THE ROLE OF EXECUTIVE FUNCTION IN LITERACY: INVESTIGATIONS OF ENGLISH READING AND CHINESE WRITING

A Dissertation

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ABSTRACT

This dissertation aimed to study the role of executive function (with a major focus on working memory [WM] skills) in English reading and Chinese writing. The first study examined the growth trajectories of WM and reading as well as the causal role of WM in reading in English monolinguals (EL1s) and English Language Learners (ELLs); the second study investigated if executive function deficits and slow growth rates were risk factors of typically developing Kindergarteners to have late-emerging reading difficulties; and the third study examined direct and indirect contributions of WM to Chinese character, word and composition writing to understand cognitive processing in Chinese writing. Results showed that WM played a causal role in initial reading development across language proficiency groups. Also, WM, shifting and inhibition deficits as well as a slow growth rate of WM were risk factors of a typical Kindergartener to have late-emerging reading difficulty. Further, WM directly contributed to character-based phono-semantic processing and word writing accuracy, and indirectly predicted Chinese writing quality through word writing accuracy. Suggestions for future research and educational implications are provided.

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CHAPTER I

INTRODUCTION

This dissertation aimed to study the role of executive function (with a major focus on working memory skills) in English reading and Chinese writing. The first study examined the growth trajectories of working memory and reading as well as the causal role of working memory in reading across English monolinguals (EL1s) and English Language Learners (ELLs); the second study investigated if executive function deficits and slow growth rates were risk factors of typically developing Kindergarteners to have late-emerging reading difficulties; the third study examined direct and indirect contributions of working memory to Chinese character, word and composition writing to understand cognitive processing in Chinese writing.

1.1 Definitions

Executive function (EF): Executive function is a set of cognitive skills that are activated in behaviors that are goal-oriented, such as in reading and writing (Ozonoff, Pennington, & Rogers, 1991). Generally, EF consists of three factors: working memory, shifting, and inhibition.

Working memory (WM): Also referred to as updating, is the ability to store, recall and process short-term information (Daneman & Merikle, 1996).

Shifting: Also referred to as cognitive flexibility, is the ability to alter attention based on task needs (Follmer, 2018).

Inhibition: Also referred to as inhibitory control, is the ability to replace automatic thinking by effortful thinking, or the ability to suppress irrelevant information in favor of relevant information (Follmer, 2018).

Morpho-syllabic orthography: A written unit (e.g., a Chinese character) represents a syllable and a morpheme (Joshi & Aaron, 2006).

1.2 Overview of the Current Studies

Executive function (EF) is defined as "the ability to maintain an appropriate problem-solving set for attainment of a future goal; it includes behaviors such as planning, impulse control, inhibition of prepotent but irrelevant responses, set maintenance, organized search, and flexibility of thought and action" (Ozonoff et al., p.1083). Generally, EF is categorized into working memory (WM), shifting, and inhibition (Bull & Lee, 2014; Bull & Scerif, 2001; Carlson & Meltzoff, 2008; Carlson, Moses, & Claxton, 2004). Studies have shown that EF plays an important role in reading and writing across English and Chinese (Baddeley, 2003; Chung & McBride-Chang, 2011; Cirino et al., 2018; Follmer, 2018; Mo, McBride, & Yip, 2018; Peng et al., 2018; Tong, He, & Deacon, 2017; Yeung, Ho, Chan, & Chung, 2017). For example, skilled readers hold letter (or character, in Chinese), word, and sentence codes for further processing, switch flexibly between phonological and semantic information, and inhibit irrelevant information to focus solely on ideas that are relevant to purposes of reading and writing tasks (Cartwright, 2002; Cartwright et al., 2016; Chiappe, Siegel, & Hasher, 2000; Oakhill, Yuill, & Garnham, 2017). However, there have been few studies on the following areas: 1) The causal role of EF in reading developments across English monolinguals and English language learners, 2) whether EF deficits and their slow growth rates are risk factors of late-emerging reading difficulties, and 3) the role of EF in character, word and composition writing in Chinese. This dissertation aimed to explore these areas with the following three studies.

1.3 Study 1

Study 1 focuses on the role of EF in early English reading development. This study adopts working memory (WM) as the proxy of EF skills. WM is defined as the ability to store and process the stored information (Baddeley, 1986, 2003; Baddeley & Hitch, 1974). Meta-analyses have found that WM had a moderate correlation with reading among English monolinguals (EL1; Daneman & Merikle, 1996; Peng et al., 2018) and English language learners (ELLs; Jeon & Yamashita, 2014; Linck, Osthus, Koeth, & Bunting, 2014). Recently, studies have investigated the longitudinal relationships between WM and reading to examine the role of WM in reading at different developmental phases. Some studies have found that earlier WM skills significantly contributed to later reading achievements (Cain, Oakhill, & Braynt, 2004; Seigneuric & Ehrlic, 2005; Swanson & Jerma, 2007; Stipek & Valentino, 2015; Morgan, Farkas, Hillemeier, Pun, & Maczuga, 2019), but other studies did not find the role of earlier WM in later reading (Monette, Bigras, & Guay, 2011; Oakhill & Cain, 2012; Vandenbroucke et al., 2018).

However, most of these longitudinal studies did not follow the participants into Grade 2, so how the changes in the relationship between WM and reading during the early school years is not clear. Therefore, examining the relationship between WM and reading growths at the early grade levels may advance understanding of the role of WM in reading. Further, such investigations may help to understand the effect of WM training to improve reading skills. Although Melby-Lervåg and Hulme's (2013) meta-analysis showed that WM training effects were difficult to transfer to reading, they suggest that this conclusion was made based on training effects of students of varying ages. If WM played a causal role in reading during early school years, then WM intervention might be worthwhile to implement on children of this age group so that educational practitioners may help reduce risk factors of future reading failure.

Thus far, very few studies have investigated the relationship between WM and reading in different language proficiency groups. In the U.S. for example, ELLs with lower English proficiency were asked to learn English as a second language (ESL, or English immersion) or bilingual (or dual language) programs (U.S. Department of Education, 2015). However, little is known about whether students in these programs show different WM and reading growth paths compared to students who speak languages other than English at home but have achieved high English proficiency. In addition, previous studies have suggested students from bilingual programs had better academic performance than their counterparts in ESL programs (Reljić, Ferring, & Martin, 2015; Rolstad, Mahoney, & Glass, 2005), thus, there may also be program-level differences on reading and WM growth factors. Therefore, the following research questions (RQs) are proposed in Study 1:

RQ 1. What are the growth trajectories of reading and WM across language proficiency groups in early school years?

RQ 2. Is reading growth rate related to WM growth rate? Do students in bilingual programs show advantage over students in ESL programs on WM and reading growths?

RQ 3. Does WM have a causal influence in reading during early school years?

1.4 Study 2

While Study 1 examined EL1 and ELL populations, Study 2 focuses on students with late-emerging reading difficulty irrespective of language proficiency. In this study, students who scored below 25th percentile on a comprehensive reading test were identified as having reading difficulty (see the same criterion used in Etmanskie, Partanen, & Siegel, 2016 and Fuchs et al., 2019). Studies have further shown that some students did not show reading difficulties until later (i.e., students with late-emerging reading difficulties, or LRD), but some students had reading difficulty from early grades (students with persistent reading difficulties or PRD; Etmanskie et al., 2016; Leach, Scarborough, & Rescorla, 2003; Lipka, Lesaux, & Siegel, 2006; Kearns et al., 2016). LRD is the primary group of interest in Study 2.

Some studies have found that both PRD and LRD were caused by poor phonological and decoding skills (Catts, Campton, Tomblin, & Bridges, 2012; Potocki, Sanchez, Ecalle, & Magna, 2017). Perhaps LRD students did not show deficits in reading at earlier years due to their adequate decoding skills, but their poor comprehension impede their reading development when comprehension becomes the focus of curriculum (Grimm, Solari, McIntyre, & Denton, 2018; Nation, Cocksey, Taylor, Bishop, 2010). However, as individual differences of EF skills may have caused future reading profiles to differ (Fuhs, Nesbitt, Farran, & Dong, 2014; Meixner, Warner, Lensing, Schiefele, & Elsner, 2019; Swanson & Berninger, 1995), perhaps early EF deficits are also risk factors of LRD. However, very few studies have investigated this hypothesis. Moreover, few research studies have attempted to understand how growth rates of EF skills differentiate students with and without LRD. Hence, Study 2 hypothesized that early EF deficits and the slow growths of EF skills are risk factors of LRD. Specifically, the following questions were examined:

RQ 1: Do students show different profiles (e.g., late-emerging reading difficulty) during the growth in reading achievement?

RQ 2: Can EF deficits at early school years predict late-emerging reading difficulties?

RQ 3: Are slow growth rates of EF skills risk factors of late-emerging reading difficulty?

1.5 Study 3

Study 3 investigated the role of WM in Chinese character, word and composition writing. Different from English, which is an alphabetic language where a written unit represents a sound, Chinese written unit is both a syllable that presents sound and a morpheme that signals meaning (Joshi & Aaron, 2006). Therefore, phonological and semantic processing capacities are important skills for Chinese character writing (Su et al., 2018; Tong, McBride, Lo, & Shu, 2017). Additionally, there are large number of shape-similar characters in Chinese orthography, and thus learning Chinese character also entails visual differentiation skills (Liu, Chen, & Wang, 2016; Kao, Wang, & Chen, 2018). Although Chung, Lam, and Cheung (2018) as well as Yeung, Co, Chan, and Chung (2017) have found unique contribution of WM to Chinese word and composition writing, respectively, few studies have investigated the role of WM in character writing. Previous studies have shown a clear distinction between character-based and word-based processing in Chinese during word context effects (Tong & Yip, 2015; Wang & McBride, 2016). However, a typical Chinese word consists of two, three, or four characters, and thus the reason why WM contributes to word writing may be explained by its contribution to character writing. That is, character writing perhaps is a mediator between WM and word writing. To better understand the mediation role of character writing in the contribution of WM to word writing, this research analyzed character-based writing errors to reflect students' phonological, semantic, orthographic, and visual processing skills, and investigated if WM contributed to word writing accuracy through these skills.

Another aim of Study 3 was to investigate the role of WM in written composition. The Simple View of Writing in Chinese (SVWC, Yeung et al., 2017) suggests that WM can be predictive of Chinese written composition after controlling for the effects of handwriting fluency and word writing accuracy, as higher WM capacity facilitates students' awareness of maintaining logic flow of ideas. While their study recruited a composite sample including Grade 1, 3, and 5 students and asked students to write in Traditional Chinese, this study aimed to investigate the role of WM in Simplified Chinese writing in Grade 5 students only. Moreover, if the contributions of WM to Chinese character and word writing were valid, WM may also be indirectly predictive of composition writing through character and word writing. Exploring these questions may be important to understand cognitive and linguistic processing skills that are involved in character, word and composition writing. Moreover, if the role of WM in Chinese writing processes was valid, then WM training should be included in Chinese writing intervention programs. Therefore, Study 3 aimed to examine the following research questions.

RQ 1: Does WM predict phonological, semantic, orthographic and visual skills that are necessary for character writing?

RQ 2: Does WM relate to word writing accuracy through character writing?

RQ 3: Does WM directly predict composition quality, as suggested by the Simple View of Writing in Chinese? Does WM contribute to composition writing through basic transcription skills such as character and word writing.

CHAPTER II

LITERATURE REVIEW

This chapter attempts to review the current theoretical explorations, empirical evidence and research gaps that are relevant to these three studies. Specifically, this chapter discusses the role of WM in English reading and Chinese writing. The roles of shifting and inhibition in English reading are also discussed.

2.1 The Role of Working Memory in Reading

According to Daneman and colleagues (Daneman & Carpenter, 1980; Daneman & Merikle, 1996), different from short-term memory that only involves storage capacity, WM involves both storage and memory processing abilities. Although very few reading models explicated the role of WM in reading, recently researchers have attempted to do so through revisiting these models. The Simple View of Reading (SVR; Gough & Tunmer, 1986; Hoover & Gough, 1990) proposed that decoding (i.e., word reading) and linguistic comprehension (including vocabulary, semantic and syntactical processing skills) are essential processes for reading comprehension. According to Joubert et al., (2004) and Purpura, Schmitta, and Ganley (2017), students with better WM should accurately retrieve the sounds of letters, store these sounds in memory, and blend them for decoding. Similarly, literal and higher-level linguistic comprehension processes, such as paraphrasing, summarization, making predictions, and evaluating information also need readers to retain text information in memory for processing (Perfetti, Stafura, & Adlof, 2013; Silva & Cain, 2015; Spencer & Wagner, 2018). The Construction-Integration model (Kintsch, 1988) as well as the Word-to-Text Integration model (Perfetti & Stafura, 2014) may have explicated the interaction of decoding and comprehension during reading. These theories propose that reading is a process of constructing the phonological and semantic representation of words and sentences, and then readers infer meaning and implicit ideas based on context of texts and background knowledge. To accomplish this process, readers should have sufficient WM capacity to store phonological and semantic codes so as to update or adjust understanding when encountering new information (Chrysochoou, Bablekou, & Tsigilis, 2011; Hua & Keenan, 2014; Shin, Dronjic, & Park, 2018). Thus, students with limited WM may experience difficulty in holding and updating sound, word, sentence and discourse information.

Chall's (1983, 1996) Reading Stage theory proposes reading as a developmental skill. Specifically, during Kindergarten and Grade 1, students are developing phonics knowledge (i.e., phonemic awareness, sound-symbol mapping), and by Grade 3, they should have consolidated these skills and achieved automaticity of reading (i.e., reading fluency). Therefore, those who possess better WM at early years may be more adept at pre-reading (e.g., phonics) and basic reading (e.g., decoding) skills, and may have more memory space for processing semantic information than their peers who have poorer WM (Knoop-van Campen, Segers, & Verhoeven, 2018; Loaiza & Camos, 2018). Hence, individual differences of WM capacity and growth rate at early years may affect the speed of reading automaticity, and also impact future reading development (Swanson & Berninger, 1995; Swanson & Jerman, 2007).

Meta-analyses. For example, Scarborough (1998) synthesized 18 studies (i.e., k=18) and found that verbal memory moderately correlated with composite reading scores (r = .33). Daneman and Merikle (1996; k=77) found that WM was related to listening and reading comprehension (r = .30 and .41; respectively). Follmer (2018; k=26) found the correlation coefficient between WM and reading comprehension to be .26, and Peng et al. (2018; k=197) found that WM was associated with decoding (r =.24 - .34) and listening comprehension skills (r = .26 -.31) across grade levels. Also, Linck et al. (2014; k=79) found that WM of second language learners was moderately correlating with second language comprehension (r = .26). Therefore, WM demonstrates a moderate concurrent relationship with reading based on meta-analytic reviews.

However, as mentioned by Follmer (2018) and Peng et al. (2018), few longitudinal studies were included in their reviews. Some longitudinal empirical studies probed if individual differences of earlier WM can cause reading skills to vary at a later time, often producing contradicting findings. For example, Oakhill and Cain (2012) found that WM of 7- and 8-year old students was not contributing to their reading outcomes three years later. Monette and colleagues (2011) found WM at Kindergarten had no direct effect on later literacy achievement after controlling for socio-emotional factors (see a similar finding in Vandenbroucke et al., 2018). However, some other studies found WM at Kindergarten or Grade 1 was predictive of later reading achievements (e.g., Alloway & Alloway, 2010; Morgan et al., 2019; Nevo & Bar-Kochva, 2015). Meanwhile, most of these studies investigated the contribution of WM on reading based on data from two grade levels, but few have examined how WM at different time points is related to reading over multiple grade levels. This research gap needs to be filled as WM is a dynamic factor that changes based on learning experience and social interactions, and thus WM skills at different grade levels may have different roles during reading development (Simmering & Perone, 2013; Swanson, Orosco, & Kudo, 2017)

Previous studies have found that early reading growth follows a nonlinear path when more time points were included (Au-Yeung et al., 2015; Cameron, Grimm, Steele, Castro-Schilo, & Grissmer, 2015; Lipka & Siegel, 2012; Lesaux, Rupp, & Siegel, 2007; Parrila, Aunola, Leskinen, Nurmi, & Kirby, 2005; Peng et al., 2018). These studies suggest that although reading growth rate was not steady from one time to another, a mean growth rate is sufficient to explain the overall growth. However, Kim, Petscher, Schatschneider, and Foorman (2010) found that from early Grade 1, the growth rate of reading fluency decelerated significantly after each summer break, and a single growth rate could not account for the entire growth from Grades 1 to 3. Clemens, Lai, Burke, and Wu (2017) found that within a Kindergarten year students showed faster growth of pre-literacy skills (letter naming and letter sound naming) in the Fall semester than in the Spring semester. Nevertheless, relatively few studies have examined the growth trajectory of WM, and whether the change of reading growth rate is related to WM's growth pattern. Swanson et al. (2017) examined the growth factor relations of WM and reading in ELLs during early elementary grades, and found that WM growth of these students indeed affected growth of reading. However, Swanson and colleagues modeled both skills using linear growth models, and this study proposes that before the growth factor relationships are investigated, there is a need to understand whether a linear model was suitable for reading and WM growth. Also, if reading had different growth rates at different grades (as suggested by Kim, Clemens, and colleagues), perhaps the decelerated reading growth rate is related to a decelerated growth of WM. However, few studies have investigated this hypothesis.

Previous studies have also examined the relation of WM and reading in ELLs, but may have examined ELLs with varying level of English proficiency (see Martínez, 2018 for a discussion of definition issues for ELL). For example, a student may speak a language other than English at home but still achieve high English proficiency due to frequent English language exposure (Hoff et al., 2012). Studies have found that students who are proficiency at both home language and English had better WM than EL1s or ELLs with lower English proficiency, due to years of maintaining and manipulating information of both languages in memory (Bialystok, 2001; Calvo & Bialystok, 2014; Morales, Calvo, & Bialystok, 2013; Namazi & Thordardottir, 2010; Nicolay & Poncelet, 2013, 2015; but also see Paap, Johnson, & Sawi, 2015 who suggested that this advantage did not exist). Therefore, for ELLs who have a higher proficiency in English (H-ELL), their reading development may also be enhanced due to high WM capacity.

For ELLs with low English proficiency (L-ELLs), in many English-speaking countries there are special programs to enhance their English proficiency and content knowledge. Some students enrolled in ESL programs where English immersion is the main method of instruction, while other L-ELLs enrolled in a bilingual program where teachers may use the students' first language to facilitate the learning of English. Therefore, after several years of enrolling in bilingual programs, perhaps these L-ELLs in bilingual programs will also have advantage of WM compared to their ESL counterparts. With the possible WM advantage, L-ELLs in bilingual programs may also have better English reading achievement than ESL students if the causal role of WM in reading is valid. If so, the WM advantage of bilingual students may explain the reason why students in bilingual programs tend to perform better at reading than ESL program students as found in previous studies (e.g., Reljić et al., 2015; Rolstad, et al., 2005).

2.2 The Roles of Shifting and Inhibition in Reading

Shifting (or cognitive flexibility) refers to "select adaptively among multiple representations of an object, perspectives or strategies in order to adjust to the demands of a situation" (Colé, Duncan, & Blaye, 2014, p. 1). Therefore, individuals with higher shifting skills can quickly and accurately shift attention based on needs of reading tasks (Kieffer, Vukovic, & Berry, 2013). Shifting is assessed through card sorting games by asking the participants to sort cards first by color and then by shape (Wisconsin Card Sorting Test; Heaton, Chelune, & Talley, 1993). Shifting can also be assessed through linguistic tasks. For instance, Cartwright and colleagues asked participants to sort words by common initial phoneme and then by word meaning (Cartwright, 2002, 2007; Cartwright et al., 2016). These tasks are measured through speed, accuracy, or both (see Yeniad, Malda, Mesman, van IJzendoorn, & Pieper, 2013, for a review).

A poor reader may not switch between decoding and comprehension with flexibility (Bialystok & Niccols, 1989; Cartwright, Marshall, Dandy, & Isaac, 2010; Pressley, 2006). Yeniad and colleagues found when composite reading score (decoding, linguistic and reading comprehension) was the outcome variable, the correlation was small yet significant (r=.21; CI= [.11–.31]) while Follmer (2018) found that when only reading comprehensions was the outcome variable, the correlation was medium to large (r= .39; CI= [.20, .56]. As reading comprehension is a multidimensional task, readers need to switch between decoding, vocabulary, syntax, discourse and visuals flexibly (Cartwright et al., 2016). Therefore, perhaps reading comprehension requires more shifting skills than other linguistic tasks.

Inhibition (or inhibitory control) refers to “the ability to suppress a proponent or automatic response in favor of a subdominant response” (Follmer, 2018, p.2). Proficient inhibition skills allow for replacing automatic thinking with effortful thinking until the task is complete; or suppressing irrelevant information in favor of useful information (Arrington, Kulesz, Francis, Fletcher, & Barnes, 2014; Conner, 2009). Inhibition can be measured through a Stroop test. For example, the inhibition subtest of Delis–Kaplan Executive Function System [D-KEFS, 2001] asks participates to name the colors of the words and not pronounce the word in a set of words written in different colors. Inhibition is also measured indirectly through self, parent, or teacher ratings (e.g., Barkley, 2012; Barkley & Murphy, 2011; Gioia, Espy, & Isquith, 2003). Fuhs, Farran, and Nesbitt (2015) suggested that both direct and indirect tests are valid measures of inhibition (but also see Toplak, West, & Stanovich, 2013 who stated that direct assessment is a more valid measure of inhibition).

Inhibition is related to linguistic or reading comprehension. Gernsbacher and colleagues found that poor readers had difficulty in suppressing irrelevant meanings when reading a multiple-meaning word (e.g., see Gernsbacher, Varner, & Faust, 1990, experiment 4), or choosing the correct word among a list of homophone words (e.g., patience vs. patients; Gernsbacher & Faust, 1991). Recent studies have also found that lower inhibition capacity may be related to vocabulary and reading comprehension difficulties (Borrela et al., 2010; Ekerim & Selcuk, 2018; Scrimin, Patron, Florit, Palomba, & Mason, 2017). However, just like WM, the contributions of shifting and inhibition skills to later reading were inconclusive. For instance, Schmitt, Geldhof, Purpura, Duncan, and McClelland (2017) found that shifting and inhibition skills at Pre-Kindergarten (Pre-K) years were not significantly related to reading growth rate from Pre-K to Kindergarten (K) years. Fuhs et al. (2014) found that EF skills (three EF skills as a composite) at pre-K did not predict reading achievements at the Kindergarten year. Similarly, Monette, Bigras, and Guay (2011) did not find a significant contribution of Kindergarten shifting and inhibition to reading or writing achievements at Grade 1, after controlling for socio-emotional factors. However, Guajardo and Cartwright (2016) found that shifting skills at age 3-5 uniquely predicted the reading achievement 3 years later, after controlling for socioeconomic status (SES), decoding and linguistic comprehension.

There are also conflicts of findings on the role of inhibition and shifting in specific components of reading. Purpura, Schmitta, and Ganley (2017) found inhibition and shifting at Pre-K as significant predictors of decoding but not vocabulary achievement in kindergartener years. On the contrary, Weiland, Barata, and Yoshikawa (2014) showed that Pre-k shifting and inhibition skills were significant predictors of vocabulary acheivement at the kindergartener year.

Similar to Weiland and colleagues, Stipek, Newton, and Chudgar (2010) found inhibition at Kindergarten and Grade 1 was predictive of reading achievements at later grades. Due to the conflicts of findings, more studies are needed to examine how early shifting and inhibition are related to reading achievements at later years.

2.3 Associations of Executive Function with Reading Difficulties

It has been found that some students did not exhibit poor reading skills until in later grades, and these students were referred to as students with late-emerging reading difficulty or LRD (Lipka et al., 2006; Kearns et al., 2016; Partenen & Siegel, 2014; Steacy et al., 2017). LRD has also been found in ELLs (Kierfer, 2010). For example, Torppa, Eklund, van Bergen, and Lyytinen (2015) found 9.9% typically developing Grade 2 students showed dyslexia syndromes at later grades.

Some studies have suggested that WM deficits may be risk factors of having persistent reading difficulties (PRD; Morgan, Li, Farkas, Cook, Pun, & Hillemeier, 2017; Morgan et al., 2019). Etmanskie, Partanen, and Siegel (2016) investigated the risk factors of late-emerging reading difficulty (LRD) and found that at early years (when these students had not shown reading difficulties) already showed poor WM skills. Kearns and colleagues (2016) found at early grades LRD outperformed PRD in orthographic, morphological, attention and rapid naming skills, but these two groups did not differ on WM skills. Therefore, poor WM at early grades perhaps is a risk factor of LRD. However, as suggested by Study 1, in these studies WM is measured as a static skill in these studies, but few have investigated if slow WM growth rate is a risk factor of having LRD. Moreover, very few studies have investigated whether poor shifting and inhibition skills are also risk factors of having LRD. Examining this question can help researchers decide whether WM training is sufficient for EF-based reading intervention or it is essential to consider all EF skills during reading intervention.

2.4 English and Chinese Writing

While more studies focus on English and reading, there have been few studies investigating the role of EF skills, such WM, in Chinese and writing. Chinese character, word, and composition writing require coordination of visual, phonological, orthographic and semantic skills, so completing writing tasks in Chinese may require high level of WM (Leck, Weekes, & Chen, 1995; Perfetti & Tan, 1998; Swanson, Trainin, Necoechea, & Hammill, 2003; Zhou, Duff, & Hulme, 2015). It has been shown that WM predicts English reading and writing (Borella, Carretti, & Pelegrina, 2010; Kim & Schatschneider, 2017; Swanson, et al., 2003) as well as Chinese reading (Peng et al., 2017; Yeung et al., 2017); however, the role of EF in Chinese writing has not been explored much. Using WM as the proxy of EF skills, Study 3 aimed to understand the role of WM in Chinese character, word, and composition writing.

While English is an alphabetic orthography in which a written unit represents a sound (or phoneme), a Chinese character is both a morpheme that suggests meaning and a syllable that signals pronunciation, which can be further explained by its constituents (Joshi & Aaron, 2006). It has been shown that 80% of Chinese characters contain phonetic and semantic strokes, which are also called phonetic and semantic radicals, respectively (Tong, He, & Deacon, 2017; Tong, McBride et al., 2017). In short, phonetic radicals indicate sounds, whereas semantic radicals indicate meaning (Qu & Damian, 2017; Tong et al., 2009). For example, in the compound character "情" (/qing/2; love) the left side radical "忄 " is a semantic radical meaning "love", and the right side has a phonetic radical "青" that gives a sound "/qing/". In Chinese orthography, semantic radicals typically occupy the left (chance of 75%) or top (chance of 15%) position of a character (Feldman & Siok, 1999). As sublexical units of Chinese characters, phonetic and semantic radical awareness are both important to Chinese character and word writing accuracy (Lau & Ma, 2018; Tsang, Wu, Ng, & Chen, 2017; Yeung et al., 2011).

A sound to be written in English may have different options depending on the position of that sound in a word (e.g., /ā/ is written as ay in the final position of a word but may be written as a in other positions), or characteristics of the surrounding sounds: (e.g., /j/ sound before /ĕ/ /ē/ / ī/ /ĭ / sounds is written as g, but it is written as j before any other sounds (Carreker, 2011). Therefore, writing basic English words primarily require phonemic awareness and orthographic skills. Also, students may additionally rely on morphemic skills to write multimorphemic words (Schiff & Joshi, 2017). Writing Chinese character or words, however, may require a variety of skills including phonological, morphemic, semantic, orthographic and visual processing capacities (Yu, Gong, Qiu, & Zhou, 2011; Wang, McBride-Chang, & Chan, 2014). Shen and Bear (2000) categorized character writing errors into phonological (e.g., homophone substitution), semantic (semantic radical substitution) as well as orthographic errors (stroke addition or deletion). However, few studies have investigated variables that are associated with these processing skills.

Empirical studies have found that WM can predict Chinese word writing accuracy (Chan, Ho, Tsang, Lee, & Chung, 2006; Li, Wang, Tong, & McBride, 2017; Mo, McBride, & Yip, 2018; Yeung et al., 2018), but few have investigated the role of WM in character writing. This research gap needs to be filled as studies have shown that processing individual characters may be distinct from processing two-character words. For example, lexical compounding effect (the meaning of a whole word) may play a more important role in processing two-character words than single characters, and thus students may make more meaning-based errors when processing two-character words (Huang et al., 2006; McBride, 2016; Wang & McBride, 2016; Zhao, Li, Ding, & Bi, 2016). On the other hand, as characters are constituents of Chinese words, understanding the cognitive processing during character writing may help us understand the cognitive and linguistic processes of Chinese character, word, and composition writing.

2.5 The Role of Working Memory in Chinese Writing

As Baddeley (2003) noted, when receiving verbal commands, students need sufficient WM capacity to store and process these codes and meanwhile retrieve their long-term memory to complete tasks with accuracy. As writing Chinese characters require both lexical and sub-lexical processing skills (Lau & Ma, 2018; Tong et al., 2009), poor WM may interfere with both processes. When adopting a lexical route, students with poor WM may not be able to store the syllable in memory while encoding it with a correct orthographic representation or differentiate semantic differences among homophone characters. When adopting a sub-lexical route, one needs to assemble the semantic and phonetic radicals to constitute the target character (Lau & Ma, 2018; Perfetti, Liu, & Tan, 2005); meanwhile, students need to evaluate the relevance of semantic and phonetic radicals to the target character (Tong & Yip, 2015). All these processes require higher WM capacity to facilitate the accuracy of Chinese character writing. Therefore, this current research first aimed to examine the relation between WM and linguistic processing during character writing. As characters are constitutes of word writing, if the contribution of WM to phonological and semantic processing was valid, then the contribution of WM to word writing may be mediated by character writing.

Another purpose of this study was to investigate the role of WM in Chinese composition quality. Studies have shown that poor WM may interfere with students' awareness of maintaining logical flow of sentences and organization in composition writing (Berninger et al., 2000; Berninger et al., 2002; Guan, Ye, Wagner, Meng, & Leong, 2014). Recently, the Simple

View of Writing in Chinese (SVWC; Yeung et al., 2017) was proposed, suggesting word writing and WM both directly explained quality of written composition. The current study proposes that, if the contribution of WM to word writing is valid, perhaps WM also predicts writing quality via word writing skills. If both direct and indirect contributions of WM to composition quality were valid, then during composition writing WM resources are allocated to both maintaining the logic flow of ideas as well as ensuring the accuracy of character and word writing.

2.6 The Current Studies

Based on the literature reviewed, three studies were conducted to address the role of EF in literacy English and Chinese literacy development. Study 1 aimed to explore growth trajectories of WM and reading as well as whether WM played a causal role in English reading. Study 2 attempted to address if poor EF skills and slow growth rates were risk factors of late emerging reading difficulties. Study 3 aimed to examine the role of WM in Chinese character, word, and composition writing. The method and results of each study are described below.

CHAPTER III

METHOD AND RESULTS OF STUDY 1

The ECLS-K: 2011 data were adopted to address the research questions in Study 1. The data were collected from 1,352 public and private schools in the U.S. The time of data collection were: Fall 2010 (Kindergarten), Spring 2011 (Kindergarten), Fall 2011 (Grade 1), Spring 2012 (Grade 1), Fall 2012 (Grade 2), Spring 2013 (Grade 2), Spring 2014 (Grade 3) and Spring 2015 (Grade 4). The data were not collected in Fall 2013 or Fall 2014. Therefore, data from eight time points (5 grade levels) were available for analyses.

3.1 Sample

The ECLS-K project adopted a complex survey design, and there were multiple stages of sampling during data collection. Therefore, at each sampling stage perhaps some students or schools were more likely to be selected than others, and this may generate estimation bias (Tourangeau et al., 2018). Hence, sampling weights were applied on the overall sample to adjust for these biases. Replicate weights were applied to correct standard errors by using the Paired Jackknife Replication method. A total of 6,109 students had sampling and replicate weights data. Although not a focus of the current study, comparing overall sample with subsamples (i.e., EL1s, H-ELLs and L-ELLs) may help us understand if the growth trajectories and causal role of WM in reading had heterogeneities.

The teacher questionnaire data collected at Kindergarten (Spring, 2011) year was used to classify students into EL1, H-ELL and L-ELL groups. One item: “Is English this child's native language?” (NCES, 2015, p.13) was used to perform the initial classification. If a teacher answered “yes” to this question, students were classified as EL1 students; if they answered “no”, they were classified as general ELL students. A follow-up question: “Would you say the instruction on this child receives is primarily" (NCES, 2015, P.13) was used to further classify general ELL students into H-ELLs and L-ELLs. If a teacher identified a child as an ELL, but the child had not enrolled in any ELL instruction programs by Grade 2, they were identified as H-ELLs. Similarly, if a general ELL had consistently enrolled in bilingual or ESL programs for three consecutive years (based on data from Spring, 2011, Spring, 2012, and Spring, 2013) they would be identified as L-ELL students. Therefore, the current research did not include those who enrolled or exited a program after Kindergarten. In the current study, bilingual students also included those who enrolled in dual-language (English-Spanish) programs, and ESL students also included those who enrolled in language immersion programs. The H-ELL and L-ELL students spoke a variety of different home languages, but most ELL students spoke Spanish as their first language. Table 1.1 shows descriptive statistics of reading and WM for the overall sample as well as EL1, H-ELL and L-ELL subsamples. Except for the overall sample, estimations on other samples were unweighted. The growths of reading and WM across subsamples were shown in Figure 1.1.

3.2 Measures

3.2.1 Working memory

WM is measured by a backward digit recall test from Woodcock-Johnson Psychoeducational Battery, Third edition (WJ-III; Woodcock, McGrew, & Mather, 2007). In this task, administrators orally presented a set of digits and then required students to reproduce the digits in the reverse order. There were seven trials of this test, and each trial had two to eight numbers for students to recall. If a student made three consecutive errors the task would end for him or her. In Kindergarten and Grade 1, WM tests were administered in Spanish for L-ELLs who spoke Spanish as their first language (Tourangeau et al., 2018). The W-ability score was selected for the current research. Similar to a Rache score, a W-ability score has accounted for the influence of item complexity. The range of the W-ability score was 393-603. The Cronbach alpha coefficients for the overall analytic sample (N = 6,109) ranged from .87-.88 across the eight time points.

3.2.2 Reading

A comprehensive reading test measuring a wide range of skills was adopted for this research. These subtests included letter recognition, onset-rime awareness, sight word knowledge, basic and multisyllabic words decoding, vocabulary knowledge, and reading comprehension. The instruments for theses subtests included Peabody Individual Achievement Test – Revised (PIAT-R; Markwardt, 1998), Peabody Picture Vocabulary Test – 3rd Edition (PPVT-III; Dunn & Dunn, 1997), Test of Early Reading Ability – 3rd edition (TERA-3; Reid, Hresko, & Hamill, 2001), Test of Preschool Early Literacy (TOPEL; Lonigan, Wagner, Torgesen, & Rashotte, 2007) and WJ-III (Woodcock et al., 2007). Then item response theory (IRT) scores (i.e., a score type that considers item difficulty, item discrimination and guessing) were adopted for analyses. There were two stages of reading test, and at the first stage test items with different difficulties were given to each student, and then based on their performance the difficulty level for the second stage asesssment was adjusted. For example, students who scored low on high complexity version of the test at the first stage were then tested using the middle complexity version at the second stage. Although students were given different items for reading test, these tests share common items and only these common items were used to calculate student IRT test scores (Tourangeau et al., 2018). The Cronbach alpha of reading scores in overall sample (N = 6,109) across the 8 time points ranged from .95-.96.

3.3 Control Variables and Program Effects

The gender and race of a child were identified from a parent interview during the kindergarten year. The variables were dummy coded into two broad categories. Specifically, “0” was set as male and “1” as female, and “0” was set as Caucasian and “1” as other races. In analyses of H-ELL and L-ELL students, the comparison on race was between Hispanic/Latino (“1”) and other races (“0”). SES factor was created using a confirmatory factor analysis (CFA) model, and the variables loading on the factor included father and mother education level, father and mother occupational prestige score as well as family household income. Factor scores were assigned to each individual. The factor loadings were 0.86 (father education level), 0.73 (father occupation prestigious score), 0.56 (mother education level), 0.18 (mother occupation prestigious score), and 0.75 (household income). Although mother’s occupation prestigious score had a low loading coefficient on SES, this variable is still retained for factor score calculations as it is theoretically related to SES (Aram & Levin, 2011). Sampling and replicate weights were used to adjust for multi-stage sampling errors of these SES variables. The weighted SES scores were applied to all students for subsequent analyses. All control variables were time-invariant variables, which means these scores would not change with time.

3.4 Model Construction

To address RQ 1 (What are the growth trajectories of reading and WM across language proficiency groups from Kindergarten to Grade 4?), a series of parallel latent growth curve models (PLGCM) were built on the overall sample (Model 1), and then the same model was built on unweighted EL1 (Model 2), H-ELL (Model 3), and L-ELL (Model 4) samples. Only for Model 1, the language status (General ELL vs. EL1) at Kindergarten was controlled.

To address RQ 2 (Is reading growth rate related to WM growth rate? Do students in bilingual programs show advantage over students in ESL programs on WM and reading growths?), for Model 4, the instruction program difference (bilingual vs. ESL) was added as an additional time-invariant predictor of reading and WM growth factors. SES, race, and gender were control variables in all models.

To address RQ 3 (Does WM have a causal influence in reading during early school years), four cross-lagged panel models (CLPMs) were then constructed to examine how WM at an earlier grade level may affect reading at a later grade, after controlling for autoregressive effects and effects from reading to WM. At each grade, reading scores at Spring and Fall semesters were combined by a CFA method (i.e., scores in both semesters loaded on a single factor). The same procedure was applied for WM. However, at Grade 3 and 4 the data were only collected during Fall semester and it may not have been suitable to combine Grades 3 and 4 scores. Therefore, the Grade 4 data were dropped for CLPM to reduce estimation biases. Each reading or WM factor was regressed on control variables. For all models, p values were adjusted using Benjamini-Hochberg (B-H; Benjamini & Hochberg, 1995) method to avoid multiple comparison errors.

Root Mean Square Error of Approximation (RMSEA) and SRMR were measures of model fit. A model fitted the data well if a RMSEA value and a SRMR value were lower than 0.08 (Hu & Bentler, 1999). Chi-square values cannot be computed with sampling weights, and thus Chi-square based indices such as Comparative Fit Indices (CFI) and Tucker Lewis Index (TLI) were not supplied for Model 1 and Model 5 (Asparouhov, 2015, June 11). When modeling on unweighted EL1, H-ELL and L-ELL samples, CFI and TLI were both supplied in addition to RMSEA and SRMR. According to Hu and Bentler (1999), if CFI and TLI values were higher than .95, a model had an acceptable fit. Full Information Maximum Likelihood (FIML) was applied for all analyses to account for the influence of missing data. The FIML method is a more robust way to handle missing data than the listwise deletion method as the data perhaps were not missing at random (Dong & Peng, 2013).

3.5 Study 1 Results

3.5.1 Growth trajectories.

As observed in Figure 1.1, across language groups the growth of reading and WM were faster from Kindergarten to Grade 1 than from the end of Grade 1 to 4. Due to possible existence of deceleration of growth, a piecewise PLGCM may be more appropriate than a single slope PLGCM model. To verify this, the model fit statistics were compared across a series of models, including single slope and piecewise models with different growth patterns (i.e., linear, quadratic, cubic, nonlinear trend without a specific pattern).

Table 1.2 shows the PLGCM estimations on overall weighted sample. The model had the best fit when reading was set as piecewise nonlinear and WM as linear at the first phase while nonlinear at the second phase. The deceleration point of the growth rates was at the second semester of Grade 1, and the same deceleration point was set for Model 2-4 as this model produced the best model fit among a series of models on each subsample. The growing phase from Kindergarten to Grade 1 is thus named as the initial phase and from the end of Grade 1 to the end of Grade 4 as the consolidation phase. Figure 1.2 depicts the piecewise PLGCM model for overall weighted sample (Model 1).

To construct nonlinear models, the time scores between the initial and final time points of each phase were estimated (Muthen & Muthen, 2010). Specifically, at the initial phase there were four time points, and the time scores for Spring of Kindergarten and Fall of Grade 1 were fixed to 1 and 4, respectively. The time scores for Fall of Kindergarten and Spring of Grade 1 semesters were estimated, so that the model could measure the mean growth at this phase

(Muthen & Muthen, 2010). Similarly, at the consolidation phase, only the time scores for Spring of Grade 1 and Fall of Grade 4 were fixed at 0 (initial time point at the consolidation phase) and 6 (final time point at the consolidation phase), and other time scores were freed to estimate the overall growth from the end of Grade 1 to the end of Grade 4. Table 1.3 shows the fixed and estimated time scores and model fit information across Model 1-4.

3.5.2 Growth rates and language program effects

As shown in Table 1.4, the piecewise PLGCM fitted the overall weighted sample well (i.e., Model 1; RMSEA=0.043, 90% CI= [0.040, 0.045]; SRMR=0.017). The growth of reading and WM was faster at the initial phase (estimated slope factor of reading: 0.70; WM: 11.50; $p<.001$) and slower at the consolidation phase (estimated slope factor of reading: 0.21; WM: 4.27; $p<.001$). The growth rates of the two skills were related significantly across the initial phase ($r=.25$; $p<.001$) and the consolidation phase ($r= .20$, $p<.001$).

Models 2-4 had even better fit than Model 1 (see Table 1.3 for details). The results showed that across EL1, H-ELL and L-ELL students the correlation of WM and reading growth rates at the initial phase were moderate (rs=.33-.47; ps<.001). At the consolidation phase the relation between WM and reading growth rates was no longer significant in H-ELLs ($r=.10$, $p>.05$), but was still significant in EL1s ($r=.17$, $p<.001$) and L-ELLs ($r=.25$, $p<.001$). Also, Table 1.4 shows that at the consolidation phase bilingual program students had a faster reading growth rate ($\beta = 0.17$, $p < .001$) and WM growth rate ($\beta = 0.17$, $p < .001$) than ESL program students.

3.5.3 The causal role of working memory in reading

Figure 1.3 shows the CLPM construction on the overall weighted sample. As shown in Table 1.5, the CLPMs across samples had acceptable model fit. In Model 5 (CLPM on the overall weighted sample) the results suggest that Grade 2 WM significantly predicted Grade 3 reading, but WM at Kindergarten and Grade 1 were not predicting reading at Grade 1 and Grade 2, respectively (Kindergarten WM to Grade 1 Reading: β=0.10, $p>.05$; Grade 1 WM to Grade 2 Reading; 0.03, $p>.05$; Grade 2 WM to Grade 3 Reading β=0.07, $p<.01$). However, as the PLGCMs already demonstrated that there were heterogeneities within the overall sample, reports on subsamples were used to explain the CLPM results. As shown in Table 1.5, across language groups, WM at Kindergarten was a significant predictor of reading at Grade 1. Nevertheless, in later grades only in EL1 students WM still had a causal role in reading (EL1: WM at Grade 1 to reading at Grade 2: β=0.05, $p<.05$; WM at Grade 2 to reading at Grade 3: β=0.04, $p<.05$).

From Models 6-8, it can be observed that across subsamples the concurrent relationships of WM and reading only existed at Kindergarten and Grade 1 and diminished at Grades 2 and 3. Also, only in Kindergarten years, the relations between WM and reading were strong (EL1: $r=.71$; H-ELL: $r=.73$; L-ELL: $r=.71$; $ps<.001$). At Grade 1, the relationship of WM and reading was moderate in EL1s ($r=.39$, $p<.001$) and L-ELLs ($r=.44$, $p<.001$), and was small-to-moderate in H-ELLs ($r=.30$; $SE=.08$; $p<.01$). Additionally, across all language groups and grade levels, there were no contributions of earlier reading to later WM ($ps>.05$). The predictive powers of control variables to WM and reading are listed in Table 1.6.

CHAPTER IV

METHOD AND RESULTS OF STUDY 2

4.1 Sample

The sample of focus in Study 2 was K-2 students. Also, as the focus in Study 2 was poor readers irrespective of English language proficiency or demographic background, students were not classified into EL1s and ELLs or include control variables. The total sample size available for analyses was 18,174. Sample or replicate weights were not applied here.

4.2 Measures

4.2.1 Reading and math

Like study 1, IRT reading scores were used. To account for the effect of math difficulty on executive function and classification of reading groups, math IRT score was included as a control variable when performing reading group classifications. Therefore, students with poor reading, poor math, and poor academic (i.e., comorbid reading and math difficulties) are three separate groups in the current study.

4.2.2 Shifting

Kindergarten and Grade 1 shifting skills were measured by card sorting activities. There are three subtests in this game: a) Pre-switching requires students to sort cards by color; b) post-switching requires students first to sort the cards by color then sort by shape; c) In mixed trials examiners randomly set up rules of sorting, and each trial may have a different rule. A composite score reflecting performance across three tasks were used for Study 2. In Kindergarten and Grade 1, a shifting score only reflects students' sorting accuracy. However, in Grade 2, students were assessed on both accuracy and reaction time. Therefore, Grade 2 scores were not suitable to be modeled together with Kindergartener and Grade 1 shifting scores as the measurement constructs were different. Thus, this study was not able to build growth models for shifting. Kindergarten and Grade 1 shifting scores were used to answer RQ 2.

4.2.3 Inhibition

Kindergarten and Grade 1 inhibition was indirectly measured by teacher response on Children's Behavior Questionnaire (CBQ; Putnam & Rothbart, 2006). Each question is designed based on a 7-point Likert scale (ranging from 0 [almost always untrue] to 7 [almost always true]), and teachers were asked to select a point that best describes a child. Grade 2 inhibition scores were not included as the measurement of inhibition changed to Temperament in Middle Childhood Questionnaire (TMCQ; Simonds and Rothbart 2004), which is designed based on 5-point Likert scale. Therefore, similar to shifting, this study was unable to build growth models on inhibition. The manual-reported reliability coefficients of inhibition was. 87.

4.2.4 Working memory

Similar to Study 1, the W-ability score was adopted as the measure of WM. The measurement of WM was consistent from Kindergarten to Grade 2 (i.e., backward digit recall), and thus WM score from these three grades were adopted to represent EF growth.

4.3 Model Construction

To answer RQ1 (Do students show different profiles (e.g., late-emerging reading difficulty) during the growth in reading achievement?), if at Kindergarten a student did not score below 25th percentile, but at Grade 1 or 2 scored below 25^{th} percentile, the student was classified as having LRD. If at Kindergarten a student scored below 25^{th} percentile but reached above 25th percentile by Grade 2, the student was classified into the reading improved (RIMP) group. If students showed reading difficulty throughout the grades, they were coded as having persistent reading difficulty (PRD). The same procedure was conducted for math ability classifications, which means students were classified into persistent math difficulty (PMD), late-emerging math difficulty (LMD), and math improved (MIMP) groups. Students who had both reading and math difficulties were combined into students with academic difficulty (AD) group. Also, students who had typically developing reading (i.e., >25th percentile) and math were classified as typically developing (TD) students. A single-indicator Latent Transition Analysis (LTA; or Latent Markov Analysis, Nylund, 2007) was conducted for reading and math separately. All these groups were independent of one another. For example, a student with PRD would not be re-classified into PMD, LMD, or MIMD. Entropy values were supplied to assess classification precision.

To answer RQ2 (Can EF deficits at early school years predict possibilities of having late-emerging reading difficulties?), two separate probit regression analyses were conducted by regressing reading profiles on EF skills at Kindergarten and Grade 1. Specifically, the first model assessed if WM, shifting and inhibition at Kindergarten and Grade 1 were significant predictors of the chance for a student to be classified as PRD rather than TD; another model was built to assess if these early EF skills predicted the chance for a student to be classified as LRD instead of TD. In both models, the TD group was the reference group, and a negative coefficient indicated that those who had lower EF skills were more likely to be classified into PRD or LRD groups. Both models adopted weighted least square with mean and variance adjusted (WLSMV) as the estimator.

To answer RQ3 (Are slow growth rates of EF skills risk factors of having late-emerging reading difficulty?), as WM was the only EF skill that can be modeled using growth models (see reasons above), for this question WM growth was the proxy of EF growth. The growth rate of WM was set as a predictor of reading profile classifications. Two probit regression models were built: The first model investigated if slow WM growth rate could be predictive of the chance for TD students to become LRD, and the second model examined if faster WM growth rate was associated with the chance of overcoming reading difficulties. In these two models, initial status (i.e., the intercepts) of WM was controlled to make the slopes comparable.

4.4 Study 2 Results

4.4.1 Profiles of readers

Table 2.1 presents LTA results of reading and math to answer RQ 1 (Do students show different profiles during the growth in reading achievement?). The results showed that 15.71% students showed PRD, 8.97% had LRD and 8.38% were RIMP. Surprisingly, students did not show improved or late-emerging math difficulties. Then those who had both reading and math difficulties were classified into academic difficulty (AD) group, so PRD and LRD students only had reading difficulty but no math difficulty (i.e., reading scores < 25 percentile but math scores > 25^{th} percentile). Therefore, subsequent analyses on PRD were controlled for the effect of math.

A series of ANOVA were conducted to examine differences of early EF skills among these groups. It was found that across the EF skills from K-2, TD students consistently had the strongest EF skills among the six groups (See Table 2.2). Similarly, except for WM at the Kindergarten, the EF skills of RIMP group were consistently better than PRD, PMD, LRD, LMD, and AD students.

4.4.2 Risk factors of late-emerging reading difficulty

When answering RQ2 (Can EF deficits at early school years predict possibilities of having late-emerging reading difficulties?), the results suggest that those with poorer EF skills had larger chance to be classified into LRD group (βs of EF skills on the difference between PRD and TD <-.05; ps<.01; see Table 2.3). However, only WM deficits rather than shifting or inhibition deficits predicted the chance for a student to be identified as PRD (WM: β=-0.27, $p<.001$; shifting: β =-0.04, $p>.05$; inhibition: β =-0.02, $p>.05$),

When answering RQ 3 (Are slow growth rates of EF skills risk factors of having late-emerging reading difficulty?), it can be observed that for PRD, LRD and TD groups WM followed a nonlinear growth pattern (see Figure 2.1). Therefore, to allow the growth from Kindergarten to Grade 2 to be nonlinear, the time score was freed. This model received perfect fit in each sample (CFI=1.00, TLI=1.00, SRMR=0.00), which is better than a linear growth model (e.g., on PRD sample CFI=0.525). Table 2.4 suggests that after controlling for initial status differences, those who had faster WM growth rate had larger chance to overcome reading difficulty (β=-0.25, $p<.05$), and those who had slower WM growth rate had larger chance to have LRD (β=-0.37, $p<.001$; see Table 2.4).

CHAPTER V

METHOD AND RESULTS OF STUDY 3

5.1 Location and Sample

The school where Study 3 was conducted is located in a small city in middle part of Shandong province in China. According to National Bureau of Statistics of China (NBSC, 2016), the GDP per capita of this city was 9,070 dollars and was much lower than that of Beijing (17,252 dollars) or other major cities in Mainland China. Consent forms were sent to 252 Grade 5 students, and 223 students from four different classrooms agreed to participate in the current study. Among the 223 students, 108 were females and 115 were males. Around 38% father and mothers of the participants were holding two-year or four-year college degrees. The student survey showed that all students spoke Mandarin as their first language, and no students had ever lived in non-Mandarin speaking countries or regions.

5.2 Measures

5.2.1 Numeric working memory

A backward digit recall test was administered based on the digit span test from Chung, Lo, Ho, Xiao, and Chan (2014). There were seven trials of the test, and each trial had two questions. Each question in the first trial only has two numbers to recall (e.g., 1, 2; 2, 3); each question in the second trial has three numbers to recall (e.g., 3, 4, 7; 5, 6, 8); each question in the third trial has four numbers to recall; each question in the fourth trial has five numbers to recall; each question in the fifth trial has six numbers to recall; each question in the sixth trial has seven numbers to recall; thus, each question in the final trial has eight numbers to recall (e.g., 71024859; 02192423). Students started to recall the digits backwards after both questions in a trial have been presented to students. The possible score range was 0-14. The internal consistency reliability (Cronbach's alpha) was reported as .74 in Chung et al.'s (2014) study. In this sample, the initial Cronbach's alpha was .79. As the two items in the first trial had poor discrimination coefficient (<.27) and low difficulty level (correct rates >.95), they were removed for this research and the Cronbach's alpha of numeric WM raised to .80.

5.2.2 Verbal working memory

This task is modeled on the verbal working memory test from Yeung et al. (2017). Two practice trials were administered before the formal test. In the formal test, 2-4 sentences were read by the researcher for each of the six trials. After each trial, each student was asked to answer a comprehension question related to the sentences, and then was required to recall the last word of each sentence in that trial. One point is given for a correctly answered question (6 questions in total) and another one point is awarded for a correctly recalled word (18 words in total). Therefore, the maximum score for this task is 24. In this sample, the Cronbach's alpha was .81.

5.2.3 Character writing

This test was modeled on Shen and Bear (2000) character dictation test to measure character writing. In this dictation test, students were asked to write down target characters. Each target character was dictated in word and sentence context. For example, the target character 感 (gan3 [feel]) was dictated as "感 (gan3 [feel]), 感谢 (gan3 xie4; [thankful]), 我们感谢你的参与 (wo3 men0 gan3 xie4 ni3 de0 can1 yu4 [We are thankful for your participation]), 感 (gan3 [feel])".

A total of 36 individual characters were dictated to students. These characters have been used in Shen and Bear's (2000) study. Character writing errors were coded into 10 categories, including 1) Character inventions (i.e., borrowing radicals from other characters and constituted a pseudo-character), 2) Adding or deleting strokes (missing or adding one or two strokes), 3)

Semantic radical substitutions (borrowed a semantic radical from another character; e.g., 怒[nu4; angry] -->努[nu3; diligence]), 4) Homophone character substitution (used a character that has a same or similar syllable to replace the target character; 必[bi4; must] --> 毕[bi 4; over]); 5) Shape-similar character substitution (used a character that a similar shape to replace the target character; 勒 [le 4; to rein in] -->勤 [qin 2; hardworking]), 6) Semi-homophone substitution (use the phonetic radical to represent the whole character; 疗[liao 2] -->了 [liao 3]), 7) Phonetic radical substitution (borrowed a phonetic radical from another character to replace the correct one; 许[xu 3;agree] -->评[ping 2;evaluate]], 8) Phonetic radical omission (used a semantic radical to represent the whole word; 讠 [a semantic radical meaning to speak]--> 许[xu 3;agree]), 9) Synonym substitution (used a character that has a similar meaning but distinct sound to replace the target character; 挣[zheng 4; make money] 赚 [zhuan 4; make money], and 10) Change of configuration (e.g., placed a radical at an unconventional position). These coding categories were modified based on guidelines provided by Shen and Bear (2000) and Tong et al. (2009).

5.2.4 Word writing

This test was modeled on Tong et al. (2009) word dictation test to measure word level writing skills. This dictation test has 30 two-character words. Each character, if written correctly, was awarded 1 point (i.e., score range is 0-60). All these words were selected from Grade 5 textbooks. Each word was orally presented by researchers, then a sentence containing that word was given, and at last the word was repeated orally to students. For example, for the target word 辨别 (bian4 bie2; differentiate), the researchers dictated as "辨别 (bian4 bie2; [differentiate]), 我们无法辨别真伪 ([we cannot differentiate between truth and lie], 辨别 (bian4 bie2;

[differentiate]). This study adopted overall accuracy score of word writing to address research questions, but also categorized word-based writing errors into the above 10 categories to compare word writing with character writing.

5.2.5 Composition writing

The topic Describe a recent incidence that made you laugh was given to students. Students were asked to generate a composition based on this topic. The minimum requirement is 250 single characters. The maximum allowed time is 30 minutes. The 4-construct rubric designed by Yeung and colleagues' study (including content, vocabulary, sentence structure, and organization) was modified for this research by separating vocabulary and figurative into two categories, as the classroom teachers reported that figurative usage was one of their main instructional focuses during writing instructions. In this research, the five constructs that reflect writing quality include content (detailed description of the incidence, relevance to the topic), vocabulary (frequency of complicated word use), figurative usage (frequency of using figurative), sentence structure (variety of sentence structures), and organization (logic connections between paragraphs). All these categories were rated based on a 5-point Likert scale (i.e., 0 [very poor]-5 [excellent]). Confirmatory factor analysis (CFA) suggested that the all the five constructs loaded significantly on a common factor. The factor loadings were .88 (content), .64 (vocabulary), .40 (sentence structure), .33 (figurative usage), .87 (organization), respectively. The 5-variable CFA model received better fit ($\chi2$ (4) = 7.32, $p>.05$; RMSEA=.07; SRMR=.04; CFI=.99) than the 4-variable (i.e., excluding figurative usage) CFA model (e.g., RMSEA=.15) that was proposed by Yeung et al. (2017).

5.3 Model Construction.

To answer RQ1 (Does WM predict phonological, semantic and visual skills that are necessary for character writing?), an exploratory factor analysis (EFA) was conducted to reduce the dimensionality of these character-based writing errors while allowing correlations of the remaining dimensions. The rotation method was promax. For comparison reasons, EFA was conducted on word writing errors to examine if the main constructs were indeed different from those of character writing errors (see introduction in the Chapter 2). As each error type was a binary variable (0=no such error; 1=error), polychoric correlation matrix was adopted for EFA as recommended by Holgado–Tello, Chacón–Moscoso, Barbero–García, and Vila–Abad (2010). Then factor scores of main constructs were regressed on verbal and numeric WM, after accounting for effects of gender (1=male, 0=female) and parent education (1=primary school, 2=middle school, 3=high school, 4=two-year college, 5=four-year college, 6=graduate degree). Hierarchical linear modeling (HLM) was conducted to examine the relation between WM and factor scores. As these factor scores reflect chances for making errors, for interpretation purpose they were multiplied by -1 to reflect correct rates or skills.

To answer RQ2 (Does WM predict word writing accuracy through character writing?), a path model was built and verbal and numeric WM scores were regressed on word writing accuracy; meanwhile, different effects of gender and parent education level were controlled for the model. Moreover, in the same model, character-based processing skills were treated as the mediators between WM skills and word reading.

To answer RQ3 (Does WM directly predict composition quality, as suggested by the Simple View of Writing in Chinese? Does WM contribute to composition writing through basic transcription skills such as character and word writing?), another path model was built. Specifically, WM skills was regressed on a 5-variable writing quality factor. Character-based writing processing skills and word accuracy were modeled as mediators. Parent education and gender were control variables for the model.

5.4 Study 3 Results

5.4.1 Error classification

Table 3.1 lists the frequency of each type of character and word writing errors. It can be observed that for character writing the most frequent error type was character invention, an orthographic-based error (Tong et al., 2009). However, for word writing the most frequent error was homophone substitution, a semantic-based error type. As described earlier, the polychoric correlation matrix of character writing error categories was used to construct an EFA model. Three factors were extracted based on the Eigenvalue > 1 rule (Kaiser, 1960; see Figure 3.1). Table 3.2 shows that homophone substitution, semi-homophone substitution and phonetic radical substitution errors loaded on the first factor (standardized loadings>. 59), which can be named as character-based phono-semantic errors. Stroke errors and character invention errors were loaded on the second factor (standardized loadings>. 61), and this factor can be named as character-based orthographic errors. Shape-similar character substitution was loaded on the third factor, which can be named as character-based visual errors. Semantic radical substitution errors had high loadings on both the orthographic error and visual error factors. After data transformation (i.e., each factor score is multiplied by -1) each factor is reflecting to 1) Phono-semantic processing, 2) orthographic processing, and 3) visual processing skills.

When addressing RQ1 (Does WM predict phonological, semantic and visual skills that are necessary for character writing?), from Table 3.3, it can be observed that only verbal WM was predictive of character-based phono-semantic processing skills. Other skills were not predictive of these skills. Verbal and numeric WM skills were not predictive of orthographic or visual processing skills. Moreover, none of these three models (see Table 3.3) suggested classroom level effect (i.e., random effects were not significant at .05 level).

5.4.2 The path from working memory to word writing

When addressing RQ2 (Does WM predict word writing accuracy through character writing?), a mediation path model was built by adopting character-based phono-semantic (factor 1), orthographic (factor 2) and visual processing skills (factor 3) as mediators of WM and word writing accuracy. Meanwhile different effects of gender and parent education effects were controlled by regressing word accuracy directly on these variables and allowing these control variables to be correlated with WM. This model received good fit (CFI=.97, TFI=.94; $\chi2$ (15) =0.17, $p>.05$; RMSEA=.038, 90% CI = [.00, .08], SRMR=0.04). From Figure 3.2, it can be observed that verbal WM directly contributed to word writing accuracy (β=.36, SE=.07, $p<.001$); meanwhile it indirectly predicted word writing accuracy through character-based phono-semantic processing skills (mediation path WM →phono-semantic writing processing →word accuracy; β=0.15, SE=.07, $p<.05$). Character-based orthographic and visual skills were not mediators of WM and word writing accuracy (ps>.05). Also, males had lower word writing scores than females (β=-.16, SE=.05, $p<.01$).

5.4.3 The path from working memory to composition quality

When addressing RQ3 (Does WM directly predict composition quality, as suggested by the Simple View of Writing in Chinese? Does WM contribute to composition writing through basic transcription skills such as character and word writing?), another path model was built by adopting character-based phono-semantic, orthographic and visual processing skills as well as word writing accuracy as mediators of WM and composition writing quality. Control variables were still gender and parent education. This model also received good fit (CFI=.97, TFI=.96; $\chi2$ (59) = 73.16, $p>.05$; RMSEA=.03, 90% CI= [.00, .06], SRMR=0.04). The results suggest that

WM was not directly predictive of written composition quality, but indirectly contributed to composition quality via word writing accuracy (mediation path WM →Word accuracy →composition quality: β=0.17, SE=.05, $p<.01$). None of other variables directly or indirectly predicted written composition quality (see Figure 3.3).

CHAPTER VI

DISCUSSION AND CONCLUSION

The three studies in this dissertation attempted to address the role of EF (with a major focus on WM) in English reading and Chinese writing. The results may provide important suggestions to the fields of early literacy education, psycholinguistic research and literacy intervention.

6.1 Relations of Working Memory and Reading across EL1s and ELLs

Study 1 adopted PLGCMs and CLPMs to investigate the longitudinal relationships between WM and reading during early school years across different language proficiency groups. The results from PLGCMs suggest that WM and reading growths were best fitted in piecewise growth models, meaning the average reading and WM growth rates were different at the initial and the consolidation phases. Moreover, bilingual students showed faster reading and WM growth rates at the consolidation phase than ESL students. CLPMs suggest that WM perhaps was a causal factor in reading at the initial phase for EL1, H-ELL, and L-ELL students. However, in the consolidation phase this causal relation was only evident in EL1 students.

The present study has several strengths. In longitudinal analyses of reading and WM relationships, most studies have only treated reading as a dynamic process, but treated WM as a static skill. However, as suggested by Simmering and Perone (2013), WM should also be understood in a developmental perspective as it changes due to learning experiences and socio-emotional factors. This research thus adopted repeated measures of WM to better understand the relation of WM and reading in early school years. Second, this study may have provided a comprehensive view of WM and reading growths at early school years, as other longitudinal studies included less time points or did not take Kindergarten learning experience into consideration. Third, this research adopted reading and WM scores that may reflect student abilities (i.e., Rasch score and W-ability score, respectively), while previous studies relied on raw or grade equivalent scores that may be biased by item difficulty levels.

6.1.1 A piecewise nonlinear trajectory of reading growth

By comparing a series of PLGCM models, it is suggested that reading demonstrated a nonlinear growth trend, and a deceleration of reading growth occurred at the end of Grade 1. Kim et al. (2010) measured reading fluency of Grade 1 students and followed their reading fluency growth until Grade 3. They found that reading fluency growth decelerated at the end of Grade 1 as well as at the end of Grade 2, and thus they fitted a piecewise model to represent three different growth rates. Clemens et al. (2017) found that within a Kindergarten year, students' pre-literacy skill growth rates were different at Fall and Spring, and thus they also fitted a piecewise model to represent two different growth rates. The current research suggests that a composite reading skill also followed a piecewise growth pattern, and when modeling the entire early school years (Kindergarten to Grade 4) the deceleration point was at the end of Grade 1. Future studies can take the deceleration of reading at the end of Grade 1 into consideration and investigate if there are reasons causing the deceleration to occur.

Some studies (e.g., Leasaux et al, 2007; Sinclair, Jang, & Vincett, 2018) have shown that ELL students followed a similar reading growth trend with their EL1 counterparts, and the current study replicated their findings, and suggest that even for L-ELL students their reading also decelerated after Grade 1. Therefore, the current study showed that across language groups students were exhibiting similar growth trends of reading, irrespective of the proficiency of English.

6.1.2 The role of working memory in reading development

WM followed a linear trend of growth at the initial phase but changes to nonlinear at the consolidation phase. Across language proficiency groups, at the initial phase reading growth rates were related to the growth rates of WM ($rs=.25$-$.46$; $ps<.001$). At the consolidation phase, the correlation of these two skills' growth rates was still significant for the overall sample ($r=.20$; $p<.001$), EL1s ($r=.17$; $p<.001$) and L-ELLs ($r=.25$, $p<.001$), but not for H-ELLs ($r=.10$, $p>.05$). Swanson et al. (2017) followed H-ELL and L-ELL students for two years, and found that in both H-ELL and L-ELL groups the growth rates of WM and reading were related. This study, however, suggests that perhaps WM growth did not underlie reading growth when students have achieved high proficiency of both home and second languages. As H-ELLs' reading ability continued to grow at the consolidation phase (latent slope factor =0.21, $p<.001$), perhaps higher-order cognitive skills are associated with this growth such as inferencing and comprehension monitoring. On the other hand, reading skills of L-ELLs were still low at the consolidation phase, so a faster WM growth rate may help these students have a faster rate to consolidate their reading skills.

The causal relation of WM in reading was evident in the initial phase in EL1, H-ELL and L-ELL students even after p value corrections (EL1: $\beta=0.09$, $p<.001$; H-ELL: $\beta=0.15$, $p<0.05$; L-ELL: $\beta=0.15$, $p<.01$; see Table 1.5). This suggests that individual differences in WM at Kindergarten may have a significant impact on reading at Grade 1, which is consistent with other findings (e.g., Nevo & Breznitz, 2011, 2013; Stevenson, Bergwerff, Heiser, & Resing, 2014). Therefore, WM may be an important skill in predicting initial reading performance, as low WM capacity may limit students' ability of holding and processing letter sounds and thus impair phonics, decoding and comprehension abilities (Peng et al., 2018; Swanson, 2015). However, at the consolidation phase only for EL1s was WM a causal factor of reading achievement (Grade 1 $\beta = 0.05$, $p < .01$; Grade 2 $\beta = 0.04$, $p < .01$). As WM played a causal role in reading at the consolidation phase for EL1s but not for H-ELLs or L-ELLs, perhaps H-ELLs and L-ELLs adopted different reading strategies from EL1s after they achieved initial reading skills. For example, Jiménez, García, and Pearson (1996) as well as García and Godina (2017) found that Latino ELLs tend to translate texts into Spanish to help their performance in English reading tasks. Therefore, reading strategy and first language comprehension skills may have confounded the contribution of WM in ELL reading (Cunnings, 2017; Prevoo, Malda, Mesman, & van IJzendoorn, 2016). On the other hand, EL1 may still rely on direct retrieval of verbal codes stored in their memory to facilitate understanding of reading material. However, these assumptions need to be examined in future studies.

Melby-Lervåg and Hulme's (2013) meta-analysis suggests that the benefits of WM training were difficult to be transferred to reading, but their conclusion was made based on students of different grade levels. As the current research found WM had strong relations with reading at Kindergarten and Grade 1, intervention studies may consider WM training at Kindergarten years, and perhaps such intervention can reduce risks of future reading failure.

6.1.3 Program enrollment effect

At the consolidation phase, those who enrolled in bilingual programs had faster reading and WM growth rates than those in ESL programs. The faster WM growth rate of L-ELLs in bilingual programs perhaps is related to the experience of holding and processing two languages in their memory for years. Bilingual program students also had faster reading growth rate maybe because at the consolidation phase among L-ELLs the growth rates of WM and reading were still significant. However, as the causal relations of WM and reading were not evident for L-ELLs at this phase, perhaps faster growth of WM cannot lead to better reading outcomes. Future studies may examine the factors associated with the reading advantage of bilingual students over ESL students as found in previous meta-analyses (Reljić et al., 2015; Rolstad et al., 2005).

6.2 Risk Factors of Late-emerging Reading Difficulty

Study 2 aimed to understand if early EF deficits and their slow growth rates are risk factors of having later emerging reading difficulty (LRD). The results were supportive of this hypothesis, thus suggesting the necessity of EF training (in addition to WM, suggested by Study 1) at Kindergarten and Grade 1 to help reduce risks of having reading difficulties.

6.2.1 Different types of reading difficulty

When answering RQ 1 (Do students show different profiles during the growth in reading achievement?), latent transition analyses suggest there were different types of learning difficulty. As students with a comorbidity of reading and math difficulty may have different EF profiles from students with reading difficulty only (De Weerdt, Desoete, & Roeyers, 2013; Peng & Fuchs, 2016), students with reading difficulty, math difficulty and a comorbidity of math and reading difficulties were categorized into separate groups to control for math's effect on EF skills in subsequent analyses. This study replicated other studies' finding by suggesting considerable number of students had LRD (9%; N=1,212; Compton, Fuchs, Fuchs, Elleman, & Gilbert, 2008; Etmanskie, Partanen, & Siegel, 2016; Grimm Solari, McIntyre, & Denton, 2018; Kearns, et al., 2016; Keresteš, Brkovic, Siegel, Tjus, & Hjelmquist, 2019; Leach et al., 2003).

6.2.2 Executive function deficits and profiles of reading

When addressing RQ 2 (Can EF deficits at early school years predict possibilities of having late-emerging reading difficulties?), the results showed that WM, shifting and inhibition deficits all predicted the chance for a TD (at Kindergarten level) reader to become LRD. Few studies have examined risk factors of LRD, so the current research provides novel suggestion that perhaps all these EF skills should be screened at Kindergarten and Grade 1 in order to identify and help students who are at risk for LRD.

When answering RQ3 (Are slow growth rates of EF skills risk factors of having late-emerging reading difficulty?), using WM growth rate as the proxy of EF growth rate, results showed those who had faster reading growth rates had better chance to overcome reading difficulty at later years. Moreover, those who had slower reading growth rates were more likely to have LRD. Swanson et al. (2017) found that the WM growth rate was a significant predictor of ELL students' reading growth, but few studies have examined this in general population. This research suggests that slow WM growth rate can be a risk factor of having LRD in general population. Therefore, perhaps EF intervention should be intensive and repetitive to make sure EF skills of students can grow at a fast rate to reduce risks of developing reading difficulties at later years.

6.3 The Role of Working Memory in Chinese Writing

While the first two studies focused on English and reading, Study 3 examines the contribution of WM to Chinese character, word, and composition writing. The finding showed that WM significantly predicted character-based phono-semantic processing skills. Moreover, WM contributed to word writing accuracy through character-based phono-semantic processing skills. When regressing composition quality on WM measures, neither verbal nor numeric WM directly predicted written quality, but verbal WM predicted composition quality via word writing. The current study offers implications to Chinese writing theory development.

6.3.1 Classifications of character and word writing errors

As a prerequisite step to answer the research questions, the dimensions of different types of character-based writing errors were analyzed using EFA. Results showed that phonological (e.g., phonetic radical errors) and semantic processing errors (e.g., homophone and semi-homophone substitution) loaded on a common factor (i.e., Factor 1; see Table 3.2). This result suggests that similar to Chinese character reading, phonological and semantic processing cannot be considered separately in Chinese character writing (Liu, Chung, McBride-Chung, & Tong, 2010; Zhou & Marslen- Wilson, 1999) Therefore, perhaps semantic and phonological processing skills collaborate to help retrieve the orthographic form of an individual character.

For comparison reasons, an error classification analysis of word writing was also conducted, and the results suggest that semantic and phonetic errors loaded on two different factors (Factor 1 and 2, respectively, see Table 3.2). Moreover, semantic error was the primary factor that explains word writing (i.e., factor 1). Therefore, perhaps during word writing semantic processing was less affected by phonological abilities, and semantic information may help students directly retrieve the orthographic form of the character. This result is consistent with the findings of Li et al. (2017) as well as Wang and McBride (2016) who suggest that semantic processing plays a more important role in word processing than in character processing. However, their studies made the conclusion based on reading tasks, and the current research suggests that semantic processing also plays a dominant role in word writing. As character and word writing perhaps involve different cognitive mechanisms, as suggested by prior works and this study, future studies on Chinese reading and writing may need to analyze character and word writing separately.

6.3.2 The role of working memory in different types of Chinese writing

When answering RQ 1 (Does WM predict phonological, semantic, orthographic and visual processing skills that are necessary for character writing?), results showed that verbal WM predicted character-based phono-semantic processing skills, but did not contribute to orthographic or visual skills. Therefore, higher abilities of retaining and processing verbal codes may help students holding phonological and semantic codes in memory while accurately encoding them into orthographic forms. However, higher verbal WM may not contribute to the refinement of character writing such as being aware of missing strokes or differentiating visual-similar characters.

When answering RQ 2 (Does WM predict word writing accuracy through character writing?), a path analysis (see Figure 3.2) showed that only verbal, but not numeric WM directly contributed to word writing accuracy. Moreover, verbal WM predicted word writing accuracy through character-based phono-semantic processing skills. The results suggest that in addition to orthographic WM as found by Mo et al. (2018), verbal WM also directly contributed to word writing accuracy. The mediation role of character-based phono-semantic processing skills suggest students with higher verbal WM skills can be more proficiently hold and encode phonological and semantic information during word writing, and thus improving the overall word writing accuracy.

To answer RQ 3 (Does WM directly predict composition quality, as suggested by the Simple View of Writing in Chinese? Does WM contribute to composition writing through basic transcription skills such as character and word writing?), another mediation path model was built to investigate the direct and indirect contribution of WM to written composition quality. Contradictory to the Simple View of Writing in Chinese (SVWC; Yeung et al., 2017), in this study verbal WM was not a significant predictor of WM quality despite two studies sharing a similar writing rubric. Several reasons may explain the conflict of findings. First, all tasks in this study were administered using Simplified Chinese while Yeung and colleagues adopted

Traditional Chinese. Writing Traditional Chinese is more complicated than writing Simplified Chinese as Traditional Chinese characters typically contain more strokes (see McBride, 2016, for a review) and children may rely heavily on memory to complete writing-related tasks in Traditional Chinese. Second, Yeung and colleagues adopted a composite sample that consists of Grades 1, 3, and 5 students, but the current study investigated Grade 5 students. Therefore, the contribution of WM to written composition perhaps has been subsumed in Chinese word writing process. Therefore, future Chinese writing research may consider lower and upper elementary students as two separate groups, and re-examine the applicability of the SVWC theory in different age groups.

In the current research, verbal WM but not numeric WM contributed to character-based phono-semantic processing skills and word reading accuracy, suggesting that Chinese writing may be only explained by verbal domain WM. As a comparison, both Study 1 and 2 adopted numeric WM and found its relation to reading, but Study 3 suggested that numeric WM may be less relevant to Chinese and writing. However, more studies are needed to investigate which types of WM can contribute to English and Chinese literacy development.

6.4 Limitations

There are several limitations in this dissertation. First, EF skills may have different predictive power to different skills of reading (Peng et al., 2018), but the first two studies had to adopt composite reading scores due to data restrictions. Future studies may consider decomposing reading into subskills and investigate if each is related to EF growth rate and deficits. Second, in the first two studies each EF construct is measured by a single task (e.g., shifting is measured by card sorting game only) and future studies may need to include at least two measures of WM to control for measurement errors. Study 2 was not able to model the growth of shifting and inhibition to investigate whether the growth rates of these two EF skills explained reading profile classifications. Future studies may consider measuring these two EF skills repeatedly with consistent measures. Moreover, future studies are suggested to exclude students who fall between 25^{th} and 30^{th} percentile to avoid estimation bias, as these students may have higher chance to drop below 25^{th} percentile at later times than others. Study 3 did not include students' handwriting fluency and morphological awareness as control variables, despite the fact that both skills are important to Chinese character, word and composition writing (Tong et al., 2009; Yeung et al., 2017). These variables are suggested to be taken into consideration in future studies on executive function and Chinese writing. Also, future research is encouraged to include samples from various grade levels or adopt longitudinal design to examine the causal relation between EF and Chinese writing across grade levels. Additionally, the control variables in these three studies may also reveal important implications, but these are out of the current study's focus. Future research may be interested in exploring how demographic variables affect the contribution of EF to reading and writing (e.g., whether the contribution of EF to reading and writing was stronger for girls than for boys). Lastly, although the results suggest that it may be necessary to incorporate EF training into literacy instruction or intervention, few studies have investigated whether such intervention can lead to better learning outcomes than interventions that only focus on literacy skills. Future studies are encouraged to conduct a randomized controlled trial study comparing the literacy growth trajectories of these two experimental groups (i.e., literacy+ EF vs. literacy only) and investigate whether EF training should replace some literacy intervention time.

6.5 Conclusion

The three studies in this dissertation attempted to address some research gaps in the field of EF-literacy relationships. Based on these findings, theoretical models of reading and writing may need to consider the role of EF skills as they may underlie differences between good and poor readers and writers. The aim of literacy education is to reduce reading and writing problems and thus to improve communication and chances of academic success (Joshi et al., 2009; National Reading Panel, 2000); if including EF training can facilitate this process, researchers, teachers and educational practitioners are encouraged to incorporate EF training in their instructions and interventions.

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Table 1.1: Descriptive statistics of reading and working memory

		Reading							
		Time 1	Time 2	Time 3	Time 4	Time 5	Time 6	Time 7	Time 8
Overall	N	5159	5732	5194	5358	4725	5093	4853	4695
	M	-0.48	-0.49	0.89	1.64	1.85	2.23	2.61	2.89
	SD	0.81	0.74	0.76	0.72	0.64	0.61	0.62	0.59
EL1	N	3480	3790	3342	3433	2986	3250	3075	2977
	M	-0.43	0.52	0.93	1.67	1.9	2.26	2.66	2.93
	SD	0.83	0.74	0.78	0.74	0.66	0.64	0.65	0.61
H-ELL	N	425	481	158	486	155	485	439	415
	M	-0.36	0.66	1.09	1.76	1.94	2.31	2.74	3.01
	SD	0.96	0.8	0.72	0.69	0.62	0.57	0.62	0.57
L-ELL-ESL	N	291	353	156	352	152	351	336	319
	M	-1.18	-0.1	0.5	1.11	1.45	1.78	2.22	2.54
	SD	0.71	0.74	0.61	0.67	0.53	0.59	0.56	0.55
L-ELL-Bilingual	N	167	213	99	213	109	213	205	205
	M	-1.09	-0.29	0.44	1.1	1.38	1.81	2.19	2.61
	SD	0.75	0.95	0.74	0.7	0.58	0.56	0.58	0.59

		Working Memory							
		Time	Time 2	Time 3	Time 4	Time 5	Time 6	Time 7	Time 8
Overall	N	5151	5724	5222	5350	4727	5091	5854	4699
	M	435.16	451.33	459.71	471.21	474.81	482.05	490.32	497.27
	SD	29.63	29.10	27.41	23.94	22.64	21.02	20.84	20.19
EL1	N	3475	3790	3339	3427	2985	3249	3073	2979
	M	435.68	451.27	459.99	471.09	475.53	481.88	490.52	497.64
	SD	30.22	29.63	27.61	24.46	22.99	22.33	21.75	21.33
H-ELL	N	419	480	158	486	155	486	439	414
	M	437.17	454.43	464.45	473.1	478.34	485.15	494.09	501.22
	SD	32.27	30.13	24.71	24.9	20.7	21.72	20.96	21.08
L-ELL-ESL	N	281	344	156	352	153	351	336	320
	M	414.93	432.53	445.31	456.8	466.71	473.30	485.67	493.26
	SD	23.7	29.14	29.01	28.61	26.39	23.77	21.45	18.62
L-ELL-Bilingual	N	171	213	107	213	109	213	205	205
	M	415.64	435.79	444.77	459.66	465.91	477.97	486.37	494.18
	SD	25.38	31.22	30.09	26.16	22.81	20.2	19.02	19.18

Note. EL1=English as first language; ELL=English as second language; H-ELL=Higher level ELLs;
L-ELL ESL=Lower achieving ELLs who had been in ESL programs for three years;
L-ELL Bilingual=Lower achieving ELLs who had been in bilingual programs for three years.

Table 1.2: Model fit comparisons

	R and WM Single Slope Linear	R and WM Single Slope Nonlinear	R: Single slope Linear WM: single slope nonlinear	R: single slope nonlinear WM: single slope linear	R: Piecewise nonlinear; WM: Piecewise linear-nonlinear (Turning point at time 3)	R: Piecewise nonlinear; WM: Piecewise linear-nonlinear (Turning point at time 4	**R: Piecewise nonlinear; WM: Piecewise linear-nonlinear (Turning point at time 4; conditional on gender, race, SES and ELL)**
RMSEA	0.227	0.078	0.208	0.109	0.093	0.059	**0.043**
RMSEA 90% CI	[0.226, 0.229]	[0.076, 0.080]	[0.206, 0.210]	[0.107, 0.111]	[0.091, 0.095]	[0.057, 0.062]	**[0.040, 0.045]**
SRMR	0.273	0.103	0.250	0.207	0.079	0.079	**0.017**
AIC	496844.25	462762.80	488948.57	467011.45	463959.67	460884.74	**319213.62**
BIC	497045.44	463044.47	489190.00	467252.87	464301.69	461226.76	**319689.71**
SABIC	496950.11	462911.00	489075.60	467138.48	464139.63	461064.69	**319451.39**

Note. R=reading; WM=working memory; AIC= Akaike information criterion; BIC= Bayesian information criterion; SABIC=Sample size adjusted BIC; Gender, race, SES and Language status were set as time-invariant covariates; bolded model is the final selected model
Bolded model is the chosen model for overall sample; the same model was selected for all the growth models for other subgroups

Table 1.3: Original and estimated time points for models 1-4

	Time 1: K (1)	Time 2: K (2)	Time 3: G1(1)	Time 4: G1(2)	Time 5: G2(1)	Time 6: G2(2)	Time 7: G3(2)	Time 8: G4(2)
Time point								
Initial phase	0	1	2	3	3	3	3	3
Consolidation phase	0	0	0	0	1	2	4	6
Model 1: Overall weighted sample								
Reading Time score initial phase	0	1.35	1.92	3	3	3	3	3
WM Time scores initial phase	0	1	2	3	3	3	3	3
Reading Time score consolidation phase	0	0	0	0	1.04	2.87	4.72	6
WM Time score consolidation phase	0	0	0	0	0.78	2.54	4.39	6
Model fit	RMSEA=0.043	90% CI= [0.040, 0.045]	SRMR=0.017	CFI=n.a	TFI=n.a			
Model 2: EL1								
Reading Time score initial phase	0	1.35	1.92	3	3	3	3	3
WM Time scores initial phase	0	1	2	3	3	3	3	3
Reading Time score consolidation phase	0	0	0	0	1.07	2.86	4.76	6
WM Time score consolidation phase	0	0	0	0	0.96	2.53	4.41	6
Model fit	RMSEA=0.037	90% CI= [0.034, 0.040]	SRMR=0.016	CFI=0.987	TFI=0.983			
Model 3: H-ELLs								
Reading Time score initial phase	0	1.43	2.04	3	3	3	3	3
WM Time scores initial phase	0	1	2	3	3	3	3	3
Reading Time score consolidation phase	0	0	0	0	1.11	2.70	4.62	6
WM Time score consolidation phase	0	0	0	0	1.27	2.27	4.33	6

Model fit	RMSEA=0.037	90% CI= [0.027, 0.047]	SRMR=0.032	CFI=0.983	TFI=0.978			
Model 4: L-ELLs								
Reading Time score initial phase	0	1.35	2.09	3	3	3	3	3
WM Time scores initial phase	0	1	2	2	2	2	2	2
Reading Time score consolidation phase	0	0	0	0	1.23	2.80	4.57	6
WM Time score consolidation phase	0	0	0	0	1.24	2.68	4.65	6
Model fit	RMSEA=0.034	90% CI= [0.028, 0.039]	SRMR=0.023	CFI=0.985	TFI=0.981			

Note. EL1= English monolinguals; H-ELL= Higher proficiency English language learners; L-ELL= Lower proficiency English language learners R=reading; WM=Working memory

Table 1.4: Correlations matrix of latent factors in models 1-4

Overall weighted sample (Model 1)	1.	2.	3.	4.	5.	6.
1. Reading Intercept	1					
2. WM Intercept	0.68***(0.03)	1				
3. Reading growth rate initial phase	-0.35***(0.04)	-0.12**(0.05)	1			
4. WM growth rate initial phase	-0.32***(0.05)	-0.61***(0.03)	**0.25***(0.07)**	1		
5. Reading growth rate consolidation phase	-0.57***(0.03)	-0.33***(0.02)	-0.12**(0.05)	0.10**(0.04)	1	
6. WM growth rate consolidation phase	-0.21***(0.05)	-0.30***(0.05)	0.02(0.07)	-0.16***(0.05)	**0.20***(0.05)**	1
Estimated growth factors	-0.46***	437.20***	0.70***	11.50***	0.21***	4.27***
β of SES	0.31***(0.03)	0.26***(0.03)	-0.01(0.03)	-0.12(0.06)	-0.06(0.04)	-0.05(0.04)
β of female	0.08**(0.02)	0.07*(0.03)	0.02(0.04)	-0.03(0.03)	-0.004(0.03)	-0.06*(0.03)
β of Non-Caucasian	-0.07(0.05)	-0.15***(0.04)	- 0.01(0.06)	0.09(0.06)	0.05(0.05)	0.11*(0.05)
β of ELL (Kindergarten)	-0.11**(0.04)	-0.10***(0.03)	0.02(0.03)	0.08(0.05)	0.09(0.03)	0.12*(0.05)
EL1 (Model 2)						
1. Reading Intercept	1					
2. WM Intercept	0.70***(0.02)	1				
3. Reading growth rate initial phase	-0.35***(0.03)	-0.16***(0.03)	1			
4. WM growth rate initial phase	-0.33***(0.03)	-0.60***(0.02)	**0.33***(0.08)**	1		
5. Reading growth rate consolidation phase	-0.57***(0.02)	-0.28***(0.03)	-0.12**(0.03)	0.002(0.04)	1	
6. WM growth rate consolidation phase	-0.17***(0.03)	-0.25***(0.04)	0.01(0.04)	-0.19***(0.05)	**0.17***(0.04)**	1
Estimated growth factors	-0.37***	438.56***	0.69***	10.99***	0.21***	4.32***
Control variable estimates						
β (SE) of SES	0.30***(0.02)	0.29***(0.02)	0.01(0.03)	-0.16***(0.03)	-0.05(0.03)	-0.02(0.03)
β (SE) of female	0.08***(0.02)	0.07**(0.02)	0.05*(0.02)	-0.02(0.03)	-0.03(0.02)	-0.04(0.03)
β (SE) of Non-Caucasian	-0.02(0.02)	-0.13***(0.02)	-0.03(0.02)	0.07*(0.03)	-0.05(0.03)	0.10**(0.03)
H-ELL (Model 3)						

1. Reading intercept	1					
2. WM intercept	0.71***(0.05)	1				
3. Reading growth rate initial phase	-0.67***(0.04)	-0.36***(0.08)	1			
4. WM growth rate initial phase	-0.48***(0.08)	-0.66***(0.06)	**0.47***(0.10)**	1		
5. Reading growth rate consolidation phase	-0.57***(0.09)	-0.31***(0.08)	0.17(0.14)	0.05(0.11)	1	
6. WM growth rate consolidation phase	-0.03(0.09)	-0.13(0.11)	-0.001(0.12)	-0.35*(0.16)	**0.10(0.11)**	1
Estimated growth factors	-0.31***	439.92***	0.69***	11.50***	0.21***	4.55***
Control variable estimates [a]						
β (SE) of SES	0.28***(0.05)	0.21**(0.06)	-0.15*(0.07)	-0.11(0.08)	-0.07 (0.07)	0.05(0.09)
β (SE) of female	0.05(0.05)	0.08 (0.06)	0.06(0.06)	-0.09 (0.08)	-0.07(0.07)	-0.01(0.08)
β (SE) of Hispanic/Latino	-0.16**(0.05)	-0.24***(0.06)	0.08(0.07)	0.19*(0.08)	0.14(0.07)	0.01(0.08）
L-ELL (Model 4)						
1. Reading Intercept	1					
2. WM Intercept	0.71***(0.04)	1				
3. Reading Growth Rate initial phase	-0.57***(0.04)	-0.27***(0.05))	1			
4. WM Growth Rate initial phase	-0.38***(0.06)	-0.53***(0.05)	**0.46***(0.07)**	1		
5. Reading Growth Rate consolidation phase	-0.38***(0.05)	-0.23***(0.05)	-0.19**(0.06)	-0.06(0.07)	1	
6. WM Growth Rate consolidation phase	-0.13*(0.06)	-0.27***(0.08)	-0.17*(0.07)	-0.25***(0.07)	**0.25***(0.07)**	1
Estimated growth factors	-0.77***	427.08***	0.72***	12.93***	0.23***	5.16***
Control variable estimates						
β (SE) of SES	0.24***(0.04)	0.16***(0.04)	-0.12*(0.05)	-0.08(0.06)	-0.06 (0.05)	0.04(0.06)
β (SE) of female	0.04(0.03)	0.02 (0.04)	0.03 (0.04)	-0.03(0.05)	-0.02(0.04)	0.01(0.05)
β (SE) of Hispanic/Latino	-0.16***(0.04)	-0.24***(0.04)	0.05 (0.05)	0.14*(0.06）	0.09(0.05)	0.09(0.06）
Program effects						
β (SE) of Bilingual program	-0.26***(0.04)	-0.22***(0.04)	**0.08(0.06)**	**0.09(0.06)**	**0.20***(0.05)**	**0.17**(0.06)**

Note. Bolded correlation coefficients are directly related to our research questions; β= standardized regression coefficient

Table 1.5: Standardized regression coefficients in models 5-8

	Model 5: Overall weighted sample	Model 6: EL1s	Model 7: H-ELLs	Model 8: L-ELLs
Concurrent relationships (r)				
K: Reading with WM	0.72***(0.03)	0.72***(0.02)	0.71***(0.04)	0.73***(0.03)
G1: Reading with WM	0.29***(0.07)	0.39***(0.04)	0.30**(0.10)	0.44***(0.08)
G2: Reading with WM	0.17*(0.07)	0.08(0.05)	-0.10(0.15)	0.04(0.10)
G3: Reading with WM	0.02(0.02)	0.04(0.02)	0.06(0.06)	0.07(0.04)
β of reading on WM				
Reading at K to WM at G1	0.06(0.03)	0.07(0.04)	-0.02(0.11)	-0.06(0.10)
Reading at G1 to WM at G2	0.03(0.04)	0.04(0.03)	0.10(0.09)	0.02(0.07)
Reading at G2 to WM at G3	0.02(0.04)	0.02(0.02)	0.08(0.07)	0.08(0.05)
β of reading on WM				
WM at K to Reading at G1	0.10(0.05)	0.09***(0.02)	0.15*(0.06)	0.15**(0.05)
WM at G1 to Reading at G2	0.03(0.02)	0.04*(0.02)	0.08(0.04)	0.05(0.03)
WM at G2 to Reading at G3	0.07**(0.02)	0.05*(0.02)	-0.01(0.02)	0.05(0.03)
Model fit				
RMSEA	0.078	0.079	0.053	0.048
RMSEA 90% CI	[0.075, 0.080]	[0.076, 0.082]	[0.042, 0.064]	[0.041, 0.054]
SRMR	0.020	0.022	0.031	0.021
CFI	n.a.	0.956	0.974	0.978
TFI	n.a.	0.927	0.957	0.963

Note. Autoregression effects were controlled in all the CLPM models; β= standardized regression coefficient

Table 1.6: Control variables in models 5-8

	Reading at K	Reading at G1	Reading at G2	Reading at G3	WM at K	WM at G1	WM at G2	WM at G3
Overall weighted sample (From M5)								
ELL	-0.12***(0.03)	0.01(0.02)	-0.02(0.01)	-0.02(0.01)	-0.13***(0.03)	0.04(0.03)	0.02(0.02)	0.03(002)
SES	0.32*** (0.03)	0.04**(0.01)	0.03(0.01)	0.07(0.02)	0.32*** (0.03)	-0.01(0.03)	0.03(0.03)	0.00(0.03)
Female	0.09***(0.02）	0.01(0.01)	0.03***(0.01)	0.02(0.01)	0.06(0.03)	0.01(0.02)	0.00(0.01)	-0.03(0.02)
Non-Caucasian	-0.04(0.04)	0.01(0.02)	0.02(0.02)	0.01(0.01)	-0.05*(0.02)	-0.02(0.03)	0.01(0.01)	0.04(0.02)
EL1 (From Model 6)								
SES	0.30*** (0.02)	0.05***(0.01)	0.03**(0.01)	0.05***(0.01)	0.29*** (0.02)	-0.01(0.02)	0.02(0.02)	0.004(0.02)
Female	0.08***(0.02)	0.03**(0.01)	0.02**(0.01)	0.02(0.01)	0.08***(0.02)	0.01(0.02)	0.01(0.02)	-0.03(0.02)
Non-Caucasian	-0.04(0.02)	0.02(0.01)	-0.03**(0.01)	-0.03*(0.01)	-0.24***(0.02)	0.01(0.02)	0.02(0.02)	0.01(0.02)
H-ELL (From Model 7)								
SES	0.25***(0,05)	0.03(0.03)	0.03(0.03)	0.05(0.03)	0.20**(0.06)	0.06(0.06)	-0.02(0.06)	0.06(0.05)
Female	0.09(0.05)	0.03(0.03)	0.01(0.03)	0.08**(0.03)	0.10(0.06)	-0.06(0.06)	-0.04(0.05)	0.06(0.04)
Hispanic/Latino	-0.14**(0.05)	-0.02(0.03)	0.05(0.03)	-0.02(0.03)	-0.24***(0.06)	0.03(0.06)	0.05(0.06)	-0.08(0.05)
L-ELL (From Model 8)								
SES	0.22**(0.06)	0.03(0.02)	0.02(0.02)	0.04(0.02)	0.15***(0.04)	0.03(0.04)	0.004(0.04)	0.07(0.03)
Female	0.07*(0.03)	0.02(0.02)	0.02(0.02)	0.04(0.02)	0.02(0.04)	-0.02(0.04)	-0.04(0.04)	0.02(0.03)
Hispanic/Latino	-0.15***(0.04)	-0.02(0.03)	0.01(0.02)	-0.01(0.02)	-0.25***(0.04)	0.02(0.05)	0.09(0.04)	-0.06(0.03)
Bilingual	-0.23***(0.04)	0.03(0.02)	0.02(0.02)	-0.03(0.02)	-0.23***(0.04)	-0.01(0.04)	0.05(0.04)	0.04(0.03)

*p<.05 **p<.01 ***p<.001

Table 2.1: Latent transition analyses

Transition pattern	N	Proportion	Entropy
PMD	3140	23.25%	0.89
MIMP	0	0.00%	
LMD	0	0.00%	
TDM	10366	76.75%	
Transition pattern	N	Proportion	Entropy
LRD	2122	15.71%	0.87
RIMP	1132	8.38%	
LRD	1212	8.97%	
TDR	9040	66.93%	

Note. PMD=Persistent math difficulty; MIMP= Math improved after Kindergarten; LMD=Late emerging math difficulty; TDM=Typically developing math skills; PRD=Persistent reading difficulty; LRD=Late emerging reading difficulty; RIMP=Reading improved after Kindergarten; TDR=Typically developing reading skills;

Table 2.2: Post-hoc comparisons of executive function skills

	N	M	SD	N	M	SD	N	M	SD	Mean comparisons
		PMD			LRD			AD		
K shifting	1601	13.19	3.77	602	14.27	3.12	490	14.88	2.58	TD>RIMP=LRD= AD>LRD>PMD
G1 shifting	1615	14.31	3.34	604	15.43	2.46	494	15.83	1.94	TD>RIMP=LRD= AD>LRD>PMD
K inhibition	1457	4.20	1.35	557	4.96	1.24	450	4.66	1.33	TD>RIMP=LRD> LRD=AD>PMD
G1 inhibition	1196	4.25	1.26	541	4.85	1.22	418	4.62	1.37	TD>RIMP=LRD> LRD=AD>PMD
K WM	1601	414.54	20.58	602	432.26	25.79	490	436.74	27.93	TD>LRD=AD=RIMP> LRD>PMD
G1 WM	1614	438.63	28.82	604	458.63	22.96	494	463.03	22.52	TD>RDIMP=AD> LRD=LRD>PMD
G2 WM	1616	456.20	28.32	606	472.09	20.37	494	475.47	18.87	TD>RDIMP=AD= LRD=LRD>PMD
		LRD			RIMP			TD		
K Shifting	1211	14.78	2.75	1120.00	14.65	2.82	8431	15.78	2.24	
G1 Shifting	1212	15.59	2.32	1130.00	15.71	2.26	8432	16.59	1.80	
K inhibition	1098	4.78	1.27	1038.00	4.91	1.20	7818	5.42	1.15	

G1 inhibition	1083	4.63	1.29	973.00	4.87	1.26	7730	5.36	1.19
K WM	1211	440.10	28.30	1120.00	435.98	27.81	8431	462.52	25.01
G1 WM	1211	461.59	24.31	1130.00	464.23	23.78	8432	478.45	19.67
G2 WM	1211	473.32	21.33	1132.00	477.99	20.57	8432	487.95	18.65

Note. WM=Working memory K=Kindergarten; G1=Grade 1; PMD=Persistent math difficulty; LRD=Persistent reading difficulty; LRD=Late emerging reading difficulty; AD=Persistent math and reading difficulty; TD=Typically developing students; RIMP=Reading improved students.

Table 2.3: Probit regression models comparing different types of readers

	Beta (LRD vs. TD)	SE	Significance
K shifting	-0.07	0.02	***
G1 shifting	-0.12	0.01	***
K inhibition	-0.05	0.02	**
G1 inhibition	-0.06	0.02	***
K WM	-0.24	0.01	***
G1 WM	-0.20	0.01	***
	Beta (LRD vs. TD)	SE	Significance
K shifting	-0.04	0.02	
G1 shifting	-0.07	0.02	***
K inhibition	-0.02	0.03	
G1 inhibition	-0.11	0.02	***
K WM	-0.27	0.01	***
G1 WM	-0.15	0.01	***

Note. WM=Working memory K=Kindergarten; G1=Grade 1; PRD=Persistent reading difficulty; LRD=Late emerging reading difficulty; TD=Typically developing students

Table 2.4: Latent growth and probit regression models comparing growth rates across different types of readers

	RIMP vs. LRD (reference) beta	SE	Sig
Initial status	-0.18	0.12	
Average growth rate	-0.25	0.12	*
	LRD vs. TD (reference) beta		
Initial status	-0.82	0.03	***
Average growth rate	-0.37	0.05	***

Note. LRD=Late emerging reading difficulty; RIMP=Reading improved students;

TD=Typically developing students;

Table 3.1: Frequency of each writing error category

		Character		Word	
	Error Type	No error	Character Error	No error	Error
Orthographic errors	1. Character invention	128	95	54	169
	2. Adding/deleting strokes	156	67	96	127
	3. Change of configuration*	213	10	165	58
Semantic errors	4. Semantic radical substitution	158	65	160	107
	5. Homophone character substitution	173	50	28	195
	6. Semi-homophone substitution	184	39	96	127
	7. Synonym substitution *	221	2	207	16
Phonetic errors	8. Phonetic radical substitution	190	33	159	64
	9. Phonetic radical omission*	223	0	221	2
Visual errors	10. Shape-similar character substitution	168	55	177	46

Note. Categories with * were excluded for further analyses due to low frequency.

Table 3.2: Exploratory factor analyses of character writing error categories

	Character-based errors			Word-based errors		
	Phono-semantic errors	Orthographic errors	Visual errors	Semantic errors	Phono-orthographic errors	Visual errors
1.Homophone substitution	**0.59**	0.17	-0.45	**0.69**	-0.06	0.20
2.Semi-homophone substitution	**0.82**	-0.16	0.12	**0.73**	0.00	0.02
3.Phonetic radical substitution	**0.74**	0.13	0.19	-0.05	**0.81**	0.03
4.Stroke addition/deletion	-0.15	**0.88**	0.08	0.38	0.17	-0.58
5.Character invention	0.24	**0.61**	-0.07	-0.03	**0.86**	-0.01
6. Shape-similar character substitution	0.13	-0.09	**0.84**	0.19	0.10	**0.85**
7. Semantic radical substitution	0.03	**0.42**	**0.57**	**0.64**	-0.06	-0.18

Note. Error categories with loading coefficients >.40 are bolded

Table 3.3: Hierarchical linear modeling of character writing errors

Dependent Variable: Character-based phono-semantic skills					
	Estimate	SE	Significance	Lower	Upper
Fixed Effects					
Intercept	0.03	0.15		-0.49	0.50
Verbal WM	0.06	0.02	***	0.03	0.10
Numeric WM	0.01	0.02		-0.02	0.06
Character based orthographic skills	0.09	0.06		-0.02	0.21
Character based visual skills	0.08	0.06		0.03	0.19
Male	-0.18	0.11		-0.39	0.03
Father Education Level	-0.10	0.11		-0.23	0.04
Mother Education Level	0.12	0.07		-0.01	0.24
Random effects (Variance of)					
Classroom	0.08	0.08			
Students	0.58	0.06	***		
Dependent Variable: Character based orthographic skills					
Fixed Effects					
Intercept	-0.004	0.06		-0.21	0.20
Verbal WM	-0.005	0.02		-0.05	0.04

Numeric WM	0.04	0.02		-0.003	0.05
Character-based phono-semantic skills	0.15	0.08		-0.01	0.31
Character based visual skills	-0.08	0.07		-0.22	0.06
Male	-0.10	0.13		-0.36	0.16
Father Education Level	0.09	0.08		-0.08	0.25
Mother Education Level	-0.05	0.08		-0.20	0.11
Random effects (variance of)					
Classroom	0.00	0.00			
Students	0.88	0.09	***		
Dependent Variable: Character based visual skills					
Fixed Effects					
Intercept	0.01	0.06		-0.21	0.20
Verbal WM	-0.001	0.02		-0.05	0.03
Numeric WM	-0.01	0.02		-0.06	0.04
Character-based phono-semantic skills	0.11	0.08		0.05	0.25
Character based orthographic skills	-0.08	0.07		-0.23	0.04
Male	-0.02	0.13		-0.28	0.24
Father Education Level	0.09	0.08		-0.07	0.26
Mother Education Level	-0.13	0.08		-0.29	0.02

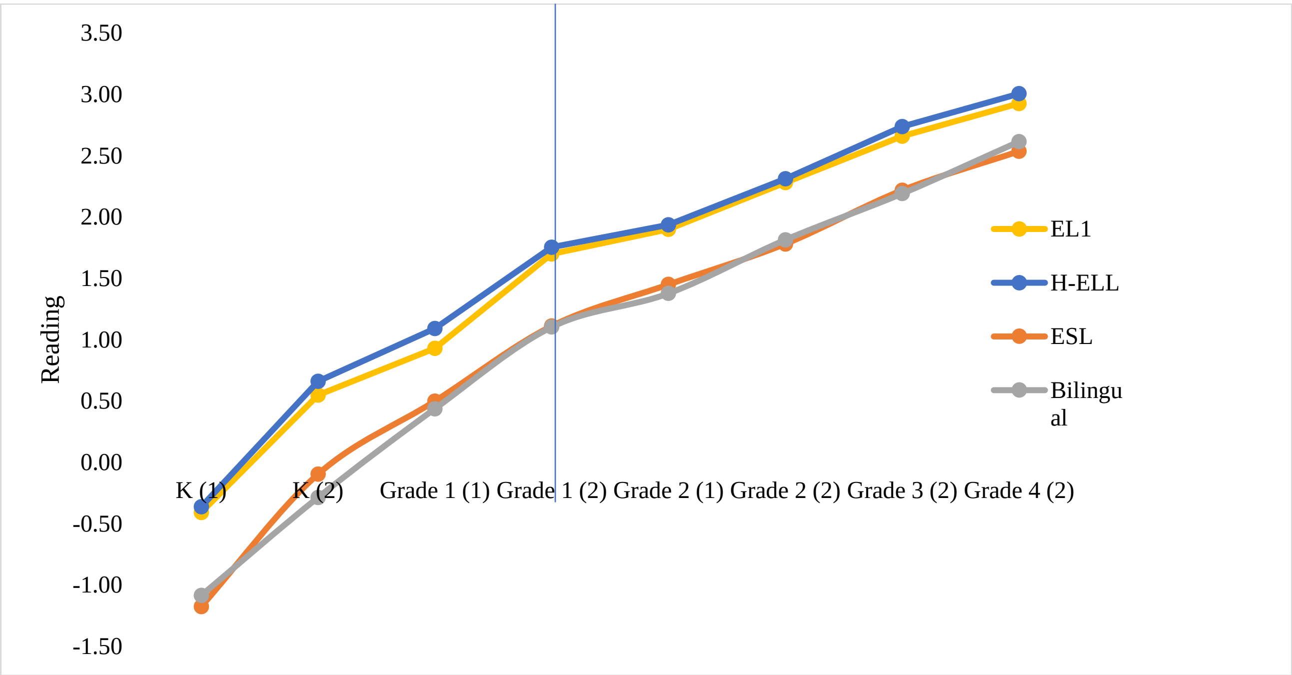
Random effects (Variance of)			
Classroom	0.00	0.00	
Students	0.88	0.08	***

Note. WM=Working memory

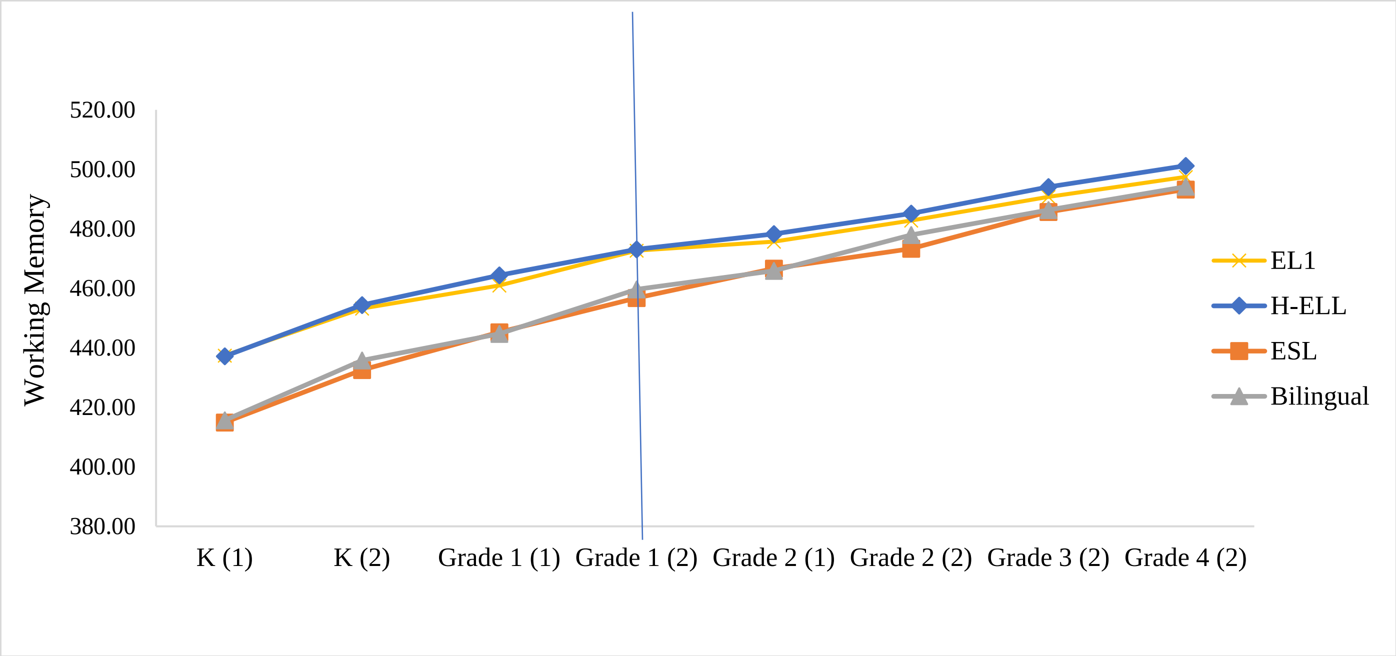
*p<.05 **p<.01 ***p<.001

APPENDIX B FIGURES

Figure 1.1: Reading and WM growth paths of subsamples

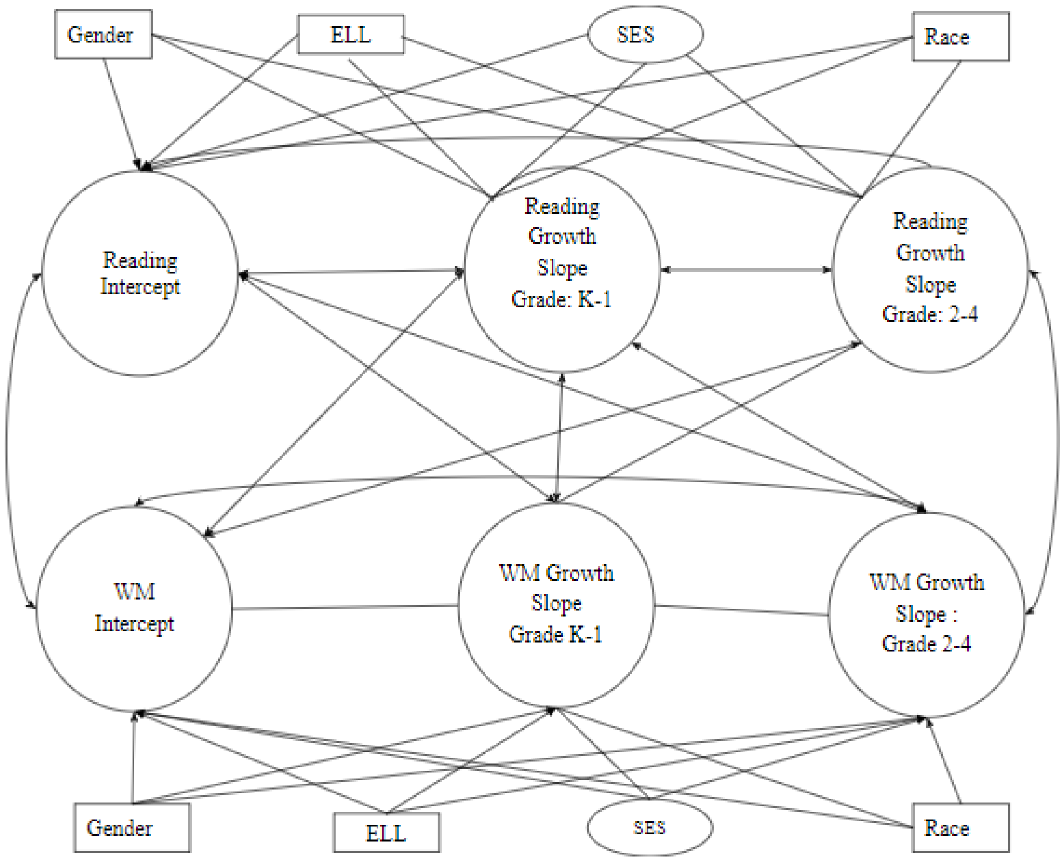


Note. the verticals lines indicate cutoff time points for piecewise models



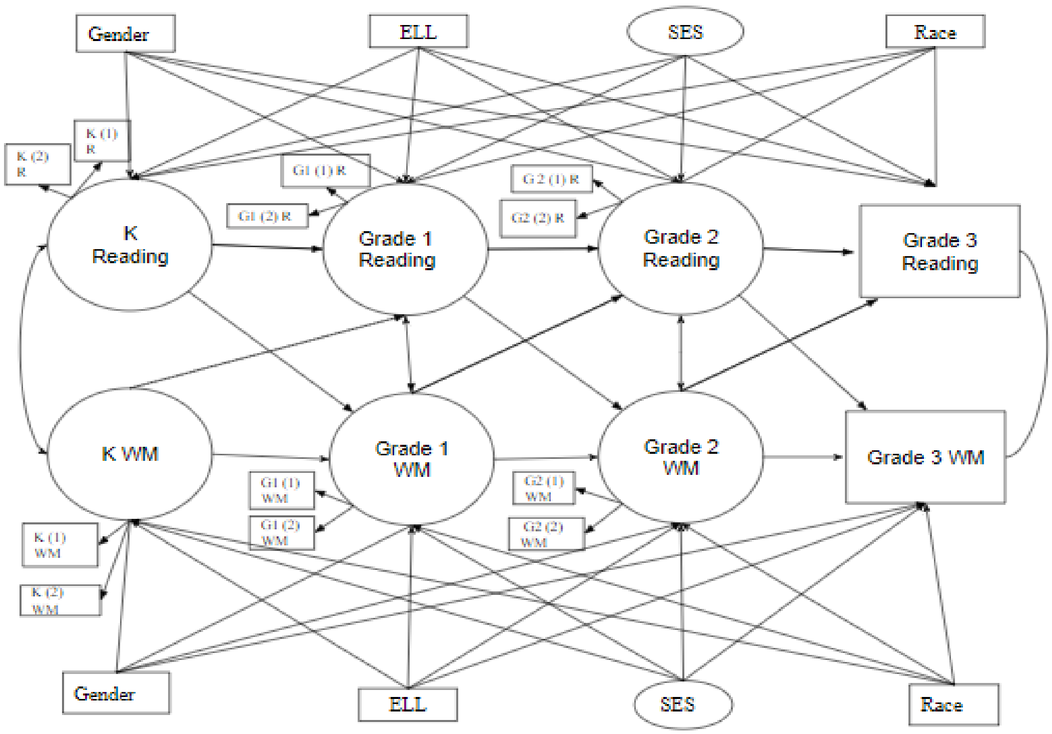
Note. The verticals lines indicate cutoff time points for piecewise models

Figure 1.2: A parallel latent growth curve model of the overall sample



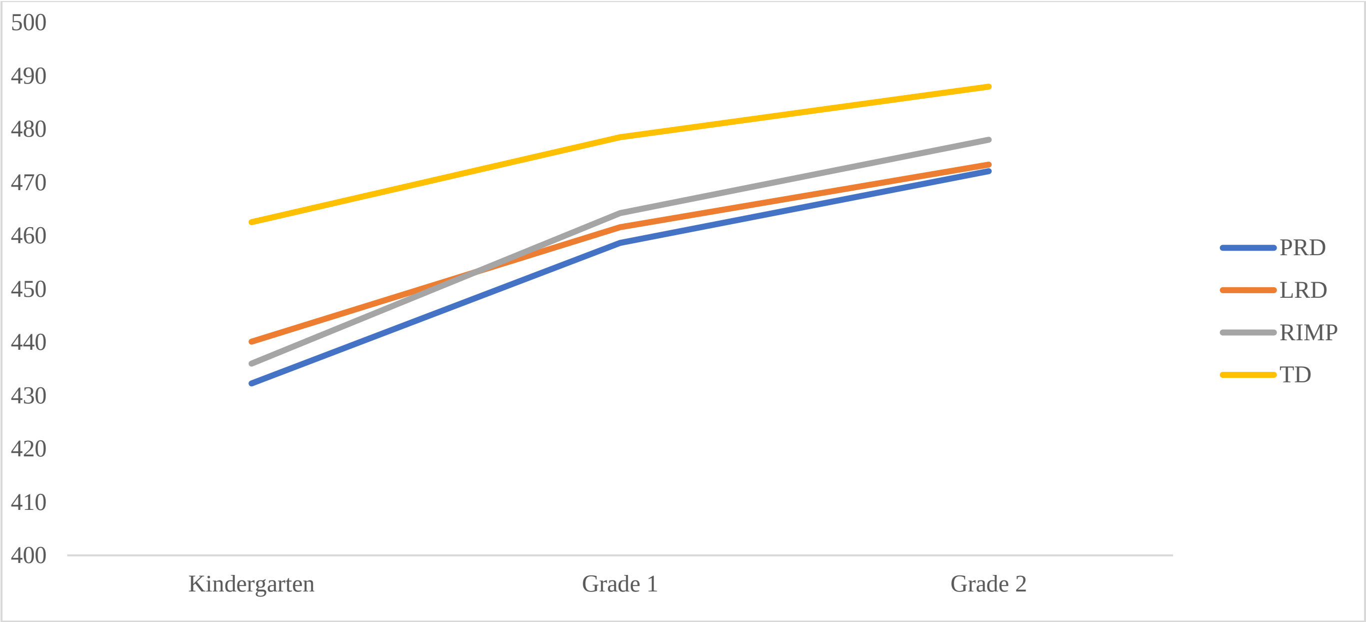
Note. K = Kindergarten; G = Grade level; WM=Working memory; SES= Socio-economic status; ELL=English language learner

Figure 1.3: A cross-lagged panel model of the overall sample



Note. Model depicted based on the overall weighted sample; K = Kindergarten;
G = Grade; WM=Working memory

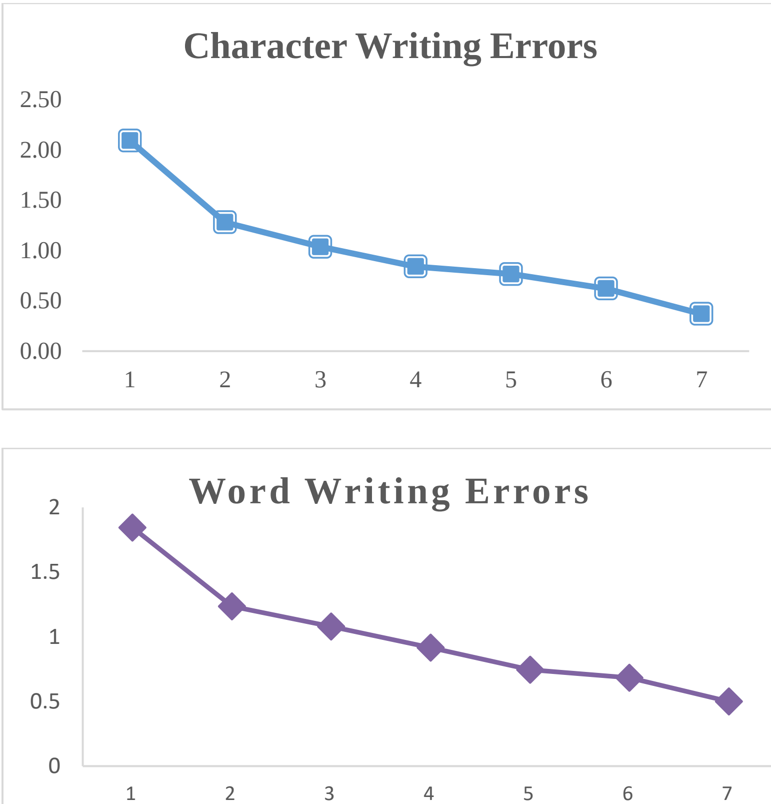
Figure 2.1: Nonlinear growths of working memory across different types of readers



Note. PRD=Persistent reading difficulty; LRD=Late emerging reading difficulty;

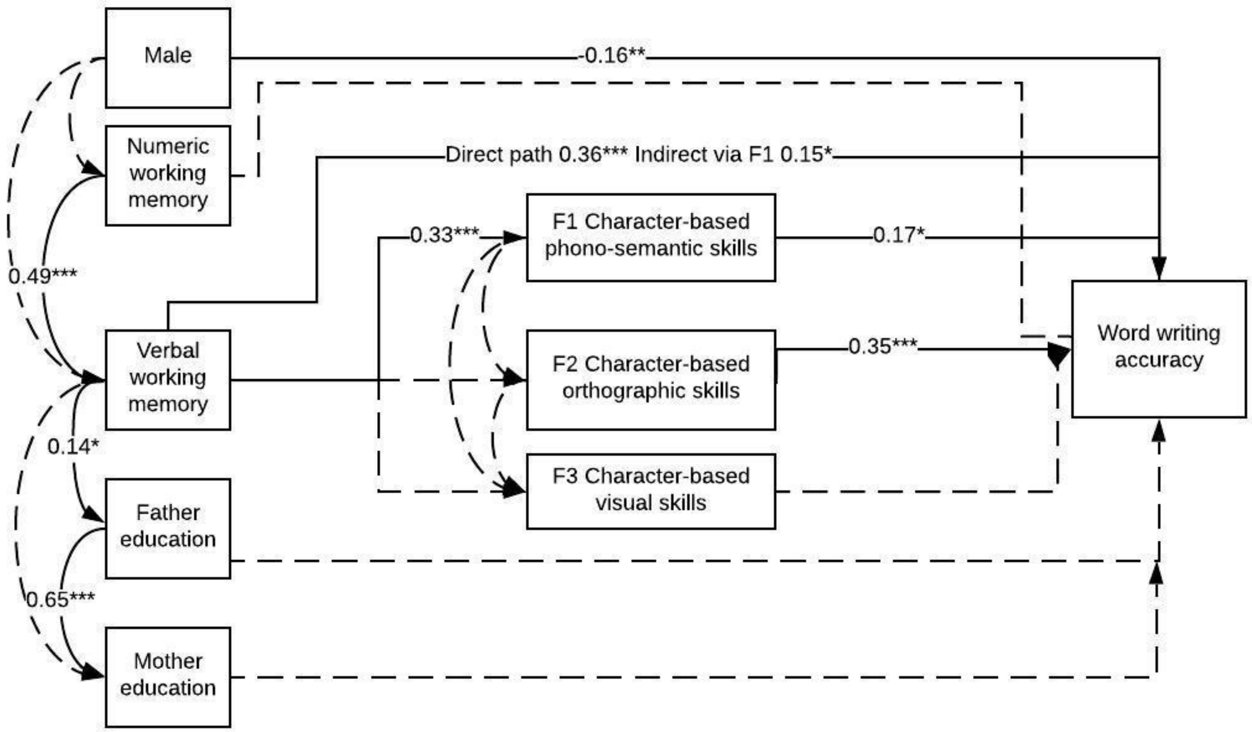
TD=Typically developing students; RIMP=Reading improved students

Figure 3.1: Scree plot of character and word error classifications



. The first three factors are retained based on the eigenvalue > 1 rule.

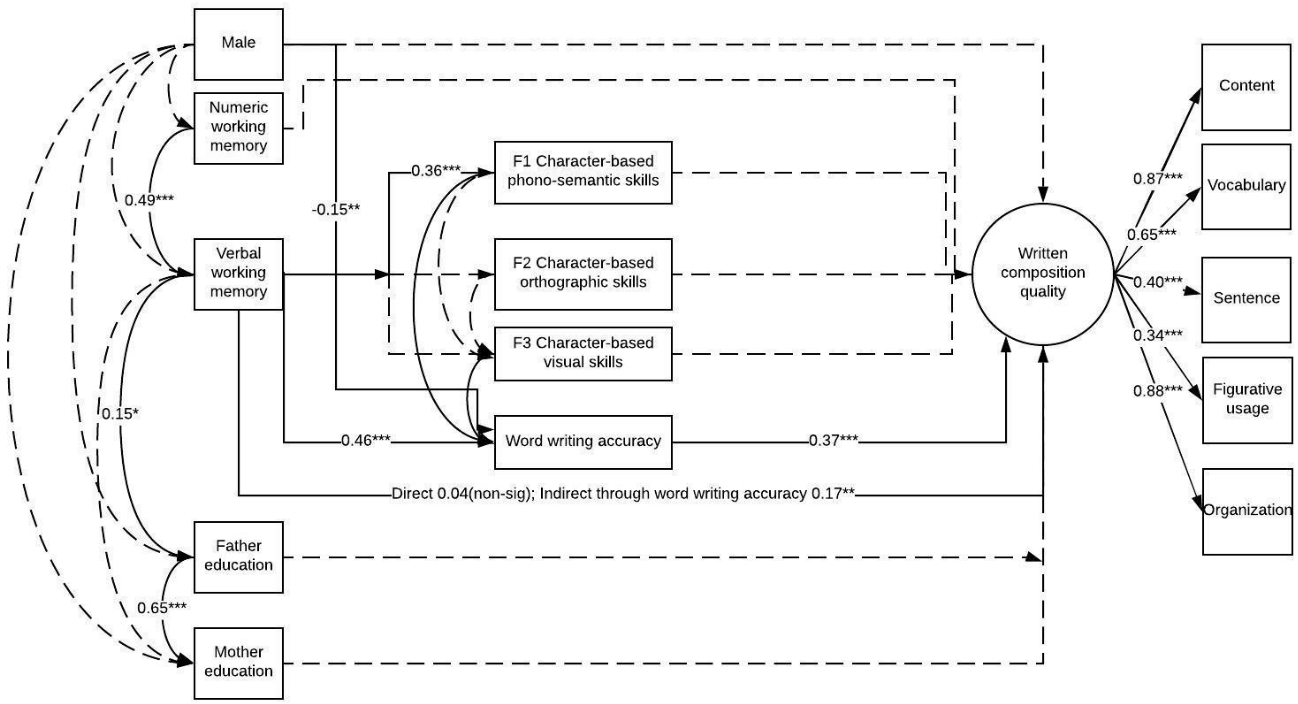
Figure 3.2: A mediation path model of working memory and word writing accuracy



Note. Significant direct effects are noted by solid lines. Significant indirect effects (where applicable) are noted in parentheses.

Model fit: CFI=.97, TFI=.94; $\chi 2$ (15) =19.93, p>.05; RMSEA=.038, 90% CI= [.00, .08], SRMR=0.04. * p<.05 *** p<.001

Figure 3.3: A mediation path model of working memory and written composition quality



Note. Significant direct effects are noted by solid lines. Significant indirect effects (where applicable) are noted in parentheses.

Model fit: CFI=.97, TFI=.96; $\chi2$ (59) = 73.16, p>.05; RMSEA=.03, 90% CI= [.00, .06], SRMR=0.04. * p<.05 ***

p<.001