Cambridge Educational Research e-Journal

ISSN: 2634-9876 Journal homepage: http://cerj.educ.cam.ac.uk

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**To cite this article:**

Rogers, T. (2022). What Role Does Working Memory Play in Primary School Reading Achievement?. Cambridge Educational Research e-Jounal, 9, 231-243. https://doi.org/10.17863/CAM.90563

Link to the article online: https://doi.org/10.17863/CAM.90563

Published online: 30 November 2022

Cambridge Educational Research e-Journal | Vol. 9 | 2022

DOI: https://doi.org/10.17863/CAM.90563

# What Role Does Working Memory Play in Primary School Reading Achievement?

Thomas Rogers

University of Cambridge, Cambridge

## ABSTRACT

Working memory (WM) has consistently been related to reading ability, but the precise nature of this relationship remains unclear. This systematic review aims to evaluate the different pathways by which working memory may influence reading. The included papers were categorised into direct, indirect, and hierarchical effect models and presented using a narrative synthesis. The findings suggest that working memory has an indirect impact on reading ability as part of a hierarchical relationship via lower and higher order cognitive abilities. Furthermore, the nature of this relationship changes over time. As skills such as decoding become automatic, the role of WM is reduced and reserved for more complex comprehension. This review sheds light on the relationship between working memory and reading and may help to frame future research into the topic.

## KEYWORDS

Working memory, reading comprehension, primary school reading, reading acquisition, executive function

## Introduction

Working memory is a cognitive capacity associated with several high-order abilities such as reasoning and information processing (Becker & Morris, 1999; Greiff et al., 2015). Its role within education has been of increasing interest in recent history. Reading is a cornerstone of education and is considered a fundamental skill for success in society (OECD, 2002). Competent reading ability is required for developing knowledge across other disciplines (Moje et al., 2011). Working memory has been shown to affect reading, but how, and to what extent the effect influences reading is still contested. Discovering the exact role working memory plays in reading could help optimise teaching methods, combat, or even eradicate reading disabilities, and possibly provide a window into understanding the nature of knowledge.

## The Present Study

This review evaluated and compared papers seeking to establish the role of WM in reading from the perspective of the different potential mechanisms explaining the relationship. WM may be an independent predictor, directly related to reading ability. Alternatively, it may play a facilitation role, indirectly influencing reading by enabling other contributory functions to occur. By reviewing the literature from the differing perspectives of direct and indirect influences of WM, a deeper insight can be gained into the role it plays in reading comprehension.

**CONTACT** Thomas Rogers, tdr35@cam.ac.uk

This paper also considered differences over time. As reading skill improves, there is a transition from learning to read towards reading to learn. There may be a difference in the role of WM in response to the maturation of reading ability. A comparison was made to compare the role of WM in reading across early and late primary years to establish any change in the nature of the relationship. The review focused on primary school because this is a key period in the development of reading skills where children first learn to read and eventually move on to secondary education with the ability to use reading to enable further learning.

Background information on theories relating to working memory and reading are followed by a systematic review of the literature. The findings were analysed and presented in a narrative synthesis from which final conclusions were made. Conclusions drawn from the literature could help provide insight into the underlying mechanics of reading ability and a clearer lens for future research to use when considering the influence of working memory in reading.

## Background

### Working Memory

The concept of working memory describes a system, or set of systems, that temporarily store and process a finite amount of information (Baddeley, 2000; Baddeley & Hitch, 1974). WM is required for holding information in mind such as a phone number whilst looking for a notepad to write on. WM is also used to manipulate information, changing it, or synthesising it with information from long-term memory. Examples of this could be mentally rearranging a series of letters to form a word, or employing long-term memory to identify the connection between the names John, Paul, George, and Ringo. WM is generally measured using span tasks such as the reverse digit span task in which the participant hears a list of numbers which they must then repeat back in reverse order (Diamond, 2013). Other variations include reordering items, such as animals, by size, or the sentence span task in which participants listen to a series of sentences, ascertain whether they are true or false, then state the last word in each sentence. The principal of these measures is to simultaneously test storage and processing; passive storage tests simply measure short term memory.

### Simple View of Reading

Understanding the skill of reading has been a topic of much investigation in the field of education. A principal theory is the Simple View of Reading (SVR) (Gough & Tunmer, 1986) which suggests that reading can be broken down into two constituent parts, ‘decoding’ and ‘linguistic comprehension’. Decoding describes the ability to identify and process written letters and derive the correct sound at a word level. Linguistic comprehension describes the ability to construct understanding at a sentence or text level from the words which make it up. The model states that the two contributory skills combine, multiplicatively (R= D x LC), to form a score for overall reading ability. This equation reflects the claim that if one skill were to have a score of 0 (i.e., that the reader has no ability in either decoding or linguistic comprehension) then reading is not possible. Successful reading is achieved via a combination of these two skills. Empirical evidence supports this theory, with decoding and linguistic comprehension found to explain between 30% and >99% of the variance in reading achievement (Cadime et al., 2017; Hjetland et al., 2019; Torppa et al., 2016).

Despite the support, there are several criticisms directed at SVR. The first is that it is, ironically, too simple (Hoffman, 2014). Whilst there is no doubt that decoding and linguistic comprehension are fundamental players in reading, there is no description given of the process by which these phenomena occur. In essence, the theory tells us that whatever allows us to comprehend letters and language

is what allows us to understand written language. Cutting and Scarborough (2012) expanded on SVR suggesting that reading is a highly complex skill composed of multiple sub-skills, within which linguistic comprehension and decoding are made up of lower-level variables such as vocabulary, understanding of grammar, background knowledge and working memory. There is a growing body of evidence to support the notion that working memory is a fundamental predictor of reading (Carretti et al., 2009; McCallum et al., 2006). There are consistent correlations between working memory and reading comprehension although there is debate over the precise nature of this relationship. Many of the SVR critics argue that WM should be included as a third pillar of reading due to observed effects beyond those explained by language skills. A second criticism of SVR is that it does not address the changing nature of reading over time (Hjetland et al., 2019; Paris & Hamilton, 2014). The model offers a multiplicative equation to explain the relationship between decoding and linguistic comprehension to explain all reading. However, the nature of reading changes over time (Peng et al., 2017) with decoding being a fundamental skill in early reading acquisition, and gradually becoming less significant over time as letter and word recognition become automated. The concrete nature of SVR fails to reflect this change.

**Working Memory and Reading**

Kintsch (1988) introduced the Construction Integration Model (CI-Model) which claims that reading comprehension is achieved by the building of mental models. Information is taken from the text and integrated with other textual information or knowledge from long-term memory. The information is combined in a process known as 'inference making' to form a mental model and an overall understanding of the text. Inference making is considered a higher-order skill along with others such as 'comprehension monitoring' which is the ability to be self-aware of understanding during the reading process. The higher-order skills are fed into via lower-order skills such as word recognition, vocabulary, and syntactic knowledge. WM is thought to be the workspace in which the higher-order skills take place (Cain et al., 2004). Kintsch (1988) introduced the Construction Integration Model (CI-Model) which claims that reading comprehension is achieved by the building of mental models. Information is taken from the text and integrated with other textual information or knowledge from long-term memory. The information is combined in a process known as 'inference making' to form a mental model and an overall understanding of the text. Inference making is considered a higher-order skill along with others such as 'comprehension monitoring' which is the ability to be self-aware of understanding during the reading process. The higher-order skills are fed into via lower-order skills such as word recognition, vocabulary, and syntactic knowledge. WM is thought to be the workspace in which the higher-order skills take place (Cain et al., 2004). When reading a text, an individual creates a mental representation of the information which is held in mind. The mental model can be changed as information is added from the text or from long-term memory. The level to which a reader can complete this task is their ability to comprehend texts. Lower skills like vocabulary provide the reader with more resources to construct the models, and thus, contribute to the higher-order skills of WM to enable reading. This model suggests that the role of WM would be integrated with language skills rather than independent of them; this implies that WM could play an indirect role via facilitation of skills such as inference making.

**Dynamic Relationship Between Working Memory and Reading**

Working memory is a cognitively demanding process which requires conscious attention and mental processing. An example of WM in use is engaging in challenging mental arithmetic (Diamond, 2013). Tasks requiring more processing, as opposed to those which can be solved by accessing long-term memory alone, put greater strain on WM (Chandler & Sweller, 1991). Dual Process Theory

(Evans & Stanovich, 2013) states that there are two modes of cognitive reasoning: Type 1, an automatic, quick-fire response associated with overlearned tasks, and Type 2, characterised by controlled thought. Type 1 processing causes minimal strain on WM and would generally be employed to deal with more simple or familiar activities. An adult reader engages with familiar words in an effortless manner; reading the word 'castle' is immediately understood without any energy wasted on trying to remember the meaning. Conversely, the Type 2 process puts greater strain on WM and is only engaged when a task requires deeper thought. The process is slower but is capable of higher-order reasoning such as hypothesising and reflection. Peng et al. (2017) commented that early readers struggle to process letters into their correct sounds, likewise older readers feel strained when reading a text with a high quantity of unfamiliar vocabulary. However, as knowledge and language skills develop, the strain on WM is reduced with rapid retrieval from long-term memory and automated processing sufficing to integrate information and comprehend text. As language skills develop over time, the role of WM may be reduced.

## Aims

The aim of this review is to explore the role of WM in reading in primary school-aged children. Primary school is a key period for reading development of initial reading acquisition skills in the early grades to advanced comprehension and reading to learn in the latter years (Verhoeven et al., 2009). Working memory may have an important role in the development of reading skills, although the precise role it plays is unknown. Understanding the role of WM in reading could help optimise teaching and inform interventions to support students with reading difficulties.

***Research Question 1*** *– What role does working memory play in primary school reading?*

Working memory may act as an independent predictor of reading alongside linguistic comprehension and decoding, or it may play a more indirect role to facilitate reading via other skills. This review evaluated studies using direct, indirect, and hierarchical relationship models to identify the possible mechanisms by which WM may influence reading.

***Research Question 2*** *– How does the role of WM change over time?*

As reading skills develop from early acquisition skills to more complex comprehension, the role of WM may change. The dual process theory states that skills which are habitually repeated can become automatic and therefore less dependent on WM. The review also considered whether the role of working memory in reading changes over time by evaluating any differences between early and late primary school years.

## Method

A systematic search was conducted to be as comprehensive as possible in the gathering of studies. The search was conducted using the following databases: British Education Index, Child Development and Adolescent Studies, ERIC, APA PsycINFO, and Scopus. The search was formed of three areas of interest: WM, reading, and primary school. Synonyms and related constructs were identified for each area and were connected using Boolean 'OR'. Each area of interest was connected using 'AND'. An example search is presented in Table 1. The original search terms used for the first three databases were generally of broader scope due to fewer results. Due to the volume of hits yielded and the limited resources available for the present review, in the APA PsycINFO and Scopus databases the search terms were refined. The final search of Scopus was further limited to 2015 onwards to reduce

the total hits. This period was selected to represent five years of recent research with an additional two to account for disruption caused by the Covid-19 pandemic.

**Table 1**

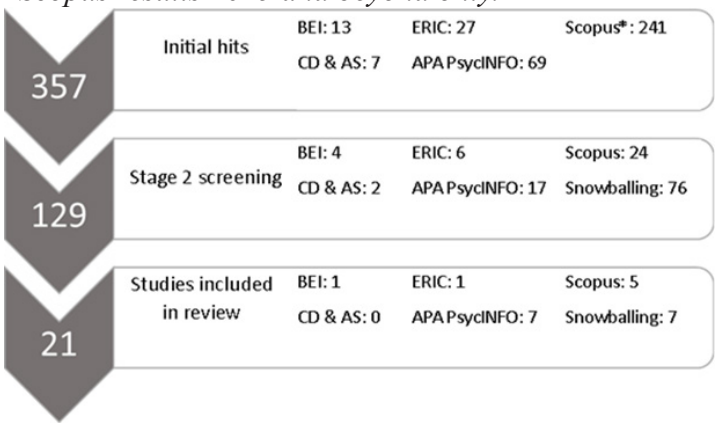
*Example search terms used to search databases.*

| Category | Search terms |
|---|---|
| Population | "Primary School Students" OR "Elementary School Students" OR "Elementary Schools" OR "Elementary Education" OR "Kindergarten" OR "Early years" |
| Outcome | "Reading Comprehension "OR "Literacy" |
| Phenomenon of interest | "Executive Function" OR "Cognitive Control" OR "Set Shifting" OR "Task Switching" OR "Executive Functioning Measures" OR "Short Term Memory" OR "Attention" OR "Working Memory" OR "Inhibition Control" |

The search was conducted in November 2021 and initial hits were screened by title, abstract, and full text availability. Any studies relating to WM, executive function, or reading were saved for processing. Stage two entailed reading through the abstracts or the full text to identify studies for the final review. Studies were removed if they focused on other constructs such as attention (Miller et al., 2013) or if they took a broad view of executive functions without a focus on WM (McClelland et al., 2021). Papers which tested the effects of WM on second language learning were also removed. All the studies at this stage were used for the snowballing process to identify further relevant papers. The 76 papers identified during the snowballing process were then evaluated in the same way for inclusion in the final review. The number of studies included at each stage are presented in Figure 1.

**Figure 1**

*Total number of studies processed at each stage of the review along with a breakdown by database. *Scopus results 2015 and beyond only.*




The studies included in this review aimed to explain the role of WM in reading. This was achieved via the use of statistical modelling in which WM is included as a predictor of reading. To answer the first research question regarding the role of WM in reading, the studies were categorised into direct and indirect models. Direct models mapped the effects of WM straight onto reading, whilst indirect models used a moderating variable or used WM to predict a reading related skill such as inference making. The hierarchical effects category was identified to account for papers in which WM predicted

reading via multiple moderators and levels. Null effects were also discussed to give a full picture of the research. To answer the second research question relating to possible changes over time, comparisons were made between early (grades 1-3) and late (grades 4-6) primary year groups. Differential effects of WM on reading were compared to draw conclusions about the dynamic effects over time.

## Results

### Direct Effects

A possible role of WM in reading is as a direct predictor alongside decoding and linguistic comprehension. There are many studies which aim to measure the direct relationship between WM and reading as illustrated by a number of literature reviews on the topic (Carretti et al., 2009; Follmer, 2018). Interest has grown in the area due to observed differences between strong readers compared to those with reading difficulties (Borella et al., 2010; Miller et al., 2013). Fowler and Swainson (2004) conducted a study using first and fourth graders divided into 'good readers' and 'bad readers'. Results indicated that there were differences in WM scores between groups, and that WM predicted reading beyond the linguistic measures by 7-10% in the overall hierarchical model. These findings are supported by both Nouwens et al. (2016) and Muijselaar et al. (2017) who tested Dutch upper-primary (fifth/ sixth grade) students for correlations between WM and reading comprehension. Both studies resulted in moderate (<0.5) correlations, and the study by Nouwens et al. (2016) found a small explanation of variance (5%) for WM beyond the effects of language skills and other cognitive abilities. Dolean et al. (2021) criticised the studies in this area for the inconsistent findings and frequent lack of appropriate controls. In their study, WM accounted for significant effects upon reading comprehension, however once decoding and oral language skills were controlled for, the effect was largely nullified. A meta-analysis by Peng et al. (2017) supported the notion that, with decoding and language skills controlled for, WM showed no direct effects on reading comprehension. However, they also concluded that there was an evident effect of WM which was likely to be of an indirect nature, in combination with language skills. The findings of this review suggest that there is limited support for the notion of a direct effect of WM as the effects seem to be nullified once controlling for decoding and language skills. However, the significant effects and positive correlations do suggest that WM plays a role in reading; the overlap with language skills may indicate an indirect relationship.

### Indirect Effects

Research has been conducted to investigate the effects of WM when mediated by individual language skills. Spencer et al. (2020) tested the effect of WM on reading comprehension via the mediated routes of decoding and oral language (b = 1.253, 95% CI [0.494, 2.054]). WM did not produce direct effects upon reading, but there was a significant effect once mediated by decoding. This finding can also be supported, in part, by Haft et al. (2019) who combined WM with 'inhibition control', the ability to manage impulses, which indirectly predicted reading in kindergarten students via the route of decoding (b = 0.236, 95% CI [0.146, 0.304]). Unsworth and McMillan (2013) found that WM capacity yielded direct (.28 p<.05) and indirect (.15 p<.05) effects on reading via mind wandering. This finding supports similar findings by McVay and Kane (2012) and indicates that WM may also be a tool in reading attention alongside comprehension. Finally, Chang (2020) found direct (.24 p<.01) and indirect (.34 p<.001) effects of WM via fluency. WM shows more consistent effects on reading when related to other linguistic or cognitive skills. The mediated effects by individual skills support the theory of an indirect relationship between WM and reading. However, in these studies WM was only able to explain a limited proportion of the variance in reading. In accordance with the CI-Model, reading requires the interplay of multiple linguistic and cognitive abilities; if this is the case, then measuring effects via individual skills will only give a partial picture of the role of WM and small

effect sizes should be expected.

**Hierarchical Effects**

Looking beyond direct relationships or single pathway mediation models, some research has been done to examine the possibility of more complex interactions between WM and reading. Hierarchical effects use WM to predict reading comprehension via multiple mediators or a combination of pathways. Hjetland et al. (2019) found that decoding and language skills explained 99.7% of the variance in reading comprehension in seven-year-olds. Whilst this finding can be seen to support SVR, the 'language skills' construct was formed through the combination of multiple variables including vocabulary, grammar, listening comprehension, and verbal working memory. The predictive power of this model supports the theory that WM plays a part alongside multiple language and cognitive skills in reading. Exploring this notion further, some studies have used hierarchical models to explain the nature of this interaction.

Nouwens et al. (2017) found that semantic storage was significantly associated with reading via semantic working memory (processing of semantic information). This reflects a relationship between more basic skills like storage and higher-order skills like information manipulation. This finding is also supported by García-Madruga et al. (2014) who observed that higher-order information processing skills of WM contributed to inference making which then predicted reading comprehension. Finally, Kim (2020) proposed a comprehensive Direct and Indirect Effects Model of Reading (DIER). In accordance with the findings presented above, DIER hypothesises that reading comprehension is achieved by a complex interaction of lower and higher-order language and cognitive skills. The model is built using a combination of direct and indirect pathways between WM and both lower-order (e.g., vocabulary and grammar) and higher-order (e.g., inference making and theory of mind) skills followed by decoding and linguistic comprehension to finally predict reading comprehension. The model predicted 95% of the variance in reading comprehension for students in grade two and grade four. DIER builds upon empirical evidence in the field to provide a strong and comprehensive explanation for the role of WM in reading.

**Null Effects**

Despite strong evidence in support of the case for WM, there are some contradictory findings in the literature which are worth addressing. Johann et al. (2020) investigated the roles of different cognitive skills on reading comprehension. The results revealed no significant link between WM and reading comprehension. However, a likely explanation for this would be the use of an image-based measure (complex span task) where participants had to memorise pictures. This task is likely to rely heavily on the visuo-spatial sketchpad element of WM, which stores images and special information, rather than the phonological loop (semantic storage) or central executive (information manipulation) which are more relevant for reading tasks. The use of inappropriate WM measures is repeated in a study by Keresteš et al. (2019), who also found no effects of WM on various reading related outcomes. As a measure of WM, they used a simple reasoning task where participants completed sentences with missing words (e.g., snow is white, grass is ___) then listed back the missing words at the end. The highest level of this test was five sentences. The limitation of this measure is that it is unlikely to require any WM reasoning or mental manipulation as the example given would only require an automated response.

Another type of limitation is exemplified in the study by Beker et al. (2019). Once again, this study found no significant correlations between WM and reading. However, by their own admission, the

measures of reading comprehension used were too simple. This highlights an important consideration regarding WM that, as stated in the Dual Process Model, WM is a system reserved for cognitively taxing tasks. Reading activities that do not challenge the reader may not require WM as much as the comprehension can be achieved through automated reasoning.

### Dynamic Effects

The second research question relates to the possibility of a change in the role of WM on reading over time. Empirical evidence in the literature supports the hypothesis that WM may be of greater relevance in challenging or unfamiliar tasks. Carretti et al. (2009) observed greater effects between WM and reading in more challenging tasks. A common finding across various studies is the differing nature of language skills across grade levels. Both Kim (2020) and Peng et al. (2017) found that decoding played a key role in early years, but by fourth grade was less relevant, whilst linguistic comprehension rose as a predictor of variance with age. These findings are supported by Ribeiro et al. (2016) who compared language skills between second grade and fourth grade students. They found that lower-level skills (word recognition, fluency, and vocabulary) were better predictors in second grade, whereas higher-level skills (verbal and non-verbal reasoning) were greater predictors of variance in fourth grade. These findings indicate that the individual effects of language in relation to WM may change over time. This evidence supports the Dual Process Model and that as language skills develop, the load placed on WM is reduced.

## Discussion

### Findings

The principal aim of this review was to determine the role of working memory in reading achievement. Critics of SVR argue that WM should be included as a third predictor alongside decoding and linguistic comprehension. Evidence for this claim was uncompelling; studies which controlled for language abilities often yielded minimal interactions between WM and reading. Moving on to indirect effects, the studies showed that WM linked, modestly, to reading via several direct mediations. However, when combined to form a more complex model with WM contributing via different pathways, the aggregated contribution of WM was highly significant. The strongest evidence to explain the role of WM in reading is for a combination of hierarchical, direct, and indirect effects via language skills and other cognitive abilities; this is best illustrated by the DIER model proposed by Kim (2020). This evidence suggests that the role of WM is highly integrated into the reading process as opposed to being a separate individual factor. Based on the explanation given by Cain et al. (2004) in relation to the CI-model (Kintsch, 1998), reading comprehension is achieved through the creation of mental models. The role that WM plays in this process could be seen as that of a builder who uses tools (linguistic and cognitive skills) to help combine materials (textual information) to construct a mental model, or as the workspace where this process occurs. By storing information from the text and combining it with knowledge or other textual information, WM can be used to manipulate and synthesise the information to form a comprehendible model.

The findings suggest that the role of WM on reading does change over time. There were stronger relationships between WM and decoding in younger children, whereas children in late primary school showed stronger relationships between WM and linguistic comprehension. This evidence supports the application of the Dual Process Theory to reading, where the development of language skills and knowledge reduces the load on WM over time. In early primary school, a child is learning to recognise the different letters and associate them with the correct sounds which actively engages WM. As this skill is developed, decoding letters becomes an automatic process which requires less

engagement of WM. Likewise, as a student develops vocabulary and language skills, these abilities can also become automatic. As letters and language become more familiar, more of the reading process becomes automatic and the role of WM diminishes. However, when comprehending advanced language and unfamiliar concepts, automatic processing cannot be used so WM must be employed. The role of WM on reading decreases over time but remains crucial for synthesising new and complex information.

**Implications**

This review contributes to the literature by providing conclusions regarding the role of WM in reading based upon the relevant findings in the area. The evidence clearly indicates a complex relationship between WM and reading, beyond that explained by SVR or a direct independent effect. Future research should aim to build upon the work of Kim (2020) by investigating the interrelation of WM and multiple language skills when predicting reading. Furthermore, additional investigation is needed regarding the role of WM as language skills develop over time; the evidence presented so far to support the Dual Process Theory is limited.

For practitioners, this review reiterates the importance of developing knowledge and language skills and highlights how WM is integrated into the process of reading. Reading instruction should aim to develop WM skills by challenging students to recall information from a text or related previous texts, and by asking them to combine the ideas of a text together by drawing inferences. In order to develop reading ability during primary school, exposure and repetition are essential for developing vocabulary and language skills which will ease the load on WM allowing more resources to be dedicated to maintaining ideas in mind and making connections between concepts.

**Limitations**

There are several limitations in the current body of research. Firstly, a combination of different WM models and sub-components, along with a range of measures used to evaluate them, means ensuring the same phenomenon is being measured across different studies can be difficult. The experiments use a range of different span tasks along with other WM measures which lead to differing results. Secondly, the measures of reading evaluation are often unclear. Whilst some papers give strong supporting details regarding the type of reading task given, the majority do not provide adequate details regarding the testing. This is important because, as discussed in this review, text level may affect the nature of the relationship with WM. To improve this, researchers should consider providing an explanation of the skills being tested (e.g., explicit information comprehension), giving an example question, or publishing the raw scores of the reading test to give some insight into the difficulty level of the test.

There are also limitations to the present review, the principal being the limited scope. Due to the breadth of theories and research avenues in the area, it was not possible to give an overall perspective on the role of WM whilst considering every theory. The review aims to shed light on the overall role that WM plays in reading, but further, in-depth analysis of relevant literature would be beneficial to support the claims made.

## Conclusion

Working memory plays an integrated role in reading alongside language skills. The information storage and manipulation abilities of the WM components combine with language skills to enable reading comprehension. As language skills and knowledge develop, reading becomes less dependent on

WM and more automated. WM is vital to reading in combination with vocabulary and linguistic development.

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