

The Relation between Shifting and Reading Comprehension in
Grade 3 Students

by

Larissa Alabe Padua
B.A., University of California, Los Angeles, 2011
MSW, California State University, Los Angeles, 2014

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

MASTER OF ARTS

In the Department of Educational Psychology and Leadership Studies

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University of Victoria

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Supervisory Committee

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Abstract

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Reading comprehension is crucial for academic achievement. While word-level reading and oral language comprehension skills are well-established predictors of reading comprehension, emerging research has been investigating the role of executive function (EF) processes in reading comprehension. The role of shifting – one of the core EF processes – still is underexplored. The purpose of this study was to examine the relation between reading comprehension, shifting, and well-established components of reading comprehension in grade 3 students, across three different shifting tasks. Thirty-six children, ages 8 to 9 years, completed a collection of word-level reading, reading comprehension, receptive vocabulary and EF tasks (working memory and shifting). Results indicated that reading comprehension was significantly and moderately associated with all shifting tasks, word-level reading skills, and receptive vocabulary, but not with WM. In addition, each shifting task explained unique variance in reading comprehension after accounting for word-level reading skills. When receptive vocabulary was added to the regression analyses, shifting tasks did not explain significant variance in reading comprehension performance. Results of this study are discussed in relation to existing models of reading comprehension.

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Acknowledgments

I would like to thank my research supervisor, Dr. Gina Harrison, for her constant support during the completion of this research project. She challenged me to think critically and become a better researcher. I would also like to extend a big thank you to Dr. Sarah Macoun for her frequent and valuable revisions, which challenged me to learn more about the topic at hand. To the teachers, parents and students at Eagle View Elementary, I sincerely appreciate your willingness to collaborate and participate in this research project. Without your collaboration, this study would not have been possible. Finally, an enormous thank you to my partner, Carlos, who has been beside me throughout this journey providing me with encouragement and support.

Introduction

Reading comprehension, the ability to understand written language, is a paramount skill for successful academic achievement and everyday living. Definitions of reading comprehension differ among researchers, but there is a general consensus that reading comprehension is a multi-componential construct encompassing word-level reading and oral language comprehension skills (Garcia & Cain, 2014; Gough & Tunmer, 1986). However, recent findings have suggested that higher order control processes, such as executive function (EF), may also be involved in reading comprehension (Christopher et al., 2012; Kieffer, Vukovic, & Berry, 2013; Swanson & Jerman, 2007).

Executive function (EF) is broadly defined as an array of top-down mental processes that control and coordinate human cognition and behavior (Diamond, 2013). Despite disagreements on the precise components of EF, contemporary views of this construct have pointed to three core processes: working memory (WM), inhibition, and shifting (Miyake, Friedman, Emerson, Witzko, & Howerter, 2000). Research on the development of EF processes in children has found these processes to go through a spurt in development before elementary education (Carlson, 2005), and they continue to develop throughout the school years (Lee, Bull, & Ho, 2013; Lehto, Juujarvi, Kooistra, & Pulkkinen, 2003).

Several studies have examined the relation of EF processes with academic achievement, including reading comprehension skills. The role of WM in reading comprehension has been extensively explored when compared to the body of research on the roles of inhibition and shifting in reading comprehension. Although inhibition has received some attention, findings on its association with reading comprehension are

mixed (Altemeier, Abbott, & Berninger, 2008; Locascio, Marrone, Eason, & Cutting, 2010). Research on the relation between shifting and reading comprehension is also limited, but emerging findings suggest that shifting and reading comprehension may be related (Altemeier et al., 2008; Kieffer et al., 2013; Nouwens, Groen, & Verhowen, 2016). The present study was particularly interested in examining the contribution of shifting to reading comprehension performance above and beyond well-established predictors of reading comprehension (word-level reading skills, receptive vocabulary, and working memory).

Within the following section, first the definition of reading comprehension and well-established factors underlying individual differences in reading comprehension performance among school age children will be described. Next, executive function (EF) processes will be introduced and reviewed within the literature of psychology, and findings on their relation to reading comprehension will be reported. Finally, the purpose and the research questions of the present study will be outlined.

Reading Comprehension: A Multi-Componential Process

Reading comprehension has been defined as the "...construction of a coherent mental representation of text in the readers' memory" (Kendeou, van den Broek, Helder, & Karlsson, 2012, p. 10), and there is strong consensus that reading comprehension is the product of multiple skills (Garcia & Cain, 2014; van der Broek & Espin, 2012). Reading comprehension should not be confused with word decoding or word recognition ability as there is evidence showing that reading comprehension and word decoding/recognition, although related, are distinct constructs (Christopher et al., 2012; Sesma, Mahone, Levine, Eason, & Cutting, 2009). The Simple View of Reading (SVR) (Gough &

Tunmer, 1986) has been a very influential model in guiding the examination of processes that contribute to individual differences in reading comprehension. The SVR postulates that reading comprehension is the product of word-level reading skills, such as word decoding and word recognition, and oral language comprehension skills. According to this model, these skills are necessary to comprehend text because readers must translate written letters and words into language, and they must understand the meaning of such language. The constructs of word decoding and word recognition are described by the SVR as the knowledge of letter-sound correspondence rules in one's language and the ability to recognize isolated words quickly and accurately, respectively. Studies in the field of reading have often assessed word decoding with non-word tasks that demand letter-sound correspondence knowledge, and word recognition with word reading tasks that involve reading a list of real words rapidly and accurately.

Oral language comprehension is referred to as the ability to understand linguistic information (Gough & Tunmer, 1986), and it involves a variety of skills such as the ability to recognize speech sounds, knowledge of individual words (vocabulary), knowledge of grammar and syntax, and inference making based on context and background knowledge (Nadig, 2013). Oral language comprehension has been frequently estimated by receptive vocabulary tasks in studies examining reading comprehension, although tasks that assess syntactic knowledge and inference making have also been used (Kieffer et al., 2013). Even though receptive vocabulary and other components of oral language comprehension (e.g. syntactic knowledge) reflect different aspects of this construct, their respective tasks have been found to be significantly

correlated (Cutting, Materek, Cole, Levine, & Mahone, 2009; Cutting & Scarborough, 2006).

There is extensive evidence supporting the SVR theory as a model for reading comprehension (Cain, Oakhill, & Bryant, 2004; Colenbrander, Kohnen, Smith-Lock, & Nickels, 2015; Cutting & Scarborough, 2006; Garcia & Cain, 2014; Keenan, Betjemann, & Olson, 2008; Muter, Hulme, Snowling, & Stevenson, 2004; Seigneuric & Ehrlic, 2005). Studies have found word-level reading and oral language comprehension skills to be significantly correlated with reading comprehension, and to explain significant variance on performance across different reading comprehension measures in school age children (Keenan et al., 2008; Muter et al., 2004). For example, Muter et al. (2004) conducted a longitudinal study with English speaking students in their first two years of formal reading instruction and found that measures of receptive vocabulary, grammatical awareness, and word recognition skills accounted for 86% of shared variance in reading comprehension performance on the Neale Analysis of Reading Ability II task (NARA II; Neale, 1997).

Similarly, in a sample of 510 English speaking participants ranging from ages 8 to 18 years, Keenan et al. (2008) found that measures of word decoding and oral language comprehension skills accounted for 24-61% of shared variance in reading comprehension performance across four distinct standardized measures of reading comprehension. Moreover, students experiencing poor reading comprehension skills between grades 3 and 5, whose word-level reading abilities were average, performed significantly lower on measures of receptive vocabulary and oral language comprehension skills than their control counterparts (Colenbrander et al., 2015), supporting the SVR's assertion that both

oral language comprehension and word-level reading skills are necessary for reading comprehension.

However, researchers have also noted that the extent to which each of these skills predicts reading comprehension is moderated by participants' age and the specific reading comprehension measure used (Cutting & Scarborough, 2006; Garcia & Cain, 2014; Keenan et al., 2008). For instance, word decoding skills have been found to explain significantly more variance in reading comprehension performance among younger children (up to the age of 10) than older children (beyond the age of 10) across several different reading comprehension tasks (Garcia & Cain, 2014). Further, the specific measure used to assess reading comprehension and its particular demands on word decoding and oral language comprehension skills also moderates this relationship. Cutting and Scarborough (2006) noted that even though both word decoding and oral language comprehension skills significantly predicted performance across three standardized reading comprehension tasks, word decoding accounted for nearly twice as much variance in the Wechsler Individual Achievement Test (WIAT) than in the Gates–MacGinitie Reading Test—Revised (GMRT-R) and the Gray Oral Reading Test—Third Edition (GORT-3). Although oral language comprehension uniquely explained a similar percentage of variance in the WIAT and GORT-3, it was significantly higher in the GMRT-R test.

In summary, these findings provide support to the SVR theory and highlight the imperative role of word-level reading and oral language comprehension skills for reading comprehension performance in school age children. Despite this evidence, a growing number of researchers have argued that the SVR provides a very simple account for the

process of reading comprehension, as this theory does not account for children who experience reading comprehension difficulties despite intact word-level reading and language comprehension skills (Catts, Hogan, & Fey, 2003; Kirby & Savage, 2008). Consequently, an increasing number of studies have examined executive function (EF) processes as cognitive abilities that may account for differences in reading comprehension performance in school age children. The next section will introduce EF processes and report on what is currently known about their association with reading comprehension.

Definitions and Models of Executive Function (EF)

The term executive function (EF) is an umbrella term for higher order cognitive processes associated with pre-frontal cortex functioning, that regulate human thought and behavior, and consequently support cognitive, social, and psychological development (Diamond, 2013). EF is a challenging construct to examine, since there is limited agreement on its definition and terminology across the literature of psychology, reflecting the lack of a unitary theoretical model describing this construct and its components (Barkley & Murphy, 2010; Salthouse, 2005; Wasserman & Wasserman, 2013). This section will introduce influential models of EF, report on the development of core EF processes (working memory, inhibition and shifting), and describe the methodological problems in the assessment of EF.

There are several existing theoretical models that attempt to define the construct of EF, and that have been influential in guiding the conceptualization of this construct across research studies. A contemporary view of EF is Miyake, Friedman, Emerson, Witzki, and Howerter's (2000) model, which defines EF as a collection of higher-order

control processes that are distinguishable from each other, but not completely independent. This model represents a non-unitary view of component EF processes, which include working memory (WM), inhibition, and shifting (Miyake et al., 2000), and it informs the operationalization of EF in the present study.

Miyake and colleagues refer to working memory (WM) as the ability to hold and manipulate perceptual representations in mind. The concept of inhibition associated with this contemporary model is the ability to deliberately suppress automatic responses (Miyake et al., 2000). Shifting, or attention shifting, is the ability to flexibly shift attention between mental sets, attributes of a stimuli, or strategies (Diamond, 2013).

Denckla's (1996) model of EF is in accordance with this contemporary conceptualization of EF (Miyake et al., 2000) in that it views EF as a non-unitary construct composed of similar components described by Miyake and his colleagues (2000). According to Denckla's model, there are four key domains involved in goal-directed behavior: 1) Initiating behavior; 2) Sustaining behavior; 3) Inhibiting behavior; and 4) Set shifting. Each one of these domains involve EF processes. Initiating behavior involves the organization and planning of future actions, which requires WM resources to hold the planning or sequence of actions in mind until they are executed, while sustaining behavior involves attention to the task at hand (Singer & Bashir, 1999). Inhibiting behavior involves the ability to suppress inappropriate or prepotent responses; set shifting refers to problem-solving and self-monitoring while executing the sequence of actions, which involves flexibility to shift attention between mental sets, attributes of a stimuli and or strategies (Hooper, Swartz, Wakely, de Kruif, & Montgomery, 2002). Denckla's

model has been adopted by previous research in educational psychology (Christopher et al., 2012; Hooper et al., 2002).

There are other influential theoretical models corresponding to the construct of EF that view EF as a unitary system. Norman and Shallice's (2002) Supervisory Attentional System (SAS) is described as a limited capacity system involved in the activation of thought, behavior, planning and decision-making in non-routine situations requiring novel or difficult actions. The top-down control processes of the SAS are responsible for inhibiting habitual responses and resolving conflicts between learned actions. In this framework, EF is operationalized as operating under the attentional control system. Baddeley and Hitch's (1994) working memory model has also been influential in investigating EF. Although this model is specifically focused on WM, its central executive component corresponds to existing conceptualizations of EF. According to Baddeley and Hitch (1994), the working memory system temporarily stores and manipulates auditory and visual information through the phonological loop and the visuospatial sketchpad components, respectively. The central executive component selectively attends to incoming perceptual information and flexibly shifts attention between tasks and strategies.

In summary, all these models have been influential in conceptualizing EF in the literature of psychology. Their distinction, however, reflects the complexity of examining the construct of EF, as these models make use of different terminology to refer to the construct of EF, and they operationalize EF with different measures.

Development of EF Processes

Miyake and colleagues (2000) argued that lower-level processes such as WM, inhibition, and shifting can be operationalized more precisely than complex EF processes such as planning and problem-solving. They added that lower-level processes are also implicated in complex executive tests, hence their focus on these three lower-level processes. Therefore, a review of the development and structure of these three EF lower-level processes (WM, inhibition and shifting) in children will follow.

Working Memory. Working Memory (WM) refers to the ability to hold and manipulate perceptual representations in mind, and infants as young as 6-month-old can hold representations in mind over a delay, as demonstrated by the Delayed Response task (Diamond, 1985), with performance gains seen between 6 to 12 months of age (Diamond & Doar, 1989). Digit and word span tasks, requiring children to recall increasingly longer lists of numbers and words verbatim, have been used in toddlers and school-age children to assess the ability to hold representations in mind. Studies have found that the ability to retain items in mind considerably improves between the ages of 3 and 5 years, and continues to develop throughout childhood (Espy & Bull, 2005; Gathercole, 1998). The ability to manipulate information in mind develops more slowly, and it has been assessed with more complex WM tasks that require participants to mentally reorder digits or words. The Digit Span Backwards (DSB) is a WM task that requires the individual to repeat lists of numbers in reverse order, with evidence that its success rate among three-year-olds is less than 10%, with gains up to 85% in 6-year-olds (Carlson, 2005). Other studies have demonstrated that performance on this task continues to improve between the ages of 7 and 15 years (Isaacs & Vargha-Khadem, 1989; Gathercole, 1998).

Inhibition. There are different conceptualizations of inhibition in the literature of psychology, but the present study purposefully focused on reviewing the concept of inhibition that is implicated in Miyake and colleagues' model of EF – the ability to deliberately suppress automatic responses (Miyake et al., 2000). This construct is frequently measured with tasks such as the Stroop paradigm which requires the ability to suppress automatic or habitual in favor of a novel response. The Shape task, for instance, is an adaptation of the classic Stroop (1935) test administered to young children, where children are shown small pictures of fruits that are embedded in larger pictures of fruits, and are required to point to the smaller fruit picture while inhibiting the dominant response to point to the larger fruit. As early as the age of two years, children can complete this task successfully (Carlson, 2005; Kochanska et al., 1996). Another modification of the Stroop paradigm is the grass-snow task, which requires children to point to a white card when the experimenter says grass, and to point to a green card when the experimenter says snow. Only 45% of 3-year-olds are successful in this task, but performance significantly improves between the ages of 4 and 5 years (Carlson, 2005). Performance on the classic Stroop, which requires participants to name the color in which words are printed and suppress the automatic response of reading the words, has been found to significantly improve between the ages of 7 and 21 years (Altemeier et al., 2008; Huizinga, Dolan, & van der Molan, 2006).

Shifting. The construct of shifting is also known in the literature of psychology as set shifting, attention shifting, switching or cognitive flexibility. It is not a very well defined construct, but it has been described as the ability to flexibly shift attention between mental sets, attributes of a stimuli, or strategies, and to be involved in problem-

solving and self-monitoring (Denckla, 1996; Diamond, 2013; Miyake et al., 2000).

According to Diamond (2013), shifting builds upon WM and inhibition processes, as it first requires the formation of a mental set in WM, and then the suppression of that initial mental set in order to activate another one. Consequently, shifting appears to develop later than WM and inhibition (Diamond, 2013; Carlson, 2005; Garon, Bryson, & Smith, 2008), with substantial improvements between the ages of 5 and 7 years, and with slower improvements throughout the school years (Best, Miller, & Naglieri, 2011).

Since there are different conceptualizations of shifting, different tasks have been used to assess this construct. For the most part, shifting tasks tend to involve a stimulus that varies on at least two dimensions whereby participants have to shift their attention between them (Bastian & Druey, 2017; Garon et al., 2008). However, the number of shifts and the nature of shifts that participants are required to make varies considerably from task to task. Goal setting demands also differ, with some tasks explicitly informing participants when to shift, and to which dimension to shift their attention, while other tasks do not inform participants of the shift rule.

As Bastian and Druey (2017) noted, shifting tasks are operationalized across different representational levels. The Trail Making Test (TMT; Reitan, 1971), for instance, has been extensively used in psychology and it involves shifting attention at the stimulus set level. On this task, participants have to connect numbered circles in the first condition, and subsequently alternate between connecting numbered and lettered circles in the second condition. Thus, they have to shift attention between two distinct stimuli in the task. The criteria for shifting in the TMT is made explicit to participants and performance is measured by completion time. Since this test relies directly on number

and alphabetic-letter sequences, adaptations for young children have been created. The Trails-P task (Espy & Cwik, 2004), for instance, requires children to stamp dogs in order of size in the first condition, and alternate between stamping dogs and bones in order of size in the second condition. Children's performance on tasks from this shifting paradigm improves considerably between the ages of 3 and 5 years (Espy & Cwik, 2004). Research using the TMT with school age children has shown that performance on this task significantly improves between the ages of 6 and 15 years, with larger improvements in the early years (Best, Miller, & Naglieri, 2011).

The Wisconsin Card Sorting Test (WCST) is another widely used task in psychology which measures shifting at the judgemental level (Bastian & Druey, 2017). This task requires participants to sort cards across three dimensions (color, shape and number), but they are not informed of the sorting criteria. Instead, participants shift their attention to task dimensions based on feedback provided by the examiner (i.e., whether their sorting was correct or incorrect). Shifting ability has been frequently measured by perseverative error scores, reflecting participants' failure to flexibly shift attention when sorting criteria has changed (Kieffer et al., 2013; Miyake et al., 2000). WCST has been widely used with adult populations, but it is also considered appropriate for assessing shifting ability in children as young as the age of 7 years (Denckla, 1994). Perseverative errors have been reported to significantly decline in school age children between 7 to 8 years of age, and then again between the ages of 9 to 10 years (Levin et al., 1991). Perseverative errors continue to decline until the ages of 21 years (Huizinga et al., 2006).

Due to the difficulty level of the WCST, similar tasks have been developed for younger children. The Dimensional Change Card Sort (DCCS), for instance, has been

extensively used with younger children (Cragg & Chevalier, 2012) requiring them to sort cards between two dimensions only (e.g., color and shape) while being explicitly informed of the sorting rule. Carlson (2005) found that although only 20% of 3-year-olds were successful in the DCCS test, 60% were successful at the age of 4 years. In addition, almost 40% of 5-year-olds were successful on a more difficult version of the DCCS test.

Researchers in the field of educational psychology have also developed shifting tasks that are domain-specific, that is, tasks in which shifting specifically operates on reading skills. The Rapid Automatic Naming of Words and Letters subtest (PAL RAS) of the Process Assessment of the Learner (PAL; Berninger, 2001), for example, involves shifting of linguistic information as participants are required to rapidly and accurately name alternating categories of stimuli that are presented to them (e.g., words and numbers). In this task, participants must scan and sequence stimuli across lines, as well as integrate visual and verbal codes to name the different stimuli presented to them (Wolf & Bowers, 1999). Performance on the PAL RAS task significantly improves in students from grades 1 to 6; however, gains are substantially larger in the first school years between grades 1 and 3, and slows down in the following three years between grades 4 and 6 (specific ages of participants were not reported by the study; Altemeier et al., 2008).

In sum, all these findings provide evidence that EF processes such as WM, inhibition, and shifting undergo significant improvements in early childhood and continue to develop during the school years. A well debated question in psychology is the structure and organization of EF processes and how this structure changes overtime. Miyake and colleagues (2000) examined the structure of EF (WM, inhibition, and

shifting) using confirmatory factor analysis (CFA), a method that extracts common variance among EF tasks and creates latent variables of EF processes. Miyake and colleagues (2000) found these EF processes to be moderately correlated but distinguishable constructs, in a sample of adults.

Other studies examining the structure of EF with these same EF processes in pre-school children followed, finding a unitary EF factor structure to best fit the data, a model in which all three EF processes represented a unitary construct (Fuhs & Day, 2011; Wiebe et al., 2008; Wiebe et al., 2011; Willoughby, Blair, Wirth, R. J., & Greenberg, M., 2012). However, a three-factor model has been found among children between the ages 8 and 13 (Lehto et al., 2013), and among 15-year-olds (Lee, Bull, & Ho, 2013), with EF processes associated with each other but representing separate constructs, consistent with the model found by Miyake and colleagues in adults (Miyake et al., 2000). In two other studies, a two-factor model of WM and shifting has been found in children between the ages of 9 and 12 years (Huizinga et al., 2006; van der Sluis, de Jong, & van der Leij, 2007). These studies, however, were unable to extract a latent variable for inhibition due to low correlations among inhibition tasks. Thus, it is unclear whether inhibition would have loaded as a separate factor were inhibition measures more highly correlated. Evidence for a two-factor model has also been found in a sample of children between the ages 5 and 14, with WM as one factor, and inhibition and shifting combined in another factor (Lee et al., 2013).

As Mueller and Kerns (2015) have noted, despite the discrepancy of findings across these studies, the pattern of findings suggest differentiation among EF processes in the early school years. In summary, research strongly suggests that differentiation of EF

processes takes place, with evidence suggesting that it is around the early school years, between ages of 8 and 9 years, reflecting an EF structure that has resemblance to the one found in adults (Huizinga et al., 2006; Lehto et al., 2013; van der Sluis, de Jong, & van der Leij, 2007). Consequently, several studies investigating the relation of EF and reading in children have operationalized EF processes (WM, inhibition and shifting) as separate constructs (Christopher et al., 2012; Swanson & Jerman, 2007), and the present study follows this same conceptualization.

The development of EF has been largely attributed to the development of language skills (Luria, 1973). Language has been defined as “the ability to communicate complex concepts, ideas, desires, and emotions to others” (Allen & MacNamara, 2016, p. 87), and it has been proposed to support the human cognitive system by providing cognitive representation of the external environment, and directing one’s attention to different concepts and perspectives (Allen & MacNamara, 2016). More specifically, Luria (1973) proposed that language mediates the development of EF processes. According to him, children develop EF processes early in life through social interactions with caregivers as they internalize caregivers’ verbalizations and consequently develop inner speech, allowing them to plan, monitor, and regulate their own thoughts and behaviors. There is evidence that language ability, assessed with expressive and receptive verbal ability tasks, significantly predicts the development of EF processes in children (Fuhs & Day, 2011; Hughes and Ensor, 2009) and that language ability and EF processes may have a reciprocal relationship overtime (Gooch, Thompson, Nash, Snowling, & Hulme, 2016; Slot & von Suchodoletz, 2018). Therefore, language skills appear to be highly

involved in EF processes, which leads to certain methodological challenges discussed in the next section.

Methodological Problems in the Assessment of EF

Measuring EF processes and examining them in relation to other variables is not free of challenges. There are several methodological problems in the assessment of EF that impact research hypotheses and interpretation. The well-known task impurity problem, for instance, refers to the difficulty of separating executive from non-executive demands in EF tasks, because EF tasks by nature operate on other cognitive abilities such as language and visuospatial processing (van der Sluis et al., 2007). This is challenging because non-executive task components may mask the commonalities among EF tasks (Miyake et al., 2008). Various studies have also found a large and significant amount of shared variance between general intelligence and EF processes, specifically with WM (Ackerman et al., 2005; Colom, Abad, Quiroga, Shih, & Flores-Mendoza, 2004; Kane, Hambrick, & Conway, 2005), intensifying the discussion on the elusive definition of EF and the challenges with its measurement.

Confirmatory Factor Analysis (CFA) has been increasingly used as a statistical method to overcome the task-impurity problem, as it allows for the extraction of common variance among several EF tasks that presumably measure the same EF process, creating a latent variable that is considered purer (Mueller & Kerns, 2015). Since EF processes work simultaneously in goal-directed behavior, it is also common for tasks to tap into multiple EF components, making it difficult to isolate one in particular and to determine which EF process that task primarily measures. For instance, the DSB is a widely used measure of WM (Diamond, 2013; Garon et al., 2008), but it has also been shown to make

demands on inhibition, since it requires suppression of the dominant response of repeating words in the same order that it was originally heard (Mueller & Kerns, 2015). The Trail Making Test (TMT) is often conceptualized as a task of shifting ability (Bastian & Druey, 2017; Espy & Cwik, 2004), but it has been also found to load on a WM factor, leading some researchers to conclude that this task involves WM resources to keep track of former responses (van der Sluis et al., 2007; Locascio et al., 2010). Similarly, although the WCST has been used as a shifting task (Kieffer et al., 2013; Miyake et al., 2000), it is also considered a complex EF measure that makes demands on multiple other abilities including WM (Huizinga et al., 2006; Wang, Kakigi, & Hoshiyama, 2001), inhibition of previous task set (Salthouse et al., 2003; Wang et al., 2001) and problem-solving skills (Greve et al., 2002). The fact that EF tasks tap into multiple executive and non-executive abilities presents considerable challenges in examining the relation of EF processes with other constructs. Despite the difficulties associated with the measurement and definition of EF, a growing number of studies have examined the association of EF processes and reading comprehension in school age children (Kieffer et al., 2013; Sesma et al., 2009; Swanson & Jerman, 2007). The next section will report on what is currently known about the contributions of EF processes to reading comprehension.

The Role of EF Processes in Reading Comprehension

The association of EF processes with pre-literacy and word-level reading skills in preschoolers and elementary school children has been well documented (Arrington, Kulesz, Francis, Fletcher, & Barnes, 2014; Bull, Espy, & Wieber, 2008; Yeniad, Malda, Mesman, van Ijzendoorn, & Pieper, 2013; Welsh, Nix, Blair, Bierman, & Nelson, 2010;

Willoughby, Blair, Wirth & Greenberg, 2012), raising speculation that these processes may also play a role in reading comprehension.

According to a more recent and elaborated model of reading comprehension – the Integrated Model of Reading Comprehension (IMRED) – reading comprehension goes beyond word-level reading and oral language comprehension skills. It also involves the ability to attend to and integrate multiple text and cognitive elements in WM simultaneously in order for the reader to create a coherent mental representation of text in mind (Broek & Espin, 2012). These elements include word and sentence meanings, concepts from background knowledge and current mental representations, as well as ongoing monitoring of comprehension. Studies investigating the association of WM and reading comprehension have found WM to significantly contribute to reading comprehension performance above and beyond word-level reading and oral language comprehension skills (Arrington et al., 2014; Cain et al., 2004; Christopher et al., 2012; Cutting et al., 2009; Seigneuric & Ehrlic, 2005; Sesma et al., 2009; Swanson & Jerman, 2007).

Sesma et al. (2009) found WM to make a significant contribution to performance on the reading comprehension subtest of the WIAT-II (Wechsler, 2005) among English speaking children between the ages of 9 and 15 years, adding 4% of shared variance to reading comprehension performance, after attention, decoding, fluency and receptive vocabulary were controlled for in their model. Using the French version of the WIAT-II test, Seigneuric and Ehrlic (2005) found WM to significantly predict reading comprehension performance among children in grade 3, after accounting for decoding and receptive vocabulary skills. These findings are relevant to the present study as it also

makes use of the WIAT-II test for assessing reading comprehension performance in grade 3 students.

Children with reading comprehension difficulties whose WM were assessed over three consecutive years were also found to have a significantly lower estimate of WM growth compared to children with intact reading comprehension skills (Swanson & Jerman, 2007). Swanson and Jerman (2007) found growth estimates of WM to significantly predict reading comprehension performance on the Woodcock Reading Mastery Test-Revised (WRMT-R) across their sample of children between the ages of 11 and 17 years, when short term memory (STM), IQ, reading fluency, and word reading ability were controlled for. Altogether, evidence strongly suggests that WM contributes to reading comprehension in school age children, supporting the IMRED framework.

Unlike the association between WM and reading comprehension, the role of inhibition in reading comprehension has been equivocal. Studies that have operationalized this construct as prepotent response inhibition have reported mixed findings. For instance, Altemeier et al. (2008) assessed inhibition with the Color-Word Interference (CWI) task (Delis, Kaplan, & Kramer, 2001) in their longitudinal study, and found that the growth of inhibition across grades 1 to 4 significantly predicted performance on the reading comprehension subtest of the WIAT-II in English speaking fourth graders (specific ages were not reported by the study). Similarly, Kieffer and colleagues (Kieffer et al., 2013) assessed inhibition with an adapted version of the Stroop test, the number-quantity Stroop, and found performance on this test to significantly predict performance on the Gates–MacGinitie Reading Comprehension Test (GMRT) (MacGinitie, MacGinitie, Maria, & Dreyer, 2000) in fourth graders (ages between 9 and

10 years) after controlling for oral language comprehension, word reading ability, and WM. Conversely, Nouwens, Groen, and Verhoben (2016) assessed inhibition with the CWI task and did not find evidence that it makes a significant contribution to reading comprehension performance in a sample of Dutch students between 9 and 12 years of age. Furthermore, Borella, Carretti, and Pelegrina (2010) found no group differences on the Animal and Color Stroop tasks between children with good and poor reading comprehension skills between ages 10 and 11 years. In summary, the role of prepotent response inhibition in reading comprehension is uncertain and more research is needed to establish this association.

Performance on tasks of shifting have been found to significantly contribute to word-level reading skills in school age children (Yeniad et al., 2013), but the role of shifting in reading comprehension is still not well understood. Cartwright (2009) hypothesized that shifting facilitates the reading comprehension process by allowing the reader to simultaneously shift attention between text and cognitive elements, actively monitor reading comprehension, and activate strategic processes for comprehension. Cartwright suggested that reading comprehension involves more than just WM resources as “holding a number of task elements in mind (...) does not ensure that one can shift attention flexibly between those elements” (Cartwright, 2009, p. 119). The few studies that have examined the relation of reading comprehension and shifting in school age children have found a significant association between these constructs. However, these studies had different sample compositions and they assessed shifting with different shifting paradigms, making comparisons across these findings somewhat difficult.

Nouwens and colleagues (Nouwens et al., 2016), who examined the relation between shifting and reading comprehension performance in a sample of Dutch native speakers (ages between 9 and 12 years) found performance on the Trail-Making Test (Delis et al., 2001) to make a significant contribution to performance on a standardized Dutch reading comprehension test after controlling for word recognition, receptive vocabulary, STM, non-verbal cognitive ability, and inhibition. Their shifting task explained a significant 3% of shared variance in reading comprehension performance. Similarly, Kieffer et al. (2013) examined the contribution of shifting ability to reading comprehension in grade 4 students in a sample where 61% of students spoke a language other than English at home. Using a multivariate path model analyses and measuring shifting with the WCST-64, they found performance on this task to make a direct contribution to performance on the GMRT reading comprehension test in grade 4 students, above and beyond phonological awareness, word recognition, oral language comprehension, processing speed and WM.

Other studies have examined the association between reading comprehension and shifting using shifting tasks that are reading-specific. For instance, a longitudinal research study with English native speaking students assessed shifting with the PAL RAS task (Altemeier et al., 2008). Altemeier and colleagues found performance on the PAL RAS test to uniquely predict performance on the reading comprehension subtest of the WIAT-II in grades 2, 3 and 5, after accounting for inhibition, explaining 10-18% of shared variance in reading comprehension across grades. These researchers also found gains in shifting across grades 1 to 4 to significantly predict reading comprehension in grade 4 (specific ages were not reported by the study).

Cole, Duncan, and Blaye (2014) assessed shifting with two double classification tasks in grade 2 students (mean age of 7 years) who were French native speaking. The first task was considered domain-general as it involved the classification of pictures. The second task was reading-specific as it involved the classification of printed words. Both tasks demanded the simultaneous processing of two dimensions (phonology and semantics), as students were required to classify stimuli by what they heard at the beginning of the picture name and printed word (phonology), and by the meaning of the picture and printed word (semantics). Cole and colleagues (2014) found the domain-specific task to uniquely predict reading comprehension performance above and beyond word-level reading skills, adding 9.7% of shared variance in the outcome variable. The domain-general shifting task, however, did not significantly contribute to reading comprehension in their sample.

Similarly, Cartwright et al. (2016) assessed shifting in English speaking first and second graders (mean age of 7 years) with domain-general and reading-specific double classification tasks. Their reading-specific shifting task required students to sort four sets of 12 printed words by initial phoneme and semantic category, while the domain-general task involved sorting pictures by color and shape. Cartwright and colleagues (2016) found that students with reading comprehension difficulties (at or below the 40th percentile on the passage comprehension of the WRMT-R) performed significantly lower than controls on both shifting tasks, but revealed that performance on the domain-general task was partially mediated by vocabulary and verbal ability. Furthermore, these researchers found that students with reading comprehension difficulties who received an intervention based on their reading-specific shifting measure for one academic school

year significantly improved in reading comprehension performance, with reading comprehension performance growth being comparable to that of typically-developing peers.

Altogether, these studies provide emerging evidence that shifting ability may support reading comprehension performance in school age children. However, more research is needed to determine the association between shifting and reading comprehension in native English speaking students in the early elementary school grades. Most studies examining the relation of shifting and reading comprehension have relied on a single measure of shifting, and the measures selected have widely varied across studies. Due to the task impurity nature of EF, it would be beneficial for studies to assess shifting with multiple tasks that differ in their non-executive components. In addition, given the different definitions of shifting in the literature and their associated tasks, examining shifting with different tasks may clarify which definition of shifting is more closely related to reading comprehension.

Executive Summary and the Present Study

Reading comprehension is a multi-componential process encompassing word-level reading and oral language comprehension skills (Gough & Tunmer, 1986), and more recently, EF processes have been implicated in the reading comprehension performance in school age children (van der Broek & Espin, 2012). Contemporary views of EF have emphasized three core EF processes: WM, inhibition, and shifting (Miyake et al., 2000). While the association of reading comprehension and WM has been well-established (Jerman and Swanson, 2007; Christopher et al., 2012) and inhibition has gained some attention despite inconclusive findings (De Beni & Palladino, 2000; Kieffer

et al., 2013), shifting ability has been underexplored in relation to reading comprehension. The purpose of the present study was to examine the relation of shifting and reading comprehension performance in third grade students. The IMRED model provides a framework to examine shifting in relation to reading comprehension; hence, the use of this reading model in guiding the present study. The few studies examining shifting and reading comprehension skills in school age children have found evidence for a positive association (Altemeier et al., 2008; Cartwright et al., 2016; Kieffer et al., 2013). However, most of these studies have relied on a single measure of shifting and these measures have widely differed across studies. There is certainly a need for assessing shifting with multiple shifting tasks to gain insight on the definition of shifting that is more likely implicated in reading comprehension and to compare findings with previous studies.

The present study addresses this gap in the literature by exploring the relation of reading comprehension, shifting, and well-established predictors of reading comprehension skills (word-level reading skills, receptive vocabulary, and WM) in English native speaking students in grade 3, using three distinct shifting tasks that have been previously used in the reading comprehension literature – the Trail Making Test, the WCST-64, and the Rapid Automated Naming and Rapid Alternating Stimulus Test (RAN/RAS). The contribution of shifting to reading comprehension performance in third graders was also examined after controlling for well-established predictors of reading comprehension.

The present study was part of a larger research study examining the influence of EF processes on reading and writing skills of grade 3 monolingual English-speaking

students and those attending early French immersion. For the current study, research analyses were only conducted on the monolingual English speaking group of participants to control for language proficiency. Examining the relation of shifting and reading comprehension in third grade students is appropriate and timely, given that shifting is differentiated and measurable at this developmental period, and students have acquired the word-level reading skills necessary for reading comprehension to take place (Best, Miller, & Naglieri, 2011; Carlson, 2005; Lehto et al., 2003). Therefore, this is a developmental period where both reading comprehension and shifting ability could be reasonably assessed. The examination of these constructs is also very relevant to the field of educational psychology, as it may expand the current knowledge on the components of reading comprehension in the early elementary school years and inform contemporary models of reading comprehension.

The present study addressed the following research questions: a) Is performance on reading comprehension associated with performance on shifting tasks and well-established predictors of reading comprehension (word decoding, word recognition, receptive vocabulary, and WM)? b) Does performance on each shifting task explain unique variance in reading comprehension performance above and beyond word-level reading skills, receptive vocabulary, and WM? The next section will describe the methods of the present study.

Methods

This study was part of a larger cross-sectional research study examining the influence of EF processes on reading and writing skills of grade 3 monolingual English-speaking students and those attending early French immersion. The present study examined the association of shifting, reading comprehension, and its well-established components, among the monolingual English-speaking sample only.

Participants

A total of 36 monolingual English-speaking children, with a mean age of 8 years and 6 months (21 girls, 15 boys) participated in the study. All participants attended third grade in the same school in a community in Western Canada in which English was the language of instruction. No formal measure was used to obtain participants' SES background; however, the school was situated in a predominantly Caucasian, middle class neighborhood, in which 91% of the region reported to be English-speaking only (Statistics Canada, 2012). Teachers nominated children who had no reported history of intellectual, motor or developmental disabilities, uncorrected visual or hearing deficits, or Attention-Deficit/Hyperactivity Disorder (ADHD), and who did not have an English Language Learner (ELL) designation. Parents provided signed consent for their children's participation and children provided verbal assent before participating in the study.

Measures

All tasks in the present study were normed on English-speaking populations and were administered according to the standardized procedures described in the test manuals.

Reading comprehension. The reading comprehension subtest of the Wechsler Individual Achievement Test-Second Edition (WIAT-II; The Psychological Corporation, 2002) was administered as a measure of reading comprehension. The WIAT-II is a standardized, norm-referenced achievement measure; the reading comprehension subtest involves reading a series of passages, silently or aloud, and answering orally posed questions about the reading passages. Questions pertain to the content of passages (e.g. main idea, story details), inferences that can be made from the story's content, and the specific meaning of certain words within text. Participants are permitted to refer back to text while answering questions. Starting and stopping rules for this subtest are based on the basal and ceiling rules described in the test manual. The internal consistency reliability of the reading comprehension subtest is high, with alpha coefficient ranging from .94 to .96 for ages 8-9, and it has been used by several studies in the research literature (Altemeier et al., 2008; Cutting & Scarborough, 2006; Garcia & Cain, 2014; Sesma et al., 2009).

Word recognition. The ability to read words accurately was measured using the word reading subtest of the WIAT-II (The Psychological Corporation, 2002), which has been previously used to assess word recognition in other studies investigating literacy skills and reading comprehension (Altemeier et al., 2008; Cutting & Scarborough, 2009; Sesma et al., 2009). This untimed subtest involves providing participants with a graded word list in which participants have to pronounce letter names and basic words accurately. Starting and stopping rules for this subtest are based on the basal and ceiling rules described in the test manual. The internal consistency reliability coefficient is .98 for this subtest between the ages of 8 and 9 years.

Decoding. The pseudo-word decoding subtest of the WIAT-II (The Psychological Corporation, 2002) was used to assess word decoding ability and it has been previously used in other studies to measure this construct (Altemeier et al., 2008; Monette, Bigras & Guay, 2011). This untimed subtest involves providing participants with a list of non-words which they have to pronounce accurately according to English phonetic rules. Starting and stopping rules for this subtest are based on the basal and ceiling rules described in the test manual. The internal consistency reliability alpha coefficient for this subtest ranges from .97 to .98 between the ages of 8 and 9 years.

Receptive vocabulary. Oral language comprehension was estimated using a measure of receptive vocabulary in the present study – the Peabody Picture Vocabulary Test – Fourth Edition (PPVT-4) (Dunn & Dunn, 2007). Despite receptive vocabulary representing only one facet of oral language comprehension, this test has been widely used across studies in the psychology literature (Cutting & Scarborough, 2009; Sesma et al., 2009; Nouwens et al., 2016) and is significantly correlated with oral language comprehension tests (Cutting et al., 2009). In this test, participants have to identify one of four pictures that correspond with a verbally presented word. Participants are given the option of selecting the corresponding picture by either pointing or naming the number on the picture. Starting and stopping rules for this subtest are based on the basal and ceiling rules described in the test manual. The internal consistency reliability alpha coefficient ranges from .93 to .94 for children between the ages of 5 and 9. The PPVT-4 is a receptive vocabulary measure strongly associated with overall cognitive ability (Cain, Oakhill, & Bryant, 2004; Cutting et al., 2009), and consequently it was also used in this study as an IQ screener.

Working memory. The Digit Span Backward (DSB) test of the Wechsler Intelligence Scale for Children, Fourth Edition (WISC-IV; Wechsler, 2003), was administered to assess verbal working memory (verbal WM), a widely used measure in the literature of clinical and educational psychology (Cutting et al., 2009; Harrison et al., 2015). The DSB requires participants to orally repeat increasingly longer number strings in the reverse order to which they were presented. Starting and stopping rules for this subtest are based on the basal and ceiling rules described in the test manual. The internal consistency reliability alpha coefficient ranges from .78 to .86 for children between the ages of 6 and 8.

Shifting. Three tasks were administered in the present study to assess shifting ability: The Trail Making test, the RAS-3 subtest of the RAN/RAS, and the WCST-64.

Trail Making test. The Trail Making test (Delis et al., 2001), previously used to assess shifting by Nouwens et al. (2016), was the first shifting measure administered. It involved connecting 16 consecutive targets on a sheet of paper as quickly and as accurately as possible. The Trail Making test consists of four conditions: The first condition involves visual scanning where participants have to find a particular number on the stimulus paper. In the second condition, participants have to connect a sequence of numbers (1, 2, 3, etc.), while in the third condition, participants have to connect a sequence of letters (A, B, C, etc.). In the fourth condition, participants must alternate between connecting numbers and letters. During the test, participants are informed when they make an error and are required to correct it before proceeding to the next target. Scores on this test were derived from the total time it took to complete the fourth

condition. The test-retest reliability coefficient for this test is reported to be .89 (Delis et al., 2001).

RAS-3. The RAS-3 Numbers, Letters and Colors task of the Rapid Automatized Naming and Rapid Alternating Stimulus Test (RAN/RAS) (Wolfe, & Denkla, 2005), was the second measure administered in this study to assess shifting. Altemeier et al. (2008) administered a similar version of this test (PAL/RAS; Berninger, 2011) in typically developing children to examine the relation of shifting and reading comprehension. Furthermore, they used the RAN/RAS test to examine the relation of shifting and reading comprehension in a sample of children with dyslexia (Altemeier et al., 2008). The RAS-3 Numbers, Letters and Colors consists of participants quickly and accurately naming a series of random letters, numbers and colors. Scores were derived from the total time it took participants to complete this task. The test-retest reliability coefficient for this test ranges from .90-.91 for samples of elementary school age children (Wolfe, & Denkla, 2005).

WCST-64. The non-computerized 64-card version of the Wisconsin Card Sorting Test (WCST-64; Kongs, Thompson, Iverson, & Heaton, 2000) previously used by Kieffer et al. (2013), was the third measure administered to assess shifting. This test involves 64 cards that display different shapes (e.g., triangle, square and circle) and these shapes differ in color and number. Participants were asked to sort cards along an unspecified dimension (e.g., color). They were not told which sorting rule was in effect, but were provided with immediate feedback regarding whether their sorting matches were correct or incorrect. After ten consecutively correct sorting matches, the sorting rule is changed without notifying participants. The sorting rules consisted of color,

shape, and number consecutively administered. Shifting score was derived from the number of perseverative errors committed by participants in the test. Perseverative errors are defined as applying a previous sorting rule after obtaining feedback that the rule is no longer in effect. Other researchers have used perseverative error scores to operationalize shifting ability in this test (Kieffer et al., 2013; Miyake et al., 2000). The generalizability coefficient of perseverative errors is .76 for children and adolescents.

Procedure

Participants completed all tasks individually in a quiet room in their school, during one session that lasted approximately an hour. All tasks were administered in counterbalanced order across 3 blocks (EF measures, receptive vocabulary, and reading measures), with a fixed order of tasks within blocks (i.e., EF tasks: Trail Making test, RAN/RAS, WCST-64, and DSB; receptive vocabulary: PPVT-IV; reading measures: pseudoword decoding, word reading, and reading comprehension subtest of the WIAT-II). Data collection took place during the midpoint (February-March) of the 2017 and 2018 school year and it was conducted by the principal investigator of the larger research project and the author of the present study.

Results

Raw scores were converted to standard scores across all measures using standard scoring guidelines for each measure. A composite word-level reading score was computed based on students' combined performance on the WIAT-II word recognition and decoding subtests. This composite score, which represented students' mean performance on both tasks, was used in subsequent regression analyses. For all analyses, all cases were included as there was no missing data. Preliminary analyses indicated a normally distributed range of residuals across all variables. Tolerance indices indicated no problems with multicollinearity as none of the values fell below .20. There was no indication of autocorrelation in the data as Durbin-Watson's *d* test values fell within 1.5 to 2.5 for all regression analyses. Furthermore, the variance of residuals was examined using q-q plots and a histogram, and residuals were found to be constant, meeting the key assumption of homoscedasticity.

First, descriptive results will be presented, followed by the results of the correlation analysis. This analysis addresses the first research question on the associations among reading comprehension, shifting and well-established predictors of reading comprehension (word recognition and word decoding skills, receptive vocabulary, and WM). Finally, to address the second research question on whether shifting significantly contributes to reading comprehension after controlling for word-level reading, receptive vocabulary skills, and WM, a series of hierarchical regression analyses were conducted. Since each shifting task was affiliated with a distinct shifting paradigm, regressions analyses were conducted separately for each shifting task. This method allows for comparison across tasks and provides insight on the role of shifting in reading comprehension.

Descriptive results are presented on Table 1. There were no significant gender differences across variables, except for performance on the reading comprehension subtest of the WIAT-II, in which female participants significantly outperformed male participants ($t = 2.81$, $df = 34$, $p = .004$). All participants fell within the average and high average range on the PPVT-4 test. The mean value for performance on all reading and EF measures was within the average range across the sample. Correlation and hierarchical regression analyses were conducted and are reported in the following sections.

Table 1

Descriptive statistics across reading, language, and EF measures

Measure	M	(SD)	Min.	Max.
Age in months	103.97	(3.52)	98	110
Pseudo-word decoding (WIAT-II)	102.97	(11.31)	80	123
Word Reading (WIAT-II)	104.14	(12.96)	77	132
Reading Comprehension (WIAT-II)	106.08	(12.77)	80	125
PPVT- 4	111.28	(10.51)	91	130
DSB (WISC-IV)*	9.50	(2.22)	6	17
Trail Making Test– Condition 4 (DKEFS)*	9.58	(3.21)	2	15
RAS-3 (RAN/RAS)	98.06	(10.04)	75	122
64-WCST	104.67	(20.37)	72	145

Note. With the exception of Age, all other values are presented in standard scores.

* Only the DSB and Trail Making Test are presented in scaled scores.

Correlations between Reading Comprehension, Shifting, and Control Measures

Correlation analyses using Pearson product moment correlations were conducted to examine the relations between reading comprehension, shifting and its well established components (word recognition and word decoding skills, receptive vocabulary, and WM). Pearson's correlation coefficients are reported on Table 2. Reading

comprehension performance had significant and moderate positive correlations with performance on all shifting tasks, with correlation coefficients ranging from $r = .35$ to $r = .45$. Performance on shifting tasks had small and nonsignificant correlations with one another, however. WM did not significantly correlate with reading comprehension performance ($r = .15, p = .362$). Reading comprehension performance also had a significant and moderate positive correlation with receptive vocabulary ($r = .51, p < .001$) and word recognition ability ($r = .54, p = .001$), while it had a smaller positive correlation with word decoding ability ($r = .38, p = .022$).

Table 2

Pearson's correlation coefficients among reading, language, and EF tasks (N = 36)

Measure	1	2	3	4	5	6	7	8
1. Reading Comprehension (WIAT-II)	–							
2. Pseudo-word decoding (WIAT-II)	.38*	–						
3. Word Reading (WIAT-II)	.54**	.85**	–					
4. PPVT- 4	.51**	.23	.26	–				
5. DSB (WISC-IV)	.15	.183	.06	.05	–			
6. Trail Making Test - condition 4 (DKEFS)	.39*	.063	.10	.37*	.04	–		
7. RAS-3 (RAN/RAS)	.45**	.27	.37*	.35*	.42*	.17	–	
8. WCST-64	.35*	.07	.20	.30	.04	.21	.32	–

* $p < .05$.

** $p < .01$.

Word decoding and word recognition skills were highly correlated ($r = .85, p < .001$), supporting the choice to create a composite variable for word-level reading skills. For a relatively small sample ($N = 36$), the current study obtained significant and small to moderate correlations between receptive vocabulary and shifting tasks, such as the RAS-3 ($r = .369, p = .033$) and the Trail Making test ($r = .372, p = .025$). Receptive vocabulary also had a positive correlation with the WCST-64 that approached significance ($r = .306, p = 0.69$).

Predictors of Reading Comprehension and Post-hoc Analyses

To answer the second research question, separate multiple regression analyses were conducted with each shifting task to examine whether shifting adds any unique variance to reading comprehension after controlling for word-level reading and receptive vocabulary skills. The composite variable for word-level reading skills was entered in step 1 of the model, followed by receptive vocabulary in step 2. Shifting was added in the last step of the model. Table 3 presents a summary of the multiple regression analyses.

WM was not entered in the regression analyses as a control variable since it did not significantly correlate with reading comprehension. Although preliminary analyses indicated gender differences on reading comprehension, there were no gender differences on the performance of all other tasks. Thus, gender was not controlled in the regression models as to not decrease the statistical power of the present study. The word-level reading composite was significant and accounted for 23.5% of variance in reading comprehension performance $F(1, 34) = 10.469, p < .01$. Receptive vocabulary added 16% of variance in reading comprehension performance, and the change in R square was

Table 3

Summary of three multiple regression analyses predicting reading comprehension

Step & Predictor	ΔR^2	ΔF	β
1. Word-level reading	.235**	10.46**	.485**
2. PPVT-4	.161**	8.77**	.415**
3. Trail Making Test - condition 4 (DKEFS)	.049	2.83	.239

Step Predictor	ΔR^2	ΔF	β
1. Word-level reading	.235**	10.46**	.485**
2. PPVT-4	.161**	8.77**	.415**
3. RAS-3	.040	2.24	.222

Step Predictor	ΔR^2	ΔF	β
1. Word-level reading	.235**	10.46**	.485**
2. PPVT-4	.161**	8.77**	.415**
3. WCST-64	.049	2.83	.239

* $p < .05$.

** $p < .01$.

also significant at $F(33, 1) = 8.77, p < .01$. Adding shifting in the last step of the model added 4% to 4.9% of variance in reading comprehension performance across all regression analyses, but this small increase in R square was not statistically significant.

Because data from the present study supported previous findings that word-level reading skills are the strongest predictor of reading comprehension in the early elementary school years (Garcia & Cain, 2014), and previous studies have controlled for word-level reading skills only (Cole et al., 2014), three post-hoc regression analyses were conducted to examine the contribution of shifting to reading comprehension performance after controlling for word-level reading skills only. The purpose of these follow-up post-hoc analyses was to compare findings with studies that have used this more refined model

(Cole et al., 2014), and to examine how the absence of a language variable from the model might impact the contribution of shifting to reading comprehension performance in this sample.

Table 4

Summary of post-hoc multiple regression analyses predicting reading comprehension

Step & Predictor	ΔR^2	ΔF	β
1. Word-level reading	.235**	10.46**	.485**
2. Trail Making Test-condition 4 (DKEFS)	.124*	6.38*	.354*

Step & Predictor	ΔR	ΔF	β
1. Word-level reading	.235**	10.46**	.485**
2. RAS-3	.095*	4.69*	.328*

Step & Predictor	ΔR^2	ΔF	β
1. Word-level reading	.235**	10.46**	.485**
2. WCST-64	.082*	3.97*	.290*

* $p < .05$.

** $p < .01$.

Summary of these analyses are displayed on Table 4. For each of the regression analyses, the word-level reading composite was entered in the first step, followed by a shifting task in the second step. A significant model emerged for all three regression analyses. Shifting tasks added unique variance to reading comprehension performance, with R square ranging from 8.2 to 12.4%, after controlling for word-level reading skills. These analyses indicate that shifting accounted for additional variance in reading

comprehension performance above word-level reading skills, when receptive vocabulary was not added to the model.

Discussion

The present study examined the associations between reading comprehension, shifting, and well-established components of reading comprehension in English native speaking students in grade 3, across three distinct shifting tasks that have been previously used in the research field of reading comprehension, contributing to the limited body of research in this area. The next section will discuss findings pertaining to the research questions, and implications and limitations of the present study.

The Association of Reading Comprehension, Shifting, and Control Measures

The first research question of the present study addressed the associations among reading comprehension, shifting, and well-established predictors of reading (word-level reading skills, receptive vocabulary, and WM). Word-level reading skills and receptive vocabulary were significantly associated with reading comprehension performance, replicating previous findings (Keenan et al., 2008). Consistent with previous research, all shifting tasks had significant associations with reading comprehension performance in the present study (Cole et al., 2014; Kieffer et al., 2013; Nouwens et al., 2016). The RAS-3 had the strongest correlation with reading comprehension performance out of the three shifting tasks administered to participants, which may be due to task demands that closely resemble the reading process (i.e. scanning across lines, integrating visual and verbal codes, rapid naming of letters). In contrast, the WCST-64, had the smallest correlation with reading comprehension performance. This finding may be indicative of a task that exerts less demand on literacy skills involved in reading or the fact that the WCST-64 is a broader and more complex EF task involving multiple processes in addition to shifting

(Greve et al., 2002; Huizinga et al., 2006), perhaps masking the association of shifting with reading comprehension.

The significant association between reading comprehension performance and all three shifting tasks may indicate that reading comprehension and shifting are indeed related. However, these findings must be considered with caution since shifting tasks significantly correlated with receptive vocabulary (the WCST-64 approached significance) in this sample. Thus, non-executive task demands important for reading comprehension, such as language, may be the underlying factor for such associations.

The shifting tasks selected in the present study are associated with different shifting paradigms and they have all been used to operationalize shifting across studies in the reading comprehension literature (Altemeier et al., 2008; Kieffer et al., 2013; Nouwens et al., 2016). Correlation analyses found that all shifting tasks had small and nonsignificant associations with each other (although the WCST-64 and the RAS-3 tasks approached significance, p -value = .054), indicating that these measures do not represent a unitary construct of shifting, or that shifting in itself is not a unitary construct. These findings reflect the elusive conceptualization of shifting as an EF process and the need for greater consensus on the conceptualization and measurement of shifting as an EF processes across the literature of psychology.

The association between WM and reading comprehension performance was also examined. Even though studies have found support for the association between these constructs (Broek & Espin, 2012; Sesma et al., 2009; Swanson & Jerman, 2007), WM did not significantly correlate with reading comprehension performance in the present study. That is not to say, however, that WM and reading comprehension is not associated. The

non-significant correlation between these two constructs may be due to the use of one single measure to assess WM, since many studies finding these two constructs to be associated have assessed WM with a combination of tasks (Christopher et al., 2012; Swanson & Jerman, 2007). Furthermore, the small sample size of the present study may have limited the statistical power of the study and the detection of significance for small effect sizes, such as the ones observed in EFs (Nouwens et al., 2016; Sesma et al., 2009). Thus, findings of the association between these two constructs should be taken with caution and further examined in future studies with larger samples.

Predictors of Reading Comprehension Performance

Preliminary data analyses revealed gender differences on reading comprehension performance among participants, with female students outperforming male students in this skill. However, there were no gender differences on the performance of other reading, receptive vocabulary and EF measures. One explanation for this finding is that the reading comprehension task (WIAT-II reading comprehension subtest) used in this study relies heavily on oral language ability, as students have to answer orally-posed questions about text. Considering the evidence that there is a female advantage on verbal ability during the childhood years (Tenenbaum, Aznar, & Leman, 2014), it is possible that gender differences in reading comprehension found in this sample were due to the task used to assess this construct. Because there were no gender differences on the performance of the other measures, gender was not controlled in the regression analyses, in order to avoid a decrease in statistical power, given the small sample size.

The word-level reading skills composite and receptive vocabulary explained approximately 21% and 16% of shared variance in reading comprehension performance,

respectively, supporting the SVR framework and the importance of these constructs to reading comprehension performance in school age children. Furthermore, the present study found that word-level reading skills contributed more to reading comprehension performance than receptive vocabulary did, replicating prior findings with children at this developmental stage (Garcia & Cain, 2014).

Contrary to studies that found shifting to significantly contribute to reading comprehension performance above and beyond word-level reading *and* oral language comprehension skills (Kieffer et al., 2013; Nouwens et al., 2016), shifting ability (across all shifting tasks) did not explain unique variance in reading comprehension performance after both word-level reading skills *and* receptive vocabulary were controlled for in this study. Possible explanations for the discrepancy in these findings include sample composition and size, and control variables across studies. For instance, Kieffer and colleagues (2013) had a sample in which approximately 60% of participants were children who spoke another language other than English at home. It has been well-documented that children who speak another language at home underperform English native speaking counterparts on measures of receptive vocabulary and syntactic awareness, but may outperform them on shifting tasks (Byalitik, 2010; Harrison et al., 2016). Therefore, language skills and EF processes may exert different demands on reading comprehension performance in first- and second-language learners. Future studies should control for the language proficiency of the sample.

Studies that controlled for word decoding *and* oral language comprehension skills in their model sampled older children (Kieffer et al., 2013; Nouwens et al., 2016) than the present study, and the proportion of variance in reading comprehension explained by

shifting may vary as a product of development. Research on the development of EF processes has demonstrated that shifting continues to develop throughout the school years (Best, Miller, & Naglieri, 2011), but it is not clear whether shifting becomes more important for reading comprehension in the earlier or later school grades. Longitudinal research may shed light on the role of shifting in reading comprehension performance in school children over time. There is one study that examined the contribution of shifting to reading comprehension performance longitudinally (Altemeier et al., 2008); however, it did not compare the proportion of variance in reading comprehension performance explained by shifting across grade levels. Thus, this possibility needs further exploration.

Additionally, although some studies have found evidence for shifting significantly contributing to reading comprehension performance, these studies used analytic models that did not include word-level reading or oral language comprehension skills. For instance, although Altemeier and colleagues (2008) found shifting to explain variance in reading comprehension performance in grades 2, 3 and 5 in typically developing children, they did not control for word-level reading and oral language comprehension skills in their analyses. Similarly, Cole et al. (2014) found shifting ability to explain variance in reading comprehension performance beyond word-level reading skills in second graders, but they did not control for oral language comprehension skills in their sample. Thus, such discrepancy in findings may be the result of models that are less conservative than the model utilized in the present study.

Finally, another viable explanation is that the contribution of shifting to reading comprehension performance might be small, as observed by Nouwens et al.'s (2016) study which found shifting to uniquely add only 3% of variance in reading

comprehension performance, after controlling for word-level reading and receptive vocabulary skills. The small sample size of the present study may have limited statistical power to detect significance for the small contribution of shifting in reading comprehension. Therefore, the possibility that shifting contributes to reading comprehension above and beyond word-level reading and oral language comprehension skills should not be discounted. Future studies examining the role of shifting in reading comprehension performance should have larger samples in order to better detect significance of small effect sizes.

Since word-level reading skills was a stronger predictor of reading comprehension than receptive vocabulary skills in this sample, replicating previous research findings (Garcia & Cain, 2014), post-hoc analyses were conducted separately for each shifting task controlling for word-level reading skills only. The post-hoc analyses indicated that all shifting tasks explained unique variance in reading comprehension performance above word-level reading skills, adding 8.2 to 12.4% of variance in reading comprehension performance. These findings replicate prior research that used a similar model, finding shifting to add a similar proportion of variance in reading comprehension performance – 9.7% (Cole et al., 2014). These findings add support to the emerging evidence that shifting contributes to reading comprehension performance in the early elementary school grades, as shifting tasks from distinct shifting paradigms all added unique variance to reading comprehension performance. The Trail Making test added the most variance in reading comprehension performance of all shifting tasks. This finding suggests that the executive (and non-executive) demands of this task are more strongly involved in reading comprehension performance of third graders than the other shifting tasks. On the other

hand, the WCST-64 added the smallest variance in reading comprehension of all shifting tasks. This finding suggests that demands of this measure are also involved in reading comprehension, although to a lesser degree. However, it is important to consider that the WCST-64 is a complex EF task involving multiple other executive and non-executive tasks which may have potentially weakened the contribution of shifting to reading comprehension.

These findings also point to the intertwined relation of shifting and language skills, as the variance in reading comprehension explained by shifting decreased with the presence of a language variable in the model. Considering that language ability and EF processes are significantly related (Fuhs & Day, 2011; Hughes and Ensor, 2009), delineating how these two processes operate together to support reading comprehension performance is very important and would improve current theoretical models of reading comprehension. Studies investigating this proposition are scarce, however. Using multivariate path analyses to examine causal relations among shifting, oral language comprehension and reading comprehension, Kieffer et al. (2013) found shifting ability to make a small, direct contribution to reading comprehension, as well as an indirect contribution to reading comprehension performance via oral language comprehension. These authors concluded that shifting may play a role in the development of oral language skills, which in turn supports reading comprehension. However, their sample had a large proportion of second-language learners, limiting the generalization of these findings to first-language learners.

A more recent longitudinal study examining the relation of EF processes (WM, inhibition and shifting) and reading comprehension over a 1-year period in children

between the ages of 7 and 9 years found evidence for a bidirectional relationship between reading comprehension and all EF processes, after SES, verbal IQ and prior achievement were controlled for (Meixner, Warner, Lensing, Schiefele, & Elsner, 2018). This study, however, assessed each EF process with one single task. Given that EF tasks often involve language ability and other non-executive components, and that language ability and EF processes may have a bidirectional relationship (Slot & von Suchodoletz, 2018), it is possible that language ability might have underlain bidirectional relations between EF processes and reading comprehension in their sample. Although Meixner and colleagues (2018) controlled for verbal IQ, they did not include a multidimensional construct of oral language comprehension as one of its control variables. Therefore, future studies should better integrate knowledge from the research domains of EFs, language, and reading comprehension, and investigate with caution the role of these skills in the context of reading comprehension.

The contribution of shifting to reading comprehension has also been examined in the literature of reading comprehension in terms of reading-specific and domain-general tasks, and it has been suggested that reading-specific shifting tasks do better at predicting reading comprehension performance (Cartwright et al., 2016; Cole et al., 2014). Studies exploring shifting ability in relation to reading comprehension using reading-specific measures are valuable, as they may shed light to the specific role of shifting ability in the reading comprehension process. Cartwright et al. (2016), for instance, have raised the hypothesis that students with reading comprehension difficulties may experience challenges in flexibly switch between letter-sound information associated with printed words and the semantic information of those words. For example, after controlling for

word decoding and language ability, students with reading comprehension difficulties significantly underperformed students in the control group on the reading-specific shifting task (Cartwright et al., 2016). Domain-general shifting tasks may not detect such difficulties as they do not involve the shifting of attention between semantic and phonological information.

Nevertheless, interpreting findings on reading-specific shifting tasks should be done with caution. Although the RAS-3 task was more strongly associated with reading comprehension than the other two shifting tasks in the present study, it added less variance in reading comprehension performance than the Trail-Making test when controlling for word-level reading skills. Furthermore, when receptive vocabulary was added in the regression models as a control variable, the RAS-3 explained the least variance in reading comprehension performance across all shifting tasks. Thus, it is very likely that the non-executive components of the RAS-3 task (letter knowledge, literacy and language skills) were underlying the associations between this measure and reading comprehension, but when these non-executive abilities were controlled for in the regression analyses, the RAS-3 was no longer the strongest shifting measure in predicting reading comprehension performance.

Additional Considerations on EFs, Language, and General Intelligence

Although all shifting tasks administered in the present study have been used across the literature of reading comprehension to operationalize the construct of shifting, shifting tasks had small and nonsignificant correlations with one another in the present study. This finding may indicate that these shifting tasks do not represent a unitary construct of shifting or that shifting is not a unitary construct after all. Evidence has also

shown that shifting tasks – particularly the Trail Making test and the WCST-64 – tap into other executive and non-executive components (Sanchez-Cubillo et al., 2009; Huizinga et al., 2006; van der Sluis et al., 2007), possibly justifying the weak associations among all these tasks in the current study. Also, a significant association between shifting tasks, particularly the WCST-64 and the RAS-3, may have been observed if the sample was larger and capable of detecting significance for small effect sizes.

Given that the Trail Making test and the WCST-64 have been found to also tap into WM and inhibition processes (Huizinga et al., 2006; Salthouse et al., 2003; van der Sluis et al., 2007), the possibility that these EF processes may have also contributed unique variance to reading comprehension performance cannot be discounted, especially because the models of the present study did not control for these two constructs. In order to better control for the measurement of shifting in the future, studies in the literature of reading comprehension should use more sophisticated statistical methods, such as Confirmatory Factor Analysis (CFA) or the use of control tasks. Such methods will provide clearer interpretations on the relations of shifting and reading comprehension.

Another important consideration when interpreting results of this study is that although receptive vocabulary tasks have been often used to estimate oral language comprehension across studies in the reading comprehension literature, receptive vocabulary is only one facet of the multidimensional construct of oral language comprehension. It is important that future studies use additional tasks to assess oral language comprehension (e.g. syntactic and grammatical knowledge, inference making) (Cutting & Scarborough, 2006), so that oral language comprehension is better defined and does not overlap with other constructs. For instance, contemporary

conceptualizations of general intelligence, particularly verbal IQ, includes vocabulary knowledge (Cain, Oakhill, & Bryant, 2004; Cutting et al., 2009; Meixner et al., 2018), and studies have used receptive vocabulary skills to operationalize both verbal IQ and oral language comprehension, leading these constructs to overlap. Therefore, defining oral language comprehension as a multi-componential construct (with additional language tasks) may allow for more distinction of this construct with verbal IQ, clarifying their roles in the reading comprehension process.

Implications of the Present Study

Students experiencing reading comprehension difficulties during the elementary school years are at higher risk for academic underachievement (Cain & Oakhill, 2006), as reading comprehension becomes increasingly relied upon to learn a variety of content disciplines. Therefore, early identification of reading comprehension difficulties and intervention in the early elementary school years is crucial for the future academic achievement of all students. The present research study supports the SVR model and it informs reading comprehension interventions, as it replicates findings on the involvement of both word-level reading and oral language comprehension skills in reading comprehension performance in school age children. Findings specially implicate the importance of word-level reading skills, such as word decoding and word recognition, to reading comprehension performance in the early elementary school years (Garcia & Cain, 2014).

This study also contributes to the limited body of research examining the association of shifting and reading comprehension performance at this grade level. Although shifting was not found to uniquely explain reading comprehension performance

above and beyond word-level reading *and* receptive vocabulary skills, it added significant variance to reading comprehension performance when word-level reading skills were controlled, across all three shifting tasks. These findings support emerging evidence that shifting is involved in reading comprehension, and it points to the complex relation of shifting and language in the process of reading comprehension. This study discusses possible explanations for these findings and agrees with recommendations that the role of shifting ability should be further explored in reading comprehension (Altemeier et al., 2008; Kieffer et al., 2013). Shifting should be integrated in reading comprehension interventions, as there is increasing evidence that this process is involved in reading comprehension (directly or indirectly via oral language comprehension). This may take place by teaching children to flexibly shift their attention between phonological and semantic information while reading, as it has been done by Cartwright and colleagues (2016) who reported significant improvements in reading comprehension performance among children who were poor reading comprehenders. Integrating shifting in reading comprehension interventions may also include teaching children to monitor their comprehension during reading by shifting their attention between their background knowledge (their knowledge before reading text) and their acquired mental representation of text (Broek & Espin, 2012).

Most importantly, the present study makes several suggestions for future research aiming to investigate the relation of shifting and reading comprehension, including considerations of the complex relation between language and EF processes, and the operationalization of these constructs which has been overlooked in research across the reading comprehension literature. Studies have shown that oral language comprehension

is a prominent component of reading comprehension, and extensive evidence in the psychology literature indicates that language supports the development of EF processes and has a reciprocal relationship with this construct overtime (Slot & von Suchodoletz, 2018). Thus, knowledge from these two literatures should be better integrated in future studies in order to examine how the interaction of these constructs impacts reading comprehension overtime (Kieffer et al., 2013). Such investigation has important theoretical and practical implications, as it will inform existing theoretical frameworks and intervention in reading comprehension with children at the early elementary school grades.

Strengths and Limitations of the Present Study

The present study examined the concept of shifting in grade 3 students to explore if this construct was associated with individual differences in reading comprehension performance in elementary school age children. The present study fills a gap in the current research literature because shifting ability has been generally underexplored in relation to reading comprehension compared to other EF processes, despite hypotheses that it supports reading comprehension by flexibly shifting the reader's attention to multiple text and cognitive elements, reading strategies and monitoring of comprehension. Furthermore, the present study measured shifting ability with three distinct tasks that have been widely used in the psychology literature. Examining shifting with tasks that are from different shifting paradigms allows for an exploration of which tasks are more closely implicated in reading comprehension. Such an examination also allows for the comparison of findings with previous studies that have used the same tasks. The present study also made use of norm-referenced measures of reading,

language and EF processes that have strong validity and reliability and that have been frequently used in the literature of educational psychology. Moreover, the administration of all tasks in participants' natural environment (i.e. at school), instead of at a research lab, increases the external validity of the findings.

The present study, however, also has its limitations. The cross-sectional nature of the study limits examination of all constructs overtime and how their interaction may change as a product of development. The small sample size of the study also limits statistical power to detect significance for small effect sizes, which could have limited the detection of significance of associations between variables (e.g. WM and reading comprehension). Due to the small sample size, findings at and around an alpha level of .05 were examined. As six multiple regression analyses were conducted and the alpha level was not adjusted, the probability of type I error is increased in this sample, resulting in analyses that are less conservative than other research studies.

Limited demographic information of the sample is another weakness of the present study. For instance, the precise participants' socioeconomic (SES) status and parental level of education is unknown, and these are social factors that have been associated with literacy achievement in children. The lack of a formal assessment of mental health, developmental history, and medication intake by participants is another limitation of this study, as it relied on teacher nominations of participants who they were aware to have no history of intellectual, developmental disabilities, or ADHD. However, there is a chance that participants might have had undiagnosed mental health and developmental conditions, as well as a history of delayed developmental milestones and medication intake unknown by teachers. Furthermore, although no participants had

formal ELL designations, they could have been exposed from an early age to another language other than English at home, without their teachers' knowledge. These factors are important to take into consideration and should be controlled for in future research as they may help explain differences in receptive vocabulary, EFs, and reading comprehension performance in school age children. Moreover, a sample including more participants who experience weaknesses in EF processes may reveal clearer associations between shifting and reading comprehension performance at this developmental period.

Furthermore, although the present study operationalized shifting with tasks that have been used frequently across the literature, EF tasks overlap with other executive and non-executive processes, making isolation of a single EF process very difficult. Shifting tasks used in this study have been reported to tap into other EF components (Mueller & Kerns, 2015; van der Sluis et al., 2007) and the task impurity nature of EF should be kept in mind when interpreting findings. Given the difficulties associated with measuring EFs, another limitation of the present study was to not have conducted a confirmatory factor analysis (CFA) with the three shifting tasks. Conducting such statistical method would have allowed for the examination of shifting tasks' unity and a clearer examination of the relation of shifting and reading comprehension. The low ecological validity of EF tasks is another limitation and future research should supplement their shifting tasks with parent and teacher reports based on close observations of children's shifting processes in the context of reading comprehension activities.

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