Unpacking the role of higher-level processing abilities in reading achievement: A review of the literature

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Introduction

Reading development related to academic achievement has been a widely studied subject. The purpose of reading is to develop a meaningful representation or understanding of the text. There are a multitude of cognitive processes that are involved in reading that have not yet been examined in theoretical models of reading development. Higher-level cognitive processes refer to cognitive functions that allow readers to be flexible with their learning when they encounter unfamiliar and novel situations by modifying what they already know and have experienced based on their prior knowledge and long-term memory. Two areas of interest are working memory, which describes the temporary storage and processing component, and executive function referring to the supervisory system that ensures that memory processes are operating in an accurate and efficient manner (Diamond, 2013). Our current understanding of reading acquisition and achievement isn’t complete, and recent research in the areas of higher-level cognitive processing may be considered predictors contributing to individual differences in reading ability. Moreover, the sub-components of higher-level cognitive processing warrant consideration in the learning process related to reading performance. The paper begins with a brief overview of higher-level cognitive processing, the reading development process, and a review of the literature highlighting the connection between the cognitive processes related to reading development, and future research considerations.

Keywords: cognitive processes, reading development; reading comprehension; working memory, executive functions.
Higher-level Cognitive Processing

Research on memory originated in the eighteenth century to describe the higher mental cognitive processes involved in the acquisition and storage of information for later retrieval. Hermann Ebbinghaus (1885) was the first to investigate this phenomenon experimentally using a single-subject design, with himself as the sole-subject to map the process of learning self-constructed lists of nonsense syllables (e.g., DAX, QEH). Ebbinghaus’ (1885) observations uncovered and defined concepts to describe the act of learning. These concepts included the learning curve, the forgetting curve, the serial position effect, limits of memory storage capacity, and speed of cognitive processing (Bower, 2000). Experimental studies have since explored the neurological underpinnings of behavioural performance in primates and humans (Baddeley, 2010; Castner, Goldman-Rakic, & Williams, 2004; Squire, 1986), and have investigated the processes involved with deficits in memory related to specific cognitive impairments i.e., neurological (e.g., mental illness, traumatic brain injury), pathology (e.g., dementia, Parkinson’s disease), and natural aging (Craik, 2008; Luo, & Craik, 2008).

Our memory serves as a mental workspace to temporarily store new and old information encoded from our environments. Originating from work on short-term memory or temporary storage of information, working memory can be described by its two components: the limited capacity for temporary storage of information and the manipulation of information in a short period of time (Baddeley, 2012). The second component refers to the process whereby we actively engage with input from our environments. This process is fundamental when connecting new and old information with our existing knowledge base and past experience. Input from the environment is
temporarily stored in one of two memory “slave” systems, the phonological loop where auditory rehearsal of phonological information takes place and the visualspatial sketchpad holding visual information from our environment (Baddeley & Logie, 1999). A third component of the multi-component model is the central executive, referring to the supervisory system that oversees the operations of these sub-processes within working memory (Baddeley, 2012).

Recent accounts indicate the need to better understand the functions of the central executive that direct our cognitive resources (Best & Miller, 2010; Diamond, 2013). Understanding the specific sub-processes as they contribute to development across the developmental lifespan provides a more complete account of the processes that need to be targeted when the cognitive system is not working productively or effectively (i.e., developmental delay, cognitive processes related to learning disabilities). In this direction, having a clearer view of all cognitive contributors to the learning process allows us to refine current methods in intervention research to improve the effectiveness of assessment and remediation.

**Cognitive Processes in Education**

The central executive is described as the attentional control system that supervises the cognitive operations needed to complete tasks in our daily life, relevant to regulating behaviour in both academic and social domains (Diamond, 2013). Three processes of executive functioning that have been most widely described are inhibitory skills, set shifting or switching attention, and updating. Inhibition refers to the ability to control automatic or prepotent responding. Shifting involves the ability to switch between two or more mental sets of information or to manage multiple tasks. Updating refers to
monitoring and maintenance of mental representations for current information to be integrated with information already held in long-term memory, in addition to filtering out irrelevant or old information (Miyake et al. 2000). The central executive system oversees the cognitive operations that support the individuals’ ability to respond flexibly and adapt appropriately when there is change in the environment. The paper continues with a description of the role of cognition in reading development. Specifically, I draw from the literature studies that have explored the role of working memory and executive functions as unique contributors to reading achievement in both typical readers and those with reading deficits as a foundation for future research.

**Reading Development.** The importance of literacy is far-reaching as it can be applied to most activities in our daily lives, including understanding the content in academic subjects when studying, oral speech, communications with others, and tasks or activities that involve words (e.g., signs, labels, books). In any language, during the beginning stages of learning how to read, individuals learn the foundations that set them up for success. In the English language, children begin by manipulating the speech sounds in the alphabet. The alphabetic principle involves the familiarization of the sounds of the alphabet that is foundational for phonological awareness. Phonological awareness refers to the ability to manipulate the smallest speech sounds (e.g., the /a/ in ‘apple’ and ‘animal’), which allow us to build our mental dictionary when we encounter new- or familiar words (Rayner, Foorman, Perfetti, Pesetsky, & Seidenberg, 2001). By Grade 3 or 4, the processes needed for word recognition in typically developing children reach a level of automaticity where children can decode with relative ease (Ehri, 2005). Younger readers allocate most of their attention and cognitive resources during the initial stages of
reading when decoding has not yet been mastered, which results in spending more
cognitive resources sounding out words. Comparatively, more experienced readers who
decode with more speed and accuracy can allocate freed up cognitive resources to more
complex reading skills such as comprehension.

The cognitive attentional system is relied on to complete tasks in our daily lives. In the context of reading achievement, once the basic processes of reading have been attained, the focus shifts from learning to read to reading to learn i.e., making inferences from text, drawing connections, and integrating current information with prior knowledge. Fluency in reading involves both automaticity and accurate pronunciation of individual words. In alphabetic orthographies, the beginning reader learns to identify individual phonological sound units heard through speech, and develop a repertoire of sounds important for listening comprehension at a young age. Reading comprehension includes both word decoding and listening comprehension (Verhoeven, Reitsma, & Siegel, 2011), and substantial research on working memory has identified it as central to phonological coding for reading (Cain, Oakhill, & Bryant, 2004). For example, a longitudinal study by Cain et al. (2004) assessed the relationship between reading comprehension and working memory capacity at three time points (during the years of their 8th, 9th, and 11th birthdays) in normal readers of English (n=102) beginning at ages 7-8. Working memory processes, which were assessed using sentence-span and digit working memory, along with comprehension skills, made independent contributions to reading comprehension above verbal word reading abilities and vocabulary. Within working memory, the amount of mental resources allocated to word decoding influences the resources made available for higher level processing such as listening comprehension.
The process of mapping speech sounds to visually represented symbols acts as the foundation for vocabulary development and reading comprehension (i.e., letters of the alphabet – “A” “B” “C”; simple words like “cat”). Therefore, mastery of letter-sound relationships becomes the basis for word recognition.

**Working memory and executive function in typical readers.** When reading, words may be processed phonologically, or visually through printed text. In both cases, resources in the phonological loop and visuo-spatial sketchpad are recruited for decoding and for maintaining an acoustic-based version of the word in working memory until a match is made (Baddeley, 2000). This typically involves retrieving the words spoken form and meaning from the word displayed in print. The acoustic trace is controlled by processes in the articulatory loop and is continually rehearsed subvocally until the phonological representation or visual representation matches a particular word in our mental lexicon (Kamhi & Catts, 2008). Moreover, deficits in this process may disrupt rehearsal leading to rapid decay, forgetting, or slowed processing of the temporary information being held in working memory. Executive functions overseeing these operations may also be considered when exploring predictors of reading development. Recent evidence supports the measurement of executive functions as a cognitive contributor to overall academic achievement as early as pre-schoolers (Foy & Mann, 2013). Children become more cognitively flexible with age, and executive functions continue to develop into early adolescence reaching their peak productivity and efficiency in middle adulthood around 25 years of age (Hunter, Edidin, & Hinkle, 2012). Taken together, our current understanding of the underlying mechanisms that support the processes of learning is far from complete and an exploration of these processes in the
context of reading achievement and its difficulties warrants further investigation (Best & Miller, 2010).

A study by Oakhill and Kyle (2000) examined the relationship between phonological awareness and working memory in a group of children 7-8 years of age (n=58). Oakhill and Kyle (2000) administered a battery of tasks that included a standardized measure of reading ability (vocabulary), and two measures each of phonemic awareness and memory. Measures of phonemic awareness skills included a sound categorization task (oddity based on judgment on phonological similarity) and phoneme deletion task. Memory measures included word span/immediate list recall (short-term memory), and an adapted version of the sentence span (working memory), which instructed participants to produce the final missing word of a sequence of sentences. The children were then instructed to recall the list at the end of each trial. Oakhill and Kyle (2000) found that working memory uniquely contributed to readers’ ability to detect the onset and rime of phonological units, whereas short-term memory demonstrated no unique variance for either phonological awareness task. A weak relationship between the two memory tasks supports the two-component model of working memory, namely storage and processing, to explain reading achievement among typically developing readers. It is important to note that the study by Oakhill and Kyle (2000) examined one particular age group with working memory measures that assessed executive functioning and verbal working memory. Although only a general statement can be made with regards to the relationship between working memory and phonological awareness based on this body of work, it would be of interest to examine more than one
cohort in a cross-sectional design to map the developmental trajectory of working memory and executive function in reading development.

An important study conducted by St. Clair-Thompson and Gathercole (2006) examined the role of executive functions - inhibition, shifting, and updating - along with working memory in 11 to 12 year old children (n=51). Two measures of each executive function were administered, along with four working memory and three scholastic achievement scores for English, mathematics, and science. The study found that inhibition represented a domain-general executive skill, meaning that it was a general cognitive ability important in processes of learning for all three subject areas. Further supporting the role of a supervisory system in cognitive operations, the study reported that the executive skill of updating was related to both verbal and visuo-spatial working memory components representing a general faculty. Both working memory and executive processes were considered in this study, indicating that some functions are dissociable as early as adolescence, and others emerge slowly across development. The types of measures and developmental age groups also need to be considered in assessing cognitive processes as each differentially contributes to the outcome measure of interest.

*Reading achievement and cognitive processing deficits.* Much of what is known about cognitive linguistic processes in typical reading development comes from research studying populations with specific language difficulties. For instance, Dyslexia, a widely known word-level reading disability, consists of difficulties in decoding monosyllabic words (Fletcher, Lyon, Fuchs, & Barnes, 2007) that affects overall reading comprehension. The deficits in word reading automaticity and processing of individual words can be observed in reading disabilities. A study by Swanson (1992) reported a
strong relationship between 11 working memory measures, short-term memory, and reading achievement. Swanson (1992) illustrated that working memory was highly correlated with reading measures, and deficits in working memory measures were found in the reading disabled. Additionally, working memory made an independent contribution above word knowledge in reading achievement, and dynamic testing for working memory measures resulted in higher predictions in reading. Dynamic testing or guided instruction/ assistance is based on Vygotsky’s (1935/ 1978) theory of “the zone of proximal development” and the learner’s potential under testing conditions (Swanson, 1992). Swanson’s (1992) study supported a general cognitive working memory process that was interconnected cross-modally in scholastic achievement, indicating the value of using measures of working memory to supplement screening, assessment and intervention.

A later study by Swanson, Howard, and Sáez (2006) explored working memory performance in three groups (n=66) of differentially skilled readers between 7-17 years of age: children with poor word recognition and poor comprehension; children with poor comprehension only; and children with poor IQ, poor word recognition and poor comprehension. The purpose of Swanson et al. (2006) was to examine whether the performance on executive functions and phonological loop measures of working memory predicted specific domains particular to reading, namely, word recognition, comprehension, or both in readers of low- and typical-levels of intelligence. They predicted that the phonological loop for word recognition would not be affected in the comprehension deficit-only group and that the phonological loop and executive processes for word recognition and comprehension would be affected in both reading-disabled
readers (those with average and below-average intelligence). It was expected that the reading-disabled group with lower intelligence scores would suffer a more general deficit in reading related to processes involved in executive functioning. The results of the Swanson et al. (2006) study indicated that children with greater reading deficits and low intelligence were outperformed on working memory, short-term memory, phonological processing, and processing speed measures by groups who had deficits only in word recognition, comprehension, or both (among the average intelligence group). The study also reported that deficits in reading were moderated by the storage component measured through short-term memory tasks, along with executive processing (updating) to provide a more accurate representation of the processes of working memory capacity.

A more recent study conducted by Locascio, Mahone, Eason, and Cutting (2010) researched a group of children (n=86) between 10 and 14 years of age including average readers, readers with word recognition deficits, and specific reading comprehension deficit. They reported that specific executive processing components underlie reading deficits: the word recognition deficits group had low performance on verbal working memory and response inhibition, and the comprehension deficits group had lower performance on planning/spatial working memory. In summary, the results of both studies suggest that the various combinations of specific reading deficits can be classified through components of working memory and executive functioning, above and beyond phonological processing. In order to illustrate the developmental trajectory and associated cognitive processing deficits contributing to reading ability and disability, future research may build off these research paradigms to investigate how deficits manifest during the early learning stages of word recognition and comprehension across age groups to
consider age-related differences, as well as grouping on the basis of reading-achievement for specific working memory and executive components. Unfortunately, many of the studies explore independent working memory components (i.e., verbal and visuo-spatial working memory without executive functions). The studies highlight the need to explore these associations by examining specific predictors (i.e., executive functions and working memory) cross-sectionally across age groups, reading abilities, and longitudinally over a developmental period.

Conclusion

Since the addition of working memory to Baddeley’s (2000) multicomponent model, researchers have sought to determine the best ways to measure and assess the components within working memory based on the characteristics of each component. The process of learning to read involves gaining flexibility and adapting ably when situations change (e.g., reading more difficult texts). The executive system is also involved in the discovery of the principles needed in word decoding, whereby reading becomes a tool used to learn new concepts and acquire knowledge through higher-order processes of comprehension (Diamond, 2013). Independent contributions of working memory (sentence- and digit-span) and specific skills related to comprehension continue to be predictive in more complex tasks of reading comprehension above and beyond verbal word reading abilities and vocabulary (Cain et al., 2004). In order to understand the underlying mechanisms that contribute to reading development and achievement, the theoretical understanding of the role of executive functions to academic-specific achievements (e.g., reading, math) necessitates further exploration. In this direction, executive functioning and working memory processes need to be investigated together.
within theoretical models of word reading and reading comprehension ability across the
developmental lifespan to account for the executive processes that may be attributed to
reading deficits important for informing both assessment and remediation. It may be of
value to examine both cognitive processes (i.e., inhibitory control and switching
attention) in a cross-sectional design to identify the ways in which the sub-components
operate on different tasks related to reading development. Furthermore, future studies in
reading research may include such processes as predictors in reading ability so as to
identify methods of assessment and ways in which to improve cognitive functioning
related reading difficulties.
References


