A Less Simple View of Reading: The Role of Inhibition and Working Memory in the Decoding-Comprehension Relationship

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Abstract

The influence of executive functions on the decoding and reading comprehension relationship.

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The present study examines the influencing effect of executive functions, specifically inhibition and working memory, on the relationship between decoding and reading comprehension. The current research suggests that the decoding-comprehension relationship is likely more complex than past theoretical models have postulated. Recently, the idea that non-linguistic cognitive skills may be responsible for this relationship has gained traction. As a part of the NHLP, a longitudinal cohort study conducted in New Haven, Connecticut, 256 students were asked to complete reading and executive function measures, as the children progressed through grade 1 and 2. These measures included tasks independently designed to assess decoding, working memory, inhibition and vocabulary, as well as two separate measures of reading comprehension. Results showed that inhibition acted as a significant mediator in both the decoding-comprehension and vocabulary-comprehension relationships. The results also showed that working memory acted as a significant moderator of the direct effect in the decoding-comprehension relationship, but did not moderate the vocabulary-comprehension relationship. These findings support the idea that decoding and language alone are not solely responsible for reading comprehension performance, and that other non-linguistic factors must be taken into consideration. Better understanding the decoding-comprehension relationship has important implications for teaching practice, and early identification and intervention required for exceptional learners.
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Introduction

In the process of learning to read, decoding has been established as a key skill in successful reading comprehension. Just as one must be able to walk before they can run, beginning readers must learn how to identify letters and string together their corresponding sounds to create words, before they can interpret the meaning of those words as a whole text.

The Simple View of Reading (Gough & Tunmer, 1986) has been a popular theoretical model used in understanding the skills required to be a successful and efficient reader. This model states that decoding and vocabulary are responsible for reading comprehension success. Discrepancies between decoding and reading comprehension have been identified in recent research, however, indicating that there may be more to this relationship (Li et al., 2018). This has important implications for how reading instruction is approached in classrooms, for typical students, as well as for those with additional learning needs, where a variety of cognitive skills may possibly be affected.

Most recently, research has turned to the possibility that non-linguistic skills may play an important role in the decoding-comprehension relationship (Patael et al., 2018). While executive functions have been identified as having a significant effect on whether someone is an efficient reader or not, these cognitive skills have more recently being investigated for their importance in both decoding and reading comprehension. Specifically, I hypothesize that inhibition can account for a portion of this relationship, functioning as a mediator. I hypothesize that working memory amplifies this relationship, with decoding more important when working memory is low, thereby functioning as a moderator. Determining exactly how executive functions affect the decoding-comprehension relationship will help educators and other professionals working with children and youth better understand how to help struggling readers. The following pages will
review reading difficulties, the reading process, executive functions, and how these three might integrate with each other.

**Components of the Reading Process**

While the process of learning to read contains multiple individual steps that must be mastered, decoding and comprehension are two critical skills that will be examined more in depth over the course of this paper. From a developmental perspective, typically one must learn how to effectively decode words, with both accuracy and fluency, before becoming successful at reading comprehension (Garcia & Cain, 2014). Many learning difficulties involve structural or chemical abnormalities in the brain that can impact these skills either directly or indirectly. Therefore, it is important to have a good understanding of decoding and comprehension before exploring in depth how precisely they may be affected by atypical cognitive functioning.

**Decoding**

Decoding, at its most basic, involves taking information presented in written form, and translating that into language (Perfetti & Hogaboam, 1975). Typically, children are first taught to recognize the shapes that represent different letters, and then assign the correct name and sound to these forms (Squires, 2018). This is referred to as the grapheme-phoneme connection. Once this connection is established, letters are grouped together, and spelling rules and patterns must be memorized. English as a language is orthographically deeper than many others, making this step especially tricky for beginning readers and some non-English speakers (Ellis et al., 2004). As readers become more practiced at letter and letter pattern recognition, they then become able to recognize whole words at a time (Squires, 2018). Perfetti and Hogaboam (1975) suggest that beginning or weak readers may actually engage in two different types of decoding: one, in which they are able to recognize a whole word because of common letter combinations or frequency of
use, such as the word *that*, and another, in which a word is not immediately recognized, and so must be broken down and decoded in pieces, be it individual letters or smaller letter combinations (Perfetti & Hogoboam, 1975).

Strong readers utilize a number of strategies that set them apart from those who might be less skilled. With unfamiliar words, strong readers are able to decode faster by breaking the word into larger chunks, thereby saving time that a weaker reader would have to use to sound out each letter individually (Gibson, Osser & Pick, 1963). Interestingly, single letter decoding rates are similar for both skilled and less skilled readers, the main difference lying in how often the reader must use this strategy (Perfetti & Hogoboam, 1975). The more fluent reader does not need to rely on single letter decoding, and is able to save more time, energy and working memory capacity for reading tasks that require higher order skills, like comprehension (Squires, 2018). Poor decoders have not yet automatized this basic process and leave themselves less equipped for the task of interpreting the meaning of the text.

**Reading Comprehension**

Reading for meaning is arguably the goal of most reading instruction. Comprehension is a higher order skill that requires mastery of more basic processes first, such as decoding. In younger readers especially, research has shown that word reading, both in terms of accuracy and fluency, is one of the largest limiters to comprehension ability (Garcia & Cain, 2014). It should be noted however, that the relationship between decoding and reading comprehension is at its strongest during the early elementary school years, peaking in grade 2 and 3 (Wang, Sabatini, O’Reilly & Weeks, 2019). Reading development growth continues well past these years as students expand their vocabularies and consider more complex concepts both in conversation and in text (Wang et al., 2019). Decoding becomes much less important in later elementary years,
through high school and beyond as the word reading process is automatized and sight word reading becomes almost completely relied upon instead (Wang et al., 2019). The period in which decoding and reading comprehension are still so tightly linked is particularly interesting and important to look further into for the potential implications to instruction and practice.

Several cognitive and environmental factors can play a role in reading comprehension performance. Though numerous theories, in particular the Simple View of Reading (Gough & Tunmer, 1986), state that reading comprehension is the sum of one’s decoding and listening comprehension abilities, there are also enough other factors that play important roles that perhaps a less simple view is necessary. This is not to discount the value of decoding or listening comprehension to one’s reading comprehension performance, as there is certainly enough research supporting both, but to state that all reading variance can be accounted for through these three skills is potentially incorrect.

**The Decoding and Comprehension Relationship**

There is a large amount of research supporting the decoding and comprehension connection. It makes sense logically that in order to become successful in understanding the meaning of a text, one would first have to be efficient decoding the letters and words it consists of. There is an emerging body of literature that suggests there is more to this relationship than was previously believed. Becoming a skilled reader involves well established skills at the word level with decoding, as described above, as well as at the text level, in which the reader must be able to make inferences, understand cause and effect and more for comprehension (Arrington, Kulesz, Francis, Fletcher & Barnes, 2014). This does not capture the whole picture however. These skills must further be coordinated by non-linguistic cognitive processes for the reader to
put together all of the information and stimuli presented to them into a whole representation of what they have read (Arrington et al., 2014).

Other factors may not only have an impact on the decoding and comprehension connection, but these cognitive skills likely are at least partially responsible for the relationship altogether. Executive functions have shown to have a significant effect on decoding and reading comprehension performance separately, which logically leads one to wonder if one or a few executive functioning skills might not even drive, or at least constrain and/or enable, the relationship (Sesma, Mahone, Levine, Eason & Cutting, 2009). Studying the impact of particular executive functions in early readers, when the decoding and reading comprehension relationship is at its strongest, is important to better understand the role these cognitive processes play.

**Reading Difficulties**

Children with dyslexia, also known as Reading Disorder, struggle with speed and accuracy in reading, due to difficulties with letter and word decoding and comprehension (Norton, Beach & Gabrieli, 2015). While the term ‘dyslexia’ is no longer used under the DSM-V, its appearance is frequent enough in the literature to warrant use. Now falling under the blanket term of Specific Learning Disorder, dyslexia affects approximately 5 to 10 percent of all children globally (Hendren et al., 2018). This developmental disorder has strong genetic roots, with a 50 to 70 percent rate of heritability (Peterson & Pennington, 2015). Certain parts of the brain have been identified as potential areas that may be impacted in individuals with dyslexia, including the neural reading network (Vanderauwera, Wouters, Vandermosten & Ghesquiere, 2017). This network consists of the inferior frontal, occipito-temporal and temporo-parietal cortex (Vanderauwera et al., 2017). There is also evidence to suggest that there may be structural abnormalities in the white matter connecting these regions in both children and adults with
dyslexia, which may impact the transference of information between regions. Environmental risk factors may also play a large role in the variation of reading abilities, including socio-economic status, home literacy environment, and parent education level, among others (Dilnot, Hamilton, Maughan & Snowling, 2017).

Reading difficulties may exist in one or several areas, including reading comprehension, accuracy, rate and fluency (DSM-5, 2013). It should be noted however, that individuals with dyslexia experience challenges with phonological awareness, but this does not impact their overall intelligence levels or IQ score (DSM-5, 2013). Academic abilities may vary widely from individual to individual, with some experiencing mild learning difficulties that may be managed fairly easily, and others displaying extreme difficulty in several academic areas that likely will require extensive support and specialized learning strategies (DSM-5, 2013).

Children exhibiting signs of a learning disability often wait for a formal diagnosis due to a variety of possible reasons. This may include a lack of trained personnel within the school board, the prohibitively expensive cost of testing, or even because the child is not yet far enough behind for professionals to make a definitive decision (Schroeder, Drefs & Cormier, 2017). This is especially unfortunate given that many educational assistance services are only available once a formal diagnosis is obtained. Many children wait to be ‘labelled’, despite displaying a need for help. The discrepancy that must exist between the child’s actual abilities and the typical achievement for their developmental level is an arbitrary, albeit widely agreed upon, number after all (Restori, Katz & Lee, 2009). Copious amounts of research exist demonstrating the importance of early intervention (Lovett, Frijters, Wolf, Steinbach, Sevcik & Morris, 2017) and this needs to be better reflected in classroom practice.
**Dyslexia and Decoding**

Phonological decoding is often evaluated through tasks that assess the reader’s ability to recall and generalize letter sounds and letter sound combinations in novel contexts, typically non-word reading (Facoetti et al., 2009). This is a skill that is critical for successful reading acquisition and is also a skill that is consistently affected in children with dyslexia (Facoetti et al., 2019). It requires significant attentional resources that can even challenge adults with dyslexia, and mentally exhaust beginning readers (Reynolds & Besner, 2006). Research suggests that individuals with dyslexia may struggle with decoding due to a larger difficulty forming mental representations of the words they hear in speech (Ramus, 2003). This leads to greater difficulty establishing the grapheme-phoneme connection when learning to read, and consequently taking a longer time committing letter sound combinations to short term memory (Facoetti et al., 2009). As will be discussed below, these aspects of decoding may be constrained or enhanced by working memory. It is possible for children with dyslexia to become successful decoders, however it may take longer to reach the same point as their peers without additional support or adapted instructional strategies.

**Dyslexia and Comprehension**

Despite significant difficulties decoding, children with dyslexia do not necessarily struggle equally with comprehension. This makes sense logically, as it is phonological awareness and not intelligence that is affected in individuals with dyslexia. Although there is certainly some impact on comprehension abilities when simply reading the text is difficult, studies have found that some individuals with dyslexia rely more heavily on context clues to improve their word recognition and are then able to avoid decoding in some scenarios and continue on with interpreting the text (Nation & Hulme, 1998). This strategy is often seen in adults with dyslexia.
who have had more time and exposure to a larger vocabulary. In younger children however, they
do not have this advantage, and so are able to use contextual clues less often to speed their
reading (Nation & Hulme, 1998). In this case, decoding must be used to read more frequently,
and comprehension will likely be impacted, simply due to the difficulty of the lower order task
and the amount of time and cognitive resources required. The actual interpreting or inferencing
abilities of a child with dyslexia are not necessarily worse than a typical student, however it may
be seen that way erroneously by educators who may not recognize that additional strategies may
need to be in place to support decoding first before assessing comprehension accurately.

**Executive Functions**

Executive functions refer to a wide variety of complex cognitive skills crucial to many
everyday tasks. These functions can be divided into three categories: shifting, updating, and
inhibiting (Miyake, Friedman, Emerson, Witzki, Howarter & Wager, 2000). Working memory is
an executive function that would fall under the updating category, however, there is some debate
as to whether it should be its own category altogether (Peng et al., 2018). Executive functioning
in children is especially important to examine as a predictor of future academic achievement.
Reading in particular has been observed to be impacted by different executive functions on a
number of different levels, from decoding to comprehension (Willoughby, Wylie & Little, 2019).

The three categories of functions, while inherently connected, do show separability
(Miyake & Friedman, 2012). Shifting involves one’s ability to switch attention from one task to
another, or back and forth between multiple attentional demands (Miyake et al., 2000). This
group of skills includes cognitive flexibility, attention switching, and executive control (Folmer,
2018). Updating consists of information being sorted and either retained or disposed of based on
relevancy to the current task (Miyake et al., 2000). Working memory is currently included in this
category, as incoming information must be actively sorted and maintained rather than simply stored indefinitely (Miyake et al., 2000). Finally, inhibition refers to the ability to stop or suppress automatic responses when not appropriate for the completion of a task (Miyake et al., 2000).

Executive functions have shown to be both significant predictors of academic achievement, and relatively stable over time (Daucourt, Schatschneider, Connor, Al-Otaiba & Hart, 2018). This makes these cognitive skills particularly important to study in younger children as a means of early identification of those who may need additional help or intervention in order to avoid falling between the cracks. In the present study, inhibition and updating, specifically working memory ability, have been shown to have significant impact on the decoding and reading relationship. The relationship between these two executive functions and the two main components of reading, decoding and comprehension, will now be reviewed.

Inhibition

The term ‘inhibition’, may refer to any of three inhibitory control related functions unless otherwise specified (Miyake & Friedman, 2004). Originally, these three functions included restraint, access and deletion (Hasher & Zacks, 1988). With Miyake and Friedman’s updated model (2004), these were redefined as follows: prepotent response inhibition, resistance to distractor interference, and resistance to proactive interference, respectively. Prepotent response inhibition is used when an individual blocks an automatic cognitive response from occurring after being triggered by a particular stimulus (Borella & Ribauipierre, 2014). Resistance to distractor interference refers to an individual’s ability to focus attention on the relevant items in the task at hand, while blocking out any extraneous irrelevant ones that may be presented simultaneously (Borella & Ribauipierre, 2014). Finally, resistance to proactive interference
involves limiting the number of unnecessary memory intrusions from items that are no longer relevant (Borella & Ribaupierre, 2014).

Inhibition has been shown in multiple studies to play a key role in the development of updating and shifting skills (Butterfuss & Kendeou, 2018). Deficits of inhibitory control or inhibition related skills are often seen in disorders like attention-deficit/hyperactive disorder or obsessive/compulsive disorder (Friedman & Miyake, 2004). Difficulties with inhibition may be seen through challenges inhibiting certain thoughts, or the retrieval of unnecessary information from the memory system, or challenges suppressing a certain response or action (Friedman & Miyake, 2004).

Within the context of reading, inhibition serves to stop or suppress cognitive responses that are not appropriate, or to suppress information that is not relevant to the task (Willoughby et al., 2019). Stronger readers have been shown to use attentional resources more efficiently, saving those resources during more basic tasks in order to have them at their disposal for more complex ones (Follmer, 2018). Inhibition is instrumental here, as it ensures that only the information that is important is kept for processing and storage.

For individuals with reading difficulties specifically, executive dysfunction, including inhibitory deficits, may be observed as a contributing factor to affected reading ability (Locascio, Mahone, Eason & Cutting, 2010). Inhibitory control plays an important part in in several stages of the reading process, as well as the learning-to-read process (Daucourt et al., 2018). There is still some debate as to whether this may be solely attributed to the high comorbidity rate between RD and ADHD, although there is some research beginning to emerge that examines executive dysfunction in RD outside of ADHD (Daucourt et al., 2018).
Inhibition and Decoding

Interestingly, while a large number of studies have been conducted that broadly state the existence of a connection between inhibitory control and academic achievement across several age groups (Follmer, 2018; Locascio et al., 2010), there are very few that explicitly investigate the link between inhibition and decoding, or any other lower order reading skills (Foy & Mann, 2013). Researchers have found that inhibition is especially crucial in tasks involving problem solving or the use of rules with some degree of strategy (Morgan, Farkas, Hillemeier, Pun & Maczuga, 2018). It could be theorized that inhibitory control may be important then, in skills like decoding, which relies on the proper retrieval of information when trying to remember spelling rules, as well as recognizing when words follow irregular patterns (Morgan et al., 2018).

On a behavioural level, inhibition has implications for general academic achievement in that the child who can suppress the desire to react to distractions around them will be able to maintain focus on the task at hand, be it decoding or otherwise (Morgan et al., 2018). Early or beginning readers who struggle with inhibitory control, may find decoding difficult in that it may take them longer to establish the grapheme-phoneme connection, and thus be more efficient in the reading process. Research is needed in this area to confirm this theoretically-plausible connection however.

Inhibition and Reading Comprehension

With reading comprehension, cognitive inhibition in particular is considered essential in becoming a skilled reader (Butterfuss & Kendeou, 2018). Students who are stronger in reading comprehension abilities, are able to inhibit irrelevant information from being retrieved from the memory system and save their attentional resources for more difficult tasks (Follmer, 2018). There is evidence to suggest that individuals with stronger inhibitory control are also able to sort
out relevant information more efficiently from the text, and therefore hold more of that information in their working memory. For the individual with weaker inhibitory control, they may retain both relevant and irrelevant details from the passage, and therefore have less space in their working memory for the information that is required and helpful to comprehension (Butterfuss & Kendeou, 2018).

In addition to inefficient, or incorrect information sorting at intake, struggling readers may demonstrate worse comprehension abilities through poor inhibition of irrelevant information at recall (Follmer, 2018). While reading, it may become necessary to remember previous information presented earlier in the text. An individual with poor cognitive inhibition, may not be able to prevent themselves from recalling information that is not necessary or correct for the task at hand (Follmer, 2018). Processing of the text may take significantly longer and an accurate mental representation of the passage may not be produced (Butterfuss & Kendeou, 2018). While strategies can be taught in school to improve reading comprehension, poor cognitive inhibition may still have a serious impact on academic performance if not addressed appropriately, and for young children, may have serious implications for future years in school and beyond.

**Working Memory**

Working memory can be defined as the temporary storage of information before it is processed and stored more permanently (Arrington, Kulesz, Francis, Fletcher & Barnes, 2014). It is an important component in the completion of many cognitive tasks and can vary widely from person to person on a spectrum of ability (Arrington et al., 2014). For someone with a working memory deficit, this could mean a smaller working memory capacity, limiting the amount of information that can be temporarily stored, or the actual intake and processing of information may be affected (McVay & Kane, 2012).
The model most commonly used in the understanding of working memory today proposes that there are several components that work together (Baddeley & Hitch, 1974) (Baddeley, 2003). These include the central executive, phonological loop, visuospatial sketchpad and episodic buffer (Yang, Peng, Zhang & Mo, 2017). The central executive acts as the main component that organizes and coordinates the information processed by other sub-components (Baddeley & Hitch, 1974). The phonological loop deals primarily with speech and is important in learning both primary and secondary languages (Yang et al., 2017). The visuospatial sketchpad is used to process information that is visual or spatial in nature (Baddeley, 2003). This portion of the working memory system is needed in the development of nonverbal abilities such as orthographic processing (Yang et al., 2017). Baddeley and Hitch originally only included the central executive, phonological loop, and visuospatial sketchpad in their model (1974). However, since then, the episodic buffer has also been added (Baddeley, 2000). This connects information from other subcomponents and from the long-term memory into a single representation (Baddeley, 2000). Each of these different components have their own unique purpose that then are brought together to form the working memory system. One affected area may impact and weaken the performance of others (Yang et al., 2017).

Dyslexia is one such example of how multiple deficits in several subcomponents may prove a significant challenge in such skills as reading and writing (Dehaene, 2009). For the individual with reading challenges, there is a much higher likelihood that they may be experiencing working memory difficulties (Poblano, Valadéz-Tepec, de Lourdes Arias & García-Pedroza, 2000). Studies have found that multiple subcomponents are affected in poor readers (Dawes, Leitao, Claessen & Nayton, 2015). The phonological loop is especially important when an individual is learning to read, as phonological representations of words must be processed
accurately and maintained (Dawes et al., 2015). For a child with reading difficulties, a deficit in this subcomponent may present as poor phonological awareness and difficulty recalling and distinguishing between phonologically similar words (Poblano et al., 2000).

As the episodic buffer was added to the model relatively recently, research is ongoing to better understand whether, and how, it is affected in individuals with reading challenges. Because this subcomponent acts to identify and create connections between information processed by the phonological loop, visuospatial sketchpad, central executive and even long-term memory, it is difficult to create a task that measures performance of the episodic buffer alone (Dawes et al., 2015). The results of some studies have suggested that individuals with reading difficulties do not display weaknesses in the episodic buffer subcomponent, but as stated, it is difficult to measure this portion of working memory in isolation, thus results should be interpreted with some degree of caution (Dawes et al., 2015).

The research is somewhat mixed as to whether the central executive is affected in individuals with reading challenges. Some studies have found that in tasks that rely on this component of working memory, children with reading difficulties are more likely to struggle (Yang et al., 2017). Others have found no difference when comparing the performance of typical students and those who experience additional reading difficulties (Poblano et al., 2000). Further research is required to determine more definitively whether weaknesses shown in this component are due to an actual deficit, or whether they are caused by the affected subcomponents that also make up the working memory system. This is also further reason to expand the Simple View of Reading to include additional influencing factors that help to determine reading performance.
**Working Memory and Decoding**

In learning to read, children must first master decoding, which involves a series of steps identifying different symbols as letters, recalling the sounds that accompany each of those letters, and recognizing the phonological patterns that change when phonemes are added as they make their way through the printed word (Squires, 2018). All of these steps rely on working memory to some degree. In beginning readers especially, when decoding can still be a laborious process as it is not yet automatized, a large amount of information must be processed simultaneously and stored efficiently (Peng et al., 2018). Struggling readers can therefore be even more greatly impacted by poor working memory.

Various models of working memory that are currently in use, despite their differences, appear to share a common theme of recognizing the importance of working memory in decoding. Based off of the component based model of working memory described earlier, the phonological loop plays a key role in decoding, helping to establish the grapheme-phoneme connection (Baddeley & Hitch, 1974). If this component is impacted, or if the other components of the system are not acting efficiently with each other, understanding the sound-symbol connection and automatizing the decoding process may be more difficult.

The Dual-Process theory, another model of working memory, focuses more on capacity and processing ability, stating that decoding may require additional cognitive resources in beginning readers (Evans & Stanovich, 2013). In this instance, not only is working memory being relied upon more heavily for foundational reading skills, but a smaller working memory capacity or less efficient processing system could result in significant challenges for the child when learning to read (Peng et al., 2018). This relationship between word decoding ability and working memory specifically is also referred to as the Verbal Efficiency theory (Hamilton, Freed
McClure & Long, 2016). When cognitive resources in the working memory system are used up by inefficient decoding, comprehension becomes exponentially more difficult for the individual.

**Working Memory and Comprehension**

Even with adequate decoding skills, if working memory is affected, reading comprehension related tasks may be more challenging for that child. Due to the increased complexity, comprehension is more reliant on higher level functions, like working memory (Nouwens, Groen & Verhoeven, 2017). As per Baddeley and Hitch’s (1974) model, the central executive, in addition to the phonological loop, are the main components used during reading comprehension (Nouwens et al., 2017). The phonological loop maintains representations of the words from the text temporarily, while the central executive makes connections between other components of the memory system, in order to make sense of the passage as a whole (Nouwens et al., 2017). In beginning readers especially, those who struggle with central executive functioning have shown a decreased ability to acquire the skills necessary in more complex tasks, like comprehension (Gathercole & Pickering, 2000).

Working memory processing and capacity play different, but important roles while a child is attempting to interpret a text. Working memory capacity consists of a finite set of cognitive resources. While capacity may be improved through training, or different memory strategies, if an individual struggles with reading, especially at the decoding level, less cognitive resources will be left for comprehension. An inefficient or diminished working memory system may also result in limitations holding and processing information simultaneously (Hamilton et al., 2016). Reading comprehension may, as a result, be more difficult in this case, as it can be harder to form connections from the text (Hamilton et al., 2016).
Based on the literature reviewed, several executive functions appear to be involved in the reading process and/or developmental difficulties in acquiring reading skills, but the literature is inconsistent regarding which of these executive functions are most important (Daucourt et al., 2018).

**Developmental Context**

When discussing executive functioning abilities, the age at which an individual’s skills are being assessed must be taken into consideration. The foundational executive functions can not only first be observed at different ages, but they then develop at somewhat different rates, depending on internal and external factors (Best & Miller, 2010).

Inhibition may first be seen at its most basic during infancy, with little working memory required for a simple inhibitory response. Inhibitory abilities improve rapidly during early childhood, in particular the preschool years, to accommodate more scenarios requiring complex response inhibition (Best & Miller, 2010). Changes may still be seen between the ages of 5 and 8 (Best & Miller, 2010). By the early school years, inhibitory abilities begin to stabilize, with few, if any, significant increases observed from ages 8 to 13, as there are unlikely to be any fundamental changes in cognition at this point (Lehto, Juujarvi, Kooistra & Pulkkinen, 2003).

Working memory ability sees a large increase during the preschool years, similar to inhibition (Best & Miller, 2010). Where inhibitory abilities may be developed enough for complex tasks during this period however, working memory does not reach this point until the child is about 6 years old. Working memory develops in a linear fashion between ages 4 and 14 before levelling off (Best & Millere, 2010).

The sample for the present study would have seen significant development in both inhibitory and working memory ability by the time assessments were completed. Had data been
collected earlier, the concern that these executive functions would have been at potentially dramatically different points in a child’s development could be valid. However, as the mean age was approximately 8 years old at the time of cognitive testing, this is not an issue. Both working memory and inhibition would have been increasing linearly and typically developing children should be capable of tasks that place complex cognitive demands on executive functioning abilities.

**Research and Rationale**

The connection between decoding abilities and reading comprehension performance is certainly not a new one, and while there are many empirical studies supporting this connection, it may be necessary to revisit why this relationship exists. The Simple View of Reading in particular has popularized the idea that decoding and language abilities are the most important predictors of reading comprehension. This does not explain, however, why some individuals are competent decoders and still experience difficulties with comprehension (Li & Kirby, 2014). Non-linguistic skills are gaining attention in the literature, as researchers attempt to better understand this discrepancy. Recent studies have shown that executive functions are likely much more important to various reading processes than previously considered (Daucourt et al., 2018).

Further exploring the role of certain executive functions in the decoding and comprehension relationship is important, not just to struggling readers, but to typical learners as well. A more nuanced understanding of the cognitive skills that contribute to the reading process can inform both intervention and instruction. Adapting teaching methods to include support for students who may struggle with executive functioning skills could lead to more effective instruction that can benefit all learners, as executive functions impact multiple academic skills outside of just reading (Morgan et al., 2018).
We hypothesize that executive functions play an important underlying role in the decoding and reading comprehension relationship. Inhibition and working memory are anticipated to have separate, significant impacts on this relationship. Specifically, we expected inhibition to act as a mediating factor that explains the decoding and comprehension relationship, while working memory was expected to moderate the relationship between the reading skills, weakening or strengthening the relationship depending on the working memory capacity of the child.

To test these hypotheses, this study examined decoding performance as a predictor of reading comprehension, with two separate comprehension measures tested for replicability. The child’s ability to inhibit irrelevant cognitive responses was included as a mediator for this relationship. Verbal working memory, assessed here with a backwards digit span task, was analyzed as a moderator in the decoding and comprehension relationship. This study offers a unique contribution to the existing research in that it goes beyond the Simple View of Reading and examines how executive functions may drive and/or modify the decoding and comprehension relationship. The goal is not to claim that this relationship does not exist, but to attempt to begin to explain some of the underlying mechanisms that are responsible for the connection. This study will also examine how two executive functions, inhibition and working memory, play separate influential roles in the reading process. This goes beyond showing how these skills act as predictors of decoding or comprehension, which has been established in the literature already, and instead shows how they influence the larger reading process.
Research Questions

The following research questions were asked based on the rationale outlined above for the examination of the role of certain executive functions in the decoding and comprehension relationship:

1. What role does inhibition and working memory play in the relationship with decoding and reading comprehension?

2. To what extent does inhibition mediate the relationship between decoding and reading comprehension?

3. Do individual differences in working memory modify (i.e., strengthen and/or weaken) the decoding and reading relationship?

4. Can the same dynamics be seen when considering the language and comprehension relationship?

Based on past research, it is likely that connections will be found with all of the executive function tasks and reading measures, though the inhibition-based tasks are expected to demonstrate the most robust correlations with decoding and comprehension as these aspects of reading are the most specific to a particular executive function. Results of the present analysis are expected to show that inhibition ability acts as an underlying mechanism behind the decoding and reading comprehension relationship. The literature has shown the importance of executive functions in multiple reading processes, and this study anticipates that the results will demonstrate the importance of inhibition in the decoding-comprehension relationship. It is also anticipated that better working memory will strengthen this relationship. The literature shows that it is important in the use of each of these skills individually; therefore, it follows that improved working memory will help these connected skills together.
Methods

The New Haven Lexinome Project

The present study uses data collected as a part of a larger longitudinal study: the New Haven Lexinome Project (NHLP). The NHLP is based out of New Haven, Connecticut. Children from two consecutive first grade classes are currently being studied, their academic development monitored for a total of five years. The NHLP uses a multidisciplinary approach that investigates environmental and genetic factors that may be used as early predictors of reading difficulties. Factors such as sex, ethnicity, race, culture, bilingualism, home literacy environment and genetic background will be examined in relation to the students’ performance on standardized assessments from grades 1 through 4.

Participants

Total Sample

Altogether, there were 487 children enrolled in the study. The children from these New Haven schools are representative of the greater population of the United States, and so the results of this data and its analysis can be generalized to this population. A questionnaire completed by the parent or guardian at the time of enrollment was used to collect demographic information about the children and their families. From this questionnaire, 300 families (61.6%) reported receiving financial assistance. 54 families (11.1%) indicated that they did not require financial assistance for food or otherwise, and 133 families (27.3%) either chose not to answer these questions or did not have data present. 112 (23%) children were reported as Caucasian, 144 (29.6%) were reported by parents as African American, 216 (44.4%) were reported as Hispanic, and 113 (23.2%) were reported as identifying as another ethnicity.
**Studied Sample**

For the present analysis, 256 students from the larger sample were included for whom data was available at the time of the present study. There were slightly more female students \((n=133)\) in the sample than male \((n=123)\). At the time of cognitive testing, which took place at the beginning of grade 2, the mean age of the students was \(8.2 (\text{SE} = 0.5)\).

**Recruitment**

The sample was recruited from schools in the New Haven Public School system. Parents of first grade students were contacted by research assistants trained in human subjects protection. Families were informed of the study itself and the NHLP’s relationship with the New Haven Public School system. Letters were mailed and/or emailed to families as well with further study description and researcher contact information. Events to encourage recruitment were held at three schools in New Haven neighbourhoods, including Newhallville, Fair Haven and the Hill. Information about the study was given by study personnel. Parents interested in participating were able to answer the screening question and fill out permission forms at the event if they wished.

Parents were invited to complete the Parent Questionnaire if their child was completing first grade either in the 2015-2016 or 2016-2017 school years. From there, screening took place based on inclusion criteria over telephone interviews. Children were then placed in the appropriate cohort if all criteria were met. Children were excluded from the study if they spoke English as a second language, missed more than 20 days of kindergarten, or if they had been diagnosed with a developmental delay or other developmental neurological condition.
Tasks

Parent Questionnaire

Parents of participants were asked to complete a questionnaire consisting of items meant to elicit demographic information, potential underlying genetic and environmental factors, or any other relevant details that may help to directly or indirectly explain reading impairments in the children. The questionnaire consisted of seven sections covering a broad range of topics, including family background, household resources, the child’s education history, their attitudes towards reading, the child’s health and family learning history.

Decoding Measure

*Test of Word Reading Efficiency (TOWRE-2)*

The TOWRE-2 was used as a measure of accuracy and word reading rate through two subtests. For the purposes of this analysis, the data from the phonetic decoding subtest was examined.

*Phonetic Decoding.* This subtest measures the child’s phonetic decoding abilities with nonwords. The tester allows 45 seconds for the child to read as many phonetically-regular nonwords as they can. If any errors are made, these are removed from their total score of items read. Test-retest reliability for the phonetic decoding task in the 6-7 year old range was .86, while for the 8-12 year old range, the test retest reliability is .91.

Vocabulary Measure

*Peabody Picture Vocabulary Test (PPVT-4)*

The PPVT-4 was used to assess participants’ vocabulary for Standard American English. Results allow the tester to compare the child’s receptive and expressive vocabulary abilities. Pictures are shown to the examinee, and a prompt is given by the examiner. The child then
identifies the correct picture in response to the prompt. There is no reading required. Children are tested until eight errors are recorded in a set of twelve items. Internal consistency reliability for the PPVT-4 was .94 for the 2-18 year range.

**Executive Function Measures**

*Wechsler Intelligence Scale for Children, Fourth Edition (WISC-IV)*

The WISC is a test for children that measures intelligence. The Backward Digit Span assessment portion of the test was used as a measure of verbal working memory. In this task, the tester verbally gives the child a series of numbers. The child must then repeat the numbers in the correct backwards order. As items are answered correctly, series are presented of increasing length. Testing is stopped once a child has made two consecutive errors.

*Neuropsychological Assessment (NEPSY-II)*

The NEPSY-II is a general assessment consisting of multiple subsections to address potential diagnostic concerns. The Attention and Executive Function subtests from the NEPSY were used as a part of the NHLP as measures of executive functioning. For the present analysis, the data from the Inhibition-Switching subtest was used. Test-retest reliability for the NEPSY-II is .78 for the 7-8 year old range. Measures included in the exploratory analysis are: Inhibition-Naming, Inhibition-Inhibition, Animal Sorting, Auditory Attention, Response Set, and Clocks.

*Inhibition-Switching*. The Inhibition subtest requires the examinee to name either the shape or direction of items in a series of black and white shapes or arrows. In this condition of the Inhibition task, an additional stimulus feature is added to indicate that a different behaviour is expected. The task challenges working memory, inhibitory control, and evaluates the child’s cognitive flexibility.
Inhibition-Naming. The Naming portion of the Inhibition subtests can identify whether a child is able to identify and self-correct their own mistakes while naming the image presented to them.

Inhibition-Inhibition. This subtest can be used to identify children with impulsive behaviour. The procedure is similar to that of the Switching condition, with the added demand of replacing an automatic response with a novel response.

Animal Sorting. The child is asked to sort cards into two groups of four using criteria to sort that is self-initiated. This task is intended to assess the individual’s ability to formulate basic concepts and to shift between concepts.

Auditory Attention. This task assesses the individual’s auditory attention and how well they are able to sustain it. It makes up one half of the combined Auditory Attention and Response Set subtest.

Response Set. The Response Set portion of the subtest assesses the individual’s ability to shift and maintain attention while inhibiting learned responses and correctly responding to stimuli. In both the Auditory Attention and Response Set tasks, the child listens to a series of words. When the target word is spoken, they must touch the appropriate circle to indicate their response.

Clocks. The Clocks task is intended to measure the child’s organizational abilities, visuospatial skills, and their understanding of time as depicted on analog clocks. The child is asked to draw a clock with hands as directed by the examiner. Additionally, the child is asked to read the time on clocks that either have numbers, or do not.
Reading Comprehension Measures

Woodcock-Johnson III (WJ-III)

The WJ-III is a comprehensive standardized testing battery consisting of subtests that measure multiple academic abilities. While multiple subtests from this battery were used in testing for the NHLP, for the present analysis, the data from the Passage Comprehension subtest was included.

Passage Comprehension. This task is used to measure the ability of the child to understand a given text that they have read. The items increase in difficulty, from identifying pictures, to providing the correct word to complete a sentence that would make sense given the context of the passage read. The task is administered as a cloze procedure, in which the child reads a passage and completes the passage by providing a single missing word. The child is stopped from continuing once six errors in a row have been made. Test-retest reliability for this task in the developmental range of the study was as follows: 7 years, .96, 8 years, .92, and 9 years, .91. Internal reliability for 5-19 years was .83.

Gray Oral Reading Test (GORT-5)

The GORT-5 was used to assess reading comprehension ability. It measures four components of reading comprehension, including accuracy, fluency, oral reading rate and comprehension. For this analysis, data from the GORT-comprehension test was included.

Comprehension. In this task, the child responds to content-based questions about a story that child reads. The questions are open-ended, ensuring that answers are passage dependent. Performance is scored based on the number of questions answered correctly. Internal consistency reliability for the GORT-5 comprehension task in the developmental range of the study was: 7 years, .9, 8 years, .9, and 9 years, .91.
Procedure

Once participants were confirmed to have met inclusion criteria, a visit was scheduled with families to meet at the NHLP study offices. At this first visit, permission was obtained from parents for their child’s participation in the study. A series of questionnaires, including the above mentioned NHLP Parent Questionnaire was given for parents to fill out, taking approximately 40 minutes to complete. While this took place, a research assistant met with the child to obtain assent, collect a saliva sample for the genetics portion of the NHLP, and conduct a battery of cognitive assessments.

During the school year, further testing took place on site at the child’s elementary school. Three testing sessions were conducted, at the beginning, middle and end of the school year. Academic assessments, such as measures of reading ability, took place at the beginning and end of the school year, while the cognitive assessments took place in the middle.

Vocabulary was assessed through PPVT before grade 1, while TOWRE phonetic decoding was assessed at the end of that school year. The WISC backward digit span and NEPSY inhibition task were both a part of the cognitive testing that occurred at the beginning of grade two. The passage comprehension measures, the WJ-III and the GORT were assessed at the end of grade two.

Parents received $20 in compensation for completing the parent questionnaire. For the academic and cognitive measures in the present assessment, $10 were given to subjects for each assessment completed. Further compensation was also given for the genetic testing portion of the study, which is not included in the present analysis.
Analysis Plan

To begin, the data was examined for sample characteristics. Data were screened and processed for entry errors, outliers, and non-normal distributions. Exploratory correlations between dimensions of reading skills and executive function were conducted. Next, mediated and/or moderated regression analyses were conducted using Hayes’ (2013) process macro, controlling for age, sex, ethnicity and SES.

Results

Data Screening

Data was first explored to determine if the assumptions of normality had been met. The Statistical Package for Social Sciences (SPSS) was used in identifying outliers that existed in the studied sample. Homogeneity of variance assumptions were met for the data.

Overall, data was missing for 36.3% of cases (n = 93). Specifically, the majority of the data appeared to be missing from the variables included as covariates. No data was missing from the Age and Sex variables, however between 15.2% (African American heritage) and 23.8% (Socio-economic status) of participants had incomplete data for the remaining covariates. Missing data appeared to be homogenously distributed across cases and variables. Little's MCAR test supported the hypothesis that data were missing completely at random, chi-square = 250.12, df = 219, p = .073. As a result, the expectation maximization algorithm was used to impute plausible values for all missing datapoints. All analyses that follow were conducted both with the complete set of cases and imputed values, and with a dataset subjected to listwise deletion in which any case with missing data was deleted (n = 93). In all cases, the substantive relationships in both correlation tables and the mediation/moderation models were very similar, so results for
the imputed data are reported below. In total, data from 256 participants was included in the present analysis.

**Mean Scores**

Shown below (Table 1) are the means and standard deviations for the key tasks included in the regression analyses.

<table>
<thead>
<tr>
<th>Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Means and standard deviations.</strong></td>
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<tr>
<td></td>
</tr>
<tr>
<td>1.</td>
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<tr>
<td>2.</td>
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<tr>
<td>3.</td>
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<tr>
<td>4.</td>
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<tr>
<td>5.</td>
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<tr>
<td>6.</td>
</tr>
</tbody>
</table>

**Correlations**

Analyses were conducted first to determine inter-correlations among reading measures.

The TOWRE phonetic decoding results were strongly correlated with both passage
comprehension measures (WJ-III and GORT), but only weakly correlated with the PPVT measure of vocabulary (Table 2). The two reading comprehension measures correlated strongly with each other, as well as with vocabulary (Table 2).

Table 2

Correlations of Reading Measures

<table>
<thead>
<tr>
<th>Variable</th>
<th>1.</th>
<th>2.</th>
<th>3.</th>
<th>4.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. TOWRE phonetic decoding</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. PPVT</td>
<td>.25**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. WJIII passage comprehension</td>
<td>.59**</td>
<td>.51**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. GORT comprehension</td>
<td>.56**</td>
<td>.52**</td>
<td>.85**</td>
<td></td>
</tr>
</tbody>
</table>

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Next, the intercorrelations among executive functions tasks were evaluated. As expected, all executive function tasks (excepting NEPSY Animal Sorting in relation to two tasks) were correlated significantly with each other. Inhibition-Switching demonstrated the strongest on average correlation and most consistent pattern of correlations with all other executive function tasks and was thus chosen for the more complex mediation models described below. WISC backwards digit span, as a measure of working memory showed somewhat moderate correlations with all the NEPSY executive functioning tasks, especially Response Set, Inhibition-Naming, Inhibition-Inhibition and Inhibition-Switching (Table 3). The results of the NEPSY Animal
Sorting task showed weak correlations with Response Set, Inhibition-Inhibition, Inhibition-Switching and the Clocks task. Animal Sorting was not significantly correlated with Auditory Attention or Inhibition-Naming. Auditory Attention showed moderate, significant correlations with Response Set, Inhibition-Inhibition, and Inhibition-Switching, and weak correlations with Inhibition-Naming and the Clocks task (Table 3). The Response Set task showed moderate correlations with the Inhibition-Naming, Inhibition-Inhibition, Inhibition-Switching, and Clocks tasks. All three of the Inhibition tasks were moderately correlated with each other. The Clocks task showed a weak correlation with the Inhibition-Naming and Inhibition-Inhibition tasks, and a moderate correlation with the Inhibition-Switching task (Table 3).

Table 3

Correlations of Executive Functioning Measures

<table>
<thead>
<tr>
<th>Variable</th>
<th>1.</th>
<th>2.</th>
<th>3.</th>
<th>4.</th>
<th>5.</th>
<th>6.</th>
<th>7.</th>
<th>8.</th>
</tr>
</thead>
<tbody>
<tr>
<td>WISC backward digit span</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Animal Sorting</td>
<td></td>
<td>.22**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Auditory Attention</td>
<td></td>
<td>.21**</td>
<td>.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Response Set</td>
<td></td>
<td>.34**</td>
<td>.19**</td>
<td>.31**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inhibition-Naming</td>
<td></td>
<td>.33**</td>
<td>.10</td>
<td>.28**</td>
<td>.37**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inhibition-Inhibition</td>
<td></td>
<td>.35**</td>
<td>.16*</td>
<td>.31**</td>
<td>.41**</td>
<td>.48**</td>
<td></td>
<td></td>
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<tr>
<td>Inhibition-Switching</td>
<td></td>
<td>.32**</td>
<td>.21**</td>
<td>.26**</td>
<td>.41**</td>
<td>.46**</td>
<td>.47**</td>
<td></td>
</tr>
<tr>
<td>Clocks</td>
<td></td>
<td>.29**</td>
<td>.25**</td>
<td>.19**</td>
<td>.35**</td>
<td>.20**</td>
<td>.26**</td>
<td>.37**</td>
</tr>
</tbody>
</table>

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Finally, the executive functioning measures and the reading measures were examined for correlations across these two domains. Overall, moderate correlations were observed between measures of executive function and decoding/comprehension, with weak and/or inconsistent correlations being observed between executive function and vocabulary. Inhibition-Switching displayed the strongest and most consistent relationships with all achievement domains and was thus employed in the mediation analysis reported below. Phonetic decoding, as measured through the TOWRE task, was weakly positively correlated with Animal Sorting, Auditory Attention, Response Set, and Inhibition Naming, and moderately positively correlated with the WISC measure of working memory, Inhibition-Inhibition, Inhibition Switching, and Clocks (Table 4). The PPVT vocabulary task showed weak positive correlations with WISC backward digit span, Animal Sorting, Auditory Attention, Inhibition-Switching and Clocks. It was not significantly correlated with Response Set, Inhibition-Naming or Inhibition-Inhibition (Table 4). The WJ-III passage comprehension task was moderately positively correlated with the working memory measure, Inhibition-Naming, Inhibition-Inhibition, Inhibition-Inhibition, and Clocks. It was weakly positively correlated with Animal Sorting, Auditory Attention and Response Set, and strongly positively correlated with Inhibition-Switching (Table 4). The GORT comprehension measure was weakly positively correlated with Auditory Attention, and moderately positively correlated with WISC backward digit span, Animal Sorting, Response Set, Inhibition-Naming, Inhibition-Inhibition, and Clocks. It was strongly positively correlated with Inhibition-Switching.
Table 4

Correlations of Executive Functioning and Reading Measures

<table>
<thead>
<tr>
<th>Variable</th>
<th>TOWRE phonetic</th>
<th>PPVT phonetic</th>
<th>WJIII passage</th>
<th>GORT comp. phonetic</th>
</tr>
</thead>
<tbody>
<tr>
<td>WISC backward digit span</td>
<td>.36**</td>
<td>.18**</td>
<td>.37**</td>
<td>.38**</td>
</tr>
<tr>
<td>Animal Sorting</td>
<td>.21**</td>
<td>.29**</td>
<td>.28**</td>
<td>.33**</td>
</tr>
<tr>
<td>Auditory Attention</td>
<td>.13**</td>
<td>.13**</td>
<td>.27**</td>
<td>.26**</td>
</tr>
<tr>
<td>Response Set</td>
<td>.26**</td>
<td>.09</td>
<td>.28**</td>
<td>.31**</td>
</tr>
<tr>
<td>Inhibition-Naming</td>
<td>.29**</td>
<td>.06</td>
<td>.33**</td>
<td>.30**</td>
</tr>
<tr>
<td>Inhibition-Inhibition</td>
<td>.32**</td>
<td>.05</td>
<td>.36**</td>
<td>.31**</td>
</tr>
<tr>
<td>Inhibition-Switching</td>
<td>.43**</td>
<td>.22**</td>
<td>.42**</td>
<td>.41**</td>
</tr>
<tr>
<td>Clocks</td>
<td>.37**</td>
<td>.20**</td>
<td>.37**</td>
<td>.37**</td>
</tr>
</tbody>
</table>

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

Regression Models

To test whether phonetic decoding and vocabulary respectively predict passage comprehension via inhibition, with working memory moderating the indirect effect, regression analyses were conducted using the PROCESS macro from SPSS (Hayes, 2013). Bootstrapping analyses were performed using 5000 bootstrap samples with 95% confidence intervals. The base model, represented conceptually in Figure 1 included the following: 1) either decoding or
vocabulary (i.e., the main components of the SVR model) as the predictor, measured in Grade 1; 2) reading comprehension as measured by WJ-III Passage Comprehension or GORT Comprehension at the end of Grade 2 as the outcome; 3) NEPSY inhibition-switching as a mediator of this relationship (measured at the beginning of Grade 2); 4) WISC digits backward as a verbal short-term memory moderator (measured at the beginning of Grade 2) of this relationship.

Figure 1. Base model showing mediation with moderation of only the direct effect run using Hayes (2013) PROCESS macro, controlling for age, sex, ethnicity and SES.

Hayes (2013) model 5 was used to evaluate all these relationships simultaneously and evaluated the total variance accounted for in reading comprehension by the SVR predictors, the executive function mediators and moderators, and the interaction between SVR predictors and executive function dimensions. The four resulting models are reported below.
Decoding as SVR component and WJ-III Passage Comprehension as Outcome

Results of the first model indicate that phonetic decoding was indirectly related to reading comprehension, but also related though its relationship to inhibition. Decoding is also shown here to have a relationship with comprehension that is moderated by working memory. This model accounts for 55% of the variance in passage comprehension as measured by the WJ-III task ($F(10,245) = 29.49, p < .001$). From Figure 1, it is clear that better decoding ability was directly associated with higher comprehension scores and better inhibition switching tasks. Ability to inhibit cognitive responses in switching tasks was associated with better reading comprehension abilities. The indirect effect ($ab = 0.026$) as indicated by a 95% bias-corrected confidence interval based on 5000 bootstrap samples was entirely above zero (0.005 to 0.051), indicating that inhibition-switching mediated the relationship between decoding and comprehension. Poor levels of working memory were associated with worse scores on the comprehension task. The interaction between decoding and working memory was significant, $F(1, 245) = 11.99, p < .001$, $\Delta R^2 = .022$, indicating that working memory moderated the relationship between decoding and comprehension. Of the covariates included in the model, Sex ($b = .89, t(245) = 1.97, p < .05$) and SES ($b = -4.49, t(245) = -5.65, p < .001$) were significant predictors of reading comprehension as measured by the WJ-III task.

The moderation effect of working memory is illustrated in Figure 3. This figure reports the results of a Johnson-Neyman analysis of the decoding-comprehension relationship at different levels of working memory. When working memory skills were weaker, the relationship between TOWRE nonword decoding and WJ-III Passage Comprehension was positive and significantly different from zero (see 95% confidence intervals in Figure 3 not crossing zero);
conversely, in the case of stronger working memory skills, decoding was weakly or not at all related to comprehension with confidence intervals that crossed zero. Above a raw score of 9 on the WISC Digits Backward task, no relationship between decoding and reading comprehension was observed.

Figure 2. Results of mediation models with moderation of only the direct effect run using Hayes (2013) PROCESS macro, controlling for age, sex, ethnicity and SES. Results indicate that the direct effect of phonetic decoding on passage comprehension (as measured through the WJ-III task) is significant when inhibition is included in the model, and is moderated by working memory ability.
Decoding as SVR component and GORT Comprehension as Outcome

Results of the second model confirmed the findings demonstrated in the first model, indicating that higher decoding scores were directly associated with better inhibition in switching tasks and also indirectly associated with higher reading comprehension scores. Decoding was again shown to have a direct relationship with comprehension, this time shown by scores received on the GORT comprehension task, and also moderated by working memory. In the second model, phonetic decoding, inhibition and working memory accounted for 49% of the variance in passage comprehension, as measured by the GORT task ($F(10,245) = 23.39, p < .001$). Inhibition was significantly associated with comprehension again, despite the different measure of reading comprehension ability. The indirect effect ($ab = 0.035$) as indicated by a 95% bias-corrected confidence interval based on 5,000 bootstrap samples was entirely above zero (0.004 to 0.068) indicating that inhibition-switching mediated the relationship between decoding
and comprehension. Poor levels of working memory were again associated with worse scores on the comprehension task. The interaction between decoding and working memory was significant, \( F(1, 245) = 13.55, p < .001, \Delta R^2 = .028 \), indicating that working memory moderated the relationship between decoding and comprehension. Of the covariates included in the model, this time only SES (\( b = -4.49, t(245) = -5.65, p < .001 \)) was a significant predictor of reading comprehension as measured by the GORT task.

The moderation effect of working memory is illustrated in Figure 5. This figure reports the results of a Johnson-Neyman analysis of the decoding-comprehension relationship at different levels of working memory. When working memory skills were weaker, the relationship between TOWRE nonword decoding and GORT Comprehension was positive and significantly different from zero (see 95% confidence intervals in Figure 5 not crossing zero); conversely, in the case of stronger working memory skills, decoding was weakly or not at all related to comprehension with confidence intervals that crossed zero. Above a raw score of 8.3 on the WISC Digits Backward task, no relationship between decoding and reading comprehension was observed.
Figure 4. Results of mediation models with moderation of only the direct effect run using Hayes (2013) PROCESS macro, controlling for age, sex, ethnicity and SES. Results indicate that the direct effect of phonetic decoding on passage comprehension (as measured through the GORT task) is significant when inhibition is included in the model, and is moderated by working memory ability.
Figure 5. Johnson-Neyman analysis showing the effect of decoding on reading comprehension, varying by level of working memory.

**Vocabulary as SVR component and WJ-III Passage Comprehension as Outcome**

Results of the third model indicated that vocabulary was indirectly related to reading comprehension through its relationship to inhibition. Vocabulary was also shown here to have a direct relationship with comprehension, however working memory was shown not to be a significant moderator. Vocabulary, inhibition and working memory account for 50% of the variance in passage comprehension as measured by the WJ-III task \( F(10,245) = 24.34, p < .001 \). From Figure 1, it is clear that better vocabulary was directly associated with higher reading comprehension scores and better inhibition in switching tasks. Ability to inhibit cognitive responses in switching tasks was associated with better reading comprehension abilities. The indirect effect \( (ab = .009) \) as indicated by a 95% bias-corrected confidence interval based on 5,000 bootstrap samples was entirely above zero (0.003 to 0.017) indicating that inhibition-switching mediated the relationship between vocabulary and comprehension. While working memory was associated with comprehension, the interaction between vocabulary and
working memory was not significant, \( F(1, 245) = 2.48, p = .12, \Delta R^2 = .01 \), indicating that working memory did not moderate the relationship between vocabulary and comprehension. Of the covariates included in the model, Sex \((b = 1.21, t(245) = 1.97, p = .01)\) and SES \((b = -4.84, t(245) = -5.79, p < .001)\) were significant predictors of reading comprehension as measured by the WJ-III task.

Figure 6. Results of mediation models testing for moderation of only the direct effect run using Hayes (2013) PROCESS macro, controlling for age, sex, ethnicity and SES. Results indicate that the direct effect of vocabulary on passage comprehension (as measured through the WJ-III task) is significant when inhibition is included in the model, but is not moderated by working memory ability.

**Vocabulary as SVR component and GORT Comprehension as Outcome**

Results of the fourth model confirmed the findings demonstrated in the third model, indicating that vocabulary was indirectly related to reading comprehension through its
relationship to inhibition. Vocabulary is shown here to have a direct relationship with comprehension, as measured by the GORT task, however, once again, working memory was shown not to be a significant moderator. In the fourth model, vocabulary, inhibition and working memory account for 46% of the variance in passage comprehension as measured by the GORT task \(F(10,245) = 20.61, p < .001\). From Figure 4, it is clear that better vocabulary was directly associated with higher reading comprehension scores and better inhibition in switching tasks. Ability to inhibit cognitive responses in switching tasks was associated with better reading comprehension abilities. The indirect effect \(ab = .012\) as indicated by a 95% bias-corrected confidence interval based on 5,000 bootstrap samples was entirely above zero (0.003 to 0.022) indicating that inhibition-switching mediated the relationship between vocabulary and comprehension. While working memory was associated with comprehension, the interaction between vocabulary and working memory was not significant, \(F(1, 245) = 1.48, p = .23, \Delta R^2 = .003\), indicating that working memory did not moderate the relationship between vocabulary and comprehension. Of the covariates included in the model, Sex \((b = 1.42, t(245) = 2.50, p = .02)\) and SES \((b = -4.36, t(245) = -3.97, p < .001)\) were significant predictors of reading comprehension as measured by the GORT task.
Figure 7. Results of mediation models testing for moderation of only the direct effect run using Hayes (2013) PROCESS macro, controlling for age, sex, ethnicity and SES. Results indicate that the direct effect of vocabulary on passage comprehension (as measured through the GORT task) is significant when inhibition is included in the model, but is not moderated by working memory ability.

**Discussion**

The present study sought to address several questions surrounding the decoding and reading comprehension relationship, including how inhibition and working memory can affect this dynamic. Specifically, the four questions are: 1) Which executive functions are associated with reading skills? 2) to what extent does inhibition mediate the relationship between decoding and comprehension? 3) Does better working memory strengthen the decoding and reading comprehension relationship? and finally 4) can the same dynamics be seen when considering the language and comprehension relationship?
Executive Functions and Reading Skills

As discussed in the literature review, there is evidence to suggest that multiple executive functions play a role in reading outcomes. As dyslexia has been shown to have a high comorbidity rate with disorders in which executive functioning is impaired, such as ADHD (Mascheretti et al., 2017) it is important to understand these dynamics in more detail.

The present analysis first sought to assess the relationships between different executive functions and reading skills. As a part of the New Haven Lexinome Project, participants had been asked to complete a series of subtests from the Attention and Executive Function portion of the NEPSY assessment. These subtests assess executive functions through a variety of tasks that require planning, organization, attention, inhibition, cognitive flexibility and more. For the present study, it was important to observe the relationship between each of these tasks and the selected reading measures, to confirm the hypothesis influenced by past literature that inhibition might play an important role in the reading process.

Correlation analyses showed that the NEPSY tasks were significantly related to most of the reading measures, which was expected. The results indicated that better executive functioning skills were correlated with higher levels of reading performance. However, it was interesting to note that the vocabulary measure, the PPVT, featured the lowest overall correlations with the executive function tasks, and showed no significant relationship with Response set, Inhibition-Naming and Inhibition-Inhibition. Not only is it interesting then, that the Inhibition-Switching task had a significant relationship with the PPVT vocabulary measure, but overall the Inhibition-Switching task had some of the strongest correlations across all of the included reading measures. This, in combination with the established literature, supported the decision to continue with the proposed analysis, focusing on inhibition, specifically through the
Inhibition-Switching task, and further investigating the implications of those particular skills and their effect on reading performance.

**Inhibition as Mediator in the Decoding-Comprehension Relationship**

The present analysis used data from a NEPSY task meant to measure an individual’s inhibition ability in switching conditions specifically. This may be a major reason why inhibition here was observed to be a driving factor behind the decoding-comprehension relationship. The English language is orthographically quite deep, and multiple spelling ‘rules’ exist that young children must learn either implicitly through experience, or explicitly via instruction during the process of learning to read (Venezky, 1967). These rules often have multiple exceptions however, and it may be necessary to inhibit one cognitive response in favour of another. For example, the word *lead* needs the context of the rest of a sentence for the reader to know whether to pronounce the *ea* sound as *eh* or *ee*. Arguably, reading can be considered a switching task in some respects. Referring back to the *lead* example, if the word appeared more than once, but in different contexts and therefore with very different meanings, the child would have to be able to switch their response appropriately in order to effectively decode the text, and thereby have a better chance of properly comprehending it. The sentence “He will lead the parade in a lead balloon” demonstrates the need to switch from one spelling rule to another correctly.

The results from the present analysis may be used to infer causality due to the timing of the tasks. While most of the tasks and measures carried out for the NHLP are conducted each year for the cohorts being followed, the data for this analysis was chosen very intentionally from certain time points. Decoding data was used from the end of grade one, executive function data from the beginning of grade 2, and data from the reading comprehension tasks was included from the end of grade 2. Because of this, the mediation model provides some support for causal
role (Kline, 2015) for decoding ability in predicting reading comprehension performance, but also for a causal role for a child’s inhibitory abilities, specifically in tasks requiring attentional switching or cognitive flexibility, on comprehension.

Two reading comprehension measures were used, and the regression analysis consequently was conducted twice, as a way of ensuring that the results were not due to any one particular measure. The Woodcock Johnson III Passage Comprehension measure requires the child to fill in the blank of a sentence after having read a passage. The child must be able to retrieve the memory of the text and provide the exact word needed. In the GORT Comprehension subtest, questions are passage dependent again, but more open ended. While both are accurate measures of reading comprehension ability, using increases the quality of evidence for the dynamics among decoding, inhibition and reading comprehension identified by the model.

**Working Memory as Moderator in the Decoding-Comprehension Relationship**

There are numerous studies that investigate the impact of working memory on various facets of the reading process, including decoding ability and comprehension (Daucourt et al., 2018; Cain et al., 2004; Gray et al., 2015). The main literature that exists however, looks purely at working memory as a predictor of these outcomes, and rarely as playing any other role in what may ultimately be a more complex relationship. The present study adds to this small body of research, and is unique in looking at the simultaneous moderation of the direct effect by working memory, and mediated indirect effect via inhibition.

Interestingly, while working memory did act as a moderator, strengthening the decoding and comprehension relationship, it was only with the low working memory skill participants that any relationship was found. Poor to average working memory impacted this dynamic, where better working memory did not. It is likely that individuals with better working memory may
also be stronger in other cognitive areas, and may not be relying on decoding as heavily, thereby making the impact of working memory on this relationship minimal. Children with poor working memory will be much more likely to have difficulties with decoding (Snowling, 2000) which will have a detrimental effect on comprehension performance, as described earlier.

Much like with the results regarding inhibition as a mediating factor in the decoding-comprehension relationship, these findings surrounding working memory may be interpreted as fairly strong given replication across two measures of reading comprehension. In addition, these findings may also support a causal interpretation, due to the developmental timing of the tasks and data collection. The decoding data was collected prior to the execution of the working memory task, and both took place before the reading comprehension measures.

**Inhibition and Working Memory in the Vocabulary-Comprehension Relationship**

The final research question asked whether the same dynamics, as seen between inhibition, working memory, decoding and comprehension, could also be observed when considering the vocabulary and comprehension relationship. This can simultaneously be answered positively and negatively. Much like with decoding, language was shown to predict reading comprehension through inhibition. However, working memory was found not to significantly interact with vocabulary, and so was determined not to be a moderator in this relationship.

**Inhibition**

Much like in online or text conversations, where one person may misinterpret the emotional meaning of a message if they fail to consider the perspective or situation of the sender, language comprehension in conversation may be affected. Young children are already more egocentric (Borke, 1971), and this is compounded if cognitive inhibition is affected. Unless they
are able to successfully inhibit their own perspective from taking over the interpretation of an unfamiliar word, the child may entirely misunderstand the meaning, or ignore it altogether (Brown-Schmidt, 2009). This then has a negative impact on reading comprehension when the same word is encountered in text form (Gernsbacher, Verner & Faust, 1990). A real life example involved the introduction of a grammar lesson to a group of grade one students. One student, having never heard (or perhaps not remembering having heard) the word ‘grammar’ before, immediately connected it with the similar sounding word ‘grandma’. Rather than inhibiting their memory of their own grandmother in favour of listening to the rest of the discussion and realizing that grandparents were not, in fact, the topic of conversation, the child clung to this concept and was understandably confused by the worksheet they were given a few minutes later, unable to understand the instructions.

It must be noted that at the outset of this analysis, the other two measures of inhibition that had been collected, that of the Inhibition-Naming and Inhibition-Inhibition tasks, did not significantly correlate with the PPVT measure of vocabulary. This begs the question of why the Inhibition-Switching task not only demonstrated a significant positive correlation with PPVT, but that it should also act in a mediating role between vocabulary and reading comprehension. As the body of research surrounding inhibition and vocabulary is quite small, it is hard to definitively determine at this stage why this should have occurred, and certainly this is a direction that should be explored more thoroughly in the future.

Recalling back to the different types of inhibitory functions, Miyake and Friedman (2004) describe inhibition as consisting of resistance to proactive interference, resistance to distractor interference and prepotent response inhibition. The Inhibition-Switching subtest stands out from the other portions of the overall Inhibition task as it requires cognitive flexibility as well
as good inhibitory ability to be successful. This task arguably is more of a measure of prepotent response inhibition, requiring the individual to recognize when to continue identifying the images by one criteria, and when to switch to another. Arguably, it is possible that this has a stronger link with the inhibitory processes required during language comprehension. The individual must know when their own connections to the conversation may be made, and when they must consider the perspective of the individual speaking. If an unfamiliar word is spoken, there are times when its meaning may be determined through one’s own memories or experiences, and other times when attention must be placed on the context in which the word has been spoken, such as who is speaking, why they said it, and what experiences they have had.

Our finding of inhibition acting as a mediator for the vocabulary-comprehension relationship has interesting implications for education, as children with attentional difficulties or who struggle with inhibitory control may require additional assistance when beginning reading instruction. There are certainly other factors that may affect whether vocabulary is effectively built through conversation, such as interest in the topics discussed or exposure to various vocabulary levels in the people speaking around them, but this may be an area that deserves more attention.

*Working Memory*

In contrast to the decoding model, in which working memory moderated the decoding-reading comprehension relationship, working memory did not moderate the vocabulary-reading comprehension relationship. This difference from the dynamics seen when predicting comprehension from decoding ability may be due to the different types of memory used while decoding as opposed to during the receptive vocabulary task. While decoding, the individual is more likely to rely on working memory for much of the task, recalling which letters have just
been read, and combining letter sounds to unlock the whole word. Language comprehension would be much more likely to rely on longer storage memories, recalling words they have seen or heard in previous conversations which may have occurred weeks or even years previously. Logically then, the results of the present study make sense, as working memory was only found to strengthen the relationship between decoding and reading comprehension, and only then in instances when working memory was poor. Working memory is still important to reading comprehension, but past research and the present results show that it does not interact significantly with an individual’s vocabulary.

Limitations and Future Directions

While the findings from the present study do offer some exciting implications in the field of early identification and intervention, there are certain limitations that should be acknowledged that may be addressed in future endeavours.

Timing of Assessments

Although assessments were conducted at roughly the same time of year for each student, the range was quite large in some instances, with as much as a four month age difference between students at the time of testing. Some of this would be due to the natural distribution of ages seen within a single grade of children, but this was also partly due to a spread in testing dates. While the difference from one student to another was not so much as to cause high levels of concern, this is a methodological issue worth noting, especially in younger children where reading development may happen in leaps and bounds over a relatively short amount of time, progressing from learning letter names and sounds to reading beginner chapter books in the space of a few years. Future studies employing similar assessments should attempt to shorten this window in order to create a more accurate snapshot of ability at those time points. It may be
worth noting that the reason behind the slightly staggered assessment timing seen here was due to working respectfully with the schools, and acknowledging that pulling children out of the classroom for testing must be done at times that will not negatively affect the child’s learning experience.

Language Comprehension vs. Vocabulary

The theoretical framework for the present study was the Simple View of Reading, with the goal of finding components not currently included in the framework, namely executive functions. Ideally, the present analysis would have included a measure of language comprehension. Within the NHLP database, the PPVT was the closest measure available, as vocabulary is a key component of language comprehension. The present study suggests that background vocabulary knowledge is reined in by inhibitory abilities in instances when it’s not needed or appropriate. With a more comprehensive language comprehension measure, or several measures that combined, could capture the other dimensions of language comprehension, the points discussed theoretically above could be better supported.

The branch of the Simple View of Reading that includes vocabulary argues that the components of language comprehension become increasingly strategic as the individual becomes a more skilled reader. Better inhibitory abilities may help the individual to be more strategic in the use of their memories and background knowledge. However, because the measure used here only captured one component of language comprehension, a more solid conclusion cannot yet be drawn, and certainly is an area that could be explored further in the future.

Future Directions

Future research could build on the present findings by extending the observed timeline. Present analysis focused on data from grade 1 through grade 2. Executive functioning may be
observed and assessed prior to the child learning to read. This could help in the identification of those children who may need additional or differentiated instruction once they do enter the classroom and begin the process of learning to read. Understanding the mechanisms behind the decoding-comprehension relationship may help educators to deliver material more impactfully, especially in the early elementary grades. Identifying where exactly the child is struggling and why could allow parents and teachers to support children more effectively.

The findings surrounding working memory offer several other paths that may be further pursued in the future. The task used in the present analysis assessed working memory capacity. Multiple studies have used backward digit span as a measure of working memory (Bull, Espy & Wiebe, 2008), but it may be interesting to further investigate whether working memory processing, as seen through the different components of working memory described earlier in this thesis, has additional impacts on the decoding-comprehension relationship. These components have been studied in the past as predictors of decoding of reading comprehension individually, but they do not appear to have been studied in depth in a moderator capacity, as was introduced here. The current findings indicate that children with poor working memory in particular may see this reading relationship affected, therefore this would appear to be a worthy direction for improving early interventions in struggling readers.

Conclusion

The current study investigated the roles of inhibition and working memory as influencing forces behind the well-established decoding and reading comprehension relationship. This is a unique stance in the literature, as executive functions, including inhibition and working memory, have most commonly been examined simply as predictors of either decoding or reading comprehension, with few studies examining them in a mediation or moderation based context.
Additionally, there does not appear to be a body of research examining both inhibition and working memory simultaneously while in different capacities. Results of the present study indicate that these executive functions are not just important to the reading process, but that the relationship between specific executive functioning and reading skills are complex enough to warrant differentiation in both early identification and intervention. These findings support the need to recognize that the Simple View of Reading, while not without merit, is likely more complex than was previously assumed. The current study confirms past suppositions that non-linguistic skills play a significant role in the reading process. This may help to shift the perception of learning in beginning readers, and open more doors for teaching approaches to address the needs of struggling children.
References

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