensions. Task formats are not explicitly addressed in the Morphological Pathways Framework; however, they may tap into broader cognitive processes outlined in the Reading Systems Framework, such as long-term memory (Perfetti & Stafura, 2014). For example, tasks that require participants to produce a short-answer response may demand more effortful memory retrieval than judgment tasks, which require participants to identify the correct answer from an array of two or more.

The total frequency of studies that distinguished between different types of morphological task features was higher in the group of younger children (total frequency of 128 across all the categories) in comparison to the groups of older children (49) and adults (37). Surprisingly, the frequency of studies that made a distinction between different types of morphological task features was lower for the group of older children compared to the group of younger children. Literacy demands increase as children age, and thus it is appropriate to investigate the unique role of different types of morphological knowledge assessments to reading outcomes in older grade-school children. Older children also demonstrate fewer limitations in terms of the range and types of morphological knowledge tasks that they can complete because morphological knowledge and literacy skills tend to increase as children progress through grade-school (Anglin et al., 1993; Van Kleeck, 1982). For example, it’s developmentally appropriate to administer derivational morphology tasks to older children because derivational knowledge accuracy increases in the later grade-school years (Berko, 1958; Berninger et al., 2010; Carlisle, 1988; Carlisle & Fleming, 2003). In contrast, it was not surprising that there were relatively fewer studies in the adult group that contained correlations across the assessment feature categories. In general, the unique influence of morphological knowledge to reading outcomes is relatively understudied in both typical (Apel & Wilson-Fowler, 2014) and atypical (Tighe & Schatsneider, 2016a) adult readers.

The total frequency of studies that distinguished between different types of morphological task features was lower for children who were atypical readers compared to children who were typical readers. This finding is surprising, given evidence suggesting that children with reading difficulties tend to struggle with specific types of morphological knowledge tasks that involve orthographic and phonological knowledge as well as short-answer responses (e.g., Carlisle, 1988; Carlisle, 2000; Champion, 1997; Windsor, 2000; Windsor & Hwang, 1997). Discriminating the unique effects of different morphological task features to reading outcomes in children who struggle with reading may help elucidate the types of morphological abilities that need to be targeted in future intervention studies. For example, children who struggle with reading may also struggle with morphological decoding, and thus not rely on morphological decoding to support their reading comprehension skills. In contrast, morphological tasks that do not involve morphological decoding may uniquely predict the reading comprehension skills of children who struggle with reading.

Interestingly, the total frequency of studies that distinguished between different types of morphological assessment features was higher in studies with atypical adult readers than studies with typical adult readers. This finding could be due to the low number of studies that examined the relations of typical adults' morphological knowledge to reading comprehension in general (Apel & Wilson-Fowler, 2014). Relatively recently researchers have become interested in struggling adult readers' reading component skills, such as decoding and vocabulary, to inform intervention studies that aim to improve their reading comprehension (Tighe & Schatsneider, 2016). In particular, some research has focused on elucidating the relations of struggling adult readers' performance on various types of morphology measures to reading comprehension (e.g., Tighe & Schatschneider, 2016; Tighe et al., 2019).

4.2 Relations of Morphological Task Features to Reading Outcomes

4.2.1 Modality

In the oral versus written path model, both the oral and written assessments were significantly predictive of paragraph reading comprehension, sentence reading comprehension, and word reading outcomes. The effects of the written morphological assessments predicting paragraph reading comprehension (0.35), sentence reading comprehension (0.64) and word reading (0.48) were larger than the effects of the oral morphological knowledge measures (0.29, 0.26, and 0.26 for paragraph comprehension, sentence comprehension, and word reading outcomes, respectively). In the spelling versus no spelling path model, the spelling and no spelling assessments were both uniquely predictive of paragraph reading comprehension and word reading outcomes; however, the effects of the spelling measures were larger for paragraph comprehension (0.51) and word reading (0.68) in comparison to the non-spelling morphology measures (0.15 and 0.14 for paragraph comprehension and word reading, respectively). In the decoding versus no decoding path model, both the decoding and no decoding morphology measures were significantly predictive of paragraph and reading comprehension outcomes, but the decoding morphology measures effects were higher for both paragraph comprehension (0.32) and word reading (0.45) than the no decoding morphology measures (0.23 and 0.25, for paragraph comprehension and word reading, respectively).

Results from the modality models support the hypothesis that morphological assessments requiring literacy skills are stronger predictors of reading outcomes than morphological knowledge tasks that do not require literacy skills. According to the Morphological Pathways Framework, morphological knowledge tasks requiring literacy skills draw on multiple knowledge bases and processes that are implicated in reading comprehension, such as the orthographic system and the linguistic system. Morphemes are specialized orthographic units that form a direct pathway from print to meaning (Levesque et al., 2020) and carry multidimensional information, such as phonological, orthographic, semantic, and syntactic information (Perfetti, 2007). Thus, written morphology tasks may activate orthographic processes that depend on orthographic and phonological units as well as morpho-orthographic and morpho-semantic processes to facilitate word identification. The results from this study suggest that the complex level of activation that occurs during morphological tasks requiring literacy skills may not occur when engaging in morphological tasks that do not require literacy skills.

4.2.2 Task/Process

In the production versus judgment path model, both judgment and production measures were uniquely predictive of paragraph reading comprehension and word reading outcomes. The effects of the production measures to paragraph comprehension (0.22) and word reading (0.28) were relatively small compared to the effects of the judgment morphology measures (0.57 and 0.69 for paragraph comprehension and word reading, respectively). In the awareness versus Processing path model, processing was uniquely predictive of both paragraph comprehension and word reading, but morphological awareness was not uniquely predictive of either of the reading outcomes. In the definition versus no definition model, morphology tasks that did not require providing a definition uniquely predicted both paragraph comprehension and word reading measures, but the definition tasks only predicted word reading.

Results from the production versus judgment model did not support this study's original hypothesis, which was that the production measures would rely more on long-term memory mechanism and subsequently demonstrate a relatively higher relation to the reading comprehension outcomes than the judgment tasks. The stronger relations between the judgment tasks and reading outcomes compared to the production tasks may have resulted from the variability in types of judgment tasks that were coded for this study. Specifically, some of the judgment tasks were lexical decision tasks that demanded use of morphological decoding and fluency skills because the participants were instructed to read the letter strings as quickly and as accurately as possible. Lexical decision tasks may therefore require increased activation of different types of processes in the reading system as opposed to simply listening to the examiner read a question stem and then picking choices from a field of two or more without having to read. Additionally, many production tasks include fill-in-the-blank question stems with lexical and syntactic cues that may lead participants to product the correct answer. Thus, judgment tasks are not necessarily always less demanding than production tasks.

Results from the awareness versus processing and definition versus no definition models also did not support this study's original hypothesis that morphological analysis and morphological structure awareness skills would demonstrate a stronger relation to reading outcomes than tasks that did not demand this skill. The results from this study suggested that morphological awareness tasks were not predictive of reading outcomes above and beyond the morphological processing tasks. The tasks that required participants to provide or identify definitions of morphemes (or morphological analysis skills) did not demonstrate larger predictive effects than the tasks that did not require these skills. The rationale for these findings parallels the explanation for the findings in the production versus judgment model. Many of the processing tasks in the awareness versus processing model involved either reading or spelling lists of words, which entailed drawing upon phonological and orthographic knowledge bases and engaging in morpho-orthographic and morpho-semantic processes with no additional linguistic or syntactic cues. In the definition versus no definition model, the tasks that did not require definitions represented multiple types of processing assessments that required participants to engage in literacy skills. Taken together, evidence from the models in the Task/Process category suggests that the relations between morphology assessment features and reading outcomes may hinge on other factors, such as whether the task was timed, whether the participants were required to engage orthographic processes and/or morphological decoding, and whether the participants were given linguistic cues.

4.2.3 Content

In the real words versus pseudowords model, tasks with pseudowords were uniquely predictive of both paragraph comprehension and word reading, but the tasks with real words were not. In the context versus no context model, the tasks with no contextual information were uniquely predictive of paragraph reading comprehension, sentence reading comprehension, and word reading. The tasks with contextual information were uniquely predictive of word reading and paragraph comprehension, but not sentence comprehension. In general, the tasks that did not provide contextual information demonstrated stronger unique effects with paragraph reading comprehension (0.32), sentence reading comprehension (0.73), and word reading (0.42) than the tasks with contextual information (0.28, 0.03, and 0.23 for paragraph comprehension, sentence comprehension, and word reading, respectively).

Results from the real words versus pseudowords model confirmed this study's hypothesis, which stated that the morphology tasks containing pseudowords would demonstrate higher relations to reading outcomes than the morphology tasks containing real words. Tasks with pseudowords embody a true representation of participants' knowledge of morphemes without the confound of memory and prior experience that may complicate assessments containing real words. These findings support the lexical quality hypothesis, which states that participants with better morphological, orthographic, and phonological representations also demonstrate higher lexical quality, which is associated with better reading outcomes (Perfetti et al., 2007; Perfetti & Stafura, 2014). Additionally, knowledge of morphological information is a powerful predictor of reading outcomes because it interacts with orthographic and phonological information (Levesque et al., 2020).

Results from the context versus no context model also confirmed this study's hypothesis, which stated that morphology tasks without contextual cues would have higher relations to reading comprehension and word reading outcomes than the tasks with contextual cues. Similar to tasks that use real words, tasks with contextual cues provide participants with additional syntactic and semantic information that may confound the ability to assess their true knowledge of morphological information. Morphology tasks with contextual cues draw upon participants' previous knowledge and experiences rather than just morphological knowledge. Thus, morphology tasks without contextual cues provide a better representation of morphological knowledge skills than tasks with contextual cues and, as a result, are expected to have higher relations with reading outcomes.

4.3 Influence of Age and Reading Ability

4.3.1 Relations of Morphology to Reading Comprehension across Age and Reading Ability

The overall relation between morphological knowledge and reading comprehension was strongest for the atypical and typical adult reader groups, followed by the older children group. Although the younger children demonstrated the weakest relation between morphological awareness and reading comprehension, the relations between morphological awareness and reading comprehension for the younger and older children were similar (effect size of .41 and .46, respectively).

These findings partially support the literature's description of how the unique role of morphology to reading comprehension changes over time. Adults demonstrated the highest relation between morphological knowledge and reading comprehension in comparison to the older and younger children, which supports arguments in the literature regarding the morphological abilities of adults. Compared to children, the morphological knowledge of most adult readers is opaque. In other words, adults can recognize and manipulate most affixes within morphologically complex words (Kuo & Anderson, 2006). Therefore, adults are more likely to show a higher reliance on morphological knowledge abilities to support reading comprehension than children.

The relations between morphological knowledge and reading comprehension were very similar for the older and younger children, which did not support previous evidence regarding the substantial development in morphological knowledge from younger to older grade-school children. According to the literature, older children exhibit improved morphological knowledge due to increased exposure to morphology in the later grade-school years (e.g., Nagy et al., 2012; Berninger et al., 2010). Thus, the older children in the current study should have demonstrated higher reliance on using morphological knowledge to support reading comprehension than the younger children. One explanation for the inconsistency between the findings in this study and the previous literature could be due to the overall small number of studies (*N*=12) and effect sizes (*N*=39) in the older children group, which may not accurately represent the relations between morphological knowledge and reading comprehension in that group.

4.3.2 Influence of Morphological Task Features on Reading Comprehension across Age and Reading Ability

Adults. The moderating effects of different types of morphological task features (context versus no context, pseudowords versus real words, oral versus written, processing versus awareness, decoding versus no decoding, and judgment versus production) explained some of the variability in the relation between morphology and reading comprehension in adults with atypical reading abilities. In the group of atypical adult readers, the relation between morphology and reading comprehension was weaker when the morphology tasks required participants to engage in morphological processing as opposed to morphological awareness skills.

The findings from this study suggest that the adults in the atypical reading group were less reliant on morphological processing than morphological awareness to support reading comprehension. One potential explanation for this finding could be due to low word reading and fluency skills in adults who struggle with reading (e.g., Mellard et al., 2009) Morphological processing tasks often require engagement in literacy skills, including decoding and spelling, as well as fluency skills if the task is timed (e.g., lexical decision tasks). Therefore, adults with atypical reading abilities may already struggle with morphological processing tasks and not rely on these skills to support reading comprehension.

Children. The morphological task features (context versus no context, pseudowords versus real words, oral versus written, processing versus awareness, decoding versus no decoding, and judgment versus production) did not explain variability in the relation between morphology and reading comprehension in the studies with younger and older children. However, these results do not necessarily suggest that morphological assessment features do not account for heterogeneity in the relation between morphological knowledge and reading outcomes in children. Other types of assessment features that were not explored, such as derivational and inflectional morphology tasks, may have explained some variability. The distinction of inflectional versus derivational in children is particularly important because inflectional morphological awareness is not as predictive of derivational outcomes, especially in the later grade-school years (Kuo & Anderson, 2006).

4.4 Study Limitations

This meta-analytic study has some limitations. First, the eight morphology assessment categories explored in Research Question 2 (e.g., oral versus written, judgment versus productive, real words versus pseudowords) were crude distinctions that may have been more informative if there were additional levels of nuance. Specifically, the relations between the judgment versus production categories to the reading comprehension outcomes were confounded by other factors, such as whether the tasks required responses with pseudowords as opposed to real words or whether they required participants to use literacy skills versus no literacy skills. Investigation of different types of response formats (judgment, productive, analogy, blending/segmenting) across various modality (e.g., oral versus written) and content (e.g., real words versus pseudowords) dimensions would have required much more correlational data with more nuanced distinctions. For example, the current study did not contain enough effect sizes that represented correlations between oral and written judgment tasks, oral and written production tasks, oral judgment tasks and written production tasks, etc. Correlational data across multiple, nuanced dimensions of morphological knowledge would have provided additional indicators to build confirmatory factor analysis (CFA) models, allowing researchers to ask interesting questions related to the structural validity of the morphological knowledge measures that have been used in the literature. There are currently mixed findings regarding whether different dimensions of morphological knowledge represent one underlying construct or distinct abilities (e.g., Goodwin et al., 2017; Muse et al., 2005; Spencer et al., 2015; Tighe & Schatschneider, 2015). Lack of agreement regarding morphological knowledge assessment may lead to inability to test the construct fully and consistently. To determine whether different morphological measures capture the full range of morphological knowledge, additional research is needed to determine whether various morphological tasks measure the same or different aspects of morphological knowledge.

Second, there was a substantial lack of correlational data available within each demographic group (age and reading ability). Many of the eligible studies in the current meta-analysis, in particular the studies with children, estimated correlations for samples containing multiple age groups and ability levels. Multiple studies did not collect and/or report demographic data pertaining to reading ability and were not used in Research Question 3. This impeded the ability to conduct multivariate analyses (i.e., path models) for the different age and ability level groups. Additionally, the reduced number of studies within the older and younger child groups may have accounted for low variability due to different types of morphological knowledge assessment features. This may have explained the failure to detect differences pertaining to morphology assessment features in the relation between morphology and reading comprehension.

Third, this study did not examine the relation between morphology and reading comprehension in individuals who demonstrated differences in dialect, and whether this relation differed across multiple types of morphology assessment features. Little is known about non-mainstream American dialects (NMAE), such as African American English (AAE), and morphology; however, some evidence suggests that morphological knowledge is important to the word reading skills of children who use AAE (Apel & Thomas-Tate, 2009; Jarmulowicz et al., 2012). Moreover, few studies have examined the relations between morphological knowledge and reading outcomes in samples of individuals who use AAE (e.g., Apel & Thomas-Tate, 2009; Jarmulowicz et al., 2012; Sligh & Conners, 2003). Thus, the number of eligible studies with samples representing non-mainstream dialects would have been too low to include this variable as a moderator in the current study.

4.5 Implications for Future Research

The findings and limitations from this meta-analytic study have several implications for future research, which include suggestions for future correlational as well as intervention studies. For correlational studies, researchers must consider the limitations that arise from ignoring various demographic factors that may moderate the relations between morphological knowledge and reading outcomes. Failing to consider demographic factors includes failure to set up eligibility criteria that will avoid reading ability level and/or linguistic diversity confounds, not describing the sample, and not reporting correlational data separately for each demographic group. Improvements across these areas may help enhance the overall quality of the literature base, thus allowing future meta-analytic studies to generate meaningful results pertaining to the moderating effects of demographic factors on the relations of different morphological assessment features to reading outcomes. Additionally, future correlational studies should continue to focus on the relations between morphological knowledge to reading outcomes in atypical readers, older children, and adults (who are relatively understudied) to elucidate their unique literacy needs. Such studies can help inform literacy interventions for those specific populations.

Correlational studies that include morphological knowledge as a predictor must also consider adopting reading theories that support the role of morphology in literacy. Simple theoretical models of literacy, such as the SVR, does not account for the complex dimensionality of morphology. The misuse of theory has led researchers to include only one morphology measure or use multiple morphology measures but combine the tasks into one composite score. One common example is the *Test of Morphological Structure*, developed by Carlisle (2000), which contains two subtests: one subtest requires participants to append a suffix onto a base word (e.g., *farm*→*farmer*) and the other requires participants to decompose a derived word into its base form (e.g., *singer*→*sing*). One subtest requires knowledge of decomposing words, and thus may also tap into phonological awareness, and the other does not. However, most studies that have used the *Test of Morphological Structure* have combined the subtests into a composite, treating the measures as one general morphology skill (e.g., Koh, 2018; Lok, 2017; Loudermill, 2015; Qiao et al., 2021). By leveraging complex reading theories, such as the Reading Systems Framework and the Morphological Pathways Framework, researchers may become more cognizant of the nuances across different types of morphological tasks and thus avoid using composite scores in their analyses. Researchers may also conscientiously choose multiple morphology measures that represent different dimensions of morphological knowledge.

Finally, the current meta-analytic study has implications for the design of future intervention studies that specifically target morphological knowledge to improve reading outcomes. In general, results from the current study emphasize the importance of a combination of knowledge sources that interact with morphology, including orthographic and linguistic knowledge bases. Structured Word Inquiry (SWI) is an intervention approach that aims to improve literacy skills and is supported by theories which view morphology is the binding agent that is linked to semantics, orthography, and phonology (e.g., Levesque et al., 2020; Kirby & Bowers, 2017). SWI teaches students that English spelling revolves around the interrelation between morphology, etymology, and phonology. Additionally, SWI leverages the connection between English spelling and semantics by focusing on meaningful morpho-orthographic units.

4.6 Conclusion

This meta-analytic study has shed light on the importance of different types of morphological assessment features for reading comprehension. Moreover, this study emphasized the role of various task features on the relation between morphology and reading comprehension across different age groups and reading abilities. The findings from this study have important implications for future studies investigating the relations between morphological knowledge and reading outcomes and reading intervention studies. Future studies should continue to examine morphological knowledge and reading ability in atypical readers and older children to understand their unique literacy needs. Interventions studies should continue to investigate the efficacy of literacy interventions that focus on the interactions between morphological, orthographic, and linguistic knowledge base

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6 TABLES

Table 1 Description and Examples of Reading Component Skills

Variables	Description	Examples
Word Reading		
Real	Decoding words, either in a fluency (timed) or untimed task.	• Woodcock Reading Mastery Tests (WRMT) Word Identification subtest • Test of Word Reading Efficiency (TOWRE) Sight Word Efficiency (SWE) subtest
Pseudo	Decoding strings of letters/non-words in a fluency (timed) or untimed task.	• WRMT Word Attack. • TOWRE Phonetic Decoding Efficiency (PDE) subtest
Reading Comp.		
Sentences	Relying on syntactic and semantic information to demonstrate reading comprehension at the sentence level in a fluency (timed) or untimed tasks.	• WRMT passage comprehension subtest • Test of Silent Reading Efficiency and Comprehension (TOSREC)
Paragraphs	Reading comprehension tasks that involve responding to questions about information presented in paragraphs or passages.	• Gates-McGinitie reading comprehension test (GMRT) • Gray's Oral Reading Test (GORT)

Table 1 Description and Examples of Examples of Reading Components Skills (Continued)

Variables	Description	Examples
Vocabulary		
Expressive	Ability to produce a specific label for a word	Expressive One-Word Picture Vocabulary Test (EOWPVT)
Receptive	Ability to recognize and/or understand words	Peabody Picture Vocabulary Test (PPVT)

Table 2 Description of Morphology Tasks Coded in the Study

Variable	Description
Task or Process	
1. Response Formats	
Judgment	When a task provides a choice between required alternatives, such as yes/no or multiple-choice responses.
Production	A task that requires production of a response with no given alternatives (e.g., fill-in-the blank, freely generating word lists, spelling, reading morphologically complex words)
Analogy	A task that provides a word pair and a second word pair with a missing word in the format a:a::b:__. A correct response requires understanding the relation in the first word pair to find the missing word in the second pair.
Blending/Segmenting	A task that either requires breaking down a word into its morphological sub-components (e.g., farmer: My uncle works on a ___.) or combining bases and/or roots with their affix to create a multimorphemic word.
2. Awareness vs. Processing	
Awareness	A task that requires explicit identification or manipulation of morphemes, involving the addition or subtraction of affixes.
Processing	A task that targets implicit knowledge of morphology, which often includes judging whether a sentence sounds correct (e.g., The man was *walked* yesterday), spelling and/or reading morphologically complex words, and judging whether a sequence of letters makes up a word.

Table 2 Description of Morphology Tasks Coded in the Study (Continued)

Variable	Description
3. Knowledge of Definitions	A task that measures knowledge of a morphologically complex word's meaning by either providing or identifying the definition of an affix or morphologically complex word.
Modality	
4. Oral vs. Written	A task that either does or does not rely on the use of literacy skills, such as spelling or decoding.
5. Knowledge of Spelling	A task where the answer relies on spelling accuracy.
6. Knowledge of Decoding	A task where the answer relies on decoding accuracy.
Content	
7. Morpheme Type	
Derivational	A task that requires adding prefixes (*un-*) or suffixes (e.g., *-ness*) to words that either change the syntactic category, meaning of a word, or both.
Inflectional	A task that requires adding suffixes to assign a particular grammatical property of a word, such as adding -*s* to make a word plural (e.g., *girl*→*girls*).
8. Real vs. Pseudowords	Tasks may require manipulating affixes with real words (e.g., *hope*→*hopeful*) or non-words (e.g., *wooty*→*wootiful*).
9. Context vs. No Context	A task that either does or does provide information in the form of a fill-in-the-blank sentence (e.g., farm; My uncle is a ____).

Table 3 Number of Studies by Study Type and Participant Demographics

	Published	Unpublished	Total
Younger Children			
Typical	33	8	41
Atypical	6	2	8
Both	8	7	15
No Information	21	2	23
Total	68	19	87
Older Children			
Typical	10	1	11
Atypical	1	1	2
Both	5	0	5
No Information	3	1	4
Total	19	3	22
Adults			
Typical	6	4	10
Atypical	8	1	9
Both	2	1	3
No Information	3	1	4
Total	19	8	26
Combined Ages			
Typical	8	3	11
Atypical	0	0	0
Both	1	0	1
No Information	2	0	2
Total	11	3	14

Note: Unpublished studies included dissertations (*n*=22), books (*n*=2), preprints, (*n*=3), and unpublished data (*n*=1).

Table 4 Frequency Table of Studies that Reported Correlations between Different Morphological Task Features

	Task/Process					Modality		Content		
	Pr. vs. Bl./Sg.	Pr. vs. Judge.	Bl./Sg. vs. Judge.	Aware. vs. Proc.	Def. (yes/no)	Oral vs. Writ.	Spell (yes/no)	Dec. (yes/no)	Real vs. Pseudo.	Context (yes/no)	Total
Younger Children											
Typical	2	5	2	9	4	13	5	5	2	9	56
Atypical	1	4	1	2	1	4	2	1	3	5	29
Both	1	1	1	1	0	0	0	1	2	4	11
No Info.	3	3	1	4	10	7	2	4	4	7	46
Total Younger	7	11	5	16	15	24	7	11	9	23	128
Older Children											
Typical	1	4	1	4	6	3	2	2	2	3	29
Atypical	0	0	0	0	0	1	0	0	0	0	1
Both	0	2	0	3	1	0	1	2	0	3	12
No Info.	0	1	0	1	0	1	1	2	1	1	8
Total Older	1	7	1	8	7	5	4	6	3	7	49

Note: Pr.=Production; Bl.=Blending; Sg. =Segmenting; Judge. =Judgment; Aware. =Awareness; Proc.=Processing; Def.=Definition; Writ. =Written; Dec.=Decoding; Pseudo. =Pseudoword

Table 4 Frequency Table of Effect Sizes Reporting the Relations between Different Morphological Task Features (continued)

	Task/Process					Modality			Content		
	Pr. vs. Bl./Sg.	Pr. vs. Judge.	Bl./Sg. vs. Judge.	Aware. vs. Proc.	Def. (yes/no)	Oral vs. Writ.	Spell (yes/no)	Dec. (yes/no)	Real vs. Pseudo.	Context (yes/no)	Total
Adults											
Typical	0	1	0	1	2	1	0	1	1	1	8
Atypical	4	1	1	1	0	1	1	0	3	4	16
Both	1	1	1	1	3	0	1	0	1	1	10
No Info.	0	0	0	0	0	1	0	1	0	1	3
Total Adults	5	3	2	3	5	3	2	2	5	7	37
Combined Ages											
Typical	0	0	0	1	0	3	1	2	1	0	8
Atypical	0	0	0	0	0	0	0	0	0	0	0
Both	0	0	0	1	0	0	0	0	0	0	0
No Info.	0	0	0	0	0	0	0	0	0	0	0
Total Combined	0	0	0	2	0	3	1	2	1	0	9
Total	13	21	8	29	28	35	14	21	18	37	223

Note: Pr.=Production; Bl.=Blending; Sg. =Segmenting; Judge. =Judgment; Aware. =Awareness; Proc.=Processing; Def.=Definition; Writ. =Written; Dec.=Decoding; Pseudo. =Pseudoword

Table 5 Total Sample Size, Number of Studies and Effect Sizes for Each Correlation Matrix

Model	N	Number of Studies	Number of Effect Sizes
Modality			
Oral vs. Written	13,483	116	1,356
Decoding vs. No Decoding	13,155	113	1,172
Spell vs. No Spell	13,256	115	1,165
Task/Process			
Judgment vs. Production	13,054	109	980
Processing vs. Awareness	13,798	115	1,226
Definition vs. No Definition	13,827	115	1,160
Content			
Real vs. Pseudoword	12,781	113	1,112
Context vs. No Context	14,668	119	1,395

Table 6 Correlations between Oral and Written Morphology, Vocabulary, and Reading

Measures	1	2	3	4	5
1. Oral					
2. Written	0.43				
3. Word Reading	0.51	0.56			
4. Sentence Comp.	0.64	0.67	0.79		
5. Passage Comp.	0.50	0.50	0.55	0.77	
6. Vocabulary	0.54	0.42	0.44	0.62	0.54

Note: Comp.=Comprehension

Table 7 Correlations between Decoding and No Decoding, Vocabulary, and Reading

Measures	1	2	3	4
1. Decoding				
2. No Decoding	0.43			
3. Word Reading	0.49	0.54		
4. Passage Comp.	0.47	0.50	0.53	
5. Vocab	0.38	0.56	0.45	0.53

Note: Comp.=Comprehension

Table 8 Correlations between Spell and No Spell, Vocabulary, and Reading

Measures	1	2	3	4
Spell				
No Spell	0.54			
Word Reading	0.65	0.51		
Passage Comp.	0.59	0.51	0.55	
Vocab	0.50	0.53	0.44	0.55

Note: Comp.=Comprehension

Table 9 Correlations between Judgement and Productive, Vocabulary, and Reading

Measures	1	2	3	4
Judgment				
Productive	0.47			
Word Reading	0.49	0.54		
Passage Comp.	0.47	0.51	0.53	
Vocab	0.48	0.54	0.45	0.54

Note: Comp.=Comprehension

Table 10 Correlations between Processing and Awareness, Vocabulary, and Reading

Measures	1	2	3	4
1. Processing				
2. Awareness	0.52			
3. Word Reading	0.62	0.52		
4. Passage Comp.	0.49	0.52	0.55	
5. Vocab	0.47	0.53	0.42	0.54

Note: Comp.=Comprehension

Table 11 Correlations between Definition, No Definition, Vocabulary, and Reading

Measures	1	2	3	4
1. Definition				
2. No Definition	0.55			
3. Word Reading	0.48	0.53		
4. Passage Comp.	0.51	0.52	0.55	
5. Vocab	0.54	0.53	0.44	0.54

Note: Comp.=Comprehension

Table 12 Correlations between Real and Pseudoword Morphology, Vocabulary, and Reading

Measures	1	2	3	4
1. Pseudo				
2. Real	0.59			
3. Word Reading	0.56	0.52		
4. Passage Comp.	0.52	0.52	0.52	
5. Vocabulary	0.43	0.53	0.44	0.55

Note: Comp.=Comprehension

Table 13 Correlations between Context and No Context Morphology, Vocabulary, and Reading

Measures	1	2	3	4	5
1. Context					
2. No Context	0.50				
3. Word Reading	0.51	0.53			
4. Sentence Comp.	0.62	0.64	0.78		
5. Passage Comp	0.52	0.48	0.55	0.78	
6. Vocabulary	0.53	0.51	0.44	0.58	0.54

Note: Comp.=Comprehension

Table 14 Model Fit Indices

Model	χ^2	df	RMSEA	LB/UB	CFI	TLI	AIC	BIC
Modality								
Oral vs. Written	15.22	3	0.017	0.009/0.003	0.99	0.94	9.22	-13.31
Decoding vs. No Decoding	8.93	1	0.025	0.012/0.04	0.99	0.92	6.93	-0.56
Spell vs. No Spell	1.97	1	0.008	0/0.026	0.998	0.99	-0.025	-7.59
Task/Process								
Judgment vs. Production	10.16	1	0.027	0.017/0.043	0.99	0.88	8.16	0.68
Processing vs. Awareness	9.59	1	0.023	0.012/0.04	0.99	0.91	7.58	0.05
Definition vs. No Definition	20.68	1	0.038	0.025/0.053	0.98	0.78	18.68	11.15
Content								
Real vs. Pseudoword	6.49	1	0.021	0.008/0.037	0.99	0.92	4.49	-2.97
Context vs. No Context	25.43	3	0.023	0.015/0.031	0.98	0.89	19.43	-3.35

Note: RMSEA= root mean square error of approximation; df=degrees of freedom; LB/UB=lower bound and upper bound 95% confidence interval for the RMSEA index; CFI=comparative fit index; TLI=Tucker-Lewis Index

Table 15 Path Estimates and Correlations for the Oral versus Written Model

Path/Relation	Estimate	SE	LB/UB	*p*
Predictive Paths				
Par. Comp. on Oral	0.29	0.09	0.125/0.464	<0.001
Par. Comp. on Vocab.	0.23	0.06	0.109/0.356	<0.001
Par. Comp on Written	0.35	0.04	0.271/0.438	<0.001
Sentence Comp. on Oral	0.26	0.07	0.128/0.389	<0.001
Sentence Comp. on Vocab.	0.22	0.1	0.029/0.403	0.024
Sentence Comp. on Written	0.64	0.11	0.427/0.85	<0.001
Word Reading on Oral	0.26	0.56	0.147/0.378	<0.001
Word Reading on Vocab	0.09	0.05	-0.014/0.186	0.093
Word Reading on Written	0.48	0.08	0.327/0.640	<0.001
Correlations				
Oral with Vocab	0.52	0.03	0.469/0.579	<0.001
Written with Vocab	0.43	0.03	0.373/0.495	<0.001
Oral with Written	0.43	0.06	0.308/0.550	<0.001

Note: SE = Standard error; LB/UB=lower bound and upper bound (95% confidence interval); Par.=Paragraph; Comp.=Comprehension; Vocab.=Vocabulary

Table 16 Path Estimates and Correlations for the Decoding versus No Decoding Model

Path/Relation	Estimate	SE	LB/UB	*p*
Predictive Paths				
Par. Comp. on Decoding	0.32	0.04	0.236/0.410	<0.001
Par. Comp. on No Decoding	0.23	0.10	0.033/0.436	0.023
Par. Comp on Vocab	0.28	0.07	0.145/0.414	<0.001
Word Reading on Decoding	0.45	0.11	0.231/0.662	<0.001
Word Reading on No Decoding	0.25	0.09	0.083/0.424	<0.001
Word Reading on Vocab	0.11	0.05	0.011/0.215	0.029
Correlations				
Decoding with No Decoding	0.5	0.09	0.323/0.677	<0.001
Decoding with Vocab	0.44	0.04	0.357/0.527	<0.001
No Decoding with Vocab	0.55	0.03	0.495/0.6	<0.001

Note: SE = standard error; LB/UB=lower bound and upper bound (95% confidence interval); Par.=paragraph; Comp.=Comprehension; Vocab.=Vocabulary

Table 17 Path Estimates and Correlations for the Spell versus No Spell Model

Path/Relation	Estimate	SE	LB/UB	*p*
Predictive Paths				
Par. Comp. on No Spell	0.151	0.06	0.039/0.262	0.008
Par. Comp. on Spell	0.511	0.10	0.313/0.716	<0.001
Par. Comp on Vocab	0.16	0.10	-0.0312/0.344	0.102
Word Reading on No Spell	0.14	0.07	0.004/0.281	0.044
Word Reading on Spell	0.68	0.13	0.434/0.931	<0.001
Word Reading on Vocab	-0.01	0.09	-0.202/0.190	0.953
Correlations				
Spell with No Spell	0.52	0.06	0.405/0.640	<0.001
No Spell with Vocab	0.51	0.0377	0.458/0.578	<0.001
Spell with Vocab	0.57	0.07	0.436/0.705	<0.001

Note: SE = standard error; LB/UB=lower bound and upper bound (95% confidence interval); Par.=Paragraph; Comp.=Comprehension; Vocab.=Vocabulary

Table 18 Path Estimates and Correlations for the Judgment versus Production Model

Path/Relation	Estimate	SE	LB/UB	*p*
Predictive Paths				
Par. Comp. on Judgment	0.569	0.131	0.311/0.826	<0.001
Par. Comp. on Production	0.222	0.054	0.116/0.328	<0.001
Par. Comp on Vocab	0.040	0.130	-0.215/0.295	0.7580
Word Reading on Judgment	0.691	0.150	0.396/0.985	<0.001
Word Reading on Production	0.283	0.061	0.163/0.403	<0.001
Word Reading on Vocab	-0.129	0.135	-0.393/ 0.136	0.3405
Correlations				
Judgment with Production	0.422	0.062	0.300/0.545	<0.001
Judgment with Vocab	0.641	0.077	0.491/0.791	<0.001
Production with Vocab	0.524	0.031	0.462/0.585	<0.001

Note: SE = standard error; LB/UB=lower bound and upper bound (95% confidence interval); Par.=Paragraph; Comp.=Comprehension; Vocab.=Vocabulary

Table 19 Path Estimates and Correlations for the Awareness versus Processing Model

Path/Relation	Estimate	SE	LB/UB	*p*
Predictive Paths				
Par. Comp. on Awareness	0.21	0.13	-0.039/0.464	0.097
Par. Comp. on Processing	0.32	0.06	0.206/0.436	<0.001
Par. Comp on Vocab	0.28	0.07	0.136/0.398	<0.001
Word Reading on Awareness	0.06	0.19	-0.311/0.422	0.768
Word Reading on Processing	0.77	0.22	0.348/1.192	<0.001
Word Reading on Vocab	-0.03	0.08	-0.188/0.122	0.677
Correlations				
Processing with Awareness	0.61	0.10	0.411/0.815	<0.001
Awareness with Vocab	0.52	0.03	0.466/0.572	<0.001
Processing with Vocab	0.55	0.04	0.46/0.635	<0.001

Note: SE = Standard error; LB/UB=lower bound and upper bound (95% confidence interval); Par.=Paragraph; Comp.=Comprehension; Vocab.=Vocabulary

Table 20 Path Estimates and Correlations for the Definition versus No Definition Model

Path/Relation	Estimate	SE	LB/UB	*p*
Predictive Paths				
Par. Comp. on Definition	0.07	0.08	-0.089/ 0.229	0.387
Par. Comp. on No Definition	0.33	0.05	0.238/0.431	<0.001
Par. Comp on Vocab	0.35	0.06	0.236/0.468	<0.001
Word Reading on Definition	0.19	0.06	0.069/0.307	0.002
Word Reading on No Definition	0.37	0.05	0.285/0.463	<0.001
Word Reading on Vocab	0.17	0.05	0.076/0.270	<0.001
Correlations				
Definition with No Definition	0.55	0.05	0.454/0.639	<0.001
Definition with Vocab	0.52	0.07	0.395/0.652	<0.001
No Definition with Vocab	0.54	0.03	0.486/ 0.592	<0.001

Note: SE = standard error; LB/UB=lower bound and upper bound (95% confidence interval); Par.=paragraph; Comp.=Comprehension; Vocab.=Vocabulary

Table 21 Path Estimates and Correlations for the Real versus Pseudowords Model

Path/Relation	Estimate	SE	LB/UB	*p*
Predictive Paths				
Par. Comp. on Pseudo	0.52	0.17	0.295/0.751	<0.001
Par. Comp. on Real	0.11	0.07	-0.0164/0.243	0.087
Par. Comp on Vocab	0.18	0.10	-0.0191/0.381	0.076
Word Reading on Pseudo	0.67	0.14	0.391/0.953	<0.001
Word Reading on Real	0.11	0.08	-0.055/0.273	0.194
Word Reading on Vocab	0.02	0.10	-0.185/0.223	0.856
Correlations				
Pseudo with Real	0.56	0.06	0.436/0.681	<0.001
Pseudo with Vocab	0.56	0.08	0.398/0.702	<0.001
Real with Vocab	0.52	0.03	0.454/0.578	<0.001

Note: SE = Standard error; LB/UB=lower bound and upper bound (95% confidence interval); Par.=Paragraph; Comp.=Comprehension; Vocab.=Vocabulary

Table 22 Path Estimates and Correlations for the Context versus No Context Model

Path/Relation	Estimate	SE	LB/UB	*p*
Predictive Paths				
Par. Comp. on Context	0.28	0.10	0.094/0.469	0.003
Par. Comp. on No Context	0.32	0.05	0.221/0.425	<0.001
Par. Comp on Vocab	0.22	0.06	0.098/0.350	<0.001
Sentence Comp. on Context	0.03	0.15	-0.259/0.325	0.824
Sentence Comp. on No Context	0.73	0.14	0.457/1.009	<0.001
Sentence Comp. on Vocab	0.33	0.13	0.0754/0.574	0.011
Word Reading on Context	0.23	0.07	0.095/0.363	<0.001
Word Reading on No Context	0.42	0.08	0.264/0.568	<0.001
Word Reading on Vocab	0.15	0.08	-0.004/0.309	0.056
Correlations				
Context with No Context	0.52	0.05	0.422/0.622	<0.001
Context with Vocab	0.53	0.03	0.480/0.579	<0.001
No Context with Vocab	0.45	0.08	0.296/0.607	<0.001

Note: SE = Standard error; LB/UB=lower bound and upper bound (95% confidence interval);

Par.=Paragraph; Comp.=Comprehension; Vocab.=Vocabulary

Table 23 Frequency of Studies, Average Effect Size, Q and I^2 statistics for the Younger Children, Older Children, and Adult Groups

	Younger Children			Older Children			Adults		
	Total	Typical	Atypical	Total	Typical	Atypical	Total	Typical	Atypical
Number of Studies	39	20	3	12	5	0	18	6	9
Number of Effect Sizes	161	91	24	39	22	0	63	17	39
Mean Effect Size	0.41***	0.32**	--	0.46***	0.38*	--	0.58***	0.68*	0.59***
Q	1752.08**	1225.10***	--	548.59***	282.22***	--	470.08***	328.28***	117.97***
I^2	91.25%	92.53%	--	95.47%	95.49%	--	90.73%	95.84%	68.45%

Note: Mean effect size represents the robust variance estimation (RVE) adjusted standard error. The Q and I^2 statistics represent the magnitude and proportion of heterogeneity across studies, respectively.

***p<0.001, **p<0.01 *p<0.05

Table 24 Atypical Adult Meta-regression model with Morphological Knowledge Task Features

Variable	Estimate	SE	*df*	*p*
Intercept	0.59	0.13	2.76	0.025*
Context	0.15	0.06	1.78	0.151
Pseudo	-0.07	0.04	2.71	0.169
Oral	-0.11	0.10	2.99	0.348
Processing	-0.47	0.07	1.94	0.027*
Decoding	-0.09	0.17	2.57	0.623
Judgment	0.04	0.02	1.57	0.169
Comp.S	0.05	0.08	1.71	0.608

Note: SE=standard error; *df*=degrees of freedom; *p*=significance value; Comp.=Comprehension. Paragraph comprehension is the comparison group for Sentence Comp.

*$p<0.05$

Table 25 Typical Adult Meta-regression model with Morphological Knowledge Task Features

Variable	estimate	SE	*df*	*p*
Intercept	1.39	0.26	1.67	0.047*
Oral	-0.23	0.22	1.37	0.445
Context	-0.79	0.26	1.67	0.112
Pseudoword	0.12	0.10	1.58	0.377
Processing	-0.31	0.23	1.15	0.372
Decoding	-0.471	0.15	2.18	0.077
Judgment	-0.08	0.08	1.67	0.438

Note: SE=standard error; *df*=degrees of freedom; *p*=significance value; Comp.=Comprehension

$*p<0.05$

7 FIGURES

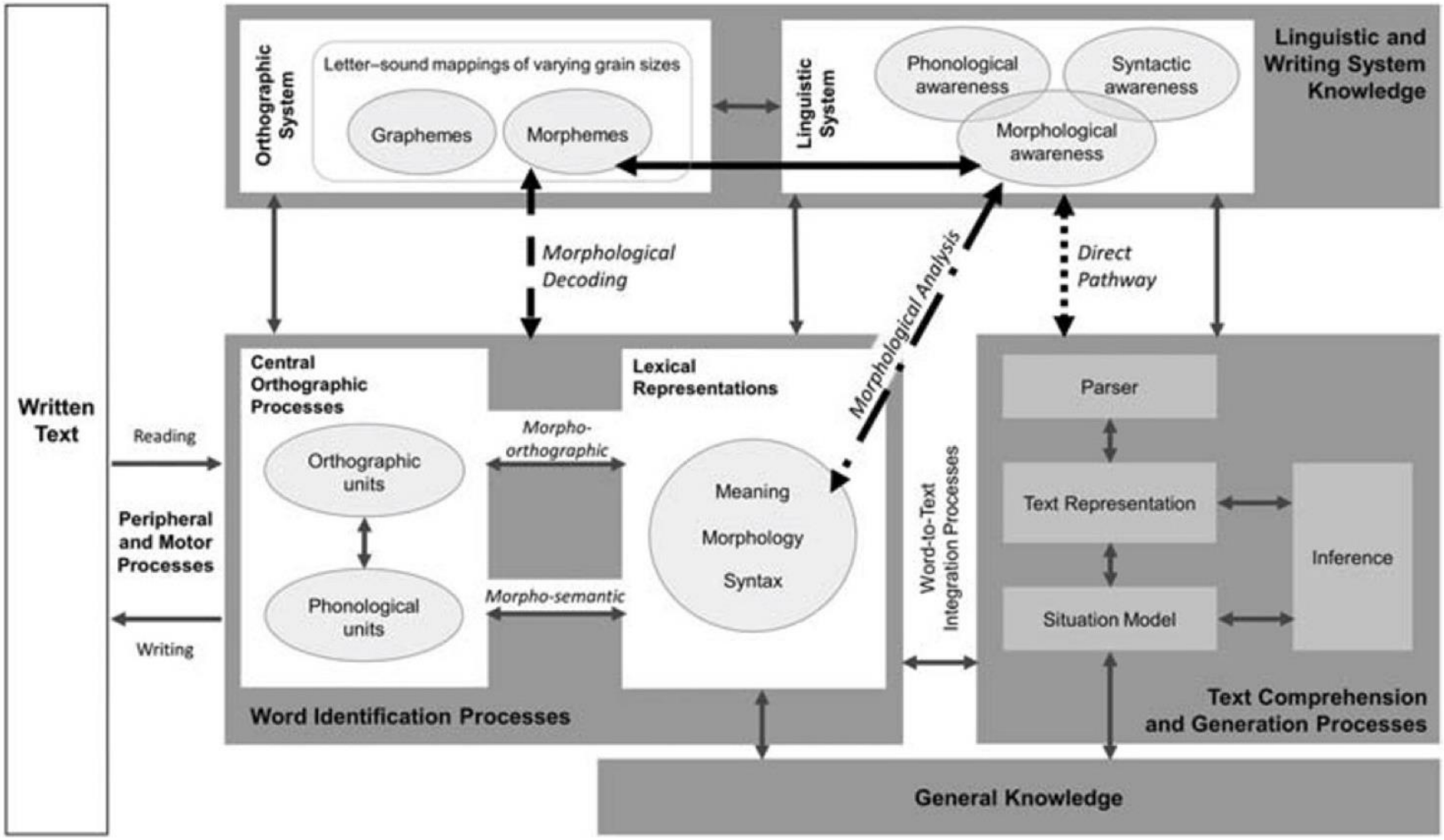

Figure 1 The Morphological Pathways Model (Levesque et al., 2020)

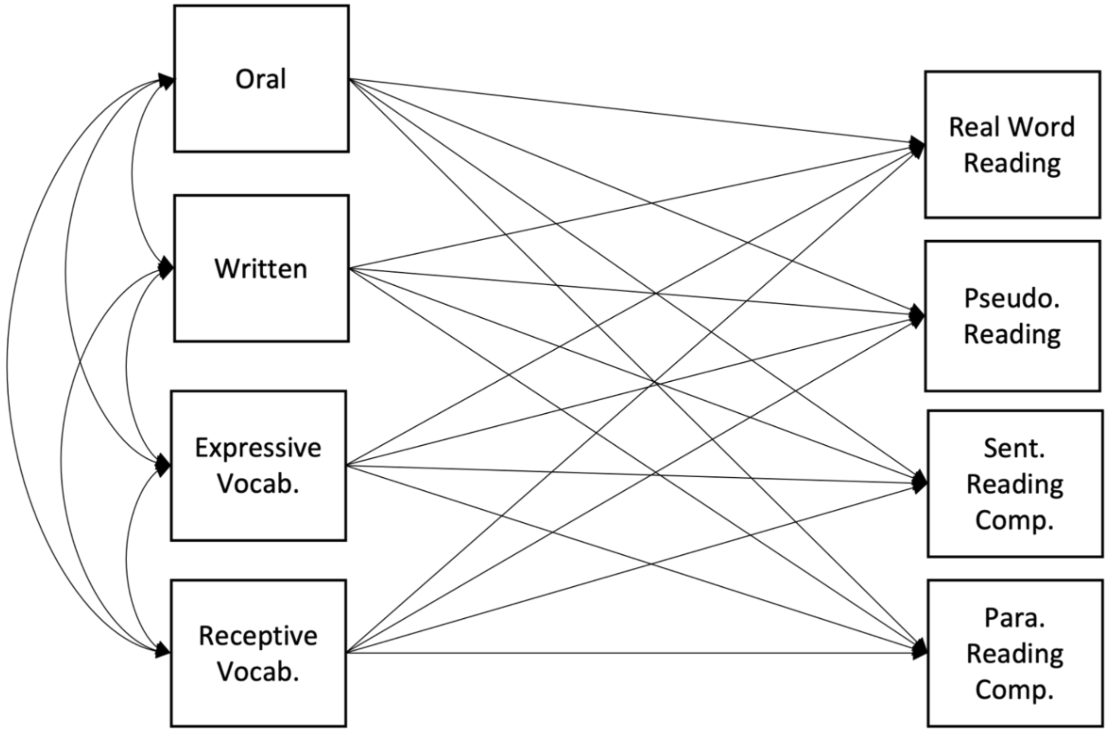

Figure 2 Example Path Model with Oral versus Written Morphological Features, Expressive, and Receptive Vocabulary Predicting Reading Outcomes.

Note: Vocab.=Vocabulary; Pseudo. = Pseudoword; Sent. =Sentence; Para. = Paragraph; Comp.= Comprehension

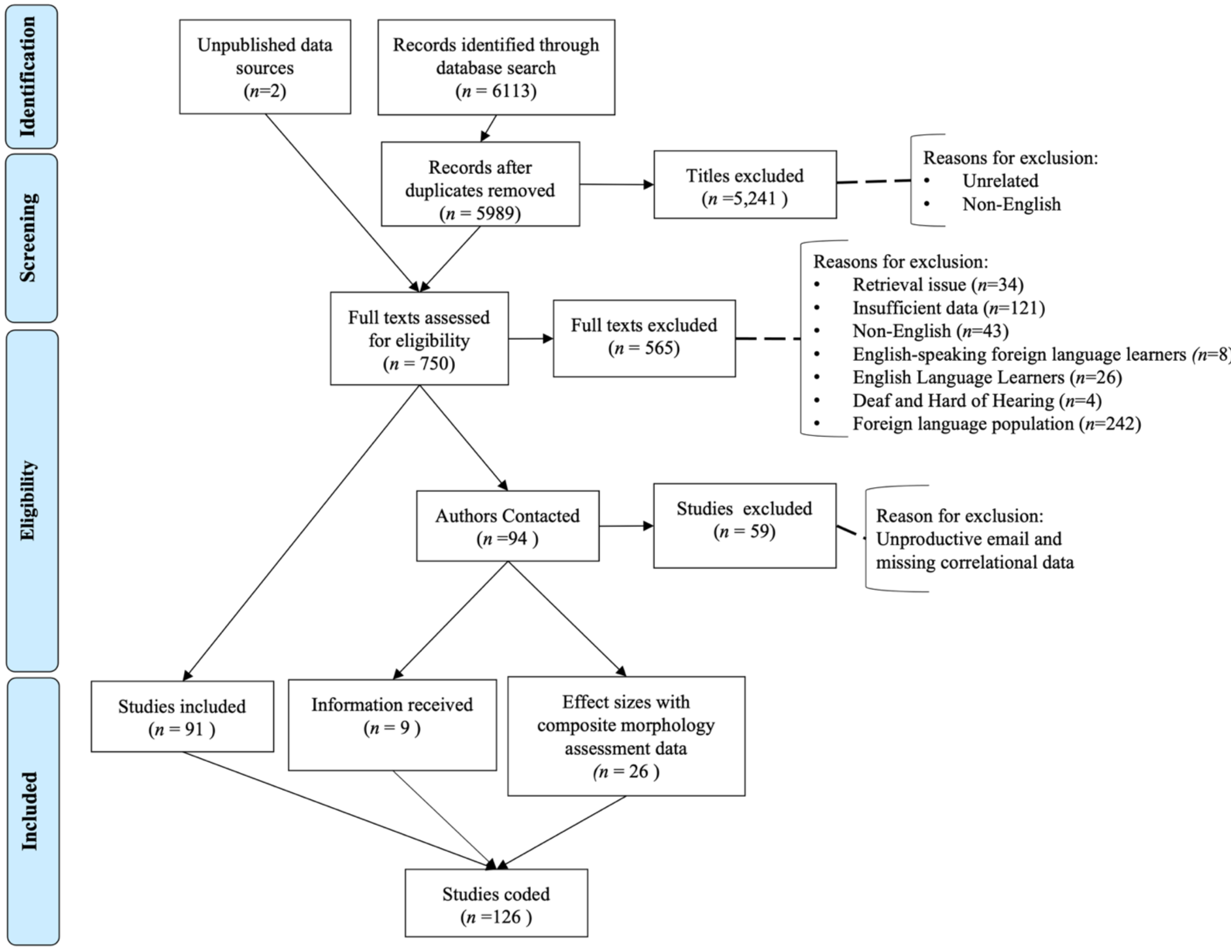

Figure 3 Prisma Diagram of Systematic Review Search Results

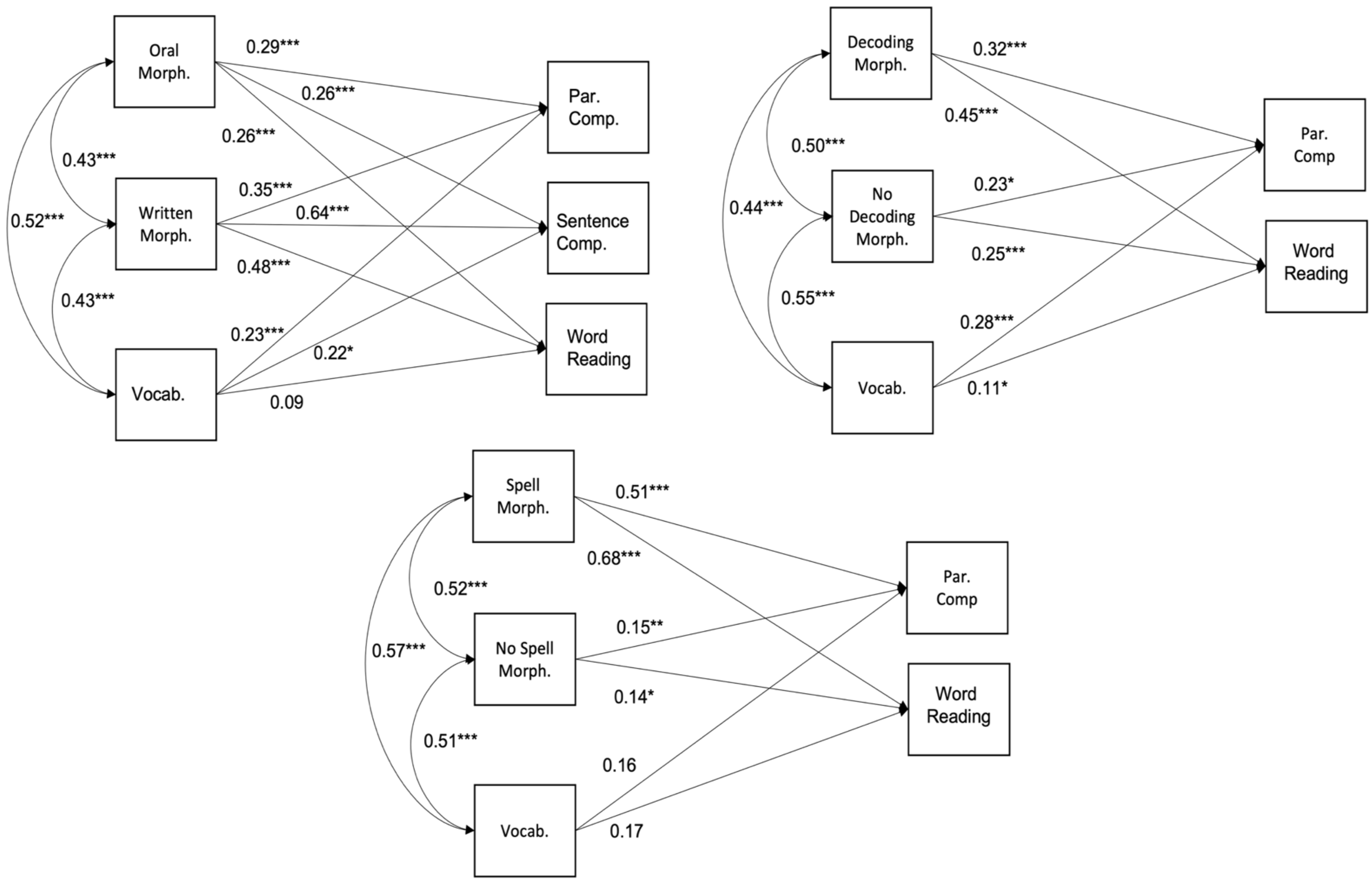

Figure 4 Modality Path Models with Standardized Estimates

Note. Oral versus written model =Figure 4a; decoding versus no decoding Model =Figure 4b; spell versus no spell model =Figure 4c;

Morph.= Morphology; Vocab.=Vocabulary; Par.=Paragraph;

***p<0.001, **p<0.01 *p<0.05

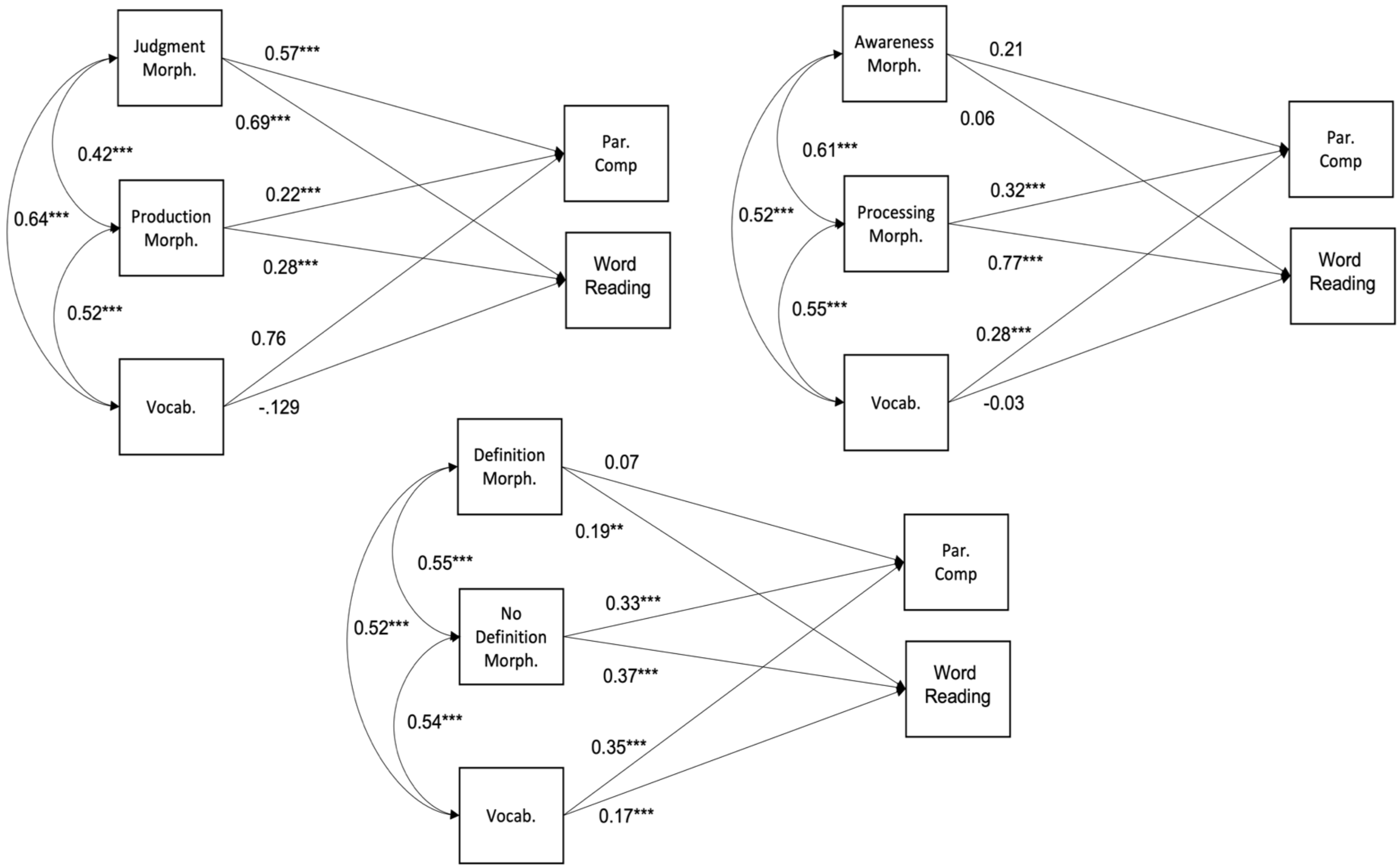

Figure 5 Task/Process Models with Standardized Estimates

Note. judgment versus production Model =Figure 5a; awareness versus processing Model =Figure 5b; definition versus no definition =Figure 5c; Morph.= Morphology; Vocab.=Vocabulary; Par.=Paragraph;

****p*<0.001, ***p*<0.01 **p*<0.05

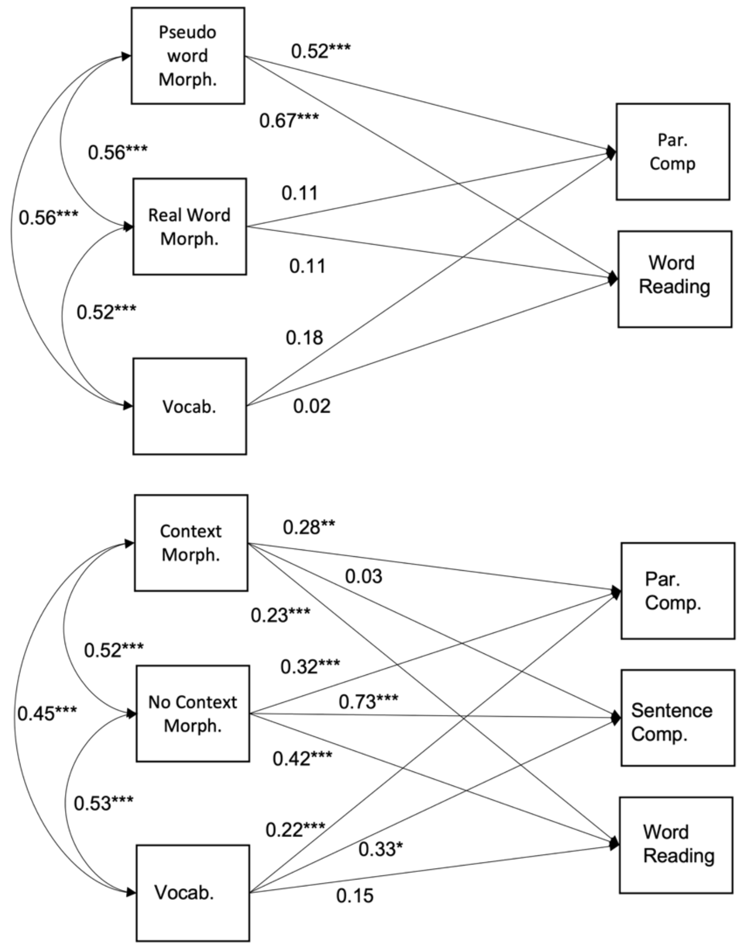

Figure 6 Context Models with Standardized Estimates

Note: pseudoword versus real word model =Figure 6a; context versus no context Model =Figure 6b; Morph.= Morphology; Vocab.=Vocabulary; Par.=Paragraph;

***p<0.001, **p<0.01 *p<0.05

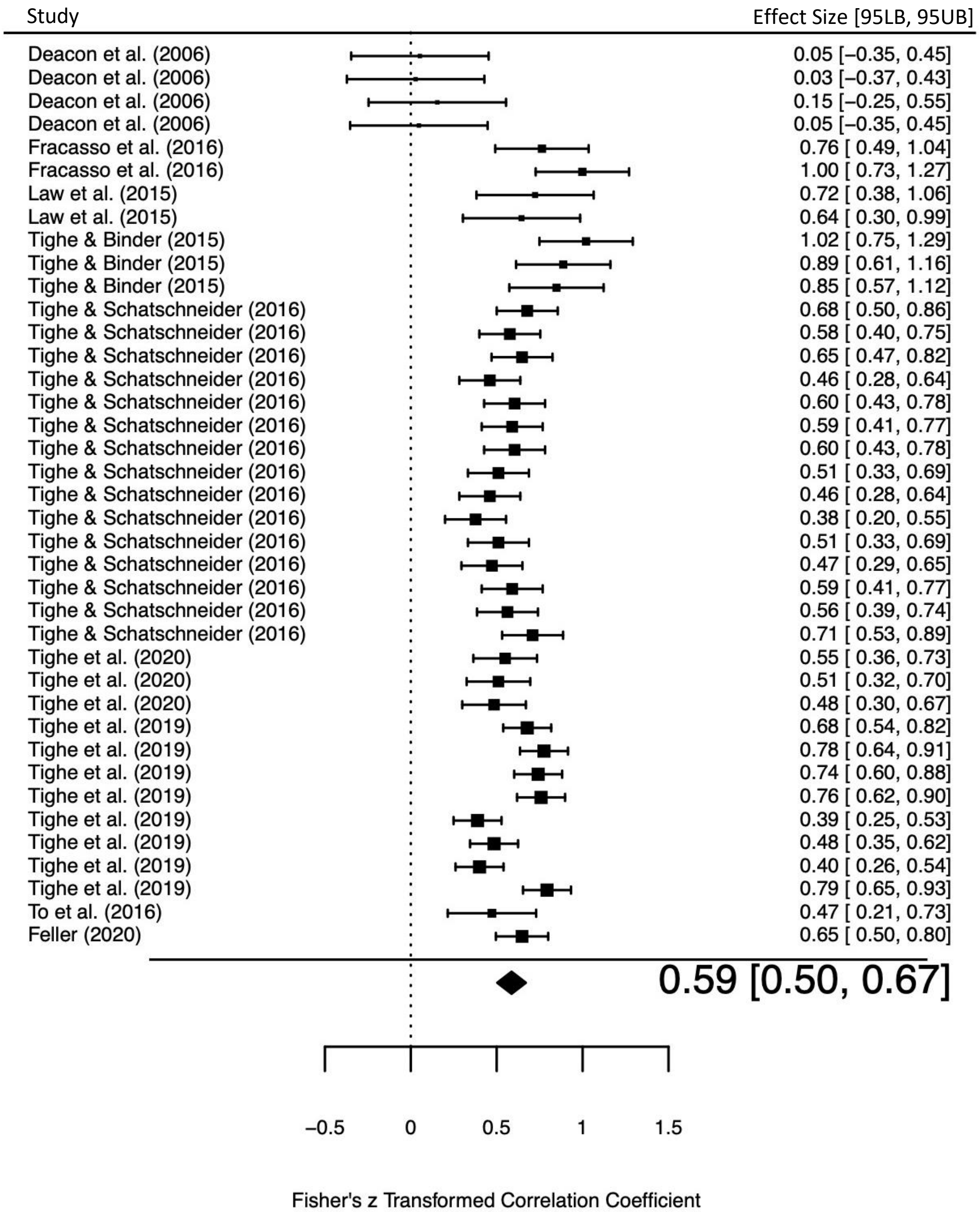

Figure 7 Forest Plot of Effect Sizes for Atypical Readers
Note: LB=Lower bound; UB=Upper Bound

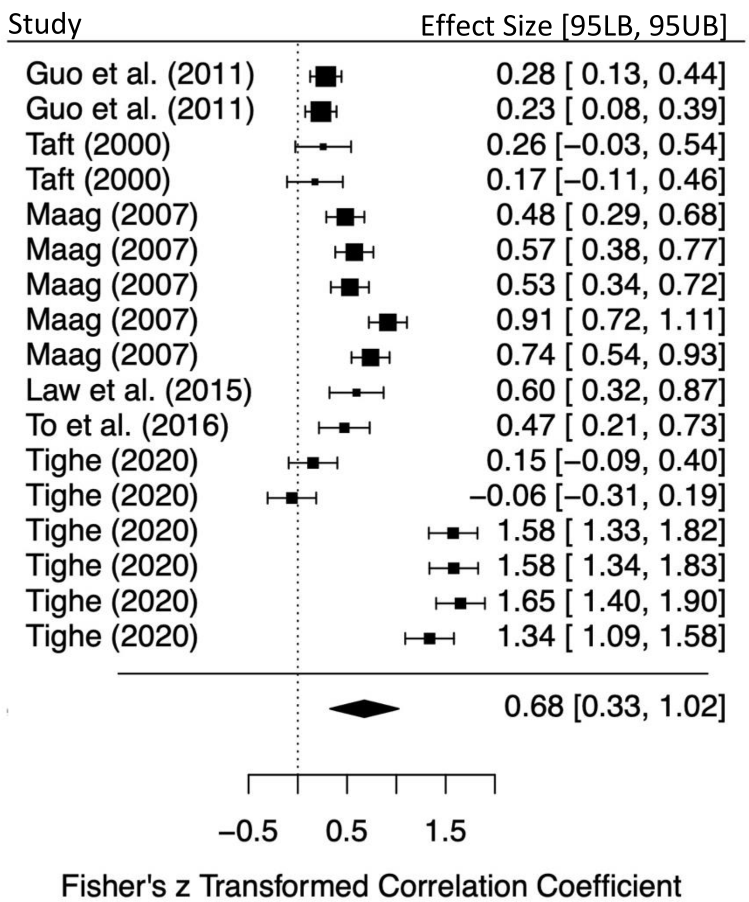

Figure 8 Forest Plot of Effect Sizes for Typical Adult Readers

Note: LB=Lower bound; UB=Upper Bound Appendices

7.1 Appendix A: Codebook

Section A—General Study Information

Note: Leave blank if the information is not applicable or unclear

A01. Study ID

A02. Effect size ID

A03. Full citation

A04. List the Authors

A05. Year of Publication

A06. Type of manuscript

1- Journal Article

2- Book or book chapter

3- Dissertation

4- MA Thesis

5- Private report

6- Government report

7- Conference paper

8- Other (specify in answer)

A07. Is this a peer-reviewed document?

0- Not peer reviewed

1- Peer reviewed

Section B—Demographic information

Note: Leave blank if the information is not applicable, available, or unclear

B01a. What is the mean age of the participants in the sample?

B02b. Was the sample composed of multiple age groups?

0-No

1-Yes

B02. What is the age range?

B03. Are participants in the sample children or adults?

0- Child

1- Adult

B04a. What was the grade level of the participants in the sample?

0- K

1- 1

2- 2

3- 3

4- 4

5- 5

6- 6

7- 7

8- 8

9- 9

10- 10

11- 11

12- 12

13- Labelled as “elementary school”

14- Labelled as “middle school”

15- Labelled as “junior high school”

16- Labelled as “high school”

8888- Combination of different grade levels

B04b. If B04b was 8888, list the grade levels included in the sample.

B05. Does the sample contain younger children (5th grade/11 years and lower)?

0-No

1-Yes

B06. Does the sample contain older children (6th-12th grade/12-17 years)?

0-No

1-Yes

B07. Does the sample contain adults (18 years and older)?

0-No

1-Yes

B08. Does the sample contain a combination of age/grade levels?

0-No

1-Yes

B08. Is the sample bilingual?

0- No

1- Yes

8888- Combination of bilingual and non-bilingual speakers

B09. Are the participants in the sample atypical readers (e.g., poor comprehenders, developmental delay, speech-language/impairments, poor readers, dyslexia, reading disability)?

0-No

1-Yes

8888-Combination of different ability levels

B10. If the participants are atypical readers (i.e., the answer to B09 is yes), what is their specific disability (leave blank if not applicable or unclear)?

Section C—Morphology and Reading Measures

Note: Leave blank if the information is not applicable, available, or unclear

Effect Size Information

C01. What is the reported effect size *r*?

C02. What is the reported sample size (N)?

Measure Information

C03a. What is the name of the first measure for the effect size *r*?

C03.b What is the name of the second measure for the effect size *r*?

C04a. Was the first measure a norm-referenced or experimental assessment?

0-experimental

1-norm-referenced

C04b. Was the second measure a norm-referenced or experimental assessment?

0-experimental

1-norm-referenced

Section D—Morphology and Reading Measures

Note: Leave blank if the information is not applicable, available, or unclear

D01a. Is Measure 1 or Measure 2 an oral morphology measure?

0-No

1-Yes

2-Both are Oral

D01b. Is Measure 1 or Measure 2 a written morphology measure?

0-No

1-Yes

2-Both are written

D02a. Is Measure 1 or Measure 2 a morphology measure with real words?

0-No

1-Yes

2-Both are real words

D02b. Is Measure 1 or Measure 2 a morphology measure with pseudowords?

0-No

1-Yes

2-Both are pseudowords

D03a. Is Measure 1 or Measure 2 a morphology measure with contextual information?

0-No

1-Yes

2-Both are morphology measures with contextual information

D03b. Is Measure 1 or Measure 2 a morphology measure with no contextual information?

0-No

1-Yes

2-Both are morphology measures with no contextual information.

D04a. Is Measure 1 or Measure 2 a processing morphology measure?

0-No

1-Yes

2-Both are processing morphology measures

D04b. Is Measure 1 or Measure 2 an awareness morphology measure?

0-No

1-Yes

2-Both are awareness morphology measures

D05a. Is Measure 1 or Measure 2 a morphology measure that requires decoding?

0-No

1-Yes

2-Both require decoding

D05b. Is Measure 1 or Measure 2 a morphology measure that does not require decoding?

0-No

1-Yes

2-Both do not require decoding

D06a. Is Measure 1 or Measure 2 a morphology measure that requires defining words/morphemes?

0-No

1-Yes

2-Both require defining words/morphemes

D06b. Is Measure 1 or Measure 2 a morphology measure that does not require defining words/morphemes?

0-No

1-Yes

2-Both do not require defining words/morphemes

D07a. Is Measure 1 or Measure 2 a morphology measure that requires spelling?

0-No

1-Yes

2-Both require spelling

D07b. Is Measure 1 or Measure 2 a morphology measure that does not require spelling?

0-No

1-Yes

2-Both do not require spelling

D08a. Is Measure 1 or Measure 2 a morphology measure that contains inflectional stimuli?

0-No

1-Yes

2-Both require inflectional stimuli

D08b. Is Measure 1 or Measure 2 a morphology measure that requires derivational stimuli?

0-No

1-Yes

2-Both do not require derivational stimuli

D09a. Is Measure 1 or Measure 2 a morphology measure with a production task format?

0-No

1-Yes

2-Both are production

D09b. Is Measure 1 or Measure 2 a morphology measure with judgment task format?

0-No

1-Yes

2-Both are judgment

D09c. Is Measure 1 or Measure 2 a morphology measure with an analogy task format?

0-No

1-Yes

2-Both are analogy

D09d. Is Measure 1 or Measure 2 a morphology measure with a blending/segmenting task f format?

0-No

1-Yes

2-Both are blending/segmenting

D10a. Is Measure 1 or Measure 2 a measure of real word decoding?

0-No

1-Yes

2-Both are real word decoding measures

D10b. Is Measure 1 or Measure 2 a measure of pseudoword decoding?

0-No

1-Yes

2-Both are pseudoword decoding measures

D10c. Is Measure 1 or Measure 2 a measure of sentence-level reading comprehension?

0-No

1-Yes

2-Both are sentence-level reading comprehension measures

D10d. Is Measure 1 or Measure 2 a measure of passage-level reading comprehension?

0-No

1-Yes

2-Both are passage-level reading comprehension measures

D10e Is Measure 1 or Measure 2 a measure of expressive vocabulary?

0-No

1-Yes

2-Both are expressive vocabulary measures

D10f. Is Measure 1 or Measure 2 a measure of receptive vocabulary?

0-No

1-Yes

2-Both are receptive vocabulary measures

7.2 Appendix B: Reference List of Eligible Studies

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