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Validation of the Reading Tendency Index in school-age children: Replication with a bilingual sample

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By

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VALIDATION OF THE READING TENDENCY INDEX IN SCHOOL-AGED CHILDREN: REPLICATION WITH A BILINGUAL SAMPLE

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Abstract

Defining deficits in reading ability may be accomplished through the analysis of a child's reading tendencies, representing a possible paradigm shift in the conceptualization and assessment of reading disabilities. Based on this premise, Mohl and colleagues (2018) developed a quantitative paradigm to measure reading tendency in children through performance on two lexical decision tasks (LDTs) that differentially rely on decoding and sightword reading abilities. The Reading Tendency Index (RTI; Mohl et al., 2018) is calculated from the differential between drift rates on the phonologic and orthographic LDTs. Scores closer to zero represent a balanced approach whereas scores as a negative or positive value suggest the tendency to rely on phonological decoding or sightword reading strategies, respectively. It was suggested that a balanced approach promotes more proficient reading abilities; however, this original study was performed with a small, male-only sample with a significant number of children with an ADHD diagnosis. The present study provided independent examination of the RTI paradigm, including the two LDT tasks and original calculations, to validate the tasks as a measure of reading abilities in a larger, representative sample of school-aged children. The present study involved the following goals: 1) to replicate the three-group reading tendency structure based on LDT performance in a larger representative sample of school-aged children, 2) to examine the construct validity of the RTI groupings and LDT tasks as a quantitative measure of reading ability, 3) to determine whether RTI group membership can be predicted based on reading and other cognitive skills, and 4) to explore performance differences, if any, in participants enrolled in French Immersion programs. The final sample included 92 participants aged 7 to 14 years (M_{age} = 9.96 years) recruited from English (*n* = 49) and French Immersion (*n* = 43) schools. Results indicated the following: 1) the three-group RTI structure was replicated in the larger sample of typically-developing school-aged children; 2) Sightword Readers had poorer performance on reading fluency, reading comprehension, and spelling than Balanced Readers and Decoders, but groups did not differ otherwise; 3) only reading comprehension predicted membership for the Sightword group; and 4) French Immersion students demonstrated similar patterns of performance on the RTI and other cognitive measures as English-only students. Supplemental post-hoc analyses were performed to explore different cut-off scores and methods for determining RTI groups. Implications and limitations of the current findings as well as considerations for future studies are discussed.

Dedication

To my loving partner, Dave, my parents, my family, and my friends. Thank you for your patience and never-ending support. The successful completion of this project and my educational journey would not have been possible without each of you.

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List of Abbreviations

ADHD – attention deficit-hyperactivity disorder

DDM – drift diffusion model(ling)

DFA – discriminant function analysis

DSM-5 – Diagnostic and Statistical Manual of Mental Disorders – 5th edition

DV – dependent variable

EZDM – EZ-Diffusion Model(ling)

FI – French immersion

fMRI – functional magnetic resonance imaging

IV – independent variable

LDT – lexical decision task

M – mean

MANCOVA – multivariate analysis of covariance

OG – Orton-Gillingham (approach)

oLDT – orthographic lexical decision task

PA – phonological awareness

PACS – phonological awareness composite score

PET – positron emission tomography

pLDT – phonologic lexical decision task

RA – research assistant

RD – reading disability

RF – Relative Fluency

RT – reaction time

RTI – Reading Tendency Index

SD – standard deviation

SFIQ – short form IQ estimate

SLD – Specific Learning Disorder

SMT – Sentence Memory Test

VWFA – visual word form area

WECDSB – Windsor-Essex Catholic District School Board

CHAPTER 1 – INTRODUCTION

Written language is used across the lifespan to communicate with others, share knowledge, and record information. Thus, the ability to read fluently is an important skill for children to master, especially as one transitions from learning to read to reading to learn. Despite its importance in society, many children and adults struggle with poor or effortful reading. Prevalence estimates for reading impairments range from 10% to 36% depending on the particular definition used (Shaywitz & Shaywitz, 2013). Generally, reading disorders are diagnosed using the IQ-achievement discrepancy, which determines whether reading performance is significantly below age-related expectations on standardized reading assessments given average intelligence (Peterson & Pennington, 2010). Although this method is useful for identifying a reading impairment, it fails to specify which cognitive deficits may be implicated, such as phonological decoding and/or word recognition. Furthermore, referrals for psychoeducational assessments to determine reading disability are generally not made until a child is performing significantly worse than their peers, criticized by some as the “wait to fail” model (Fuchs & Fuchs, 1998; Lyon, 1995; Vellutino et al., 1996).

With this in mind, Mohl (2015) suggested the need for a paradigm shift from disability-based classifications to the identification of reading tendencies, and developed a Reading Tendency Index (RTI) based on a child’s performance on two lexical decision tasks. The RTI is rooted in the dual-route theory of reading development (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). It is assumed that fluent readers are able to flexibly use both types of reading networks (i.e., phonological and orthographic), whereas an over-reliance on either network may suggest a deficit in the other that leads to impaired reading (Kuhn & Stahl, 2003). From the RTI, readers are classified as Balanced Readers, Decoders, or Sightword Readers depending on their propensity to use a balanced approach or to favor phonological decoding or sightword recognition to complete the tasks (Mohl, 2015; Mohl et al., 2018). The RTI paradigm was tested on a small, clinical sample of boys between the ages of 9 and 16 years. Although the preliminary evidence suggested that the task may be an effective screening tool for identifying specific reading impairments in children and adolescents (Mohl et al., 2018), independent validation studies are needed.

The aim of the current project was to provide independent validation of the Reading Tendency Index and associated lexical decision tasks with a sample representative of the general population of school-aged children in Grade 2 through 8. It was predicted that the three-group structure would be replicated with this larger sample. The concurrent and predictive validity of the RTI would be examined through comparisons with existing standardized measures of reading and related cognitive abilities. Validation of this quantitative measure would provide support for its use as a screening tool for reading difficulties in educational and clinical settings. Before providing a more detailed description of the current study, relevant literature from the following topics will be reviewed: foundations of reading and writing, reading development, reading skills, neuroanatomical correlates of reading, reading disability, development of the Reading Tendency Index, and an explanation of drift diffusion modeling.

The following research goals were examined as part of the dissertation project: 1) to replicate the three-group reading tendency structure based on LDT performance in a larger sample, 2) to examine the construct validity of the RTI groupings and LDT tasks as a quantitative measure of reading ability, 3) to determine whether RTI group membership can be predicted based on reading and other cognitive skills, and 4) to explore performance differences, if any, in participants enrolled in French Immersion programs. Detailed methods along with the results and overall discussion are then outlined followed by supplemental analyses, a summary of the findings, and implications for clinical and educational practice.

CHAPTER 2 – LITERATURE REVIEW

Foundations of Reading and Writing

Literacy is an essential skillset for success in society as humans use the written word in one form or another for many daily activities. As a concept, literacy can involve more than just reading and writing, and may include a variety of educational outcomes, such as disposition toward learning, interests in reading and writing, and knowledge of specific domains like computer or scientific literacy (Perfetti & Marron, 1998). Reading and writing, as specific components of literacy, are the main focus here.

Reading is a language-based skill that involves the complex process of deriving meaning from written text (Cline, Johnstone, & King, 2006). To understand the underlying processes involved in reading, the foundations of spoken and written language need to be considered. Language is composed of five highly complex parameters: phonology, semantics, morphology, syntax, and pragmatics. Phonology includes both the distribution and frequency of speech sounds in language as well as the associated rules to govern spoken language (Kamhi & Catts, 2012a). Semantics refers to an understanding of the meanings of words and relationships between word combinations whereas morphology involves the grammatical morphemes that moderate sentence meanings (Kamhi & Catts, 2012a). In other words, semantics relates to word content while morphemes alter the tense and aspect of sentences. Syntax involves understanding the rules that specify word order, sentence organization, and relationships between words, word classes, and sentence elements (Kamhi & Catts, 2012a). Finally, pragmatics involves the contextual use of language, including the rules of conversation or discourse (Kamhi & Catts, 2012a). While each of these language parameters play an important role in reading and writing, *phonology* appears to be most important for the initial development of reading skills in children. In other words, an understanding of the sound structure of language provides a foundation upon which reading skills can be built; however, the sound of language must first be mapped on to the written word (Kamhi & Catts, 2012a).

Writing systems use graphic units to represent the abstract language units used in spoken language (Rayner, Foorman, Perfetti, Pesetsky, & Seidenberg, 2001). Language in its relation to reading can be described in terms of its *phonology*, or the sound structure of language, and *orthography*, the graphic structure of language (Schlaggar & McCandliss, 2007). English and French, Canada's official languages, use alphabetic writing systems in which graphic units (i.e., letters) are associated with phonemes, as opposed to syllabary (e.g., Japanese Kana) or morpho-syllabic systems (e.g., Chinese; Rayner et al., 2001). The latter two systems are considered logographic systems where characters map on syllable units, or morphemes. Instead, alphabetic systems use letters for phonemes, which represent the smallest component of spoken language (Schlaggar & McCandliss, 2007). This association of letters to phonemes is referred to as the *alphabetic principle*, which allows for this writing system to be productive such that a small set of letters can be used to write an indefinite number of words (Rayner et al., 2001). Children must learn, and ideally master, this alphabetic principle before reading can occur.

Despite the economic benefits of the alphabetic writing system, learning to read in English is still quite difficult given its "deep" orthography (Rayner et al., 2001). This means that symbol-sound correspondences in English are more variable compared to languages with shallow orthography, or a highly consistent correspondence between letters and sounds (Rayner et al., 2001), such as Spanish and Italian. Two issues contribute to this difficulty in English. First, phonemes, particularly consonants, are quite abstract and are not necessarily natural physical segments of speech (Rayner et al., 2001). For example, the letter *c* corresponds to the phonemic representation of /c/ sounds but the acoustic representation changes across words (e.g., *cat* vs. *mice* vs. *witch*). Thus, it may be difficult for children to initially develop these different mental representations of phonemes. Secondly, different vowel sounds are not uniquely coded. While there are five standard vowels in the English writing system, each vowel has multiple phonemic representations (Rayner et al., 2001). For example, *cat*, *car*, and *cake* use the letter *a* for three different phonemic representations. Thus, although the alphabetic principle in English is productive and exhibits economy, this occurs at the expense of complexity (Rayner et al., 2001).

Reading Development

Various definitions of reading have been proposed. Gates (1949) stated that reading is "a complex organization of patterns of higher mental processes… [embracing] all types of thinking, evaluating, judging, imagining, reasoning, and problem-solving". This broad view is problematic because it conflates word recognition and comprehension, and instead appears to describe a theory of inferencing and learning as opposed to a theory of reading development per se (Perfetti, 1986). In contrast, the Simple View of Reading postulates that reading involves two specific cognitive skills: decoding and linguistic comprehension (Hoover & Gough, 1990). Even people who have not mastered reading can utilize the skills mentioned by Gates (i.e., thinking, reasoning, problem-solving), so what really distinguishes reading ability is the distinct capacity to decode graphic units. As such, the Simple View appeals to many researchers and clinicians. According to this view, decoding refers to word recognition processes that transform print into words (Hoover & Gough, 1990), which will be discussed in further detail. Linguistic comprehension is the process by which words, sentences, and discourses are then interpreted (Hoover & Gough, 1990).

To understand how reading ability develops, it is helpful to consider what it means to be a proficient reader. Proficient reading occurs accurately and effortlessly because appropriate word recognition uses a direct visual route without phonological mediation to access semantic memory and word meaning (Kamhi & Catts, 2012b). Even though phonological decoding is necessary to develop good word recognition skills, proficient readers rarely break down words to individual sounds since even novel words utilize familiar syllable structures or orthographic sequences (Kamhi & Catts, 2012b). Thus, the acquisition of reading skills must initially involve phonological decoding, followed by the development of automatic sight word recognition as reading fluency increases.

To further understand the acquisition of reading skills, the theories of reading development should be explored. The following sections summarize various theories that have been proposed over the years from developmental and cognitive research. Specifically, the stage theory (Chall, 1996) and self-teaching hypothesis (Share & Stanovich, 1995) will be reviewed, as well as the following cognitive models: dual-route (Coltheart, 1978), connectionist (Schneider & Graham, 1992), combined (Bjaalid et al., 1997), and comprehensive (Vellutino et al., 2004).

Stage Theories of Reading

The stage theory of reading (Chall, 1996) provides a useful framework for understanding basic developmental changes that children experience as they acquire reading skills. This theory proposes six stages through which readers must proceed while learning to read. First, children engage in the emergent literacy period where they acquire knowledge about letters, words, and books through interactions with literacy artifacts and events (Kamhi & Catts, 2012b). It is important to recognize that the material children learn in this stage is highly dependent on their socio-cultural and linguistic environment and thus varies between children (Kuhn & Stahl, 2003).

The next stage occurs at the start of conventional literacy and formal reading instruction. At this stage, children are taught to recognize and understand the basic sound-symbol correspondence and to initiate basic decoding skills (Chall, 1996). Others have referred to this stage as the "alphabetic stage" (Ehri, 1995; Kamhi & Catts, 2012b). Not only do children need to memorize sounds that go with each letter, letters need to be specifically linked to the particular set of phonemic sounds that comprise spoken language (Adams, 1990). This alphabetic insight, considered phonological awareness for current purposes, underlies the ability to phonologically decode new words. The "logographic stage" was proposed as a transition period between emergent literacy and alphabetic reading (Frith, 1985). Instead of using knowledge of letter names or sound-letter relationships to recognize words, children who are in the logographic stage make associations with unanalyzed spoken words and one or more salient graphic features of the printed word or its surrounding context (Kamhi & Catts, 2012b). As such, these children cannot read new words since they do not employ decoding strategies and can be misled by changing the visual cues surrounding a word. The logographic stage is suggested to be a transition period as children develop alphabetic insight needed for decoding; however, some children may never fully transition from logographic to alphabetic.

According to Chall (1996), the next stage is referred to as confirmation and fluency or "ungluing from print". In this stage, readers use their decoding skills to facilitate the development of automaticity with print. In addition to decoding in an automatic way, children at this stage begin using prosodic features of language in their reading to imitate natural or conversational tones (Kuhn & Stahl, 2003). Others have described this in terms of the "orthographic stage" whereby automatic, effortless sightword recognition is ultimately achieved (Ehri, 1995). This stage involves the use of letter sequences and spelling patterns to recognize words by sight without overt use of phonological decoding (Kamhi & Catts, 2012b). Orthographic knowledge is accumulated as readers phonologically decode different words that share similar letter sequences, recognize these similarities, and then store this information in memory (Ehri, 1991, 2005). The stage is reached once sufficient knowledge of these orthographic patterns has been accumulated, leading to visual word recognition without phonological conversion (Ehri, 1991, 2005; Frith, 1985).

As children progress through schooling, the demands and requirements of reading shifts from learning to read to reading to learn. As such, the following stage of development is referred to as "reading for learning new" (Chall, 1996). At this stage, children are expected to be able to gather content-rich information through texts to learn specific material, which is facilitated through automatic processing. If a child has not progressed through the orthographic stage successfully, they will expend a disproportionately large percentage of their attention on decoding and will not have enough mental resources to adequately comprehend what is being read (Adams, 1990). Therefore, reading fluency is an essential skill to master if children are to succeed at the primary purpose of reading, that is constructing meaning from text (Cline et al., 2006). The two final stages of reading according to Chall (1996) involve "multiple viewpoints" and "construction and reconstruction." In these stages, readers begin to develop critical analysis skills to synthesize and use print material to determine their own perspective on a given subject (Kuhn & Stahl, 2003).

Self-Teaching Hypothesis

While the stage theory may accurately describe the progression of knowledge and skills needed to become a proficient reader, it fails to consider the underlying mechanisms of these changes in proficiency (Ehri, 2005; Share & Stanovich, 1995). In addition, it assumes that all words are read using the same approach at a particular stage and tends to obscure individual differences (Kamhi & Catts, 2012b). Given these perceived limitations of the stage theory, Share and Stanovich (1995) offered an alternative explanation: the self-teaching hypothesis.

According to Share and Stanovich (1995), the self-teaching hypothesis describes that the learner employs phonological decoding as a self-teaching mechanism enabling them to obtain detailed orthographic representations that facilitate fast and accurate visual word recognition. In their own words,

> … each successful decoding encounter with an unfamiliar word provides an opportunity to acquire the word-specific orthographic information that is the foundation of skilled word recognition and spelling. In this way, phonological recoding acts as a self-teaching mechanism or built-in teacher enabling the child to independently develop knowledge of specific word spellings and more general knowledge of orthographic conventions. (p. 18)

Essentially, this hypothesis suggests that children teach themselves to read fluently through phonological recoding. One way to achieve this is for the child to read aloud to a parent or teacher and the feedback from these attempts builds up the orthographic representations of specific words (Share, 1995). During this process, the child learns decoding rules and specific word forms, leading to a rapid buildup of the child's lexicon as words become familiar (Rayner et al., 2001). Thus, it seems that practice would improve one's knowledge of individual words by increasing the accurate representation of a word's spelling and strengthening the connection between phonological form and spelling, which improves the speed of word recognition (Rayner et al., 2001).

Cognitive Models of Reading

Although these theories of reading development describe the steps through which children acquire various reading skills, they do not outline the specific cognitive or neural processes that underlie these skills. As such, several cognitive models have also been proposed to explain the process of reading. There are two prominent models that have dominated research for the last 40 years: dual-route and connectionist. More recently, additional models based on these two have been built in order to be more inclusive of a variety of inter-related cognitive processes. Each will be described in further detail below.

Dual-route model. Dual-route models of reading posit that skilled readers utilize two different procedures for converting print to speech (Coltheart, 1978). The direct route, also known as lexical or visual-orthographic, refers to reading words by activating direct connections between the visual forms of words and their meanings based on their orthographic representation (Bjaalid, Hoien, & Lundberg, 1997). The indirect route, also referred to as phonological or nonlexical, involves the translation of letters into sounds (Bjaalid et al., 1997). Initial versions of the dual-route theory postulated that these routes were completely distinct from one another. According to this version of the model, exception words would be processed via the direct route, regular words could be processed by either route, and nonwords were processed solely by the indirect route (Coltheart, 1978). A modified version of the dual-route theory suggested that the routes are somewhat dependent on each other while maintaining a firm distinction between lexical and sublexical processing (Paap, McDonald, Schvaneveldt, & Noel, 1987). Nevertheless, the dual-route model has been challenged due to some of its limitations. In particular, the dual-route distinction has been criticized as being artificial since non-word processing is not fully distinct from lexical processing (Humphreys & Evett, 1985). For instance, non-word processing is at least partially impacted by lexical knowledge, including the spelling-to-sound regularity of the non-word and whether the phonological consistency of a non-word is orthographically similar to a similar word (Humphreys & Evett, 1985). Another limiting factor of the dual-route theory is evidence suggesting that there could be more than two ways to read words (e.g., through the use of analogies; Goswami, 1986).

Connectionist model. The connectionist model emphasizes a single interconnected system in which phonological activation is intrinsic to word identification at all levels (Bjaalid et al., 1997). Specifically, information processing occurs through the interaction of large numbers of simple processing units that are activated through connection weights that change as learning occurs (Schneider & Graham, 1992). To illustrate, a connectionist computer simulation of word recognition was generated with three sets of processing units: orthographic units to code letter strings, phonological units to code phonological information, and a set of connection units (Seidenberg & McClelland, 1989). The model was programmed to associate the letters it encounters with phonemes, and subsequently, spelling patterns with phonological patterns. As the machine attempts to sound out a word, its response is automatically compared with the word's correct pronunciation and adjusted accordingly (Seidenberg & McClelland, 1989). This simulation and the connectionist model more generally have been criticized for failing to account for prior knowledge and skills that children obtain during reading acquisition (Hulme, Snowling, & Quinlan, 1991). Most importantly, many children have already developed highly specific phonological knowledge in preschool years prior to learning to read.

Combined framework. It has been suggested that perhaps there are critical elements in both the dual-route and connectionist models of reading development. As such, Bjaalid et al. (1997) have proposed a combined framework that incorporates these crucial and similar elements. Most notably, both theories assume that three processors are used when decoding words: orthographic, phonological, and semantic. Since skillful reading appears to be the product of the coordinated and highly interactive cooperation of these processors (Ehri, 1992), the combined framework suggests that these three processors plus visual and articulatory processors are highly interconnected with bidirectional pathways (Bjaalid et al., 1997). In addition, the combined framework adapted the excitation and inhibition aspects of the connectionist model while maintaining a distinction between lexical and sublexical processes. Each processor will be outlined below.

The orthographic processor facilitates accurate and rapid word reading by sight through the storage and access of letter knowledge in a memory storage called the lexicon (Bjaalid et al., 1997). Visual letter recognition, especially initially, occurs through associated feature recognizers that excite and inhibit each other to facilitate letter recognition. Letters that are often seen together receive positive excitation, while letters rarely seen together receive inhibition, or negative excitation. The orthographic processor also works with units at various levels that each have bidirectional connections, such as graphemic features, single and complex graphemes, syllables, letter patterns, morphemes, and whole words (Bjaalid et al., 1997). The phonological processor involves knowledge about phonemes and the phonological equivalents corresponding to different orthographic units (e.g., letters, syllables, letter patterns, morphemes, and words; Bjaalid et al., 1997). Again, there is one phonological processor in this combined model that involves both lexical and sublexical processing. This framework also allows for phonological activation to be influenced by patterns of excitation and inhibition from the orthographic and semantic processors. Thirdly, the semantic processor deals with the meanings of morphemes and whole words, and interacts closely with the orthographic and phonological processors (Bjaalid et al., 1997). Essentially, meanings of familiar words are represented in the semantic processor as an associated set of more basic meaning elements that become more strongly linked through repetition, learning, and context.

There are two additional processors within the combined framework that are not included in either dual-route or connectionist models. The visual processor produces clear visual images from each eye fixation, then analyzes and integrates the images into patterns across the fixation-saccade sequences (Bjaalid et al., 1997). This processor is particularly important for reading since accurate word recognition cannot occur if the child does not see the word properly. Research suggests that there are two distinct but associated subsystems for visual processing: sustained and transient systems. The sustained system is likely involved with the identification of patterns, resolution of fine details, and perception of color, while the transient system is designed for the perception of motion and depth, control of eye movements, and localization of targets in space (Breitmeyer, 1984; Breitmeyer & Ganz, 1976). Indeed, it appears that the transient system may be defective in up to 75% of disabled readers without deficits in the sustained system (Lovegrove, Martin, & Slaghuis, 1986). Finally, the articulatory processor is closely linked with the phonological processor but is specifically related to the production of speech through neuromuscular activities (Bjaalid et al., 1997). These neuromuscular activities have been shown to register during silent reading (Edfeldt, 1960) and even thinking (Sokolov, 1972), suggesting that there is a close relation between speech and thought. Essentially, the word's articulatory code activates the articulatory processor during reading activities, demonstrating how closely semantic, phonological, and articulatory knowledge are associated (Bjaalid et al., 1997).

Essentially, the combined framework for reading ability outlined by Bjaalid et al. (1997) involves closely interconnected processors for orthographic, phonological, semantic, visual, and articulatory information. Each of these processors are subdivided into lexical and sublexical systems since subwords are processed differently from whole words. That is, the sublexical systems separate letters into potential orthographic units, recode into phonological equivalents, and assemble these units into whole words (Bjaalid et al., 1997). Parsing and blending does not occur in lexical reading of whole words.

Comprehensive model. More recently, a comprehensive model of reading ability has been described that illustrates the various cognitive processes and different types of knowledge involved in learning to read. In addition to the five processors described by Bjaalid et al. (1997), this highly interconnected and comprehensive model also considers the role of permanent memory, working memory, knowledge of print concepts, metalinguistic processes and knowledge, and both linguistic and visual coding processes on the ability to read (Vellutino, Fletcher, Snowling, & Scanlon, 2004). See Figure 1 for a depiction of the comprehensive model.

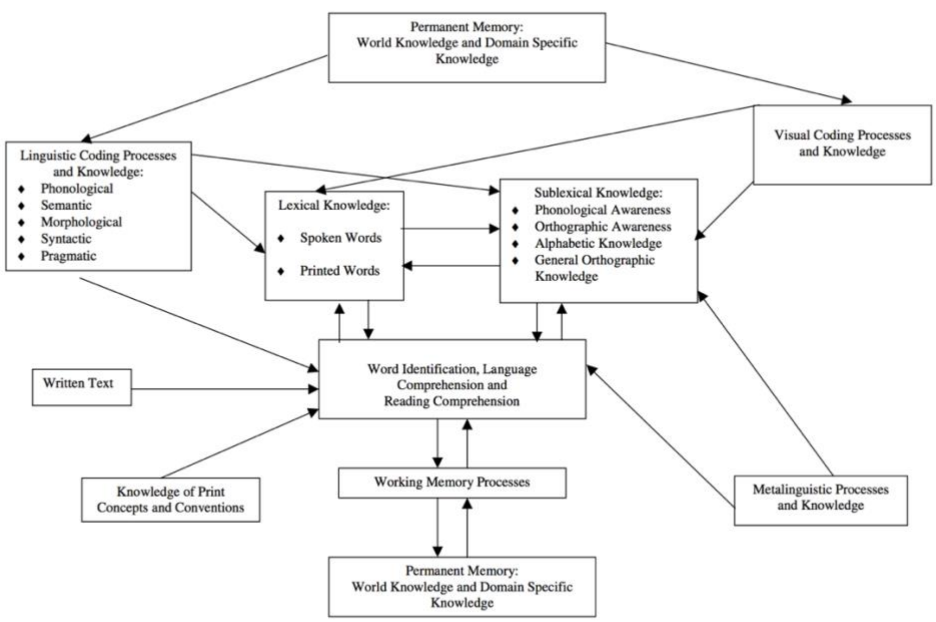

Figure 1. Cognitive processes involved in learning to read (Reproduced from Vellutino et al., 2004 with permission of John Wiley and Sons in the format Thesis/Dissertation via Copyright Clearance Center).

Essentially, this model includes processes that transform world knowledge and domain-specific knowledge stored in permanent memory into units of spoken or written language (Vellutino et al., 2004). Visual coding processes involve sensory and higher-level visualization processes that facilitate the storage of visual representations, such as graphic symbols used to represent written words (Vellutino et al., 2004). Linguistic coding involves four distinct processes that facilitate the acquisition and use of language. First, phonological coding uses speech codes to represent information in the form of words (Vellutino et al., 2004). Semantic and morphological coding involves the ability to store information about the meanings of words and word parts (e.g., -ing), whereas syntactic coding stores word order rules to describe how words are organized in sentences (Vellutino et al., 2004). Lastly, pragmatic coding involves the storage of information about conventions governing the use of language for communication (e.g., use of punctuation marks and changes in volume, pitch, or intensity; Vellutino et al., 2004). Although these various coding processes help establish firm associations between the spoken and written counterparts of printed words and facilitate the development of a sight word vocabulary, this associative learning process depends on the child's understanding that written words represent words in spoken language, that words are composed of letters, that word forms are processed from left to right in English, and that separate words are demarcated by spaces (Vellutino et al., 2004). A sight word vocabulary is not sufficient to ensure adequate reading since there is a high degree of similarity between many characteristics of words that creates a heavy load on visual memory. As such, children must have a firm understanding of the alphabetic principle in order to utilize phonological (letter-sound) decoding in addition to visual memory to become proficient readers (Vellutino et al., 2004).

To achieve proficiency, Vellutino et al. (2004) suggest that the child must actively engage in a type of metalinguistic analysis. First, phonological awareness refers to "the understanding and awareness that spoken words consist of individual speech sounds (i.e., phonemes) and combinations of speech sounds (i.e., syllables)", which is important for learning how to map letters onto sounds (Vellutino et al., 2004). Orthographic awareness is another metalinguistic concept whereby the child has an understanding of the constraints on how letters in written words can be organized (Vellutino et al., 2004). Lastly, syntactic awareness refers to the child's sensitivity to grammatical errors that violate conventional rules in spoken and written language. Together, these three types of metalinguistic analyses help the child to acquire and understand alphabetic and orthographic knowledge leading to mastery of the alphabetic code and increased fluency and accuracy in reading and spelling (Vellutino et al., 2004). Finally, permanent memory and working memory systems are essential for establishing connections between lexical and sublexical components of spoken and printed words, and for encoding, storing, and retrieving all types of information required for learning to read.

Relevance to current project. Although the Reading Tendency Index was developed primarily on the basis of the dual-route model of reading development, especially in terms of brain networks, which are discussed in more detail in the neuroanatomy section below, the comprehensive model encompasses many of the other processes inherent to the RTI protocol. For instance, the RTI protocol assumes that children use both word recognition and phonological decoding skills to read words, all the while relying on other cognitive skills, including working memory, cognitive flexibility, and attention (Mohl et al., 2018).

Reading Skills

The models of reading development describe several essential component skills, including phonological decoding, word recognition, reading fluency, and reading comprehension. Each of these skills is distinct in its contribution to reading development and may develop differently for each individual. That is, a child may have impairments in some skills and not others that lead to functional challenges with reading. Each of these skills will be discussed in more detail in this section to provide a summary of existing research in these areas to inform the research questions of the present study.

Phonological Awareness

Each of the reading development models discussed thus far has mentioned phonological decoding in some capacity as an essential skill for reading acquisition. Children must be able to apply the alphabetic principle successfully when learning to read. Phonological awareness (PA) refers to the child's specific knowledge of the internal sound structure of oral language (Rayner et al., 2001). More specifically, it involves the explicit understanding that words are composed of sound segments smaller than syllables (Otaiba, Kosanovich, & Torgesen, 2012). Children who perform well on tasks of PA score significantly better in early reading compared to those who do not, whereas children who score poorly on PA tasks are at an increased risk for reading difficulties (Bradley & Bryant, 1978, 1983; Lonigan, Schatschneider, & Westberg, 2008). In fact, a two-year longitudinal study of British children beginning when they first entered school demonstrated that word recognition skills appear to be predicted by early phonological skills, particularly letter knowledge and phoneme sensitivity (Muter, Hulme, Snowling, & Stevenson, 2004). In contrast, rhyme skills, vocabulary knowledge, and grammatical skills appear relatively unimportant in predicting later word recognition ability.

Indeed, PA contributes to the development of early reading skills in at least three ways. First, it helps children to understand the alphabetic principle and develop alphabetic knowledge (Otaiba et al., 2012). Children must be aware that sounds match letter symbols for the rationale of learning individual letter sounds to make sense. Second, PA helps children notice the regular ways that letters represent sounds in words, which reinforces sound-symbol correspondences and helps form mental representations of words to facilitate eventual word recognition (Otaiba et al., 2012). Finally, PA allows for children to become flexible decoders and facilitates reading of irregular words (Otaiba et al., 2012).

The strong relationship between PA and learning to read has been shown by numerous studies across languages (Ball & Blachman, 1988; Blachman, 1989; Fox & Routh, 1976; Lundberg, Olofsson, & Wall, 1980; Stanovich, Cunningham, & Cramer, 1984; Tunmer, Herriman, & Nesdale, 1988; Wagner & Torgesen, 1987). Furthermore, studies have suggested that instruction in PA can have a positive effect on reading ability (Ball & Blachman, 1988; Bradley & Bryant, 1983; Byrne & Fielding-Barnsley, 1991; Lundberg, Frost, & Petersen, 1988; Mann, 1991; Perfetti, Beck, Bell, & Hughes, 1987; Treiman & Baron, 1983; Vellutino & Scanlon, 1991).

Word Recognition

Orthographic processing, or reading via word recognition, is an important skill for promoting reading fluency and reading comprehension, although there are extensive debates concerning whether this occurs in a bottom-up or a top-down fashion (Carreiras, Armstrong, Perea, & Frost, 2014). Specifically, there are two main conceptualizations: the feedforward approach and the interactive approach. In the feedforward approach to orthographic processing, a significant portion of the recognition process involves the consideration of structural properties of the printed stimulus (i.e., letters and letter sequences). In essence, this view considers that the general identification of visual forms, and of letter strings in particular, are facilitated through low-level visual pattern recognition systems (Norris, McQueen, & Cutler, 2000). Thus, processing within the orthographic system occurs in a bottom-up manner from the identification of low-level visual features to the recognition of full orthographic words.

The contrasting view argues that there is full interactivity between lower- and higher-order representations at all processing levels. The interactive approach implies that high-level linguistic considerations that are not solely dependent on orthography influence the distributional properties of letters in a given language, which allows the word recognition system to learn these features enabling efficient, fluent reading (Carreiras et al., 2014). For instance, learning how letters correlate with phonology and meaning or how letter clusters are constrained by lexical, morphological, and phonological structure facilitates efficient whole word recognition (Carreiras et al., 2014). In addition, frequently encountered visual representations result in perceptual learning and allow for rapid and efficient word recognition, which are influenced by the association between orthography and language-specific phonology and meaning (R. Frost, 2012). In fact, R. Frost (2012) suggests that learning models of visual word recognition have ecological validity since they incorporate the full linguistic environment of the reader as achieved through implicit learning. It is argued that orthographic processing (i.e., visual word recognition) is achieved through intricate weighting of phonological and semantic factors in order to convey optimal phonological and morphological information to the reader (R. Frost, 2012).

Despite contrasting views on the specific mechanisms involved, word recognition is evidently an important skill in the reading development process. Specifically, word recognition serves as an essential skill in developing reading fluency as children can read more efficiently when they shift from decoding each word to relying on their repertoire of recognizable words. Less cognitive resources are thus used for recognizing a word compared to having to decode it, and the reader can use their available resources on reading fluency and comprehension.

Reading Fluency & Comprehension

Skilled or fluent reading involves the rapid processing of visual information found in print (Rayner et al., 2001). This is particularly important given that the primary goal of reading is to gather information from text. Readers who continue to rely primarily on decoding strategies while reading will have limited mental resources remaining to accurately and efficiently comprehend the material being read (Kuhn & Stahl, 2003). Although fluent reading often involves automatic visual recognition of words, phonological codes continue to be used by highly skilled readers. In fact, this phonological information is helpful for accessing the meaning of words and remembering information in the text (Rayner et al., 2001). As such, reading fluency appears to depend on the interplay of multiple cognitive skills.

Researchers appear to have come to a consensus regarding the three primary components of reading fluency: accurate decoding, automatic word recognition, and appropriate use of prosody (Kuhn & Stahl, 2003). Accurate decoding, which is acquired through the alphabetic stage of reading (Chall, 1996) and with the onset of phonological awareness (Otaiba et al., 2012), serves as a prerequisite to reading fluency. Accurate and automatic decoding facilitates the reader's ability to simultaneously determine which words comprise the text while constructing meaning from the words (Kuhn & Stahl, 2003). According to the interactive-compensatory model (Stanovich, 1980), readers can use multiple sources of information (e.g., orthographic, phonological, semantic, and syntactic) to assist with the construction of meaning. If a reader is unable to make use of the information from one of those sources, they may be over-reliant on other sources limiting the efficiency of their reading fluency (Kuhn & Stahl, 2003; Stanovich, 1980). Automaticity theorists suggest that extensive practice facilitates the transition from decoding to automatic word recognition. That is, as letters and words become more familiar, less attention is directed towards processing the text at a phonological level (Kuhn & Stahl, 2003).

In addition to automatic visual processing, reading fluency entails “reading with expression” through the use of prosodic features (Kuhn & Stahl, 2003). In fact, prosody may provide the link between fluency and comprehension by facilitating the connection between written and oral language (Kuhn & Stahl, 2003). Six distinct markers of prosodic reading have been identified: pausal intrusions, length of phrases, appropriateness of phrases, final phrase lengthening, terminal intonation, and stress (Dowhower, 1991). By applying these prosodic features to reading, readers transfer their knowledge of syntax from speech to text, and facilitate reading comprehension (Kuhn & Stahl, 2003).

Alternatively, reading fluency is considered by some to be a componential process involving the integration of various reading sub-skills (Wolf & Katzir-Cohen, 2001). According to this conceptualization, proficiency in and automatization of all lower-order reading skills are required to facilitate fluent reading. As such, fluency is a resultant property of the key cognitive processes involved in reading (e.g., orthographic, phonologic, and semantic processing) as well as perceptual, attentive, and executive skills (Wolf & Katzir-Cohen, 2001). In fact, evidence suggests that distinct reading sub-skills (i.e., orthography, phonological processing, and rapid naming) predict fluency at the word reading level, and different elements of fluency (i.e., reading rate, accuracy, and comprehension) at the connected text level (Katzir et al., 2006). This componential process is supported by functional magnetic resonance imaging (fMRI) evidence demonstrating that reading-related brain regions responded differently as the ability to read fluently was manipulated (Benjamin & Gaab, 2012). For instance, fluent sentence reading at various speeds engaged brain regions typically activated during tasks assessing the various reading sub-skills. These regions also responded differently as speed increased (Benjamin & Gaab, 2012).

It has been demonstrated that difficulties in reading comprehension in younger children appear to be due to problems with word reading accuracy and reading fluency, but that these factors are no longer a source of variability in older children (Johnston, Barnes, & Desrochers, 2008). For instance, a longitudinal study that followed children from pre-school through Grade 4 found that the primary predictors of reading comprehension accuracy in early grades were word reading skills (including letter knowledge and phonological awareness) whereas by Grades 3 and 4 oral language skills were the primary predictor for comprehension (Storch & Whitehurst, 2002). Another longitudinal study followed children at three time points from age 7 to 11 years, which may be the period where comprehension skills show the most rapid development, and found that reading comprehension was predicted by inference-making ability, comprehension monitoring, and sensitivity to story structure when comprehension from earlier time points was controlled (Oakhill, Cain, & Bryant, 2003; Oakhill & Cain, 2007). As such, the primary factors influencing reading comprehension skills appear to be age-related.

Furthermore, other cognitive skills have been implicated in reading comprehension, including working memory and knowledge of text structure. Not only do poor comprehenders often have deficits in working memory, these deficits have been linked to variability in reading comprehension ability over and above short-term memory, phonological skills, and vocabulary (Cain, Oakhill, & Bryant, 2004). Despite this finding, not all poor comprehenders have poor working memory (Cornoldi, De Beni, & Pazzaglia, 1996); instead, research has found that exposure to narrative stories prior to independent reading was predictive of later reading comprehension after accounting for phonological awareness, word reading, and vocabulary (Kendeou et al., 2006). Thus, comprehension of narratives across media styles serves to bridge the gap between oral language and text comprehension, and lack of exposure to narratives ahead of reading instruction may impact the successful building of this bridge (Perfetti, 1994).

In summary, reading fluency and comprehension skills are built upon more fundamental skills in phonological decoding and word recognition as well as working memory and vocabulary knowledge. Given that there are multiple skills involved in reading development, it is no surprise that a number of brain structures would be involved in reading. It is therefore important to consider these skills and the overall development of reading in the context of the neuroanatomical correlates of reading ability.

Neuroanatomical Correlates of Reading

Traditionally, the brain regions involved in reading have been studied via examination of skilled adult readers with "acquired dyslexia," or those who develop a reading impairment secondary to focal brain lesions (Warrington & Shallice, 1980). Functional imaging techniques, such as positron emission tomography (PET) and fMRI, have primarily been used to investigate the functional neuroanatomy of reading. Many studies have attempted to identify brain areas associated with the various components of reading (Schlaggar & McCandliss, 2007), but differences in study tasks and stimuli, the language of study, and theoretical interpretations make it difficult to compare findings across studies. Notwithstanding, the convergence of data suggests that there are three distinct brain regions involved in skilled reading in adults (Sandak, Mencl, Frost, & Pugh, 2004; Schlaggar & McCandliss, 2007): occipitotemporal, temporoparietal, and inferior frontal areas of the left hemisphere. Each will be discussed in further detail below, followed by a summary of theorized reading networks.

Temporoparietal Area (Dorsal System)

The dorsal temporoparietal region is involved in word analysis and is responsible for decoding novel or unfamiliar words (Hickok, 2009; Shaywitz & Shaywitz, 2013). This system includes the angular gyrus and supramarginal gyrus in the left inferior parietal lobule as well as the posterior region of the left superior temporal gyrus (Wernicke's area), connected by the arcuate fasciculus (Hickok, 2009; Sandak et al., 2004). Essentially, this system is involved in mapping visual aspects of print onto the phonological and semantic structures of language (Black & Behrmann, 1994), and serves to integrate orthographic and phonological information (Schlaggar & McCandliss, 2007). Indeed, the supramarginal gyrus responds with greater activity to pseudowords than familiar words in skilled readers, suggesting that this system plays a particular role in phonological processing (Church, Coalson, Lugar, Petersen, & Schlaggar, 2008; Sandak et al., 2004).

Occipitotemporal Area (Ventral System)

The occipitotemporal area, often referred to as the ventral system, includes the left hemisphere inferior occipitotemporal/fusiform area extending anteriorly into the middle and inferior temporal gyri (McCandliss, Cohen, & Dehaene, 2003). It has been suggested that the occipitotemporal/fusiform area functions as the visual word form area (VWFA) and processes prelexical representations of letter patterns within visual words (Schlaggar & McCandliss, 2007). Multiple studies have also demonstrated that other visually-complex stimuli also activate the VWFA, leading people to doubt the specificity of this area as a visual word processor. Yet, studies using higher spatial resolution techniques have demonstrated increased activity for letter strings over other complex visual stimuli, suggesting preferential, but not exclusive, processing of word form-related stimuli in the VWFA (Schlaggar & McCandliss, 2007).

The ventral system appears to function as an orthographic processor or word recognition system (Shaywitz & Shaywitz, 2013). Word recognition is accomplished through connections of occipital, temporal, and frontal cortices by the extreme capsule and inferior longitudinal fasciculus to the inferior frontal gyrus (Saur et al., 2008). Research suggests that this *ventral recognition subnetwork* (Mohl, 2015) reorganizes itself as reading fluency develops. Examination of timing and stimulus-type effects indicate that posterior extrastriate regions respond to letter strings early in processing, followed by a preference for pseudowords and words in the anterior VWFA (Sandak et al., 2004). Later in processing, the anterior inferior frontal gyrus is preferentially activated for real words, particularly familiar ones, compared to other types of letter strings (Binder et al., 2003; Sandak et al., 2004).

Inferior Frontal Area (Anterior System)

The anterior system includes the inferior frontal gyrus (including Broca's area) and extends into the premotor cortex (Shaywitz & Shaywitz, 2013). This area is proposed to be involved with speech production, phonological analysis (Schlaggar & McCandliss, 2007), silent reading, naming (Shaywitz & Shaywitz, 2013), phonological memory (Poldrack et al., 1999), and syntactic processing (Sandak et al., 2004). Further, the posterior region of the inferior frontal gyrus (i.e., Brodmann Area 44) appears to be more specialized for phonological processing with the anterior region (i.e., Brodmann Area 45) responsible for semantic processing (Poldrack et al., 1999). This system operates closely with the dorsal system to decode new words during reading development (Pugh et al., 2000), such that the dorsal and anterior systems predominate during initial reading acquisition with an increase in ventral system activity occurring as proficiency in word recognition increases (Shaywitz et al., 2002).

Reading Networks

Reading development does not occur through activations in isolated brain regions. Rather, reading involves distributed processing through networks of brain areas with functions related to the various components of reading ability (Vogel et al., 2013). For instance, a meta-analysis of neuroimaging studies conceptualized reading networks within the dual-route theory of reading (Jobard, Crivello, & Tzourio-Mazoyer, 2003). Essentially, related brain areas involved one of the two routes to access words: "graphophonological" and "lexicosemantic". The graphophonological route included left superior temporal areas, supramarginal gyrus, and the opercular area of the inferior frontal gyrus (Jobard et al., 2003). This route performed grapheme-phoneme integration, corresponding to the indirect route proposed by Bjaalid et al. (1997) and the dorsal system mentioned above (Sandak et al., 2004). The direct route (Bjaalid et al., 1997) is represented by the lexicosemantic pathway, which involves direct access of a word's meaning through visual processing of the word (Jobard et al., 2003). This pathway involves the ventral system (McCandliss et al., 2003), including co-activation of the left occipitotemporal region, including the VWFA, and the basal inferior temporal area, posterior middle temporal gyrus, and triangular area of the inferior frontal gyrus.

A recent review of reading neuroimaging studies looked separately at research that examined visual word processing and the mapping of orthography to phonology (Price, 2012). Studies examining visual word processing found that this skill involves the ventral occipitotemporal cortex, with posterior areas being responsible for visual feature extraction and anterior areas performing lexico-semantic processing of the whole word (Price, 2012). For converting orthography to phonology, the review proposes two routes similar to Jobard's (2003) meta-analysis: a lexico-semantic reading route involving the left ventral occipitotemporal cortex and the left ventral inferior frontal gyrus, and a non-semantic phonological decoding route involving the superior temporal cortex, ventral inferior parietal cortex, and dorsal precentral cortex (Price, 2012).

Development of Neural Systems for Reading

Much of the research discussed thus far has been completed with skilled adult readers. As such, this does not provide an understanding of how these systems develop in emerging readers. Therefore, studies with children are important to understand how these reading systems emerge and change with the development of reading skills. Based on a meta-analysis of fMRI studies investigating reading in children, it appears that similar brain regions are engaged as found with adults, namely the left frontal, temporoparietal, and occipitotemporal regions including activations of the VWFA, the inferior frontal gyrus and precentral gyrus, and the inferior, middle and superior temporal gyri and inferior parietal gyrus (Houdé, Rossi, Lubin, & Joliot, 2010). Although given that the mean age for these studies was 10.8 years, these findings likely reflect reading systems that are nearly fully developed, which may explain why similar brain regions as with adults were identified.

Studies using a cross-sectional approach to compare differences in functional neuroanatomy between adults and children on reading tasks have suggested that children use similar networks overall with some differences in activation patterns. For instance, an fMRI study comparing children between 7 and 10 years of age to adults on a task requiring participants to read single words aloud found two age-related differences in left hemisphere activation patterns (Schlaggar et al., 2002). The left extrastriate region showed greater activation in children whereas one left frontal region had greater activation in adults. Another study demonstrated that young readers primarily activated the left posterior superior temporal cortex, which was modulated by the level of the child's phonological skill (Turkeltaub, Gareau, Flowers, Zeffiro, & Eden, 2003). Thus, these findings suggest that the temporoparietal system is particularly involved in early reading development. In addition, learning to read was associated with an increase in activation of the left middle temporal and left inferior frontal gyri and a decrease in the right inferio-temporal area (Turkeltaub et al., 2003). Thus, as children learn to read the right hemisphere neural systems associated with memory are recruited less (Shaywitz & Shaywitz, 2013).

Additional studies have focused specifically on the functional neuroanatomy of phonological skills in children. One study examined the relationship between PA and functional activation during speech and print processing in beginning readers between the age of 6 and 10 years (S. J. Frost et al., 2009). Researchers found that behavioural measures of PA were positively correlated with activation in left superior temporal and occipitotemporal regions for print. In fact, activity in the left occipitotemporal area increased in response to print but decreased in response to speech as the child's PA increased, which suggests that this area becomes increasingly specialized for processing print as reading skills are acquired (S. J. Frost et al., 2009). Bitan and colleagues (2007) identified age-related patterns of activation such that older children demonstrated increased activation in the left inferior frontal gyrus and decreased activity in the dorsal superior temporal regions, which may indicate a transition from the use of auditory phonological skills in younger children to greater use of phonological segmentation and articulation in older children. An age-related increase in activation of the posterior parietal region was also found, which appears to be an area involved with mapping orthography to phonology (Bitan et al., 2007).

Reading also involves the association of phonology (i.e., language sounds) to visual print (i.e., orthography). Booth and colleagues (2004) found that this interaction is mediated by posterior heteromodal regions, including the supramarginal and angular gyri in adults and children. However, adults showed greater activation in the angular gyrus, suggesting that better reading skill is associated with a more complex system for integrating orthographic and phonological representations (Booth et al., 2004). Focusing specifically on the functional activation of associations between letters and speech sounds (i.e., grapheme to phoneme matching), Blau and colleagues (2010) found that the dorsal area of the left superior temporal gyrus near the primary auditory cortex and the bilateral superior temporal sulci were involved in the integration of letter and speech sounds.

The studies discussed thus far have demonstrated that different brain regions are involved in learning to read at various points in the developmental process. Figure 2 provides a summary of these findings, with the goal of depicting the brain regions primarily recruited for each type of reader. It appears that emergent readers rely more heavily on vision and memory centres of the brain to facilitate the recognition of sight words as decoding skills and phonological awareness develop. Once children have developed these reading skills, often by age 10, there are fewer activation differences compared to adult readers, as demonstrated in the aforementioned meta-analysis (Houdé et al., 2010). These brain activation differences are relevant considerations in understanding reading disabilities, to be discussed in the following section.

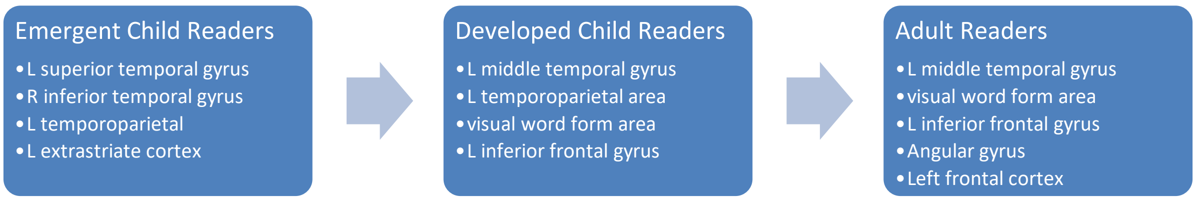

Figure 2. The progression of primary brain regions recruited during reading at each developmental level.

Reading Disability

Although reading is an important skill to master particularly as one progresses through school, learning to read can be a difficult process, with many children struggling with inaccurate or effortful reading. Reading disability (RD) involves a heterogeneous group of individuals who have difficulty learning to read (Catts, Kamhi, & Adlof, 2012). Reading disabilities commonly have other names, such as specific reading disability, reading disorder, specific reading disorder, dyslexia, and developmental dyslexia. The term 'developmental' is sometimes added to distinguish from acquired dyslexia, which is impaired reading following a brain injury despite appropriate premorbid reading ability. The definition of RD has changed over the years and these varying definitions differentially influence the identification, assessment, treatment, and research of disordered reading (Catts et al., 2012).

According to the 5th edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5), RD is classified under the broad category of Specific Learning Disorder (SLD). Diagnosis of a SLD requires persistent learning difficulties involving key academic skills, such as accurate and fluent reading of single words, reading comprehension, written expression and spelling, or those related to mathematics (American Psychiatric Association, 2013). In addition, performance on affected academic skills must be well below average for age and cause significant interference in school performance.

Although there is no specific cut-off score for academic impairment, a score of 1.5 standard deviations below the population mean for age is recommended for the greatest diagnostic certainty (American Psychiatric Association, 2013). Children who meet criteria for RD receive a diagnosis of a SLD with impairment in reading, which may include additional impairment qualifiers of either word reading accuracy, reading rate or fluency, and/or reading comprehension (American Psychiatric Association, 2013). Further, diagnosis of RD involves many exclusionary causal factors. That is, reading impairment cannot be caused by inadequate instruction, lack of opportunity, low intelligence, problems with hearing or visual acuity, emotional disturbances, and/or brain damage (Catts et al., 2012).

Given the heterogeneous nature of the reading disabilities and the significant changes to the definition over the years, it is important to understand the historical context and past research related to reading disabilities. As such, this section will provide a review of the various subtypes of reading disability proposed over the years along with the functional neuroanatomical differences in reading disability relative to typical readers. This review is essential to understand the theoretical background for the creation of the Reading Tendency Index and its usefulness in identifying challenges with a particular reading skill.

Types of Reading Disability

Various subtypes of RD have been suggested to account for different presentations of reading impairment in children. Two main grouping systems will be summarized here. The first involves distinguishing between readers who have deficits in word recognition, listening comprehension, or both based on the Simple View of Reading (Hoover & Gough, 1990). The second system, and most applicable to this project, involves the distinction between phonological and surface dyslexia subgroups, or readers who struggle with either decoding or visual word recognition.

As previously discussed, the Simple View of Reading posits that reading comprehension is the product of word recognition and listening comprehension. That is, effective readers should decode fluently and understand the words and sentences read to them (Hoover & Gough, 1990). Multiple studies have demonstrated that these two skills account for independent levels of variance in reading comprehension (Aaron, Joshi, & Williams, 1999; Adlof, Catts, & Little, 2006; Carver, 1993; Catts, Hogan, & Adlof, 2005). According to this view (Catts et al., 2012), four subgroups of poor readers can be identified based on strengths and weaknesses in word recognition and listening comprehension as outlined in Table 1. Children with difficulties in word recognition but intact listening comprehension would be considered to have dyslexia while those with deficits in both areas are classified as mixed RD. The fourth group, with weaknesses in listening comprehension and intact word recognition, was described as children with a specific comprehension deficit. Various studies provide support for these subgroups given the identified word recognition deficits in children diagnosed with dyslexia while other children experience deficits in both phonological processing and word recognition, meeting criteria for mixed RD (Catts et al., 2012). Of particular relevance is that this view does not necessarily discuss the role of phonological processing or awareness. Instead, this skill is conceptualized as 'listening comprehension'.

Table 1
Depiction of Subgroup Characteristics Based on Simple View of Reading

Subgroups	Listening Comprehension	Word Recognition
Non-specified	+	+
Dyslexia	+	-
Mixed reading disability	-	-
Specific comprehension deficit	-	+

Another classification system of RD involves distinguishing between phonological and surface dyslexia, or deficits in decoding and word recognition, respectively. This system is based off the dual-route perspective of reading (Bergmann & Wimmer, 2008). Children who have specific difficulties with non-word decoding have been referred to as having 'dysphonetic' (Boder, 1973) or 'phonological' dyslexia (Coltheart, Patterson, & Marshall, 1980; Marshall & Newcombe, 1973; Wang, Marinus, Nickels, & Castles, 2014). Conversely, children with difficulties in exception-word reading are classified as having 'visuospatial' (Ingram, 1964) or 'surface' dyslexia (Marshall & Newcombe, 1973; Wang et al., 2014). For example, children with surface dyslexia struggle to read irregular words like *yacht* but can read nonwords due to intact decoding ability (Wang et al., 2014). The opposite is true for impaired readers with phonological dyslexia. Children with deficits in both areas are considered to display ‘deep’ dyslexia (Coltheart et al., 1980).

Similarly, Bakker (1990) proposed two types of dyslexia that fit within the dual-route perspective of reading, which he termed L-type and P-type. L-type stands for ‘left hemisphere’ since these children appear to shift to left hemisphere strategies too early, whereas P-type represents ‘perceptual’ since these children predominantly use right hemisphere strategies failing to make the hemispheric shift (Bakker, 1992). L-type dyslexia involves reading in a hurried fashion with many errors while relying on word recognition skills or the direct, lexical route (Bakker, 1992; Bakker, Licht, & van Strien, 1991). In contrast, P-type readers are slow and fragmented with relatively preserved accuracy who rely on decoding skills via the indirect, phonological route (Bakker, 1992; Bakker et al., 1991).

Functional Neuroanatomical Differences in Reading Disability

Neuroanatomical evidence provides additional support for the dual-route perspective as it applies to subtypes of reading disabilities. Functional imaging studies have identified differential patterns of reduced activation in left occipitotemporal (Brunswick, McCrory, Price, Frith, & Frith, 1999; Paulesu et al., 2001; Paulesu, Danelli, & Berlingeri, 2014; Shaywitz et al., 2003) and temporoparietal regions (Shaywitz et al., 2002; Shaywitz et al., 2003; Temple et al., 2001), with variable differences seen in the activation of the inferior frontal gyrus with some studies showing increases (Brunswick et al., 1999; Shaywitz et al., 1998; Temple et al., 2001) and others decreases (Aylward et al., 2003; Corina et al., 2001; Georgiewa et al., 1999). Based on these studies, a common interpretation of the activation pattern in RDs is that decreased left-hemisphere occipitotemporal activity corresponds to deficits in word recognition processes, decreased temporoparietal activity to deficits in phonological processing, and increased inferior frontal gyrus activity is related to compensatory processes (Peterson & Pennington, 2010). In fact, Shaywitz (2003) has indicated that the neural signature for dyslexia involves the underactivation of left posterior reading systems and overactivation of the left anterior regions, namely the inferior frontal gyrus, as depicted in Figure 3.

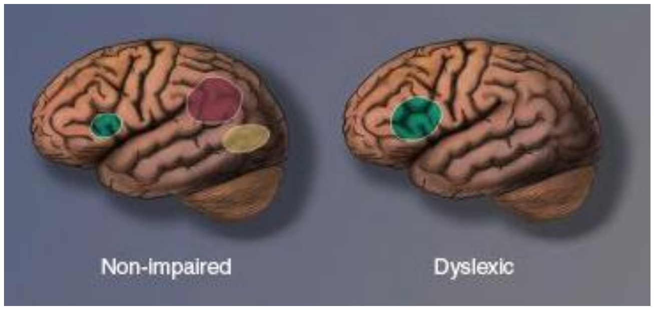

Figure 3. Neural signature for dyslexia depicting left hemisphere brain systems for reading in non-impaired (left) and dyslexic (right) readers (Reproduced from Shaywitz & Shaywitz, 2013 with permission of Springer Publishing Company in the format Thesis/Dissertation via Copyright Clearance Center).

Indeed, there are differences in functional activation patterns within RD subtypes that align well with the dual-route perspective for reading. For instance, Mohl (2015) identified different activity patterns based on whether children preferred using decoding or sightword reading strategies on lexical decision tasks (LDTs). Increased activation was seen in the ventral subnetwork involving occipitotemporal regions for children who utilize sightword reading strategies during a high-frequency word recognition task relative to those who rely primarily on decoding skills (Mohl, 2015). Decoders also demonstrated hypoactivation of the ventral network during the word recognition task when compared to children who preferred using recognition strategies or who employed a balanced approach. Conversely, there was increased activation in the dorsal subnetwork involving temporoparietal regions for Decoders compared to Sightword Readers during a phonological condition requiring the identification of pseudowords (Mohl, 2015). This study demonstrated that a child's reading tendency can be predictive of functional neural subnetworks responsible for decoding and word recognition processes (i.e., dual-route theory; Jobard et al., 2003).

The notion that a child's reading tendency is a better predictor of these specific neural subnetworks than the diagnostic group is compelling and suggests another approach to assessing and diagnosing reading disabilities may provide better insight into these individual differences. Moreover, Mohl's (2015) findings are in line with the dual-route cognitive theory of reading skills (Paap et al., 1987), dual-route neuroanatomical networks (Jobard et al., 2003), and the two-fold distinction in dyslexia subtypes detailed by multiple researchers (Bakker, 1990, 1992; Bakker et al., 1991; Coltheart et al., 1980;

Marshall & Newcombe, 1973; Wang et al., 2014). Given these robust findings, the Reading Tendency Index (RTI) protocol was described as a possible means for identifying reading tendencies in children as well as areas of challenge to then target for intervention, if appropriate.

Reading Tendency Index

This dissertation project is a follow-up to Dr. Brianne Mohl's 2015 dissertation project by examining broadly the validity of the RTI model while addressing many of the limitations discussed in the published manuscript (Mohl et al., 2018). Prior to introducing the rationale for the present study, several dimensions relevant to the RTI will be discussed, including the development of the RTI, the associated LDT tasks, the cognitive and neural profiles of participants based on RTI groups, the original study limitations, and next steps.

Development of the RTI protocol

As part of a larger study examining neural differences between children with ADHD and typically-developing controls using fMRI, Mohl (2015) created a Reading Tendency Index (RTI) based on the trade-off in performance on two forced-choice LDTs. When implemented, this value facilitated the association between a child's default reading tendency and the reading subnetworks proposed in the dual-route perspective described above. Although the idea of separate distributions of readers based on two dimensions of reading deficits (either phonological or orthographic) has previously been proposed (Stanovich, 1988), there has been no metric to date that quantifies individuals on this continuum while taking into account the effects of processing speed.

The purpose of the RTI involves describing a continuum of readers based on their propensity to use one or more strategies for single word reading and identifying clusters of readers that use similar cognitive approaches. Three groups have been identified using the RTI: Decoders, Sightword Readers, and Balanced Readers (Mohl et al., 2018). Readers who are balanced in their approach to reading are likely to be more fluent readers and can engage flexibly in either subnetwork as needed through appropriate activation of the two reading neural subnetworks (Booth et al., 2004). Conversely, specific impairments in one of the systems may produce an over-dependence on one reading strategy over the other (Mohl, 2015). Specifically, it was suggested that poor visual working memory and poor cognitive flexibility may lead to underdeveloped mental lexicon in Decoders, limiting the use of automatic word recognition skills (Mohl et al., 2018). Furthermore, greater inattention, poor verbal working memory, and deficits in phonological awareness may produce a dependence on word recognition in Sightword Readers due to impaired decoding skills (Mohl, 2015).

To validate the RTI classification model and test hypotheses, a clinical sample of 42 boys between the ages of 9 and 16 years completed an orthographic and a phonological lexical decision task (LDT) in an fMRI scanner (Mohl, 2015; Mohl et al., 2018). Participants were recruited to fit one of three diagnostic groups: ADHD plus RD, ADHD without RD, or a typically-developing control group. Results from performance on these two tasks were determined using a simplified version of drift diffusion modelling (DDM) and then combined to generate a Reading Tendency Index with an associated grouping (i.e., Decoder, Sightword Reader, or Balanced Reader). Details from the original study will be described below, including information about DDM, the experimental tasks and RTI calculations, cognitive profiles, and neural patterns of activation as well as limitations and next steps as described by Mohl et al (2018).

Drift Diffusion Modelling

DDM has been applied with numerous studies involving LDTs (Ratcliff, Gomez, & McKoon, 2004; Ratcliff, Perea, Colangelo, & Buchanan, 2004). It is an effective strategy for examining reaction time data from two-choice decision tasks because it also takes into account both speed and accuracy data (Ratcliff, Gomez, et al., 2004). Specifically, confounding effects of processing speed, attentiveness, and motor speed variations are addressed in this mathematical model (Philiastides, Auksztulewicz, Heekeren, & Blankenburg, 2011). It has also been validated for use with special populations, including impaired readers (Ratcliff, Perea, et al., 2004). According to these authors,

> DDM assumes that decisions are made by a noisy process that accumulates noisy information over time from a starting point toward one of two response criteria or boundaries (‘word’ and ‘nonword’ boundaries in the lexical decision task)… When one of the boundaries is reached, a response is

initiated. Speed-accuracy trade-offs occur when the boundaries change their distance from the starting point. Boundaries far from the starting point produce slow and accurate responses, while boundaries close to the starting point produce fast and inaccurate responses. (pg 375)

DDM accounts for differences in processing speed, and neural models have validated the notion that specific parameters reflect underlying cognitive abilities (Philiastides et al., 2011). Essentially, underlying cognitive skills can be inferred from the drift rate of specific tasks, which reflects how quickly information is accumulated to make a choice (Bogacz, Brown, Moehlis, Holmes, & Cohen, 2006). That is, drift rate represents how long it takes a child to choose whether a stimulus is a word or non-word. For example, a familiar word in a LDT would have high evidence accumulation and a large drift rate. DDM also assumes variability within the drift rates and accounts for this variability as well as variability in starting points (Ratcliff, Perea, et al., 2004). See Figure 4 for an illustration of the drift diffusion model.

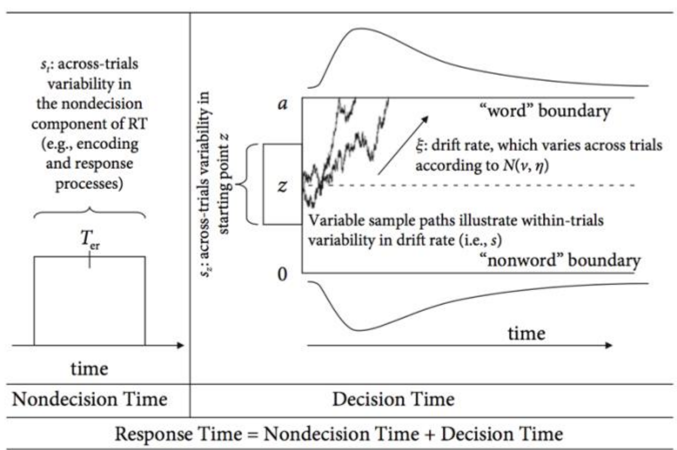

Figure 4. An illustration of the drift diffusion model (Reproduced from Wagenmakers et al., 2007 with permission of Springer Nature in the format Thesis/Dissertation via Copyright Clearance Center).

The phonologic and orthographic LDTs created for Dr. Brianne Mohl's dissertation were developed such that participants would be highly successful (Mohl, 2015), thereby limiting the applicability of full DDM since this conventional method requires at least 10 errors to accurately model drift rate. As such, EZ-Diffusion modeling (EZDM) was used. EZDM is a simplified, six parameter version of DDM, which adjusts for data with too few errors and requires that similar assumptions be met, including right-skewed distributions (Wagenmakers et al., 2007). This model is described as being the response time analogue to classical signal theory (Wagenmakers et al., 2007), such that hit rate and false alarm rate are observable input variables with unobserved output variables being discriminability and bias. EZDM has similar input variables (i.e., reaction time mean, variance, accuracy), which outputs unobserved variables (i.e., drift rate, boundary separation, nondecision time). EZDM is depicted in Figure 5. The particular variable of interest in this study is *drift rate*.

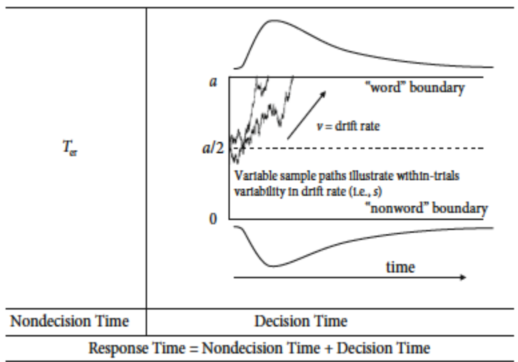

Figure 5. An illustration of the EZ-diffusion model (Reproduced from Wagenmakers et al., 2007 with permission of Springer Nature in the format Thesis/Dissertation via Copyright Clearance Center).

In regards to the RTI model, drift rate represents the underlying reading skill depending on the specific LDT. A larger drift rate on the decoding task reflects a quicker process to decipher whether a stimulus is a pseudoword or real word, and either involves cognitive processes related to phonological decoding of words (i.e., sounding it out) or the realization that it is an unfamiliar stimulus (Mohl et al., 2018). Similarly, a large drift rate on the word recognition task reflects shorter time to make a decision about whether the stimulus is a word (Mohl, 2015). This method also controls for confounds of motor speed and inattentive responses. Theoretically, proficiency translates to faster cognitive processes that increase the rate of responding and decrease the threshold needed to be certain of the choice.

Description of RTI Tasks

As described by Mohl (2015), the phonologic lexical decision task (pLDT) contained pseudowords and low frequency words chosen for their ability to elicit responses based on the dorsal decoding subnetwork (Bergmann & Wimmer, 2008; Binder et al., 2003; Hickok, 2009; Hickok & Poeppel, 2007). Pseudowords were pronounceable combinations of graphemes that were not pseudohomophones of real words (e.g., bofty, thant) to prevent the possibility of explicit prior exposure to the stimuli. As such, participants were required to decode the string of letters to make their response. Low frequency words (e.g., dough, shelf) were chosen to specifically elicit decoding processes. Each of the 12 pLDT decoding blocks was 18 seconds long, followed by a 13.75 second fixation on multiple pound symbols (i.e., “####”), resulting in a total task time of 5 minutes and 42 seconds. Subjects needed to identify 3- to 5- letter, monosyllabic pseudowords from low frequency words (duration = 1.6 seconds; interstimulus interval = 2.25 seconds) during 12 decoding blocks. Half of the blocks were mostly (>60%) pseudowords and the other half were mostly low frequency words. This was done to limit the chances of guessing with 50% accuracy (Mohl et al., 2018).

For the orthographic LDT (oLDT), consonant strings (e.g., kspq, swnr) and high-frequency words (e.g., black, great) were selected in order to measure word recognition processing of the ventral recognition subnetwork (Hickok, 2009). The presentation of oLDT items was half the duration of items from the pLDT to encourage reading via recognition memory and not overt decoding processes (duration = 0.8 seconds; interstimulus interval = 1.2 seconds). Consonant strings provided information about participants’ skill in pure symbol processing since there is no phonological equivalent and ensures that there are no perceptual differences in groups (Mohl, 2015). One hundred and twelve monosyllabic, high-frequency words were selected from the English Lexicon Project (Balota et al., 2007) and matched with consonant strings. Thirteen sightword blocks were administered; seven word blocks had target ratios of 4 words to 1 string and six consonant string blocks with a ratio of 4 strings to 1 word. These were presented in alternating fashion with nine fixation blocks (i.e., “####” with no required response) of 13.75 seconds. The total task time for the oLDT was 6 minutes and 35 seconds (Mohl, 2015).

Drift rate, a metric used in forced-choice tasks, for responding to pseudowords in the pLDT and to high-frequency words in the oLDT were calculated using EZ Diffusion instead of full Drift Diffusion Modelling (DDM). Full DDM requires a minimum of 10 errors to accurately model drift rate (Wagenmakers, van der Maas, & Grasman, 2007), so it was not useable in Mohl’s study since the LDTs were created to ensure a high success rate among participants (Mohl, 2015). As such, EZ Diffusion was used instead, which produces comparable outcomes with simpler calculations (Wagenmakers et al., 2007). This method calculates a “drift rate” based on the participant’s reaction time for each item and proportion correct on the LDTs.

To create the Index score itself, the inverse word recognition drift rate obtained from EZ Diffusion modeling was subtracted from the inverse of the corrected pseudoword drift rate to estimate the balance of the two skills (Mohl, 2015). Additional details about DDM will be explained below. A score on the RTI closer to 0 would suggest a balanced approach, a negative value suggests relying on decoding skills, and a positive value as relying on word recognition skills. To ensure that Balanced Readers were also fluent, Mohl (2015) plotted RTI scores against another dimension: ratio of Relative Fluency, which was calculated by adding pseudoword and word recognition drift rates together, to Reading Tendency. As shown in Figure 6, readers in this original study tended to be more fluent (y-axis) as their reading tendency was more balanced (x-axis).

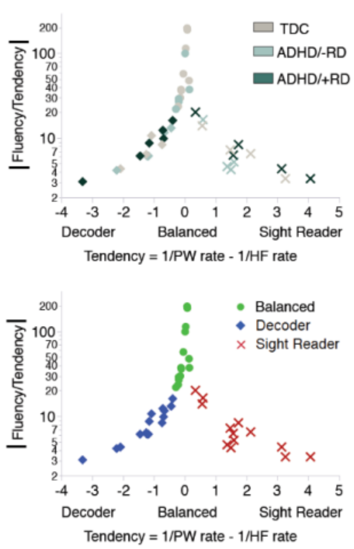

Figure 6. Comparison of reading fluency and reading tendency groups (adapted with permission from Mohl, 2015). Top graph is colour-coded to depict existing diagnoses with data shapes illustrating RTI group membership. Bottom graph is colour-coded by RTI group membership.

Examination of Cognitive and Neural Profiles of RTI Groups

In an attempt to validate the RTI groupings, Mohl et al. (2018) examined differences in performance on standardized measures of reading, pseudoword decoding, spelling, verbal working memory, and cognitive flexibility across groups. In general, readers in the Balanced group demonstrated the highest scores on all neuropsychological and reading assessments while Decoders demonstrated poorer word recognition and cognitive flexibility relative to Balanced Readers (Mohl et al., 2018). Sightword Readers also demonstrated poorer cognitive flexibility and verbal working memory (Mohl et al., 2018).

The RTI groupings were also successful in predicting subnetwork neural dysfunction in these individuals regardless of reading disability diagnosis. That is, the classification of children based on their reading tendencies better captured cognitive and neural profiles than traditional ADHD and RD diagnostic criteria (Mohl, 2015). When required to use word recognition skills, Decoders demonstrated hypoactivation of ventral network areas compared to Sightword and Balanced Readers (Mohl, 2015). Conversely, increased activation was seen in the ventral subnetwork for Sightword Readers during the word recognition task. In addition, Decoders demonstrated increased activation of dorsal subnetwork regions during the phonological condition (Mohl, 2015). Although the sample was originally separated into three diagnostic groups (ADHD + RD, ADHD without RD, typically-developing controls), this grouping configuration did not accurately capture neural activation patterns whereas grouping based on RTI drift rates did. In fact, the RTI groups involved a heterogeneous mix of children from each of the diagnostic groups as seen in the top of Figure 6 (Mohl, 2015). Additionally, 84% of the participants with ADHD were classified as having sub-optimal reading strategies (i.e., utilizing a non-balanced approach) compared to only 44% when considering an existing RD diagnosis (Mohl et al., 2018).

Thus, this preliminary evidence suggests that the RTI may serve as an effective, quantitative tool for examining reading tendencies in school-age children, and by consequence screening for reading impairments (Mohl, 2015; Mohl et al., 2018). The computerized LDTs can be administered and the Index subsequently calculated within 20 minutes, providing an affordable potential screening mechanism that could be implemented in schools. Since the Index direction reflects relative strengths in reading approaches, the RTI protocol also provides teachers and special education staff with information about which reading skills should be targeted to improve overall reading ability (Mohl et al., 2018).

Limitations and Next Steps

Given the results from the preliminary study, Mohl (2015) suggested the need for a paradigm shift for assessing reading skills from traditional disability-based categorizations to the quantitative estimation of reading tendencies. This tendency-based approach would focus on intact processing pathways and provide insight into possible implications regarding higher order reading tasks, such as comprehension and fluency (Mohl, 2015). Although Mohl's studies provide some preliminary evidence in support of the RTI as a quantitative tool for measuring reading tendencies based on neural activation patterns, there were significant limitations with the study that signal the need for additional research to validate its use.

First, the RTI was developed and subsequently tested on a small, clinical sample of boys, which may limit the generalizability of the results to a large representative sample of children. Many of the boys had a diagnosis of ADHD, so it was unclear whether any psychiatric comorbidities in this sample influenced any outcome measures (Mohl et al., 2018). Also, the tasks were administered in an fMRI scanner, not in a school environment. In order to determine the appropriateness of using the RTI as an educational or clinical screening tool for children with possible reading difficulties, the task should be validated with a large, representative school-aged sample and administered in an environment similar to a clinical or educational setting rather than in a scanner (Mohl et al., 2018). It was also recommended that the predictive ability of the RTI be compared to other predictors, such as phonological awareness and reading abilities (Mohl et al., 2018). Thus, validation efforts should also take into account these limitations by administering the RTI tasks and additional measures of reading-related cognitive abilities to a group of typically-developing school-aged children in their school setting.

Rationale for the Present Study

The purpose of this dissertation project was to examine the validity of the Reading Tendency Index protocol as a screening tool for identifying reading impairments in school-aged children by addressing the limitations discussed in the original study (Mohl et al., 2018). It was designed to address a series of individual research questions with the overarching goal of evaluating the validity of the RTI protocol and exploring its clinical implications. Given the strong theoretical basis for Mohl's original findings in support of the RTI groupings (Mohl, 2015; Mohl et al., 2018), the goal of this project was to extend the original work to evaluate whether this tool is appropriate for use in educational and, by extension, clinical settings. A sample meant to be representative of Ontario school-aged children was recruited and the tasks were administered in a school setting on a laptop. Separate research questions explored the replicability of the original RTI findings, the construct and criterion validity as a measure of reading ability, and the potential differences when used with a French language sample.

Research Questions & Hypotheses

Research Question #1: Do the RTI groupings replicate in a larger, representative sample?

One objective of the present study was to replicate the three-group structure of the original protocol (Mohl et al., 2018) by administering the LDTs with a larger representative sample of school-aged children. To do so, drift rates for individual performance on both LDTs were calculated using EZ Diffusion Modelling software (EZDM; Wagenmakers et al., 2007). Readers were grouped using the same equations as Mohl et al. (2018) to calculate the Reading Tendency Index (RTI). Given the theoretical basis and functional neuroanatomical evidence in support of the RTI's three groups (Mohl, 2015; Mohl et al., 2018), it was expected that this categorization would be upheld with the entire mixed-language sample of the current study that is meant to be representative of Ontario school-aged children.

This research question also examined whether this protocol was applicable for children studying in French Immersion programs. This is an important validation effort should the RTI be used as a screening tool in Canada given that nearly 10% of Canadian students are enrolled in French immersion programs (Canadian Parents for French, 2015) with nearly 400,000 students enrolled in 2016, a 20% increase since 2011 (Statistics Canada, 2017). Moreover, there are even more students enrolled in full French language programs who also learn to read in English. That being said, there is limited research that examines reading abilities in children studying in French immersion and no studies examining their specific English reading tendencies.

Hypothesis 1a. It was predicted based on the findings of Mohl et al. (2018) that three groups—Balanced Readers, Decoders, or Sightword Readers—would emerge from the entire sample based on the propensity to use and potentially favour specific reading skills on the two LDTs, with Balanced Readers having greater relative fluency.

Hypothesis 1b. Since students enrolled in French Immersion schools are expected to be able to read in both French and English, it was predicted that the same RTI groupings would also be achieved in this sub-sample. As such, the three groupings should be upheld with the French Immersion and English-only sub-samples.

Research Question #2: Do the RTI tasks possess adequate construct and criterion validity as a measure of reading ability?

After replication of the groupings, the next objective of the study involved multiple statistical analyses to evaluate the construct and criterion validity of the RTI protocol. In addition to the LDTs, participants were administered standardized reading and cognitive measures to explore the concurrent and predictive validity of the RTI group characteristics. To examine the concurrent validity of the RTI protocol, the performance of each group on standardized measures of reading and other cognitive skills was compared using multivariate analysis of variance (MANOVA). Nine measures were used as outcome variables: WIAT-III Word Reading, Pseudoword Decoding, and Spelling; GORT-5 Fluency and Comprehension; auditory working memory (composite of Sentence Memory Test and WISC-V Digit Span); CTOPP-2 Phonological Awareness Composite (PAC); WISC-V Coding (digital; measure of processing speed) and WISC-V Picture Span (measure of visual working memory).

Hypothesis 2a. Given that reading is a developmental process (Chall, 1996) and that Balanced Readers tended to have better reading fluency (Mohl et al., 2018), it was predicted that there would be a larger proportion of readers classified as Balanced when older children were compared to younger children as demonstrated with chi-squared analysis.

Hypothesis 2b. Based on results from the preliminary study (Mohl et al., 2018), it was predicted that Balanced Readers would perform better on all reading and cognitive measures compared with Sightword Readers and Decoders.

Hypothesis 2c. It was predicted that Decoders would perform better on measures of phonological awareness and pseudoword decoding compared with Sightword Readers given the propensity for decoding skills and hyperactivation of the phonological (dorsal) subnetwork (Mohl, 2015; Mohl et al., 2018).

Hypothesis 2d. Conversely, Sightword Readers should perform better than Decoders on tasks of working memory given the preliminary findings that Decoders demonstrated relative weaknesses in working memory (Mohl, 2015; Mohl et al., 2018).

Research Question #3: Can RTI three-group membership be predicted by performance on reading and other cognitive measures?

The predictive validity of the RTI group memberships was also examined. A discriminant function analysis was performed to determine which of the significant measures from the MANOVA best predict group membership within one of the three RTI groups.

Hypothesis 3. It was predicted that participants with better reading fluency would be more likely to be classified as Balanced Readers compared to Decoders and Sightword Readers.

Research Question #4: If three group membership cannot be predicted from reading performance, does reading fluency predict dichotomous group membership (i.e., Balanced vs. Non-balanced)?

To account for the possibility that there may be little predictive distinction between the two non-balanced groups (i.e., Decoders and Sightword Readers), a logistic regression was proposed as another analysis to determine whether reading fluency predicted dichotomous group membership, as either balanced or non-balanced.

Hypothesis 4. Similar to Hypothesis 3, it was predicted that participants with better reading fluency would be classified as Balanced Readers than non-balanced readers.

Research Question #5: Do Canadian students enrolled in French Immersion programs perform differently on RTI tasks and other English reading and cognitive measures?

Given the increasing number of students enrolled in French Immersion (FI) programs, it is important to explore potential differences in English reading tendency and performance on standardized reading and cognitive measures compared to their English counterparts. Although there have been many studies highlighting the cognitive benefits of bilingualism, including precocious development of attentional control, working memory, metalinguistic awareness, cognitive flexibility, and abstract and symbolic representation skills (Adesope, Lavin, Thompson, & Ungerleider, 2010), much of this research has been performed with participants who are equally proficient in both languages. Fewer studies have been performed with English-speakers who are studying in FI programs (i.e., second language learners), especially in regard to their preferred reading tendencies.

Indeed, students in FI appear to be more proficient at phonological awareness than English-only students, even on English tasks (Rubin & Turner, 1989). English-only participants only performed better at reading orthographically irregular English words, suggesting that bilingualism may promote metalinguistic awareness (Rubin & Turner, 1989). Additional research suggests the presence of a language effect across ages, with younger FI students lagging behind English counterparts in terms of their English reading comprehension and word knowledge, becoming roughly equivalent by Grade 3, and then even outperforming them by Grade 6 (Genesee & Jared, 2008; Lapkin, Hart, & Turnbull, 2003). That these students eventually catch up to their English-only peers suggests that the literary skills acquired in French may be transferable to English and possibly vice versa (Genesee & Jared, 2008). What is currently unclear is a) whether the proportion of balanced vs. non-balanced readers will differ based on language of instruction, and b) how FI and English learners differ on measures of English reading fluency and comprehension.

Hypothesis 5a. Given that students in French Immersion programs have increased metalinguistic awareness (Rubin & Turner, 1989) and tend to outperform English-only students on reading achievement measures even when gender, socioeconomic status, and parental education were taken into account

(Allen, 2004), it is likely that a language effect will be seen for reading tendency. Thus, it is predicted that there will be a higher proportion of Balanced Readers in the FI compared to English-only groups.

Hypothesis 5b. Given the limited research comparing reading performance between Ontario students enrolled in English and French Immersion schools, secondary analyses were performed to explore cognitive and reading performance across language groups. It is predicted that French Immersion students will perform better on tasks of reading fluency, pseudoword decoding, word reading, and phonological awareness compared to English students.

CHAPTER 3 – METHODS

Participants

Ninety-nine children between the ages of 7 and 14 years were recruited from the Windsor-Essex Catholic District School Board (WECDSB) and the Windsor-Essex County community whose parents contacted the researcher and provided informed consent for participation (see Appendix B) via online survey. Participant descriptive information is summarized in Table 3 in the Results chapter. The research protocol received clearance from the University of Windsor's Research Ethics Board as well as the administration at WECDSB prior to the start of recruitment. Data collection occurred from December 2017 through June 2018 at seven local schools. Two participants did not complete the study after providing consent due to scheduling issues, so consent to proceed was withdrawn. One other participant was removed from the dataset for failing to complete the experimental task (i.e., child requested to end study prematurely without attempting LDT tasks) for a final sample of 96 participants (50 from English-only schools, 46 from French Immersion schools; M_{age} = 9.96 years, SD = 1.82). Informed consent was also obtained from each child prior to participation using age-appropriate assent forms (see Appendix C).

After obtaining permission from principals at selected schools to conduct research with the students in their building, short classroom presentations were given to eligible classrooms and a study advertisement (see Appendix D) was sent home to parents along with a copy of the consent form, which provided more detail regarding the study. If the child and parent were interested in becoming study participants, the parent contacted the researcher via email or phone and was then asked to complete the online consent form and a brief demographic questionnaire to gather relevant information about the participant (see Appendix E). Appointments were then scheduled at the child's school in coordination with the classroom teacher.

Recruitment occurred at targeted schools to address potential differences in demographic variables across WECDSB schools. Originally, it was planned that three city of Windsor schools and three Essex county schools would be recruited initially as study sites given differences in median household total income (Statistics Canada, 2013) between the city of Windsor ($49,100) and the Essex County towns of LaSalle ($90,700) and Tecumseh ($84,800). In total, recruitment occurred at two inner city schools (one French Immersion, one with dual language programs) and five county schools (two English, two French Immersion, and one dual language). A small subset of participants (n = 4) were recruited through the general community and were all enrolled in county French Immersion schools within the public school board. Community participants were recruited through the use of a public Facebook page, titled *uWindsor Reading Study 2018*, which shared REB-approved recruitment materials online asking interested parents to contact the researcher via email if interested. Overall, 25 students from city schools and 71 from county schools were recruited. Median parental education, a proxy estimate for SES, did not differ between participants from city and county schools or English and French Immersion programs.

Materials and Apparatus

Demographic Information

For purposes of sample description and scheduling of appointments, demographic (e.g., age, sex, ethnicity, child and family language, parental education, and neurodevelopmental histories) and school (e.g., school name, grade, and teacher's name) information was collected via online survey (see Appendix E), which also included the parent consent form embedded within. Parental education level was based on self-reported highest level completed or attended (e.g., high school graduate, college diploma, bachelor's degree, graduate level degree/training, some high school/college/university).

Lexical Decision Tasks

The lexical decision tasks (LDTs) used in this project were based on those created for Dr. Brianne Mohl's dissertation project at Wayne State University (Mohl, 2015) from which the Reading Tendency Index (RTI) protocol was developed. Mohl's LDT tasks were replicated using PsychoPy© software (Peirce, 2007, 2009) and developed for use on a laptop in a school setting. The original tasks were short to facilitate their use in an fMRI scanner, and EZ Diffusion modeling was used to calculate drift rates

(Wagenmakers et al., 2007). These tasks were replicated in the present study to uphold similitude with previous results (Mohl et al., 2018) and to be clinically parsimonious for task administration and statistical analysis. It was concluded that a major clinical benefit of the RTI was that the tasks were brief, providing a potentially broad-reaching and affordable screening tool for schools to use to determine possible reading difficulties in children through overreliance on one tendency versus the other (Mohl et al., 2018). Given the purposes of the present study, it was decided that replicating the tasks as originally designed would offer distinct clinical benefits for use in schools as well as offer more rigorous psychometric validation. If results from the original studies were upheld, this Index could benefit students by screening for their tendencies as they perhaps wait for a formal psychoeducational assessment through the current model.

As previously described, the phonologic lexical decision task (pLDT) contained pseudowords and low frequency words, and participants needed to quickly identify whether the word presented was a real word by pressing Z for yes or M for no. The orthographic LDT (oLDT) contained consonant strings and high-frequency words, with participants needing to quickly decide if it was a real word in the same manner. The words used in each LDT are listed in Appendix F. Responses on the current tasks were recorded using Z and M letter keys on the laptop's keyboard. All stimuli were presented in white, Arial font size 112 on a gray background in the centre of the screen (see Figure 7 for schematic representation of LDT stimuli). As in the previous study (Mohl, 2015), the presentation time for oLDT items was half the duration from the pLDT (i.e., 0.8 seconds compared to 1.65 seconds) to encourage use of recognition skills instead of decoding. Breaks of 14 seconds were built in to the tasks in order to minimize fatigue and promote engaged performance.

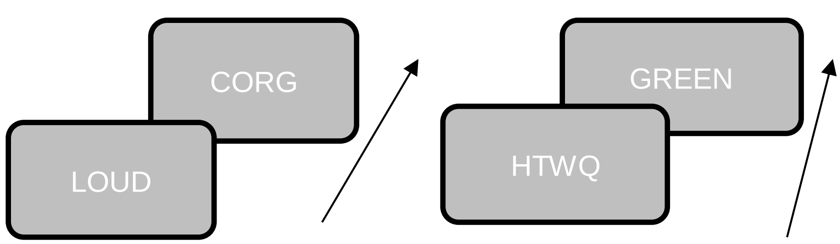

Figure 7. Schematic representation of stimuli for pLDT (left) and oLDT (right) to demonstrate what is depicted on the laptop screen during the tasks.

Neuropsychological Measures

WISC-V. An estimate of intellectual functioning (i.e., Short Form IQ, SFIQ) was derived using the Vocabulary (VC) and Information (IN) subtests of the Wechsler Intelligence Scale for Children – Fifth Edition (WISC-V; (Wechsler, 2014a) based on the recommendations of Sattler, Dumont, and Coalson (2016). This combination of subtests as a SFIQ yields the highest reliability and validity to the complete test, with coefficients of .921 and .811 respectively (Sattler et al., 2016). The SFIQ based on these subtests were obtained using the procedure outlined by Tellegan and Briggs (1967), which is referenced in Sattler (2016). More specifically, Table A-7 in Appendix A of Sattler et al. (2016) was used to obtain the SFIQ standard score given the sum of scaled scores for this specific combination (i.e., Combination 11 according to Sattler et al., 2016). VC measures knowledge of words by asking examinees to name objects in a picture (younger starting point) and to define words (Wechsler, 2014a). This subtest is conceptualized as a measure of crystallized knowledge, lexical knowledge, verbal comprehension, long-term memory, receptive and expressive language, and conceptual knowledge (Sattler et al., 2016). Performance on this subtest also tends to be stable over time and resistant to neurological or psychological disturbance. In the IN subtest, examinees are asked to answer questions about a range of different topics, assessing long-term memory for factual information (Wechsler, 2014a). This subtest is also a measure of crystallized knowledge, verbal comprehension, and receptive and expressive language. The purpose of the subtest is to sample knowledge that the average child with average educational opportunities has acquired through typical home and school environments (Sattler et al., 2016).

Digit Span (DS), Picture Span (PS), and Coding (CD) subtests from the WISC-V were also administered to assess participants' auditory and visual working memory, and visual symbol processing speed, respectively. DS and CD have been a part of the WISC since the first version published in 1949 and has undergone minor revisions since, whereas PS is a new addition to the WISC-V. DS has three separate tasks that requires the examinee to repeat a series of digits in forward, backward, and ascending order that increase in length incrementally (Wechsler, 2014a). An important update introduced with the

WISC-V was the addition of a third, sequencing task to better align with the adult version of the Wechsler Scales (Wechsler, 2008). Although this subtest is considered to measure auditory short-term memory, it relies heavily on working memory, memory span, rote learning, auditory sequential processing, and attention (Sattler et al., 2016). PS requires the child to view an increasing number of pictures and then select them in sequential order from a larger array (Wechsler, 2014a). This subtest involves visual working memory, visual span, sequential processing, and proactive interference (Sattler et al., 2016). CD requires the student to copy/identify symbols that are paired with numbers in a key under timed conditions (Wechsler, 2014a). This subtest primarily examines speed of mental operation and graphomotor speed, but also involves visual-motor coordination, rate of test taking, scanning ability, visual short-term memory, symbol-associative skills, visual processing, fine-motor coordination, attention, and concentration (Sattler et al., 2016).

Major revisions were made with regards to the theoretical foundations, developmental appropriateness, and psychometric properties of the WISC-V (Canivez & Watkins, 2016). The *WISC-V Technical and Interpretive Manual* outlines specific standardization procedures and details regarding the normative sample that comprised 2,200 children between the ages of 6 and 16 years, with 100 boys and 100 girls at each age level (Wechsler, 2014b). The WISC-V has strong psychometric properties with good reliability and validity. Internal consistency reliability estimates of subtests range from .81 to .94 and short-term test-retest reliability coefficients range from .63 to .89 after an average re-test interval of 26 days (Wechsler, 2014b). In terms of criterion validity, the WISC-V maintains moderate to high correlations with other measures of intelligence (i.e., WISC-IV) and measures of academic achievement (Wechsler, 2014b).

For this study, all five WISC-V subtests were administered via iPad using Q-interactive™ software. This included the new digital version of Coding that requires participants to touch the appropriate symbol using their index finger as opposed to writing out the symbol in a stimulus book, effectively removing the graphomotor component to the task (Wechsler, 2014a). Three pilot studies conducted by the publisher demonstrated equivalence of these formats (Raiford et al., 2016), supporting the publisher's decision to apply the same normative data to raw scores obtained from the iPad and paper versions. As such, the new digital version provided a cleaner measurement of processing speed by removing the fine motor component.

GORT-5. To assess comprehensive readings skills, including rate, accuracy, fluency, and comprehension (Strauss, Sherman, & Spreen, 2006), the Gray Oral Reading Test (GORT-5) was administered to participants. The GORT-5 (Wiederholt & Bryant, 2012) is a standardized, norm-referenced test with two equivalent forms that can be administered to youth between 6 years and 23 years, 11 months. The measure has excellent psychometric properties (Wiederholt & Bryant, 2012), including internal consistency and alternate forms reliability coefficients above .90 and test-retest reliability coefficients greater than .85 for identical and alternate forms. The GORT-5 also has good sensitivity (.82) and specificity (.86) for classifying children with reading difficulties. Five scores can be derived from the GORT-5, including four subtest scores and one composite (Wiederholt & Bryant, 2012). Rate is defined as the total time taken to read each story out loud, while Accuracy is the number of pronunciation errors. The Fluency score is the combined total of rate and accuracy, and Comprehension is the number of correct answers to questions asked after each story is read aloud. The Oral Reading Index is derived from the Fluency and Comprehension scaled scores.

WIAT-III. In addition to the GORT-5, specific subtests that relate to reading ability from the Wechsler Individual Achievement Test – 3rd Edition (WIAT-III; Wechsler, 2009) were administered to examine the concurrent validity of the RTI and explore the pattern of strengths and weaknesses for the different groups of readers. The Word Reading (WR), Pseudoword Decoding (PD), and Spelling (SP) subtests were administered to participants via an iPad using Q-Interactive™ software. For WR the student is asked to read single words aloud from a word list while being timed. This subtest assesses the speed and accuracy of single word reading. For PD the student is instructed to read pseudowords as if the items were real words. This subtest measures the speed and accuracy of reading decoding skills. The SP subtest measures the ability to correctly spell individual words, and correlates well with WR scores given that these abilities are related (McCrimmon & Climie, 2011).

The WIAT-III is an individually administered norm-referenced measure of academic achievement that was standardized on a sample of 2,775 students from kindergarten to grade 12 (Wechsler, 2009). The measure maintains strong psychometric properties. The internal consistency scores using split-half reliability are between .83 and .97 while test-retest reliability scores are between .82 and .94 (McCrimmon & Climie, 2011). Inter-rater reliability was also found to be excellent (98-99%) given the straight-forward correct/incorrect nature of most of the scoring. In terms of validity, the WIAT-III aligns closely with theoretical frameworks and appears to adequately measure the intended constructs (McCrimmon & Climie, 2011).

CTOPP-2. The Comprehensive Test of Phonological Processing – Second Edition (CTOPP-2) is a comprehensive measure of phonological processing abilities, including phonological awareness, phonological memory, and rapid naming (Wagner, Torgesen, Rashotte, & Pearson, 2013) with two forms: one for children ages 4 to 6 years and another for ages 7 to 24 years. For the older age group, seven subtests can be administered to obtain three composite scores. Of interest for this study is the Phonological Awareness Composite Score (PACS), which represents the student's awareness of and access to the phonological structure of oral language. All three PACS subtests were administered: Elision, Blending Words, and Phoneme Isolation (Wagner et al., 2013). Elision requires the student to remove phonological segments from spoken words to form other words. Blending Words involves the ability combine individual sounds to form words, and Phoneme Isolation involves the ability to isolate individual sounds within words.

The CTOPP-2 is an updated version of the CTOPP with a representative normative sample of 1,900 individuals between the ages of 6 and 24 years (Wagner et al., 2013). This measure has good psychometric properties with internal consistency coefficients exceeding .80 for subtest and .85 for composite scores. Validity was demonstrated by correlational analyses with measures assessing similar constructs whereby subtest coefficients range from .49 to .84 and composite coefficients between .65 to .76 (Wagner et al., 2013). This measure is viewed as a valuable norm-referenced tool for assessing phonological processing in school-aged children (Tennant, 2014).

Sentence Memory Test. Another measure of verbal immediate memory ability are sentence repetition tasks of which there are several standardized measures available, including the Sentence Memory Test (Benton, 1965), the Sentence Repetition Test (Spreen & Benton, 1963; Spreen & Benton, 1969; Spreen & Strauss, 1998), the Sentence Memory subtest of the Stanford-Binet (4th edition; Thorndike, Hagen, & Sattler, 1986), and the Sentence Imitation subtest of the Test of Language Development Primary (3rd edition; Newcomer & Hammill, 1997). The Sentence Memory Test (SMT; Benton, 1965), a 26-item measure appropriate for those aged 3 to 87 years (Strauss et al., 2006), was used in this study. Subjects are asked to repeat immediately following oral presentation sentences that increase in length from 1 syllable (i.e., *Look.*) to a maximum of 26 syllables. The test is discontinued after three consecutive failures are made. A score of 1 is given for each correctly repeated response for a maximum of 26 points (Strauss et al., 2006). The SMT has good psychometric properties, including adequate test-retest reliability in children with a correlation of 0.71 (Brown, Rourke, & Cicchetti, 1989). Raw scores were age-corrected using the "Windsor Norms" for neuropsychological test performance, which include means and standard deviations for Benton's SMT for children aged 5 to 14. *Z*-scores were calculated and then transformed into T-scores (M = 50; SD = 10) for ease of interpretation.

Normative data for French Immersion sample. The same normative data was used for all cognitive and academic measures for both English and French Immersion samples. It is still common procedure to use normative data from monolingual children in neuropsychological assessments with bilingual children (Barac, Bialystok, Castro & Sanchez, 2014). Moreover, a recent study confirmed similar academic achievement scores in mathematics and reading for bilingual and monolingual children with some differences in other neuropsychological domains (Barac et al., 2014; Garratt & Kelly, 2008). Specifically, bilinguals outperformed on visuospatial skills and high executive demands whereas monolinguals outperformed on visual attention and verbal processing (Garratt & Kelly, 2008; Rosselli, Ardila, Navarrete, & Matute, 2010; Westman, Korkman, Mickos, & Byring., 2008). Despite these differences, there are currently no alternative normative datasets available for use with French Immersion samples. As such, the same normative data was used for all participants in the present study regardless of language of instruction.

Procedure

Research Assistants

In addition to the principal investigator, five research assistants (RAs) conducted the data collection sessions. All RAs were graduate or senior undergraduate students in psychology and were all provided extensive training for the experimental and assessment tasks. A comprehensive manual detailing all procedures was created and made available to each RA. Appendix G includes an abbreviated version of the manual with sensitive test instructions and personal information removed to uphold copyright and privacy protections. Relevant details to RA training were retained. Each RA was required to pass a "check" procedure demonstrating appropriate administration of standardized tests and operation of the experimental tasks on the laptop. Regular communication was maintained through email, text messaging, and in-person meetings to address any issues that arose. The principal investigator was solely responsible for contacting school principals, teachers, and parents, scheduling participants, scoring protocols, and inputting data. Electronic files from the LDTs were automatically saved onto the laptop and were then periodically uploaded to a folder on the Dropbox server by the principal investigator. Participant files were delivered by RAs to the principal investigator, who then scored the assessments and input the anonymized data into a spreadsheet. In total, the principal investigator conducted 25 participant sessions with the two graduate student RAs conducting two and 30 sessions, respectively, and the three senior undergraduate student RAs conducting 20, 14, and six participant sessions.

Data Collection

All data collection occurred in one session on site at WECDSB schools, except for the four community participants who were tested in an office at the University of Windsor. Dates and times for data collection were coordinated with the school's principal and classroom teachers to ensure minimal disruption to regular classroom activities. Once parental consent was received, participants met with the principal investigator (or RA) in a pre-determined room at the school to complete the study. The protocol was explained in detail to the participant and informed consent was obtained prior to beginning the study.

Data collection involved one session conducted in the same manner for all participants with administration order counter-balanced. Even-numbered participants first completed the two LDTs using a laptop and keyboard. Each task had a completion time of approximately 7 minutes. Participants used the keyboard to identify whether words presented on screen were real words. For the phonologic task (pLDT), pseudowords and real, low frequency words were presented. For the orthographic task (oLDT), real, high frequency words and a string of consonants were used. The order of the pLDT and oLDT was also counterbalanced. After the LDTs were administered, participants completed the 5 subtests from the WISC-V (15 minutes), 3 subtests from the WIAT-III (10 minutes), the Sentence Memory Test (2-5 minutes), 3 subtests from the CTOPP-2 (10 minutes), and the GORT-5 (20-30 minutes), which were administered in standardized fashion in that order. Odd-numbered participants started with the neuropsychological testing first, in the same order as above, and then ended with the two LDTs.

Counter-balancing of administration order was often, but not always, maintained for an RA completing two (or three) sessions in one day. Generally, participants seen in the same day would each have consecutive participant numbers, so both the odd and even administration order would be completed by the RA that day. This was not always the case, however, if scheduling changes were made after participant numbers were assigned. Administration order of the LDT tasks were also counter-balanced such that both even and odd participants receiving the experimental vs. cognitive counter-balancing would also have within-group orthographic vs. phonologic LDT task counter-balancing (see Appendix H for administration order for English and French participants).

Total participation time for the study was approximately 75 to 90 minutes. Participants were able to refuse any activities they did not want to complete and could end a task whenever they chose, so not every participant completed all of the neuropsychological tasks. Most often, the GORT-5 (n = 16) or CTOPP-2 (n = 5) were discontinued early. All participants except one, as previously mentioned, completed both LDTs. As compensation for their participation, participants were entered into a random draw to win one of four gift-cards to Chapters/Indigo worth $50 each. The draw was performed in August 2018 using Microsoft Excel to randomize participant numbers for selection. Parents of the four winners were emailed the electronic gift-cards through Indigo's online system.

Study Variables

Table 2

Descriptions of Variables Used in Each Study

Variable Name	Description	Calculation	Variable Type
Research Question #1			
pLDT mRT	Speed of response on pLDT items	Average reaction time in seconds of speed of response	DV to calculate pLDT drift rate
pLDT % correct	Percentage correct on pLDT items	Average proportion correct of each pLDT item	DV to calculate pLDT drift rate
pLDT drift rate	Estimate of how long it takes to correctly determine if item is word or non-word; represents decoding reading ability	Calculated via EZDM from average reaction time, variance, and proportion correct on pLDT tasks	
pLDT corrected drift rate	Correction on pLDT drift rate to account for faster speed on oLDT and centers variables on same scale	$pLDTdrift_{corrected}$ = pLDTdrift + (average oLDTdrift – average pLDTdrift)	DV to calculate RTI
oLDT mRT	Speed of response on oLDT items	Average reaction time in seconds of speed of response	DV to calculate oLDT drift rate
oLDT % correct	Percentage correct on oLDT items	Average proportion correct of each oLDT item	DV to calculate oLDT drift rate
oLDT drift rate	Estimate of how long it takes to correctly determine if item is word or non-word; represents word recognition reading ability	Calculated via EZDM from average reaction time, variance, and % correct on oLDT tasks	DV to calculate RTI
RTI score	Comparison of performance on oLDT and pLDT tasks using inverse scores to center at zero, denotes preferred reading tendency	Inverse of oLDT drift rate subtracted from inverse of pLDT corrected drift rate	Outcome variable used to determine RTI group cut-off
Relative Fluency	Metric of fluency across LDT tasks	Sum of oLDT drift rate and pLDT corrected drift rate	DV to calculate ratio
|RF:RTI|	Ratio comparing relative fluency to reading tendency, to provide a metric of proficiency and tendency.	Relative fluency divided by RTI	Variable used to determine RTI group cut-off
Research Questions #2 – 5			
RTI group	Group membership as Balanced, Decoder, or Sightword	Groups calculated based on RTI score and ratio RF:RTI	IV
Balanced vs. Non-balanced	Dichotomous variable classifying participants as Balanced or Non-balanced Readers	Decoders and Sightword Readers from RTI group coded as Non-balanced	IV for chi-squared
School Language	Group variable based on participants' school language	Determined by enrollment in English or French immersion	IV for chi-squared
Young vs. Old	Dichotomous variable classifying subset of participants as youngest or oldest	Participants aged 7-8 years old grouped as 'young'; aged 12-14 years old grouped as 'old'; in between removed from analysis	IV for chi-squared
Auditory Working Memory	Composite score estimating auditory working memory	T-score calculated from average of Digit Span (WISC-V) and Sentence Memory Test	DV for MANOVA
Visual Working Memory	Estimate of visual working memory	Scaled score from Picture Span (WISC-V)	DV for MANOVA

Word Reading	Estimate of single word reading	Standard score from WIAT-III Word Reading	DV for MANOVA & DFA
Pseudoword Decoding	Estimate of phonological decoding	Standard score from WIAT-III Pseudoword Decoding	DV for MANOVA
Spelling	Estimate of age-based spelling skills	Standard score from WIAT-III Spelling	DV for MANOVA & DFA
Phonological Awareness	Composite score estimating phonological awareness	Standard score calculated from scaled scores of CTOPP-2 PACS subtests: Elision, Blending Words, Phonome Isolation	DV for MANOVA
Reading Fluency	Estimate of reading fluency based on rate and accuracy	Scaled score based on pooled performance on GORT-5 Rate and Accuracy subtests	DV for MANOVA & DFA
Reading Comprehension	Estimate of reading comprehension for stories read aloud	Scaled score from GORT-5 Comprehension subtest.	DV for MANOVA & DFA

Note. DFA = discriminant function analysis; DV = dependent variable; EZDM = EZ drift diffusion modeling; IV = independent variable; MANOVA = multivariate analysis of variance; PACS = phonological awareness composite score.

CHAPTER 4 – RESULTS

All statistical analyses were performed using IBM SPSS Statistics, Version 22. EZ-Diffusion Modeling was performed using the available online applet (Wagenmakers et al., 2007). Unless otherwise indicated, an alpha level of 0.05 was used to indicate statistical significance for findings related to each research question. Bonferroni correction for multiple comparisons was used when appropriate.

Preliminary Quantitative Analyses

Data Cleaning

Prior to performing any statistical analyses, assumptions were verified and participants/trials with extreme outliers were removed. First, trials on both LDTs were examined for abnormally fast or slow reaction times for individual items on each task. Trials were removed if the response time was abnormally fast (less than 150ms) or slow (greater than 3s or 3000ms). Very fast response times were removed because it is impossible to tell whether the child was trying to correct their previous answer or was exceedingly fast on the current item. Moreover, very slow response times were removed as it was thought these response times were likely the result of inattention or a temporary disruption to the testing environment.

As described in more detail below, the application of EZ Diffusion on a particular dataset requires that response reaction time be positively skewed. Although positive skewness was evident statistically for the reaction time of both tasks (pLDT=2.43, oLDT=5.47), inspection of the histogram revealed three participants who completed at least one of the tasks exceedingly fast (average RT < 750ms) even after trials were removed coupled with poor performance (% correct ≤ 50%), ultimately having an impact on skewness. Additionally, multivariate outliers were checked for important dependent variables, Reading Tendency and Relative Fluency, with all 96 participants. Four participants were identified as significant outliers on both variables (see Figure 8); three of whom were already highlighted based on the reaction time and accuracy data described above related to skewness. As such, these three participants were removed from the dataset for violating assumptions given abnormally poor performance on both tasks.

The fourth participant was also removed despite appropriate mean reaction times due to extremely elevated pLDT reaction time variance (> 4 SD) and poor accuracy on both LDTs. This participant had also refused to complete many of the neuropsychological activities administered as part of the study, resulting in multiple missing data points across other measures. Consequently, all four participants were removed based on outliers in their experimental data for a final sample of 92 participants across the two school language groups. LDT reaction times for the final sample maintained positive skewness (pLDT = 3.40, oLDT = 5.45).

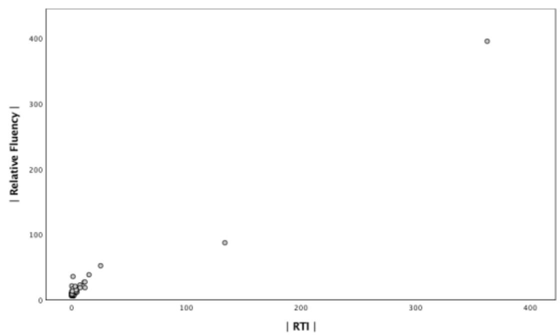

Figure 8. Scatterplot comparing absolute value of RTI and RF to examine multivariate outliers on dependent variables for Research Question #1.

Statistical Assumptions

Prior to performing statistical analyses with the specific research questions, assumptions of chi-squared, multivariate analysis of variance (MANOVA), and discriminant function analysis (DFA) were verified. The main assumption for chi-squared, that there be no expected counts below 5, was checked and confirmed when performing the analysis in SPSS. Multivariate normality was confirmed by analyzing univariate normality for the residuals of all 9 dependent variables (Stevens, 2009). Shapiro-Wilks' statistic was non-significant for all residual DVs, except for Picture Span and Phonological Awareness (PACS). Skewness and kurtosis of the residuals were within appropriate range (i.e., skewness within |2|; kurtosis within |3|) except for PACS (kurtosis > 5). Homogeneity of covariance matrices was confirmed by non-significant Box's M, $p = .195$, and univariate Levene's tests for homogeneity of variance, $p > .05$ (Stevens, 2009). Thus, no cases were removed for assumption violations.

Participant Descriptive Statistics

Participants were school-aged children (M_{age}= 9.96 years), with a majority identifying as female (67%) and of Caucasian/White/European descent (80%). Five participants reported learning English as a second language and seven reported speaking a language other than English at home. Of note, all of these language-diverse participants were enrolled in French Immersion programs yet French was never reported as a primary home language. School language groups were equal in terms of age, $t(91) = 1.88$, $p > 0.05$, and estimates of general intellectual functioning, $t(91) = 0.62$, $p > 0.05$. All participants had an estimated IQ above 70. See Table 3 for complete descriptive statistics detailing participant demographic information.

There was no difference between the performance of English and French Immersion participants in all areas of cognitive functioning, including verbal abilities ($F(1, 90) = .274$, $p > .05$), auditory ($F(1, 86) = .0001$, $p > .05$) and visual working memory ($F(1, 90) = .193$, $p > .05$), and phonological awareness ($F(1, 85) = .0001$, $p > .05$). Although English only participants performed marginally better on a task of processing speed relative to French Immersion participants, $F(1, 89) = 5.28$, $p = .024$, the difference was no longer significant when Bonferroni correction for multiple comparisons was used (i.e., $\alpha = .006$ for comparisons with the eight cognitive and academic variables). There was also no difference in academic performance between groups as measured by the WIAT-III [word reading: $F(1, 90) = .007$, $p > .05$; pseudoword decoding: $F(1, 90) = 1.53$, $p > .05$; spelling: $F(1, 90) = .91$, $p > .05$]. Furthermore, no group differences were found for reading rate, $F(1, 74) = 3.47$, $p > .05$, or reading accuracy, $F(1, 74) = .962$, $p > .05$, as measured by the GORT-5, with the exception of the English group who had marginally better performance on reading comprehension, $F(1,74) = 4.23$, $p = .043$, yet this difference was again no longer significant with a Bonferroni correction (i.e., $\alpha = .02$ for comparison of the three GORT-5 subtests). Given no group differences in GORT-5 reading rate and accuracy, the composite Fluency score will be used as a predictor variable in the quantitative analyses. See Table 4 below for complete descriptive information pertaining to cognitive and academic performance across school language groups.

Table 3

Participant Descriptive Statistics: Demographic Information

	English			French Immersion		
	n (%)	*M*	*SD*	*n (%)*	*M*	*SD*
Total	49 (100%)			43 (100%)		
Age (years)		10.29	1.73		9.63	1.84
Estimate of intellectual functioning		106.45	12.83		105.19	9.87
Sex						
Female	34 (69%)			27 (63%)		
Male	15 (31%)			16 (37%)		
Ethnicity						
Asian	0 (0%)			4 (9%)		
Black/African/Caribbean	0 (0%)			2 (5%)		
Caucasian/European/White	45 (92%)			26 (61%)		
Hispanic/Latina/Latino	1 (2%)			1 (2%)		
Middle Eastern	0 (0%)			1 (2%)		
Multiracial	0 (0%)			9 (21%)		
Missing	3 (6%)			0 (0%)		
Parent Education Level	*Parent 1*	*Parent 2*		*Parent 1*	*Parent 2*	
< High School	2 (4%)	1 (2%)		1 (2%)	2 (5%)	
High School graduate	3 (6%)	8 (17%)		2 (5%)	8 (19%)	
Some college	5 (10%)	4 (8%)		7 (16%)	6 (12%)	
College graduate	25 (51%)	19 (39%)		14 (33%)	11 (26%)	
Some university	1 (2%)	3 (6%)		1 (2%)	0 (0%)	
University graduate	6 (12%)	6 (12%)		11 (26%)	8 (19%)	
Graduate school	7 (15%)	8 (16%)		7 (16%)	8 (19%)	
Number of Schools	2 (+2 dual-language)			3 (+2 dual-language)		
School Location						
Urban	3 (6%)			22 (51%)		
Rural	46 (94%)			21 (49%)		
Neurodevelopmental Diagnoses						
ADHD / Attention issues	5 (10%)			3 (7%)		
Autism Spectrum Disorder	1 (2%)			- (0%)		
Learning Disability	1 (2%)			1 (2%)		
Speech/Language Impairment	2 (4%)			- (0%)		
Family History: Reading Disability	5 (10%)			6 (14%)		
English as a Second Language	0 (0%)			5 (12%)		
French as a First Language	0 (0%)			0 (0%)		

Table 4
Participant Descriptive Statistics: Cognitive & Academic Performance

		English		French Immersion	
		M	*SD*	*M*	*SD*
WISC-V	*Estimated IQ*	106.45[a]	12.83	105.19[c]	9.87
	Vocabulary	11.59[a]	2.40	11.35[c]	2.21
	Information	10.80[a]	2.83	10.58[c]	2.10
	Digit Span	11.39[a]	3.07	10.91[c]	2.86
	Digit Span Forward	10.67	2.67	11.00	2.61
	Digit Span Backward	10.88	2.76	10.67	2.99
	Digit Span Sequence	11.51	3.04	10.33	2.88
	Picture Span	12.59[a]	2.56	12.81[c]	2.25
	Coding	13.61[a]	3.01	12.26[d]	2.52
WIAT-III	Word Reading	107.92[a]	11.99	108.16[c]	16.74
	Pseudoword Decoding	105.55[a]	13.61	101.72[c]	16.10
	Spelling	103.63[a]	13.57	100.70[c]	15.94
Sentence Memory	Raw score	15.92	1.78	15.61	2.49
	Age-corrected T-score	49.85[b]	8.64	50.96[e]	10.46
CTOPP-2	*Phonological Awareness Composite*	98.36[b]	15.43	98.40[f]	12.51
	Elision	10.43[b]	2.16	10.17[e]	2.55
	Blending Words	10.02[b]	3.00	9.17[e]	2.90
	Phoneme Isolation	9.17[b]	1.95	9.63[f]	2.64
GORT-5	*Oral Reading Index*	98.41[d]	10.42	93.50[g]	11.74
	Accuracy	8.62	2.23	8.06	2.75
	Rate	10.86	2.45	9.74	2.80
	Fluency	9.69	2.26	8.79	2.66
	Comprehension	9.86	2.01	8.91	1.97

[a] n = 49; [b] n = 47; [c] n = 43; [d] n = 42; [e] n = 41; [f] n = 40; [g] n = 34

Primary Quantitative Analyses

The following sections detail the primary quantitative analyses performed to answer the five research questions and test the hypotheses. First, a description of each statistical analysis used is provided, including details about drift diffusion modelling and calculation of the Reading Tendency Index itself. Next, detailed results for each of the five research questions will be provided. This includes any relevant descriptive statistics that differs from what was provided above for the entire sample.

Description of Statistical Analyses

The Reading Tendency Index (RTI) value was calculated by comparing drift rate performance across both LDTs. The same calculations were used to determine RTI values for group membership as in the original study (Mohl et al., 2018), namely using the online EZ Diffusion modeling software

(Wagenmakers et al., 2007). EZ Diffusion calculations and subsequent RTI classifications were performed separately for English and French Immersion participants to document reading tendency group membership separately based on language of instruction. Given no significant differences in RTI scores between groups (i.e., language; $t(91) = -.685$, $p > .05$), RTI calculations and classifications were then performed with the entire sample as a whole to maximize power. Furthermore, validity analyses for the subsequent research questions were performed with the entire mixed language sample.

Drift diffusion modeling (DDM). Drift rates for the oLDT and pLDT tasks were calculated using the EZ Diffusion system (Wagenmakers et al., 2007) once the mean and standard deviation for reaction time (in seconds), as well as percentage correct, were calculated for each participant from both LDT raw data files. The EZ Diffusion model uses reaction time mean and variance along with proportion correct to calculate drift rate (ν), boundary separation, and nondecision time (in seconds). Of these, drift rate was the variable of interest for calculating the Reading Tendency Index (described in further detail below).

As described by Mohl (2015), the pseudoword drift rate must be corrected to maintain zero-centering of the overall index to facilitate its understanding and direct comparisons with the oLDT. The difference between the oLDT drift rate sample average and pLDT drift rate sample average was added to each individual pLDT drift rate (see formula below). By allowing the pLDT rate to mirror the oLDT rate, this correction ensures that an interpretation of zero on the RTI represents a balanced approach to using both reading strategies. The average drift rates for both LDTs were calculated for each round of analyses (i.e., English school, French Immersion, entire sample) and placed in the formula below to compute new variables using SPSS.

$$pLDTdrift_{corrected} = pLDTdrift + (m_{oLDTdrift} - m_{pLDTdrift})$$

Reading Tendency Index (RTI). The RTI is derived by mathematically combining the drift rates from the phonological and orthographic LDTs (i.e., decoding and recognizing words, respectively), and provides an estimate of the child's reading tendency (Mohl et al., 2018). Following the steps outlined in previous work (Mohl, 2015; Mohl et al., 2018), the Reading Tendency Index (RTI) variable for each participant was computed by subtracting the inverse oLDT drift rate from the inverse pLDT corrected drift rate (see formula below).

$$RTI = \frac{1}{pLDTdrift_{corrected}} - \frac{1}{oLDTdrift}$$

To ensure that a 'balanced' value is not due to poor drift rates obtained on both tasks, Relative Fluency (RF) was developed as another dimension to provide confidence that 'Balanced Readers' are also fluent; it is the sum of the two drift rates. A ratio variable of the absolute value of RF to RTI was also computed to provide a metric of proficiency and tendency (Mohl, 2015). Groupings from the RTI are thus based on the individual's distance from zero on the RTI score and the absolute value of RF divided by RTI (RF/RTI ratio; Mohl, 2015). Participants were then assigned to one of three groups depending on their RTI score (Balanced: $-1 < RTI < 1$; Decoder: $RTI \geq -1$; Sightword Reader: $RTI \geq 1$), plus a RF/RTI ratio greater than or equal to 21 in order to be classified as Balanced. If a participant's RTI score was between ±1 but the RF/RTI ratio was less than 21, then the participant was classified as either Decoder or Sightword Reader, instead of Balanced Reader based on lower fluency. Specifically, participants are classified as Decoders if their RTI is a negative value, highlighting their propensity for decoding given faster drift rates on the phonological task. Comparatively, Sightword Readers have a positive RTI value given better drift rates on the orthographic task.

Parametric analyses. To examine the construct validity of the RTI protocol as it relates to the theoretical understanding that reading fluency tends to increase as cognitive development progresses (Hypothesis 2a), a 2 by 2 chi-squared analysis was used to compare the proportion of Balanced versus non-balanced Readers in older and younger children. If Balanced group membership indeed signifies more fluent reading, then it was predicted that a larger proportion of older students would be classified as 'Balanced Readers' compared to younger students given the assumed increase in reading fluency as children develop. Given that older children are generally more fluent readers compared to younger children, it was predicted that there will be a greater proportion of Balanced Readers in the older age group (i.e., 12 to 14 years) compared to the younger group (i.e., 7 to 8 years). These age groupings were chosen to maximize spread in years between the age groups to elucidate potential age differences in reading fluency ability. Ideally, only 7- and 14-year-olds would have been included in these groups, but the current sample makeup did not permit for this with fewer than five participants of either age.

To analyze the concurrent validity of the RTI groupings, multivariate analysis of variance (MANOVA) was used to compare neuropsychological performance across groups. As mentioned, it is hypothesized that groups will differ in their performance on various cognitive measures related to reading. Should the RTI groupings truly represent different reading tendencies in students, performance on reading measures reflecting the skills inherent to these tendencies should differ based on the expected pattern of cognitive strengths and weaknesses. Nine dependent variables were used in the model: WIAT-III Word Reading, Pseudoword Decoding, and Spelling; GORT-5 Fluency and Comprehension; auditory working memory (composite score of Sentence Memory Test [SMT] and WISC-V Digit Span [DS]); WISC-V Picture Span (visual working memory); WISC-V Coding (processing speed); and, CTOPP-2 Phonological Awareness Composite (PACS). To derive the auditory working memory composite, scores from SMT and DS were converted to T-scores and an average score was calculated. It was predicted that Balanced Readers would perform better on all measures compared to non-balanced readers (e.g., Decoders and Sightword Readers). Decoders should also perform better than Sightword Readers on PD and PACS whereas the opposite was expected for auditory working memory. Since these measures were expected to be correlated and multiple comparisons were planned, MANOVA was most appropriate to examine group differences as it controls for type 1 error and considers associations between dependent variables (Grice & Iwasaki, 2007). Although there were significant correlations between dependent variables and possible covariates of age and estimated IQ, ultimately MANOVA was still used for two specific reasons. Firstly, performance scores were already age-corrected via normative data so additional adjustments are not needed. Moreover, the inclusion of IQ as a covariate in research with children should only be done in rare circumstances where selection bias produces non-representativeness in the sample (Dennis et al., 2009), which was not the case in the present study.

Following the completion of the MANOVA, a DFA was performed to determine the reading measures that best predict group membership (Balanced vs. Decoders vs. Sightword Readers). Any significant outcome variables from the MANOVA served as predictors of group membership in the DFA, in this case only the WIAT and GORT reading subtests. Wilks' lambda was used as the significance test for functions, while squared canonical correlations are reported to describe the amount of variance explained by each function. Variable weights (i.e., standardized discriminant function coefficients) and correlations (i.e., structure coefficients) were examined to determine which predictors contributed most to group membership.

A logistic regression was originally proposed as a subsequent statistical analysis should the RTI groups not be distinguishable with the multivariate analyses. This binary regression would test whether Balanced Readers could be separated from non-balanced readers (sum of Decoders and Sightword Readers) on reading-related variables. Since the MANOVA only revealed group separation for Sightword Readers from the Balanced Readers and Decoders but no separation between the latter two groups, it was decided that a logistic regression between Balanced and non-balanced groups was no longer appropriate. Therefore, Research Question #4 was not evaluated and no such analysis was performed.

French Immersion analyses. As previously described, drift rates and relative fluency from the EZ Diffusion modelling were used to determine the RTI classifications for the French Immersion group. Another 2 by 2 chi-squared analysis was performed to determine whether the proportion of Balanced vs. non-balanced Readers differs as a function of language of instruction (English-only vs. French Immersion). Based on previous studies documenting better reading achievement in French Immersion students, it was predicted that there would be a larger proportion of French participants in the Balanced group compared to English students.

Supplementary analyses for Research Question #5 include exploring group differences in cognitive and reading abilities as a function of language instruction. As such, MANOVA was used to examine potential differences in performance on the nine outcome variables (see Table 2) between English-only and French Immersion groups.

Research Question #1: Replication of RTI groupings

To address the first research question, EZ Diffusion Modeling software (Wagenmakers et al., 2007) was applied with the entire mixed-language sample to determine replicability of the RTI model with a representative sample of Ontario school-aged children. Groupings within language sub-samples were also examined, primarily to determine whether the model would replicate with a FI-only sample.

<u>*Entire sample.*</u> Drift rates and RTI variables were calculated with the entire sample of 92 participants. Average drift rates were calculated for both LDTs ($M_{oLDTdrift} = 0.2016$; $M_{pLDTdrift} = 0.1414$), which were then used to compute corrected pLDT drift rates for each case in this entire sample. High-frequency words were identified more quickly than pseudowords, $t(91) = -32.07$, $p < .001$, with faster oLDT reaction time ($M = 1.11$) compared to pLDT reaction time ($M = 1.65$). The high-frequency word task was easier on average (92% correct) than the pseudoword task (85%), $t(91) = 5.77$, $p < .001$. oLDT drift rates ranged from 0.058 to 0.354 ($M = 0.202$, $SD = 0.054$). pLDT corrected drift rates ranged from .06 to 0.49 ($M = 0.206$, $SD = 0.075$). RTI scores ranged from -4.88 to 10.50 ($M = 0.284$, $SD = 2.62$). RF scores ranged from 6.01 to 34.00 ($M = 11.23$, $SD = 4.55$). The RF / RTI ratio ranged from 1.67 to 3935.55 ($M = 97.30$, $SD = 439.51$).

Table 5
Paired-sample t-Tests Exploring Differences in Pseudoword and High Frequency Word Performance with Entire Sample (n=92)

Variable	oLDT - pLDT Mean (SD)	*t* (df = 91)	*p*
Mean RT	-.541 (.162)	-32.07	< .001
Mean % correct	.069 (.115)	5.77	< .001
Mean Drift Rate	.005 (.07)	-.632	.529

Based on the adopted RTI and RF/RTI cut-offs, participants were classified as Decoders ($n = 36$), Balanced Readers ($n = 26$), or Sightword Readers ($n = 30$). Figure 9 demonstrates all reading preferences plotted in view of their abilities, which supports Hypothesis 1a that the RTI groupings could be replicated using the entire mixed-language sample.

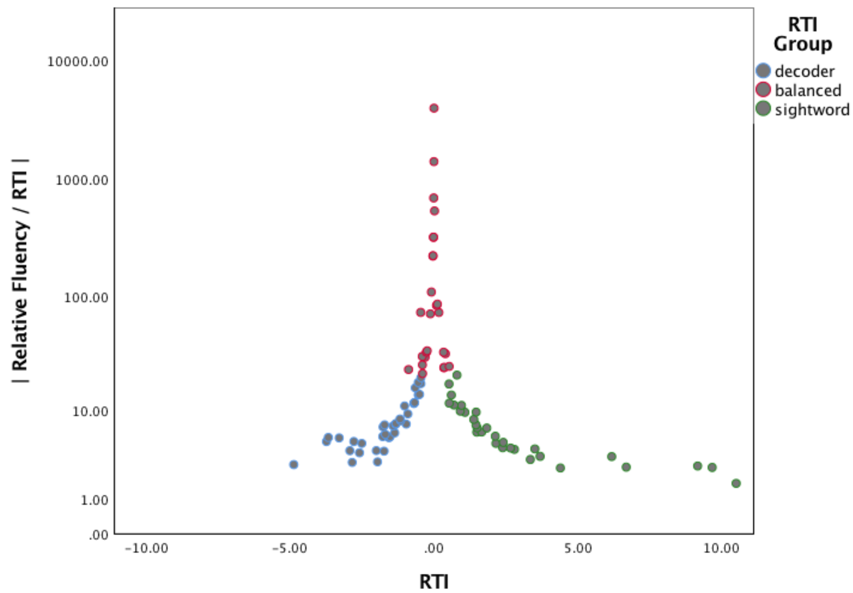

Figure 9. Total participants from the three reading tendency groups are depicted by comparing Reading Tendency (RTI) and the absolute value of Relative Fluency/Reading Tendency.

French Immersion participants. Drift rates and RTI variables were also calculated for the sub-sample of French Immersion school participants (n = 43) per Hypothesis 1b. Average drift rates were calculated for both LDTs ($M_{oLDTdrift}$ = 0.188; $M_{pLDTdrift}$ = 0.123), which were then used to calculate corrected pLDT drift rates for the French sub-sample. High-frequency words continued to be identified more quickly than pseudowords, $t(42) = -18.30$, $p < .001$, with faster oLDT reaction time (M = 1.15) compared to pLDT reaction time (M = 1.69), yet speed of reaction time on each tasks did not differ across language groups. Similarly, the high frequency word task was easier on average (91% correct) for FI students than the pseudoword task (81%), $t(42) = 5.23$, $p < .001$. oLDT drift rates ranged from 0.083 to 0.284 (M = 0.188, SD = 0.052). pLDT corrected drift rates ranged from .06 to 0.49 (M = 0.188, SD = 0.088). See Table 6 for a list of all paired-sample RTI-related t-test statistics for the FI group. RTI scores ranged from -3.74 to 10.50 (M = 0.810, SD = 3.30). RF scores ranged from 6.01 to 25.54 (M = 12.53, SD = 4.89). The RF / RTI ratio ranged from 1.67 to 3925.55 (M = 150.38, SD = 633.31). Figure 10 demonstrates the French Immersion participant's reading preferences plotted in view of their abilities. Based on reading tendency scores and relative fluency, participants were classified as Decoders (n = 16), Balanced Readers (n = 11), or Sightword Readers (n = 16).

Table 6
Paired-sample t-Tests Exploring Differences in Pseudoword and High Frequency Word Performance with French Immersion Group (n=43)

Variable	oLDT - pLDT Mean (SD)	*t* (df = 42)	*p*
Mean RT	-.538 (.193)	-18.30	< .001
Mean % correct	.105 (.132)	5.23	< .001
Mean Drift Rate	.00004(.076)	.004	.997

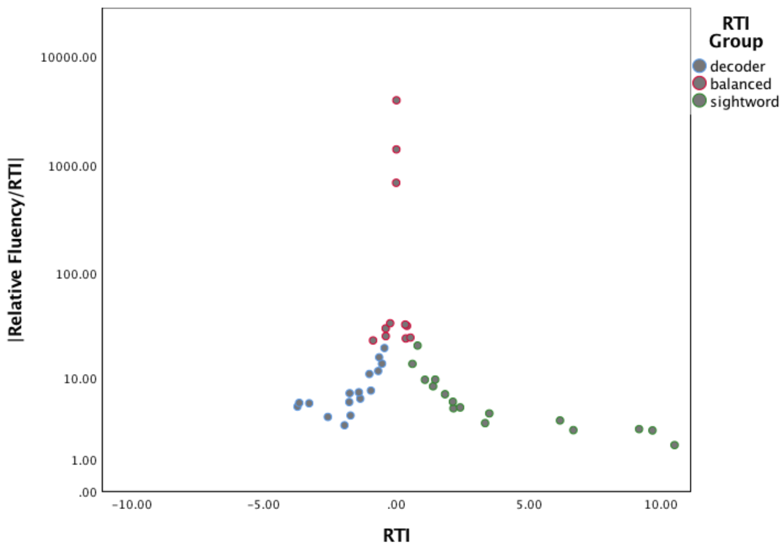

Figure 10. French Immersion school participants from the three reading tendency groups are depicted, comparing Reading Tendency (RTI) by the absolute value of Relative Fluency/Reading Tendency, an approximation of overall reading ability.

<u>English participants.</u> In order to compare performance with entire sample and FI sub-sample, drift rates and RTI variables were also calculated for the sub-sample of English only participants (*n* = 49) as described above. Average drift rates were calculated for both LDTs ($M_{oLDTdrift}$ = 0.2137 ; $M_{pLDTdrift}$ = 0.1576) to compute corrected pLDT drift rates for this sub-sample. High-frequency words were once again identified more quickly than pseudowords, $t(48) = 29.10$, $p < .001$, with faster oLDT reaction time (*M* = 1.07) compared to pLDT reaction time (*M* = 1.62). The high frequency word task was easier on average (93% correct) for English students than the pseudoword task (89%), $t(48) = 3.00$, $p = .004$. oLDT drift rates ranged from 0.058 to 0.354 (*M* = 0.214, *SD* = 0.054). pLDT corrected drift rates ranged from .05 to 0.34 (*M* = 0.222, *SD* = 0.058). See Table 7 for a list of all paired-sample RTI-related t-test statistics for the English group. RTI scores ranged from -4.69 to 4.98 (*M* = -0.178, *SD* = 1.72). Relative Fluency

(RF) scores ranged from 6.28 to 36.86 (*M* = 10.09, *SD* = 3.94). The ratio between RF and RTI, a metric of proficiency and tendency of use, ranged from 2.41 to 167.99 (*M* = 50.72, *SD* = 102.61). Figure 11 demonstrates the English participant's reading tendency preferences plotted in view of their abilities. Based on the adopted cut-offs for reading tendency scores and RF/RTI ratio, participants were classified as Decoders (*n* = 20), Balanced Readers (*n* = 15), or Sightword Readers (*n* = 14).

Table 7
Paired-sample t-Tests Exploring Differences in Pseudoword and High Frequency Word Performance with English Participants (n=49)

Variable	oLDT - pLDT Mean (SD)	*t* (df = 48)	*p*
Mean RT	-.543 (.131)	-29.10	< .001
Mean % correct	.038 (.088)	3.00	.004
Mean Drift Rate	.00003 (.064)	.004	.997

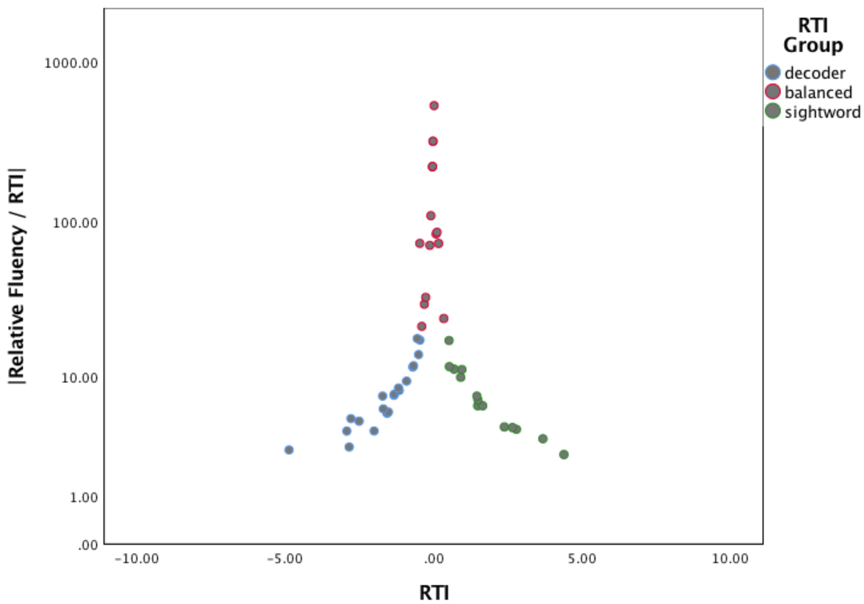

Figure 11. English school participants from the three reading tendency groups are depicted, comparing Reading Tendency (RTI) by the absolute value of Relative Fluency/Reading Tendency, an approximation of overall reading ability.

<u>*Comparing FI vs. English sub-samples.*</u> To explore potential language group differences for the RTI variables, multiple t-tests were conducted and a Bonferroni correction of $p = .006$ was used to determine significance in this section (see Table 8 for independent-sample t-tests comparing group means across RTI-related tasks). English and French groups were significantly different for proportion

correction on the pLDT task, $t(70.54) = 3.08$, $p = .003$, with higher performance for English (89%) than FI (81%) students. No group differences were found for oLDT performance, $p > .05$. Similarly, there were no group differences in drift rates for pseudowords, $t(71.62) = 2.20$, $p = .031$, or high frequency words, $t(90) = 2.33$, $p = .022$. Groups also did not differ in terms of mean RTI scores, mean Relative Fluency, or the absolute value of RF/RTI once Bonferroni correction was applied (see Table 8).

Table 8
Comparing Language Group Differences Across RTI-related Variables

	Mean (SD)		Levene's test for equality of variances		t-test for equality of group means		
Variable	English	FI	F	*p*	*t*	*df*	*p*
oLDT mean RT	1.07 (0.09)	1.16 (0.30)	4.49	.037	-1.71	47.86	.095
pLDT mean RT	1.62 (0.18)	1.69 (0.39)	2.41	.124	-1.24	90	.217
oLDT % correct	0.93 (0.05)	0.91 (0.05)	.199	.656	1.33	90	.185
pLDT % correct	**0.89 (0.10)**	**0.81 (0.15)**	**12.08**	**.001**	**3.08**	**70.54**	**.003**
oLDT drift rate	0.21 (0.05)	0.19 (0.05)	.246	.621	2.33	90	.022
pLDT corrected drift rate	0.22 (0.06)	0.19 (0.09)	5.29	.024	2.20	71.62	.031
RTI	-0.18 (1.72)	0.81 (3.30)	8.40	.005	-1.76	61.44	.083
Relative Fluency	10.09 (3.94)	12.53 (4.89)	7.00	.010	-2.61	80.65	.011
Ratio: RF / RTI	50.72 (102.6)	150.4 (633.3)	5.47	.022	-1.02	43.94	.313

The similarities in performance and group distributions found between the FI and English-only groups provide support for Hypothesis 1b, which suggests that the protocol could be applied with the both French Immersion and English-only samples. Table 9 summarizes the proportion of participants in each RTI group across all samples.

Table 9
Summary of RTI Group Frequencies Across Samples

	n (%)		
RTI Group	English only	French Immersion	Total
Decoders	20 (41%)	16 (37%)	36 (39%)
Balanced	15 (31%)	11 (26%)	26 (28%)
Sightword	14 (28%)	16 (37%)	30 (33%)
Total	49	43	92

Research Question #2: Construct & criterion validity of RTI protocol

To explore properties relating to the construct and criterion validity of the RTI protocol, a number of distinct analyses were performed to address the second research question and related hypotheses. Since reading fluency develops with age, a chi-squared analysis was used to test Hypothesis 2a and provide information about the RTI protocol's construct validity as a measure of reading ability. To examine the concurrent validity of the hypothesized characteristics of RTI group membership, a MANOVA was used to determine whether group differences in reading and cognitive abilities occurred as predicted in Hypotheses 2b, 2c, and 2d.

Participant Descriptive Statistics for Hypothesis 2a. To analyze Hypothesis 2a, in which the proportion of Balanced and non-balanced group membership was compared for younger and older participants (i.e., chi-squared), data from the 21 youngest and 25 oldest participants was used (46 participants total). Descriptive frequency variables for the two age groups are summarized in Table 10. Participant age ranged from 7 to 8 years in the young group (M_{age} = 7.86, *SD* = 0.36) and 12 to 14 years the old group (M_{age} = 12.48, *SD* = 0.57). Groups did not differ in terms of norm-referenced SFIQ, $t(44)$ = 1.47, p = .15, or word reading, $t(44)$ = 1.24, p = .22.

Table 10
Descriptive Frequencies (Proportions) of Young and Old Age Groups

		Age Group	
Demographic Variable		Young (7-8 yrs)	Older (12-14 yrs)
Sex			
	Female	12 (57%)	19 (76%)
	Male	9 (43%)	6 (24%)
School Language			
	English	7 (33%)	15 (60%)
	French	14 (67%)	10 (40%)
RTI group			
	Decoder	11 (52%)	9 (36%)
	Balanced	5 (24%)	11 (44%)
	Sightword	5 (24%)	5 (20%)

Testing Hypothesis 2a. The association between age group and classification as Balanced reading tendency was not significant, $\chi^2(1) = 2.05$, $p > 0.05$, $\varphi = 0.21$, when a 2 by 2 chi-squared analysis was performed with the two groups totalling 46 participants. Based on the effect size and odds ratio, a small to medium effect was found and the odds of a Balanced Reader being older was 2.51 times greater than being younger. As shown in Table 11, a greater proportion of Balanced Readers was classified in the older age group (44%) compared to the younger group (24%), although this difference did not reach significance with the current sample. In contrast, 56% of older readers were classified as non-balanced compared to 76% of younger readers. It appears that classification as a Balanced Reader may reflect increased reading fluency if it is presumed that older readers are more fluent than younger ones; however, the analysis did not reach statistical significance. As such, there is only partial support for Hypothesis 2a.

Table 11

Chi-squared Contingency Table for RTI Dichotomy by Age Group

		Young	Old	Total
Non-balanced	Count	16	14	30
	% within B vs. NB	53.3	46.7	100
	% within Y vs. O	76.2	56.0	65.2
	% of Total	34.8	30.4	65.2
Balanced	Count	5	11	16
	% within B vs. NB	31.3	68.8	100
	% within Y vs. O	23.8	44.0	34.8
	% of Total	10.9	23.9	34.8

Participant Descriptive Statistics for Hypotheses 2b, 2c, 2d. For the multivariate analyses performed to examine Hypothesis 2b, 2c, and 2d, data from 70 participants who completed all neuropsychological measures related to DVs was used. In terms of reading tendency group membership, 25 were classified as Decoders, 22 as Balanced Readers, and 23 as Sightword Readers. Within this sub-sample, 56% attended English schools, 70% identified as female, and 79% were Caucasian with only two participants (3%) not speaking English or French as a first language. Parent-reported neurodevelopmental disorders within this sample included seven participants (10%) with attention problems, one with autism spectrum disorder, two (3%) with a learning disability, two (3%) with speech-language impairments, and nine (13%) with a family history of dyslexia. Table 12 includes the group means and standard deviations for all reading and cognitive variables, with dependent variables used for Research Question #2 in bold. Of note, after data collection was complete, it was found that the sample mean for the processing speed task (i.e., using digital Coding) was nearly 3 scaled scores higher than the average normative score using the traditional paper-and-pencil version (N. Frost, O’Brien, Bartlett, & Casey, 2019).

Table 12

Means and Standard Deviations of Dependent Variables across Reading Tendency Groups

	Reading Tendency Group		
Variables	Decoder (n = 25)	Balanced (n = 22)	Sightword (n = 23)
Age (yrs)[a]	9.9 (1.7)	10.4 (2.0)	9.8 (1.5)
SFIQ[b]	109.6 (12.1)	107.2 (11.5)	100.3 (7.8)
Vocabulary [a]	12.4 (2.0)	11.5 (2.2)	10.3 (1.7)
Information [a]	11.1 (3.0)	11.2 (2.5)	9.8 (1.8)
Word Reading[b]	110.28 (10.6)	111.18 (13.6)	100.3 (17.7)
Pseudoword Decoding[b]	105.3 (11.3)	105.6 (16.4)	96.2 (17.0)
Spelling[b]	104.96 (12.1)	103.5 (14.9)	93.9 (13.7)
Reading Fluency [a]	10.1 (2.2)	9.9 (2.3)	7.9 (2.4)
Reading Accuracy [a]	8.9 (2.2)	9.1 (2.1)	7.3 (2.7)
Reading Rate [a]	11.5 (2.5)	10.8 (2.4)	8.7 (2.3)
Reading Comprehension [a]	9.9 (2.3)	10.4 (1.5)	8.0 (1.6)
Phonological Awareness[b]	100.6 (16.8)	98.4 (15.0)	93.3 (11.5)
Elision [a]	11.3 (1.6)	9.9 (2.8)	9.2 (2.2)
Blending Words [a]	10.5 (3.2)	9.7 (2.8)	8.3 (2.5)
Phoneme Isolation [a]	9.6 (1.5)	9.2 (2.7)	9.1 (2.7)
Auditory Working Memory[c]	54.2 (7.7)	51.3 (8.7)	49.8 (6.6)
Digit Span [a]	11.7 (3.0)	11.1 (3.5)	10.6 (2.5)
Sentence Memory[c]	52.7 (8.5)	48.9 (9.0)	47.7 (8.1)
Visual Working Memory [a]	12.9 (2.7)	13.5 (2.3)	11.8 (2.2)
Processing Speed [a]	13.2 (2.4)	13.3 (3.5)	12.6 (2.7)

[a] scaled score (*M*=10, SD=3); [b] standard score (*M*=100, SD=15); [c] T score (*M*=50, SD=10)

Testing Hypothesis 2b,2c, 2d. Multivariate analysis of variance (MANOVA) was performed to examine the concurrent validity of the RTI tasks and classification scheme. Using Roy's largest root, as recommended by Grice and Iwasaki (2007), there was a significant effect of reading tendency group on reading abilities and related cognitive variables, $\theta = 0.37$, $F(9,60) = 2.46$, $p = .018$. Separate univariate ANOVAs on the outcome variables revealed significant effects of reading tendency group on word reading, $F(2,67) = 4.17$, $p = .02$, , spelling, $F(2,67) = 4.58$, $p = .014$, reading fluency, $F(2,67) = 6.65$, $p = .002$, and reading comprehension, $F(2,67) = 10.3$, $p < .001$. Non-significant effects were found for visual working memory, auditory working memory, processing speed, phonological awareness, and pseudoword decoding. Table 13 summarizes the individual ANOVAs for between-group mean differences.

Table 13

Tests of Equality of Group Means for Predictor Variables

	F (2, 67)	Sig.	Partial eta
WIAT Word Reading	4.17	.02	.111
WIAT Pseudoword Decoding	2.94	.06	.081
WIAT Spelling	4.58	.014	.120
WISC Picture Span	2.62	.08	.072
WISC Coding	.476	.623	.014
Auditory Working Memory Composite	2.06	.135	.058
CTOPP Phonological Awareness Composite	1.56	.218	.044
GORT Reading Fluency	6.65	.002	.166
GORT Reading Comprehension	10.3	.000	.235

The MANOVA results did not support Hypothesis 2b that Balanced Readers would perform better overall than other groups. Decoders were also not distinguishable from other groups based on pseudoword decoding, phonological awareness, or auditory working memory as predicted (Hypotheses 2c and 2d). Instead, post-hoc multiple comparisons with Bonferroni correction found that, compared to Decoders and Balanced Readers, Sightword Readers tended to have lower scores on reading fluency ($p_D = .004$, $p_B = .014$) and reading comprehension ($p_D = .003$, $p_B < .001$). Sightword Readers also demonstrated lower scores on spelling ($p = .019$) compared to Decoders and lower scores on word reading ($p = .037$) compared with Balanced Readers but did not significantly differ from Decoders on the latter. Post-hoc comparisons are listed in Table 14 with significant group differences in bold.

Table 14

Bonferroni Post-hoc Multiple Comparisons of Mean Group Differences

Dependent Variable	RTI groups		$M_{difference}$	Std. Error	*p*
WIAT Word Reading	*Decoder*	*Balanced*	-.902	4.15	1.0
	Sightword	*Decoder*	-9.98	4.1	.053
	Sightword	***Balanced***	**-10.88**	**4.2**	**.037**
WIAT Pseudoword Decoding	*Decoder*	*Balanced*	-.316	4.4	1.0
	Sightword	*Decoder*	-9.10	4.3	-.119
	Sightword	*Balanced*	-9.42	4.5	.117
WIAT Spelling	*Decoder*	*Balanced*	1.46	3.9	1.0
	Sightword	***Decoder***	**-11.05**	**3.9**	**.019**
	Sightword	*Balanced*	-9.59	4.04	.062
GORT Reading Fluency	*Decoder*	*Balanced*	.211	0.67	1.0
	Sightword	***Decoder***	**-2.21**	**0.66**	**.004**
	Sightword	***Balanced***	**-1.99**	**0.68**	**.014**
GORT Reading Comprehension	*Decoder*	*Balanced*	-.529	0.54	.993
	Sightword	***Decoder***	**-1.84**	**0.53**	**.003**
	Sightword	***Balanced***	**-2.37**	**0.55**	**.000**
WISC Picture Span	*Decoder*	*Balanced*	-.575	0.71	1.0
	Sightword	*Decoder*	-1.05	0.70	.414
	Sightword	*Balanced*	-1.63	0.72	.084
WISC Coding	*Decoder*	*Balanced*	-.078	0.84	1.0
	Sightword	*Decoder*	-.675	0.83	1.0
	Sightword	*Balanced*	-.753	0.86	1.0
Auditory Working Memory Composite	*Decoder*	*Balanced*	2.93	2.24	.591
	Sightword	*Decoder*	-4.41	2.22	.153
	Sightword	*Balanced*	-1.49	2.29	1.0
CTOPP Phonological Awareness Composite	*Decoder*	*Balanced*	2.28	4.28	1.0
	Sightword	*Decoder*	-7.34	4.23	.263
	Sightword	*Balanced*	-5.06	4.37	.752

Research Question #3: Predictive validity of RTI group membership

Testing Hypothesis 3. The MANOVA was followed up with a DFA to determine which combination(s) of the four significant variables best predict group membership, revealing two discriminant functions (see Table 15). The first linear combination explained 88.3% of the variance, canonical R^2 = 0.49, whereas the second only explained 11.7% of the variance, canonical R^2 = 0.20. In combination these discriminant functions significantly differentiated reading tendency groups, λ = 0.728, $\chi^2(8)$ = 20.8, p = .008, but removing the first function indicated that the second function did not significantly differentiate the reading tendency groups, λ = 0.96, $\chi^2(3)$ = 2.71, p > .05. Thus, only the first linear combination was interpreted.

Table 15
Summary of Discriminant Function Analysis

LC	Eigenvalue	Canonical Correlation	Wilks' λ	χ^2	df	Sig.
1	.319	.492	.728	20.83	8	.008
2	.042	.201	.960	2.71	3	.439

The variable weights and correlations between outcomes on the first linear combination revealed that reading comprehension contributed most to reading tendency group membership (see Table 16), such that those who score lowest on this measure were classified as Sightword Readers instead of Decoders or Balanced Readers (see Table 17 for group centroids). Figure 12 depicts the spread of group centroids based on these discriminant functions. Given the predictors and linear combinations of the model, only 50% of original grouped cases were correctly classified (see Table 18), with Sightword and Balanced Readers classified near chance-level and Decoders correctly classified below chance. Thus, the findings did not support Hypothesis 3 that reading fluency would predict Balanced group membership. Instead, it was lower reading comprehension that best distinguished Sightword Readers from the other two groups.

Table 16
Summary of Discriminant Function Coefficients

	Standardized Discriminant Function Coefficients		Structure Coefficients	
Predictors	1	2	1	2
WIAT Word Reading	.187	-.147	.619	.220
WIAT Spelling	.082	.313	.620	.577
GORT Reading Fluency	-.089	1.304	.756	.623
GORT Reading Comprehension	**.917**	-1.109	**.982**	-.036

Note. Standardized coefficients = variable weights; structure coefficients = correlations

Table 17
Functions at Group Centroids

	Function	
RTI group	1	2
Decoder	.250	.254
Balanced	.524	-.227
Sightword	-.773	-.058

Table 18

Cross-Validated Classification Results of Model (%)

	Predicted Group Membership			
RTI group	Decoder	Balanced	Sightword	Total
Decoder	**40**	32	28	100
Balanced	27.3	**54.5**	18.2	100
Sightword	26.1	17.4	**56.5**	100

Note: Bold-face indicate correct classifications.

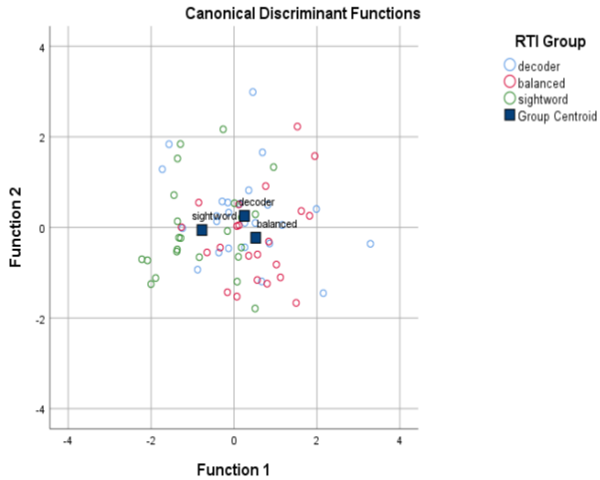

Figure 12. Spread of scores on discriminant functions for the model, including group centroids.

Research Question #4: Prediction of dichotomous group membership

<u>Testing Hypothesis 4.</u> Because Balanced Readers were not distinguishable from Decoders using any of the measures, Hypothesis 4 was not tested using logistic regression as predicted. It was proposed that this would be done only if there was little predictive distinction between the two non-balanced groups, which is the opposite of what was found.

Research Question #5: Exploring differences in French Immersion and English instruction groups

<u>Testing Hypothesis 5a.</u> There was not a significant association found between language of instruction and Balanced reading tendency, $\chi^2(1) = 0.286$, $p > .05$, $\varphi = .056$, when a 2 by 2 chi-squared analysis was performed with the two school language groups totalling 92 participants. Contrary to hypothesis 5a that predicted a higher proportion of Balanced Readers in French Immersion group, the contingency table (see Table 19) suggests instead that the proportion of Balanced Readers was comparable across English and French language groups.

Table 19
Chi-squared Contingency Table for RTI Dichotomy by Age Group

		English	French	Total
Non-balanced	Count	34	32	66
	% within B vs. NB	51.5	48.5	100
	% within E vs. F	69.4	74.4	71.7
	% of Total	37	34.8	71.7
Balanced	Count	15	11	26
	% within B vs. NB	57.7	42.3	100
	% within E vs. F	30.6	25.6	28.3
	% of Total	16.3	12	28.3

Testing Hypothesis 5b. Supplementary analyses were employed to further explore whether language of school instruction impacts on English reading ability given a paucity of existing research in this area. Using Roy's largest root, there was no significant effect of language of instruction on reading abilities in this sample when using MANOVA, $\theta = 0.15$, $F(5,70) = 2.08$, $p = .078$. Pairwise comparisons using Bonferroni correction revealed significant effects of language for only reading comprehension, $F(1,74) = 4.23$, $p = .043$, with French Immersion students obtaining significantly lower scores on this task. Non-significant language effects were found for word reading, pseudoword decoding, spelling, and reading fluency in this sample. Moreover, there was no significant effect of language of instruction on other cognitive abilities, $\theta = 0.082$, $F(5,78) = 1.29$, $p = .279$, and no differences in any specific cognitive ability, as shown in Table 20. Thus, Hypothesis 5b was not supported. FI student did not outperform English students on tests of reading fluency, pseudoword decoding, word reading, or phonological awareness.

Table 20
Tests of Equality of Language Group Means for Cognitive Measures

	df	*F*	*p*	Partial eta^2
WIAT Word Reading	1,74	.014	.906	.000
WIAT Pseudoword Decoding	1,74	2.13	.149	.028
WIAT Spelling	1,74	1.49	.226	.020
GORT Reading Fluency	1,74	2.52	.116	.033
GORT Reading Comprehension	**1,74**	**4.23**	**.043**	**.054**
WISC Picture Span	1,82	.916	.341	.011
WISC Coding	1,82	3.57	.062	.042
Auditory Working Memory Composite	1,82	.030	.863	.000
CTOPP Phonological Awareness Composite	1,82	.013	.909	.000

CHAPTER 5 – GENERAL DISCUSSION

The purpose of this dissertation project was three-fold: a) replicate the three-group structure of the RTI model (Mohl, 2015; Mohl et al., 2018) in a large representative sample of school-aged children; b) explore the construct and criterion validity of RTI tasks; and, c) examine the effect of language instruction (i.e., French Immersion) on task performance. The project was designed to address many of the limitations discussed by Mohl while also extending the application of the RTI to English-speaking students studying in French Immersion.

In all, five research questions were asked and ten predictions were made, of which two were confirmed, two partially upheld, and five others not supported along with one prediction not tested. Research Question #1 applied the RTI protocol and LDT tasks to a large sample of representative school-aged children to test whether Mohl's three-group structure would replicate. The distribution of Balanced Readers, Decoders, and Sightword Readers mimicked that of Mohl with Balanced Readers also reflecting higher reading fluency, supporting Hypotheses 1a and 1b. The three reading types were replicated in the whole sample, as well as with the subsamples of English and French Immersion students.

As such, the subsequent research questions were performed with the entire dataset to examine the construct and criterion validity of the RTI protocol as a measure of reading ability. None of the predictions in Research Question #2 were fully supported. Instead, Hypothesis 2a was partially supported, highlighting that Balanced Readers seem to be more fluent since a greater proportion of Balanced Readers were seen in the oldest group compared to the youngest group, despite not reaching statistical significance. Hypotheses 2b, 2c, and 2d, which all related to the criterion validity of the RTI, involved exploring the differences in cognitive and reading skills for each group, and none of these specific predictions were supported. Instead, Sightword Readers differed from Decoders and Balanced Readers only with regards to lower performance on word reading, spelling, reading fluency, and reading comprehension. Otherwise, Decoders and Balanced groups did not differ on any measured construct. The significant variables from the MANOVA were then used as predictor variables for Research Question #3 and Hypothesis 3 was partially supported. Instead of reading fluency distinguishing Balanced Readers from other groups, reading comprehension best separated the Sightword group from Balanced and Decoder groups, with better performance favouring the latter two. Research Question #4 was not analyzed with the normative sample since there was no separation between the Balanced and non-balanced groups.

Research Question #5 explored any potential effects of language instruction (i.e., French Immersion, FI) on cognitive ability and reading skills. The final two predictions (Hypotheses 5a and 5b) that FI participants would have better performance were not upheld. Instead, English and French Immersion participants did not significantly differ in terms of balanced/non-balanced group makeup, and FI participants performed worse than English counterparts on reading comprehension with the groups found to be comparable on all other measures.

In response to the limitations and recommendations made by Mohl and colleagues (2018), this dissertation project provided further validation for the RTI task in a non-clinical sample. The findings are elaborated in more detail below within the context of the goals, strengths, and limitations of this project.

Replication of Reading Tendency Groups

The results from the current study provide replication of the Reading Tendency Index as a metric for identifying and classifying school-aged children based on their preferred reading tendencies, first described by Dr. Mohl in her 2015 dissertation (Mohl, 2015) and later in a recently published manuscript (Mohl et al., 2018). That is, three groups of readers were distinguished within the sample based on their propensity to use specific reading skills as inferred through the dual LDT performance, supporting Research Question #1. Not only were participants classified in the Balanced, Decoder, and Sightword groups based on the comparative drift rates across both tasks, but these classifications also reflected differences in Relative Fluency as expected. That is, Balanced Readers tended have higher proficiency, as reflected by the large ratios between RF and RTI and as demonstrated visually in the figures included in Chapter 4. Indeed, the plots from this sample closely resemble that of the original study, both reproduced below (Figure 13). As depicted, the overall shapes of the distributions are quite similar across clinical (left) and normative (right) samples. Balanced Readers tended to cluster around 0 for tendency and above

20 for the fluency/RTI ratio, whereas Decoders and Sightword Readers tended to have a lower ratio and tendencies greater than ± 1.

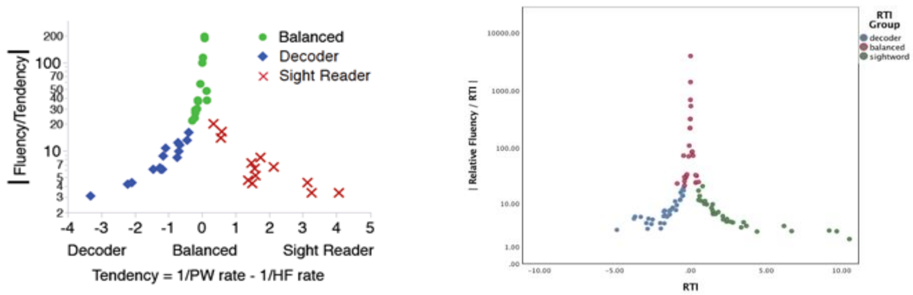

Figure 13. Visual comparison of RTI group distributions from Mohl's original sample of 42 participants (depicted on the left; adapted with permission) to the current sample with 92 participants (depicted on the right).

Although the same task stimuli and statistical analyses were used in both studies, there are significant differences in terms of the sample composition (e.g., age, gender, neurodevelopmental diagnoses), study setting, and method of administration. First, the current sample size was more than double that of the original project (Mohl, 2015; Mohl et al., 2018) and contained a large proportion of female participants (66%), compared to Mohl's sample of only male participants. The age ranges also varied, with Mohl's sample being older (M = 12.0, Range = 9 – 16 years) compared to the current sample (M = 9.96, Range = 7 – 14 years). Secondly, whereas Mohl's sample was mostly clinical in nature (i.e., more than 60% of sample had a diagnosis of ADHD, reading disorder, or both), the current sample was recruited with the purpose of being representative of the typical population of school-aged children. As such, the current sample included roughly 85% typically-developing children with 8% self-reporting attention issues (or ADHD) and 4% reporting a learning disability and/or speech-language impairment. As such, the present sample is a closer representation of a normative group compared to the clinical makeup of the original study. The current sample also included English-speaking students learning in French Immersion. The successful replication of previous findings (Mohl, 2015; Mohl et al., 2018) in light of these substantial sample differences supports the robustness of the RTI protocol.

In addition to addressing sample limitations discussed in the original study (Mohl et al., 2018), the present study was performed in a school setting and outside of the fMRI scanner. Thus, the adaptation to a laptop computer for use in an educational or clinical setting was successful and yielded similar groupings using the RTI protocol to when the tasks were administered in the scanner.

Construct & Criterion Validity of RTI Protocol

The purpose of Research Question #2, #3 and, #4 was to examine the construct and criterion validity of the RTI model as it applies to the assessment of reading development in typically-developing school-aged children. Theoretical underpinnings of the RTI tasks suggest that individuals classified as Balanced Readers would be more fluent readers than non-balanced groups. To examine this aspect of its construct validity, groups of the youngest and oldest participants were compared using chi-squared analysis yielding a larger proportion of Balanced Readers in the older group; however, the analysis did not reach statistical significance. Therefore, results suggest that individuals in the balanced group likely have better reading fluency than non-balanced readers (i.e., Decoders, Sightword), and that balanced use of reading subnetworks may increase with age as reading fluency skills develop.

In exploration of the criterion validity for RTI group membership and whether groups differ in predicted ways based on phonological awareness, working memory, and various reading abilities, MANOVA yielded inconsistent results. Balanced Readers did not perform better than Decoders on any measure, but performed better than Sightword Readers on word reading, reading fluency, and reading comprehension. Additionally, Sightword Readers differed from Decoders only in terms of spelling, reading fluency, and reading comprehension. These two groups did not differ in terms of phonological awareness or pseudoword decoding as predicted. Decoders did not differ in any predictable way from Balanced Readers contrary to predictions. Finally, there were no differences in working memory ability across RTI groups. DFA results revealed that lower performance on reading comprehension contributed most to classification as a Sightword Reader as opposed to Decoder or Balanced reader, accounting for 88% of the variance in this function. Decoders and Balanced Readers were not distinguishable in the model using the current DVs. Instead, these results suggest that individuals classified as Sightword

Readers distinguish best from Decoders and Balanced Readers based on lower scores on measures of reading comprehension.

Taken together, Research Question #2 and #3 provide preliminary support for the construct and criterion validity of what the RTI measures and how classification groups differ despite the limitations inherent with a normative sample. Specifically, Balanced Readers tend to demonstrate better reading fluency as a result of the high fluency-tendency ratios responsible for their group assignment and the finding that there is a higher proportion of Balanced Readers in the oldest age group versus the youngest. Sightword Readers also performed worse on tasks of word reading, spelling, reading fluency, and reading comprehension, supporting existing research that individuals who rely solely on word recognition strategies perform worse on reading tasks overall (Deacon, Benere, & Castles, 2012; McNorgan et al., 2011). Predictions that Decoders would differ from other groups in terms of phonological awareness or pseudoword decoding, however, were not supported.

Lack of differentiation between Decoders and Balanced Readers may have been influenced by the lack of variability in reading ability in the sample (i.e., normative sample; few participants with diagnosed RDs) and lack of sensitivity and specificity of measures used to distinguish these groups. For instance, Decoders were purported to have better pseudword decoding and phonological awareness as well as lower visual working memory than Sightword and Balanced Readers. Instead, it appears that the WIAT-III Pseudoword Decoding subtest, CTOPP-2 phonological awareness composite, and Picture Span subtest (a measure of visual working memory on the WISC-V) were perhaps not sensitive enough to elucidate the previously demonstrated group differences (Mohl et al., 2018). This is plausible since these measures are generally used to detect clinically meaningful differences in these skills and generally not administered to children of average ability. Thus, more subtle differences in ability would not be reflected in the scores.

Applicability with French Immersion student sample

Given Canada's official bilingualism status and the high enrollment of school-aged children in French Immersion programs, Research Question #5 examined the effects of French Immersion instruction on RTI task performance and group membership as well as performance on administered neuropsychological and academic variables. It was predicted that RTI performance and group membership would be replicated with French Immersion participants since they will also become proficient readers in English throughout their education. As first described in Chapter 4, RTI group membership was replicated in the FI group, supporting Hypothesis 1b. In addition, RTI scores plus the fluency-tendency ratio were not significantly different across language groups. Additional group-level analyses of RTI variables revealed significant differences in pLDT proportion correct between language groups after performing the Bonferroni correction. Otherwise, reaction times, drift rates, RTI, and RF variables were not significantly different for English vs. FI instruction. Indeed, differences in performance on oLDT vs. pLDT tasks followed the same trend with the FI group as was discussed with the English group; that is, high-frequency words were correctly identified more quickly and more often than pseudowords for both language groups.

Based on previous research suggesting that bilingualism promotes metalinguistic awareness (Rubin & Turner, 1989) and higher reading achievement for FI students on average (Allen, 2004), it was predicted that a language effect would be seen such that a higher proportion of Balanced Readers would be in the FI group than the English group. Contrary to the prediction of Hypothesis 5a, there was no significant effect of language of instruction on balanced reading tendency, particularly not with FI participants being more balanced. In fact, results suggest that balanced group membership is comparable for English participants (31%) and FI participants (26%). Supplementary analyses comparing FI and English groups on the other cognitive and reading variables found significant group differences for reading comprehension. French Immersion participants performed significantly lower on this task than English participants. Non-significant differences in word reading, pseudoword decoding, spelling, and reading fluency were found in this sample. As such, Hypothesis 5b, which predicted better performance on various measures of reading ability for FI participants, was not supported. Moreover, no significant group differences were found for working memory, processing speed, or phonological awareness.

Poorer performance by FI students may be explained in part by the "extended lag" effect, first described by Swain and Lapkin (1982). That is, FI students in grades 3 and 4 experience a temporary lag in English skills until formal instruction begins, at which point FI students tend to then outperform English peers (Lapkin, Hart, & Turnbull, 2003). Thus, a proportion of the FI group in the current sample would belong to this early immersion group with limited English instruction, particularly in reading, who may be experiencing a lag in skills. Furthermore, their scores were normed relative to English-only individuals, potentially impacting the results.

Limitations and Additional Steps

Persistent limitations inherent to both RTI studies involve the use of arguably arbitrary cut-off scores using a tertile method for determining groups. For instance, Mohl (2015) describes creating cut-off scores for the RTI to maximize equality of sample size across groups due to small sample size. Thus, group membership was determined by the participant's distance from zero on the RTI and the ratio between RF and RTI in the following manner: Balanced Readers near 0 on RTI and greater than 21 on RF/RTI ratio, Decoders less than 0 on RTI and less than 21 on ratio, and Sightword Readers greater than 0 on RTI and less than 21 on ratio (Mohl, 2015). With the current normative sample, it was thought that these cut-offs were perhaps too restrictive since it resulted in too many participants being classified as non-Balanced Readers (72% of sample) despite the sample containing a majority of typically-developing children with mostly average reading abilities across other standardized measures. Moreover, the tertile method may be increasing the variance among groups and leading to confusion for those on the cusp of being classified as balanced versus a non-balanced group.

Next steps for research with the RTI should include further exploration of group characteristics by including only the extreme ends of Decoders and Sightword along with Balanced Readers. This would eliminate potential confounding individuals who may be in a 'gray' zone when it comes to group membership. Results here could perhaps provide evidence for the use of five groups instead of three to account for individuals who may fall in this gray zone. One research question may be whether there are groups of readers (i.e., in the gray zones) who tend to rely more on one reading tendency than the other, but who are not necessarily functionally impaired in their reading abilities.

To address the limitations based on conservative cut-offs and tertile divisions for group membership, two sets of supplementary analyses were performed and are described in Chapter 6. First, the cut-offs were expanded to be less conservative when classifying individuals in the balanced group. Second, the original cut-offs were used with a reduced sample, excluding participants who fell in the 'gray' zone and including only those who were classified as Balanced or at the extreme ends of the Decoder and Sightword groups. Following a discussion of the results of these supplementary analyses, Chapter 7 will provide a more critical analysis of the findings and implications of this research project, including the potential limitations and directions for future research.

CHAPTER 6 – SUPPLEMENTAL ANALYSES

To further address limitations to the original study and those not considered in the proposed methods of the current study, two sets of supplemental analyses were performed regarding the RTI protocol. First, the analyses were replicated with the current sample using more liberal cut-off values for determining RTI group membership. Second, the original cut-offs were applied and then the sample was reduced to include only the more extreme values of each RTI group; that is, the most balanced (RTI below 0.6; ratio above 21) and most extreme Decoders and Sightword Readers (RTI above 1; ratio below 10). Relevant tables and figures are included in Appendix I for reference.

Liberal Cut-off Scores

Since the original RTI group cut-off scores were created to maximize equality of sample size across groups due to the small overall sample size (Mohl, 2015), the RF/RTI ratio cut-off score for Balanced classification was greater than 21. Based on the results of the present study, it was thought that these cut-offs may be too restrictive, resulting in too many participants being classified as non-balanced readers (72% of the sample) despite the sample containing a majority of typically-developing children with mostly average reading abilities across other measures. As such, supplemental analyses were performed using expanded cut-offs to be less conservative when classifying individuals as Balanced.

Specifically, a RF/RTI ratio of greater than 12 was used to determine Balanced group classification along with the RTI being close to 0 (i.e., less than ±1). Based on this new RTI and RF/RTI cut-off, participants were classified as Decoders (n = 30), Balanced Readers (n = 35), or Sightword Readers (n = 27). Table 21 summarizes the proportions of RTI group membership using the new cut-off score across language sub-samples. Figure 14 demonstrates all reading preferences plotted in view of their abilities. All other tables and figures for the supplemental analysis may be found in Appendix I (Tables I1-I8; Figure I1).

Table 21

Summary of RTI Group Frequencies Across Samples with Liberal Cut-offs

	n (%)		
RTI Group	English only	French Immersion	Total
Decoders	17 (35%)	13 (30%)	30 (33%)
Balanced	19 (39%)	16 (37%)	35 (38%)
Sightword	13 (26%)	14 (33%)	27 (29%)

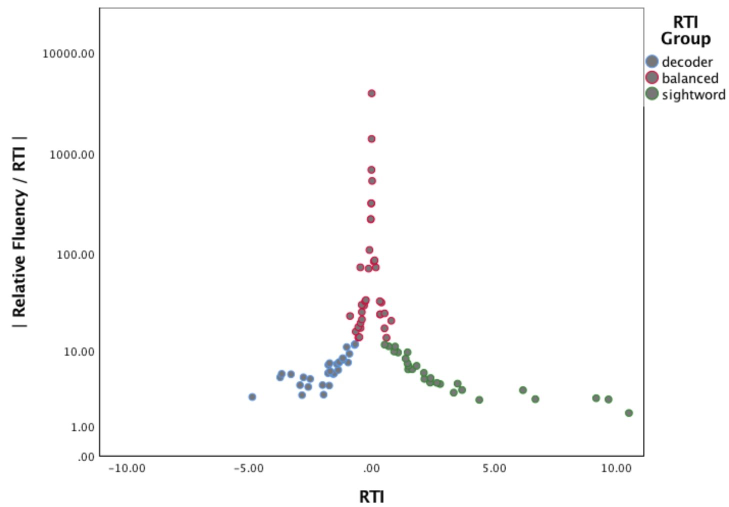

Figure 14. Participants from the three reading tendency groups using liberal cut-offs are depicted by comparing Reading Tendency (RTI) and the absolute value of Relative Fluency/Reading Tendency.

Similar to the findings obtained with the original cut-off scores, the association between age group and classification as balanced reading tendency was not significant, $\chi^2(1) = 0.889$, $p > 0.05$, $\varphi = 0.14$, when a 2 by 2 chi-squared analysis was performed with the two groups totalling 46 participants. Based on the effect size and odds ratio, a small to medium effect was found and the odds of a Balanced Reader being older was 1.76 times greater than if they were younger. A greater proportion of Balanced Readers was found in the older age group (52%) compared to the younger group (38%), although this difference did not reach significance with the current sample. In contrast, 48% of older readers were classified as non-balanced compared to 62% of younger readers. As such, a similar age-related pattern emerged with the less conservative cut-offs. That is, classification as a Balanced Reader may reflect increased reading fluency if it is presumed that older readers have better fluency than younger ones.

For the multivariate analyses, data from the same 70 participants who completed all neuropsychological measures related to DVs was used. In terms of reading tendency group membership, 21 were classified as Decoders, 28 as Balanced Readers, and 21 as Sightword Readers. Multivariate analysis of variance (MANOVA) was again performed to examine the concurrent validity of the RTI tasks and classification scheme using the new cut-off criteria (RF/RTI ratio > 12 instead of > 21). See Tables I3 and I4 in the appendix for detailed information.

In contrast to the results using the original cut-off score, there was not a significant effect of reading tendency group on reading abilities and related cognitive variables, $\theta = 0.27$, $F(9,60) = 1.82$, $p = .083$. Separate univariate ANOVAs on the outcome variables revealed significant effects of reading tendency group on visual working memory, $F(2,67) = 3.86$, $p = .026$, reading fluency, $F(2,67) = 5.34$, $p = .007$, and reading comprehension, $F(2,67) = 6.83$, $p = .002$. Post-hoc multiple comparisons with Bonferroni correction found that, compared to Decoders and Balanced Readers, Sightword Readers tended to have lower scores on reading fluency ($p_D = .017$, $p_B = .018$) and reading comprehension ($p_D = .047$, $p_B = .002$). Sightword Readers also demonstrated lower scores on visual working memory ($p = .021$) compared to Balanced Readers, which was contrary to the original hypothesis, but did not differ from Decoders on this measure. Non-significant effects were found for auditory working memory, processing speed, phonological awareness, word reading, spelling, and pseudoword decoding. Once again, the MANOVA results did not support the predicted hypotheses in terms of distinguishing between groups.

This supplemental MANOVA was followed up with a DFA to determine which combination(s) of the three significant variables best predict group membership, revealing two discriminant functions. The first linear combination explained 84.3% of the variance, canonical $R^2 = 0.45$, whereas the second only explained 15.7% of the variance, canonical $R^2 = 0.21$. In combination these discriminant functions significantly differentiated reading tendency groups, $\lambda = 0.762$, $\chi^2(6) = 17.96$, $p = .006$, but removing the first function indicated that the second function did not significantly differentiate the reading tendency groups, $\lambda = 0.955$, $\chi^2(2) = 3.05$, $p > .05$. Thus, only the first linear combination was interpreted.

As was previously demonstrated with the original cut-off criteria, the variable weights and correlations between outcomes on the first linear combination revealed that reading comprehension continues to contribute most to reading tendency group membership, such that those who score lowest on this measure were classified as Sightword Readers instead of as Decoders or Balanced Readers. Given the predictors and linear combinations of the model, only 50% of original grouped cases were correctly classified (see Table I8 in the appendix). Sightword Readers were most often correctly classified (71%) with members of the other tendency groups correctly predicted near or below chance-level.

Restricted (Non-tertile) Sample

The other limitation discussed in the original study with respect to the cut-offs was that it created three groups based on tertiles with arbitrary distinctions between those on the cusp of being classified in the Balanced or one of the non-balanced groups. As such, another set of supplemental analyses was performed on a restricted sample with participants removed who could be considered within the "gray zone". That is, Balanced participants were included in the dataset if their RTI score was between 0 and ±0.6 and RF/RTI ratio above 21, whereas Decoders or Sightword Readers were included if the RTI score exceeded negative or positive 1, respectively, and the RF/RTI ratio was below 10 (i.e., most 'extreme').

In total, the same number of Balanced participants was retained (n = 26); however, in removing "gray zone" participants with RTI score below ±1 but less fluency in terms of lower ratio scores, the final number of Decoders and Sightword Readers retained was 24 and 23, respectively, for a final sample of 73 participants (see Figure 15). Table 22 provides the group breakdown for each of the three analyses using different cut-offs (main analysis plus the two supplemental analyses discussed in this section).

Table 22

Summary of RTI Group Frequencies Dependent on Cut-off Used

	n (%)		
RTI Group	Original cut-off (ratio > 21)	Liberal cut-off (ratio > 12)	Non-tertile (ratio > 21 for B & < 10 for NB)
Decoders	36 (39%)	30 (33%)	24 (33%)
Balanced	26 (28%)	35 (38%)	26 (36%)
Sightword	30 (33%)	27 (29%)	23 (31%)
Total	92 (100%)	92 (100%)	73 (100%)

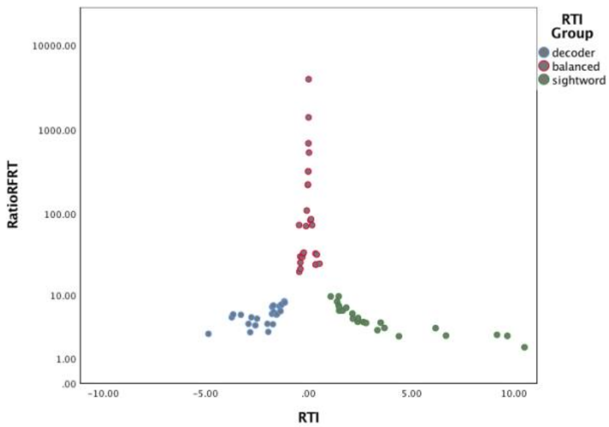

Figure 15. Participants from the three reading tendency groups in the reduced sample are depicted by comparing Reading Tendency (RTI) and the absolute value of Relative Fluency/Reading Tendency.

All other relevant tables and figures are found in Appendix I (i.e., Table I9-I16, Figure I2), but the results of each analysis will be detailed below. The RTI groups in this reduced sample did not differ in terms of age, $F(2, 70) = 2.37$, $p > .05$, or SFIQ, $F(2, 70) = 1.77$, $p > .05$.

Similar to the findings obtained with the original cut-off scores, the association between age group and classification as balanced reading tendency was not significant, $\chi^2(1) = 3.42$, $p = 0.065$, $\varphi = 0.304$, when a 2 by 2 chi-squared analysis was performed with the two groups totalling 37 participants. Based on the effect size and odds ratio, a medium effect was found and the odds of a Balanced Reader being older was 3.57 times greater than being younger. A greater proportion of Balanced Readers was found in the older age group (58%) compared to the younger group (28%), although this difference did not reach significance with the current sample. In contrast, 42% of older readers were classified as non-balanced compared to 72% of younger readers. As such, a similar age-related pattern emerged with the reduced sample using the original cut-off for Balanced classification. That is, classification as a Balanced Reader may reflect increased reading fluency if it is presumed that older readers are more fluent than younger ones. Indeed, this restricted sample appears to best demonstrate the age-related difference in RTI group composition.

For the multivariate analyses, data from 61 of the 73 participants was used as this sub-sample had completed all reading measures being used as DVs. In terms of reading tendency group membership, 19 were classified as Decoders, 23 as Balanced Readers, and 19 as Sightword Readers. Group statistics on the administered reading and cognitive measures are listed in Table I9 of the appendix. MANOVA was again performed to examine the concurrent validity of the RTI tasks and classification scheme using the reduced sample, which had removed Decoders and Sightword Readers who fell in the "gray zone". Specifically, only the five measures of reading ability (i.e., WIAT WR, PD, SP; GORT-5 Fluency, Comprehension) were included in the model given the non-significant differences in other cognitive measures across the other two analyses as well as the reduction in sample size. See Tables I11 and I12 in the appendix for detailed information. In this case, there was a significant effect of reading tendency group on reading variables, $\theta = 0.42$, $F(5,55) = 4.66$, $p = .001$. Separate univariate ANOVAs on the outcome variables revealed significant effects of reading tendency group on spelling, $F(2,58) = 4.32$, $p = .018$, reading fluency, $F(2,58) = 4.8$, $p = .012$, and reading comprehension, $F(2,58) = 10.82$, $p < .001$. Instead, post-hoc multiple comparisons with Bonferroni correction found that, compared to Decoders and Balanced Readers, Sightword Readers tended to have lower scores on reading fluency ($p_D = .043$, $p_B = .018$) and reading comprehension ($p_D = .024$, $p_B < .001$). Sightword Readers also demonstrated lower scores on spelling ($p = .027$) compared to Decoders, but did not differ from Balanced Readers on this measure. Non-significant effects were found for word reading and pseudoword decoding. Once again, the MANOVA results did not support the predicted hypotheses in terms of distinguishing between groups.

This supplemental MANOVA was followed up with a DFA to determine which combination(s) of the three significant variables best predict group membership, revealing the same pattern as previously demonstrated. The first linear combination explained 85.8% of the variance, canonical $R^2 = 0.53$, whereas the second only explained 14.2% of the variance, canonical $R^2 = 0.25$. In combination these discriminant functions significantly differentiated reading tendency groups, $\lambda = 0.67$, $\chi^2(6) = 22.79$, $p = .001$, but removing the first function indicated that the second function did not significantly differentiate the reading tendency groups, $\lambda = 0.938$, $\chi^2(2) = 3.65$, $p > .05$. Thus, only the first linear combination was interpreted.

As was previously demonstrated with the original cut-off criteria, the variable weights and correlations between outcomes on the first linear combination revealed that reading comprehension continues to contribute most to reading tendency group membership, such that those who score lowest on this measure were classified as Sightword Readers instead of as Decoders or Balanced Readers. Given the predictors and linear combinations of the model, 64% of original grouped cases were correctly classified (up from 50% with previous two 'full' samples). Balanced Readers were most often correctly classified (78%) with members of the other tendency groups correctly predicted near chance-level.

Discussion

The purpose of the supplemental analyses was two-fold. First, the RTI group characteristics were explored using more liberal cut-off scores since the original cut-off scores led to a higher proportion of the current sample classified as non-balanced readers despite the typically-developing (i.e., normative) nature of the sample. Secondly, the group characteristics were explored when the sample was reduced to remove equivocal cases based on the original cut-off criteria (e.g., those with RTI scores close to 0 yet poor fluency based on the ratio). Although these post-hoc analyses were exploratory, it was anticipated that the reduced sample would provide better delineation of groups relative to the tertile method.

Both sets of supplemental analyses demonstrated a similar pattern of results as was found in the main analyses. That is, there was a trend towards a higher proportion of older readers being classified as balanced compared to younger readers, and reading comprehension best predicted group membership for each set of analyses. Adjusting the cut-offs and reducing the sample to remove the equivocal cases did not necessarily improve the delineation of groups based on cognitive and reading ability predictors. Instead, the predictive power of reading comprehension scores was improved when the equivocal cases were removed such that Balanced Readers were correctly classified nearly 80% of the time compared to chance-level with the entire sample. Although removing these cases provided an improvement in terms of reducing the variance within the two non-balanced groups, doing so did not improve group separation based on cognitive and reading skills as predicted. Instead, the same significant predictors were identified and reading comprehension score best separated groups, particularly Sightword from Balanced Readers. Even with the reduced sample or less conservative cut-off scores, Decoders were quite similar to Balanced Readers in terms of performance on reading and cognitive measures, which further suggests that the current findings are impacted by the normative sample characteristics.

CHAPTER 7 – SUMMARY OF FINDINGS

The fundamental goal of this dissertation project was to address the limitations described by Mohl and colleagues (2018) and to replicate the three-group structure of readers based on the RTI model. The authors suggested that by comparing the relative proficiency in decoding versus word recognition head-to-head, the Reading Tendency Index (RTI) serves as a metric for characterizing the individual's intrinsic preferred approach for single word reading (Mohl et al., 2018). This method also mathematically controls for confounding effects such as processing speed, attention, and motor speed variations by using drift diffusion modelling (Philiastides et al., 2011; Ratcliff et al., 2004). The two lexical decision tasks used to develop the RTI were adapted for use on a laptop and administered to a large, normative sample of school-aged children. Compared to Mohl's clinical sample, the current study included female participants, was somewhat younger (i.e., 7 through 14 years old vs. 9 through 16 years old), was more representative of the population with respect to neurodevelopmental diagnoses (14% of sample versus 63% of Mohl's sample), and included students learning in French Immersion as well as in English. Despite these major differences, the three-group structure based on RTI task performance was easily replicated, supporting the robustness of the RTI model.

Moreover, a similar trend in the results was found across all analyses, including with the application of different cut-off scores and the reduced sample. That is, Balanced group membership appeared to be associated with better reading fluency as demonstrated by a greater proportion of older participants being classified as Balanced Readers compared to younger participants across all three analyses. This hypothesis was made based on the assumption that older children generally have better developed reading fluency relative to younger children in earlier stages of reading development. Furthermore, lower performance on a measure of reading comprehension best predicted Sightword reading tendency along with lower scores on measures of reading fluency and single word reading relative to Balanced Readers.

The predictive accuracy of reading comprehension appeared to be best when the tertile method was not used (i.e., when only the non-equivocal participants were included in the analysis). Classification accuracy improved from 50% with the original cut-off scores to 64% with the reduced non-tertile sample, including 78% accuracy in classifying Balanced Readers (up from 55%). Given the similarities in findings across all three sets of analyses, determining the most robust cut-off scores for RTI group membership should be explored. Nonetheless, findings from the current project provided independent replication of the three-groups of readers based on reading tendency and reading proficiency using a quantitative task that measures rate of response and accuracy for decoding and word recognition skills.

The major findings are discussed in more detail below within the context of potential clinical and educational implications. Specifically, the important replication of the RTI model in a normative sample as well as the potential use of the RTI protocol as a screening tool for reading difficulties is explored. Moreover, findings with the French Immersion sub-sample are discussed in terms of advancing our understanding of similarities and differences in this group compared to their English-instructed peers. Finally, limitations of the project are discussed as well as next steps to build upon the robustness of the RTI groupings and this preliminary validity research with a partially bi-lingual Canadian demographic.

Replication of RTI Model with a Normative Sample

The most salient finding from the current study involved the replication of the RTI model (i.e., three groupings of readers) with a normative sample. With the primary goal of the project to replicate the model by addressing many of the limitations discussed in the original study (Mohl et al., 2018), the successful replication of the groupings with a sample involving few participants with reading difficulties demonstrates the robustness of the model. Although the current sample was recruited with the goal to be representative of Ontario school-aged children with a spectrum of reading abilities from proficient readers to those with reading disabilities, the final sample probably lacked the representative proportions of neurodevelopmental disabilities (e.g., learning disability, ADHD, etc.) typically observed in the general population of school-aged children. Indeed, it was likely this lack of diversity in cognitive and reading skills that impacted the other predictions of the study (i.e., that RTI groups would differ in cognitive skills in predictable ways). Nonetheless, the RTI model was replicated with the current normative sample.

Not only was the current sample normative in nature as compared to Mohl's clinical sample, the RTI model was also replicated with a mixed-language sample. The fact that there were virtually no differences in performance on the RTI protocol across English-only and French Immersion groups provides additional support for the robustness of the model. Language groups differed only in proportion correct on the pseudoword task (i.e., lower for FI), otherwise maintaining similar levels of performance on other RTI variables. Moreover, a similar trend in the pattern of results across language groups further substantiates this claim. That is, high-frequency words were correctly identified more quickly and more often than pseudowords for both language groups. Therefore, French Immersion instruction did not impact performance on the RTI protocol, supporting the potential for use with FI students as well.

The importance of having replicated the RTI model in a normative sample cannot be stressed enough. As an important first step in validating the protocol, this suggests that the original findings with the clinical sample were indeed robust. It was perhaps apparent that participants with reading impairments would differ in terms of their reading tendencies and thus be classified into non-balanced groups. By replicating the protocol with a normative sample in a school setting, it suggests a continuum of reading proficiency outside of those diagnosed with a reading disability. Specific cut-offs for best determining group classification have yet to be determined and this was not possible with the normative sample. Nonetheless, the current study builds upon the original RTI study by addressing such limitations as a small male-only, clinical sample and task administration in fMRI scanner (Mohl et al., 2018) and replicating the RTI model.

RTI as a Screening Tool for Reading Difficulties

In the original study, all participants with a diagnosed RD were classified as non-balanced yet there was an equal split between Decoders and Sightword Readers (Mohl et al., 2018). Furthermore, different cognitive strengths and weaknesses across RTI groupings were obtained, with Balanced Readers demonstrating better fluency, Decoders demonstrating poorer visual working memory, cognitive flexibility, and word recognition skills, and Sightword Readers demonstrating poorer verbal working memory, phonological awareness, and pseudoword decoding (Mohl et al., 2018). Based on these findings, a conceptual framework of cognitive skills influencing single word reading approaches was outlined (see Table 23).

Table 23
Conceptual Framework of Cognitive Skills Influencing Single Word Reading Approaches

	Decoders	Balanced Readers	Sightword Readers
Decoding Skills	Limited	Good	Poorly developed
Word recognition	Poorly developed	Good	Limited
Cognitive flexibility	Delayed	Good	Poorly developed
Verbal working memory	Limited	Good	Poorly developed
Visual working memory	Poorly developed	Good	Limited
Overall fluency	Delayed	Good	Limited *

Adapted from Mohl et al., 2018; * upheld in current study

Given that the RTI is rooted in the dual-route theory of reading (Coltheart et al., 2001), which delineates two neural subnetworks involved in phonological processing (dorsal network) and word recognition (ventral network), it is no surprise that Mohl (2015) discovered that grouping participants based on reading tendency better mapped onto functional neural subnetwork activation patterns than when analyzed based on diagnostic groups (i.e., ADHD, ADHD + RD, typically-developing). In this study, Balanced Readers were found to be the most proficient with high Relative Fluency scores whereas non-balanced readers (i.e., Decoders and Sightword Readers) were less proficient, suggesting that these participants over-rely on one reading strategy and cannot reliably adapt their strategy to improve reading fluency. Results from fMRI analyses revealed that Decoders demonstrated hypoactivation of ventral network areas during the oLDT (i.e., word recognition) task and hyperactivation of dorsal network areas during the pLDT (i.e., decoding) task compared to Sightword and Balanced Readers (Mohl, 2015), over-relying on the dorsal reading subnetwork. It was suggested that the Sightword group over-relies on the ventral recognition subnetwork and use of word recognition skills in lieu of phonological decoding whereas Balanced Readers are able to engage flexibly in both networks as needed (Mohl, 2015), likely utilizing neural regions associated with cognitive flexibility and the integration of cross-modal information as described by Booth and colleagues (2004). Although neural activation patterns were not verified in the present study, the fact that the pattern of results regarding RTI group membership was upheld suggests that Mohl's findings are indeed robust with a sample more representative of the general population of school-aged children.

In the current study, Sightword Readers only distinguished from Decoders and Balanced Readers based on lower scores on tasks of word reading, spelling, reading fluency, and reading comprehension. Otherwise, Decoders and Balanced Readers did not significantly differ in this sample. In contrast to findings with the clinical sample (Mohl et al., 2018), pseudoword decoding, phonological awareness, and working memory performance were not predictive of group membership in this sample. These findings were likely impacted by the normative characteristics of the sample as well as limitations related to the measurement of these areas (i.e., lack of sensitivity for measures to detect differences in a normative sample). Nonetheless, performance on the phonologic and orthographic LDT tasks that lead to the creation of the RTI and subsequent group classification based on tendency appears to be robust across both samples.

Classification as a non-balanced reader with lower reading fluency and comprehension, especially as a Sightword reader in the case of this study, provides an indication of potential reading difficulties in this group. Those who were classified in the Sightword group had significantly lower scores on a variety of age-normed tasks of reading skills. Thus, this quantitative task may have the potential to serve as an appropriate and quick screening tool for reading impairments in school-aged children. Unfortunately, this could not be further explored with the current sample since the limited number of participants diagnosed with reading disorders likely influenced the lack of spread between Decoders and Balanced Readers, leading to the incongruence between the current results and those of the original study (Mohl, 2015; Mohl et al., 2018). Although the data suggests that Sightword Readers perform lower on tasks measuring reading ability, there was not enough diversity in the sample to determine cognitive differences between Decoder and Balanced Readers.

Based on these findings, the concurrent and predictive validity of the RTI protocol as a measure of reading difficulties is still unresolved. There was an insufficient number of children with reading and associated cognitive impairments to demonstrate predicted associations based on RTI group membership. Indeed, scores on measures of working memory and phonological awareness were all in the average range (refer back to Table 12 in Chapter 4 for means and standard deviations across RTI groups), with only three and eleven participants falling one standard deviation below the mean, respectively. The recommendation to include children with reading disabilities as a comparison group in future studies is echoed here to further explore the validity of the RTI as a measure of reading tendencies and impairments.

Advances in Knowledge about French Immersion Programming on Reading

Another primary purpose of the current project was to include participants who were enrolled in French Immersion programs to examine whether FI language instruction impacted English reading performance. Firstly, the three-group structure of the RTI was replicated in the FI group and there were no differences in performance compared to English-only participants. As such, the RTI task appears to be robust for use with English-speaking students even if they are enrolled in FI programs, which has important implications for use in Canada. Approaches in single word reading tendency followed the same pattern regardless of whether individuals were instructed in English or French.

Analyses exploring potential differences in cognitive and academic performance across language groups revealed findings contrary to hypothesized predictions. Instead of FI participants outperforming English ones on measures of reading and other cognitive skills, the FI group obtained significantly lower scores on reading comprehension. The results may be considered in the context of the lag effect seen in early immersion grades (Lapkin et al., 2003) since the mean age of the group is 9 years, or grade 4. A large proportion of the sample may have been exposed to fewer hours of English language instruction compared to their English counterparts and even the older FI individuals in the sample, and may not have had much official exposure to English reading aloud let alone being asked to answer English reading comprehension questions.

Nonetheless, findings from the current study extended the scientific knowledge regarding English reading performance in French Immersion students in Canada. Much of the existing literature to date has described differences in terms of performance on standardized provincial testing (e.g., EQAO; Lapkin et al., 2003) or direct assessment of reading skills through PISA, or the Programme for International Student Assessment (Allen, 2004). In contrast, the present study compared performance on common standardized measures used in psychoeducational assessments, including the WISC-V (cognitive), WIAT-III (academic), and GORT-5 (reading fluency and comprehension). FI participants did not differ from English ones on measures of single word reading, pseudoword decoding, spelling, phonological awareness, or working memory. Of note, FI participants performed worse on measures of reading comprehension.

Limitations and Next Steps

Although the present study addressed many of the limitations listed by Mohl and colleagues (2018), including male-only gender, high rate of ADHD participants, and administration in an fMRI scanner, the current study is not without its own limitations. Whereas the original sample was heavily clinical in nature, the current sample may have gone too far the other way resulting in a lack of diversity in reading abilities. For instance, the majority of participants were typically-developing students who performed in the average range or better across the reading and cognitive tasks. As such, the narrow spread of scores may have contributed to the lack of differentiation between Decoders and Balanced groups. As such, the status of the concurrent and predictive validity is still unresolved. Thus, it is recommended that future studies further explore the validity of the RTI protocol by adding a reading disability group, as originally suggested by Mohl et al., (2018), perhaps while participating in a reading intervention program. Next steps should also include studies of the reliability of RTI scores and group classification, particularly test-retest reliability – to ensure that participant’s scores are generally stable across assessment timepoints. Another limitation inherent to the current project involves a lack of consensus regarding the most appropriate cut-off scores to determine RTI group membership. Although the cut-offs were adjusted to better reflect sample characteristics in a supplemental analysis, the tertile method of determining group membership continues to create some confusion about how to best determine the cut-off, especially for those individuals on the cusp of being classified as Balanced or Non-balanced.

The findings from the present study suggest that further research is needed with a reading disability sample to explore the validity of the RTI model. Specific directions for future research will be elaborated below. These additional research efforts are recommended before the RTI protocol can be used as a clinical or educational screening tool for reading challenges.

Application with a Reading Disability Sample

By including a reading disability sample with a typically-developing group, one may be able to better delineate cognitive and reading differences between RTI groups. Ideally, replication efforts of the original cognitive findings (see Table 23; Mohl et al., 2018) would be the next step in this area of research before clinical or educational implications can be considered. One such example of a future research study could involve the examination of children at various ages who are participating in a reading intervention program, such as the Orton-Gillingham (OG) approach (Gillingham & Stillman, 1956, 1997) or Empower Reading (Lovett, Lacerenza, & Borden, 2000; Lovett et al., 2000).

The OG approach is a "systematic, sequential, multisensory, synthetic, and phonics-based approach to teaching reading" (Ritchey & Goeke, 2006, p.1). It uses explicit one-on-one instruction in phonology, phonological awareness, sound-symbol correspondence, syllables, morphology, syntax, and semantics while also involving visual, auditory, and kinesthetic/tactile learning pathways (Gillingham & Stillman, 1997; Ritchey & Goeke, 2006). Research has demonstrated the effectiveness of OG interventions on many reading skills, particularly for elementary students (Foorman et al., 1997; Hook, Macaruso, & Jones, 2001; Joshi, Dahlgreen, & Boulware-Gooden, 2002; Oakland, Black, Stanford, Nussbaum, & Balise, 1998; Stoner, 1991). Therefore, it could be hypothesized that intervention with the

OG approach could have a positive impact on Sightword Readers, as determined by RTI classification, who tend not to utilize the phonological decoding pathways in an efficient or effective manner.

As an example of a future research project, children participating in the Orton-Gillingham approach as applied through the Scottish Rite Learning Centres in southwestern Ontario could complete the LDTs at the start of their program and then at subsequent time points to track changes in RTI scores and group membership as a function of intervention. Participants at different ages could also be enrolled (e.g., 6-, 8-, 10-, and 12-year-olds) in order to provide cross-sectional data for comparison at different age points, and then retested at regular intervals as they progress through intervention. This study design, along with the inclusion of a typically-developing control group, would facilitate examination of concurrent and predictive validity, and potentially better support the RTI as a screening tool for reading tendencies and reading difficulties. The impact of an intervention program aimed at targeting phonological awareness could be tracked using RTI scores. If the RTI model is indeed valid and rooted in the appropriate theory, then it is expected that performance changes based on participation in the OG intervention would occur, particularly for Sightword Readers. Such findings would support the need for instructionally relevant intervention strategies informed by the RTI classifications and then applied by special educators to target specific weaknesses in reading strategies depending on their affinity for decoding (i.e., use of dorsal network) or word recognition (i.e., use of ventral network).

Sensitivity & Specificity of RTI Cut-offs

Future studies using a reading impaired sample are encouraged to explore the sensitivity and specificity of specific cut-off scores to determine the most appropriate and robust score to be used. Indeed, these studies should also examine other methods of determining group membership outside of tertile cut-offs. Mohl and colleagues (2018) suggest perhaps adopting machine learning approaches to address the discontinuous nature of the Index. Moreover, future research should examine the level of difficulty of the current LDT items and perhaps increase the difficulty in order to apply full drift diffusion modeling with the data. Although this was a limitation highlighted by Mohl and colleagues (2018), the current project did not address the limitation because one of the primary goals was to replicate the original study with a non-clinical sample. Now replicated with a larger, non-clinical sample, future studies should replicate the groupings using full DDM to increase statistical power for exploring the most robust cut-offs. To do this, items may need to be made more difficult so that each participant makes at least 10 errors per the assumptions of DDM.

Potential for Clinical/Educational Implications

The potential use of the RTI as a screening tool for reading impairments in school-aged children would have important implications for clinical and educational practices. The use of the RTI protocol and associated LDT tasks as a way to screen for reading impairments in school-aged children would not only reduce the pressure on school boards to conduct lengthy psychoeducational assessments for each student thought to struggle with inefficient reading but could enable for early identification and personalized interventions. The administration time for the LDTs is no longer than 20 minutes per child, with the potential for computerized scoring to take only a few minutes. Thus, the RTI may potentially be a broad-reaching and affordable screening mechanism that can be readily applied in schools (Mohl et al., 2018). As an example of a potential application, if classified as a Sightword Reader, educators would know to target phonological decoding skills and phonological awareness to increase reading proficiency in these individuals (e.g., Orton-Gillingham approach; Gillingham & Stillman, 1997). Nonetheless, additional studies are needed to explore the validity, reliability, appropriate cut-offs, and other psychometric properties before it can be used reliably for clinical purposes.

As a final suggestion, data should be collected with a large sample of school-aged children with and without learning disabilities and other neurodevelopmental disorders (e.g., ADHD) to obtain enough data to create normative estimates of performance as well as the best cut-off scores for group classification. With this normative data available, a child’s individual score may be age-normed to control for possible confounding effects of age differences in RTI performance. Indeed, the fact that RTI scores are not normed (i.e., raw scores) and were compared to age-normed scores for cognitive and academic measures may have created a confound that contributed to the lack of group differences in these skills.

Conclusion

In conclusion, the present study provides independent preliminary support for the RTI model and associated LDT tasks given that the three-group structure was replicated with the current sample. Indeed, this study replicated the original findings while addressing many of the limitations, including the clinical, male-only sample and administration of tasks in an fMRI scanner. Although most predictions were not upheld with respect to validating characteristics of each group due to the normative nature of the sample, the results suggest that, at the very least, reading comprehension skills are impacted by group membership. That is, participants classified as non-balanced, particularly in the Sightword group, had lower scores on the standardized measure of reading comprehension compared to Balanced Readers. Otherwise, the concurrent and predictive validity of the RTI model is still unresolved and future studies are needed.

Furthermore, this project advances the understanding of reading and cognitive abilities in English-speaking students who are studying in French Immersion elementary school programs in Ontario. In most cases, the two language groups were indistinguishable based on intellectual functioning, cognitive skills (including working memory, processing speed, and phonological awareness), and reading achievement (i.e., single word reading, pseudoword decoding, spelling). Language groups did differ significantly in terms of reading comprehension skills, with French Immersion students scoring significantly lower than their English counterparts. Indeed, French Immersion instruction had little-to-no impact on RTI performance, which suggests that the model is robust for English-speaking Ontario school-aged children studying in either of Canada's official languages.

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APPENDICES

Appendix A: Copyright Permissions

Permissions to reproduce copyright figures and materials were obtained by publisher and copyright holder as appropriate. Information is documented in Table A1 below, and copies of official copyright licenses and emails documenting permission are retained and available by request.

Table A1

Information about Copyright Permission

Fig. # (pg)	License #	Publisher/Copyright Holder
1 (p.12)	4419450011412	John Wiley & Sons
3 (p.29)	4419460952145	Springer Publishing Co.
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5 (p.33)	4419470376051	Springer Publishing Co.
6 (p.35)	N/A (permission via email)	Dr. Brianne Mohl
13 (p.80)	N/A (permission via email)	Dr. Brianne Mohl

Appendix B: Parent Consent Form

CONSENT TO PARTICIPATE IN RESEARCH

Title of Study: **Validation of the Reading Tendency Index in school-aged children**

You and your child are asked to participate in a research study conducted by Amanda O'Brien (graduate student) and Dr. Joseph Casey (faculty supervisor) from the Psychology Department at the University of Windsor. The results of this study will contribute to Amanda O'Brien's doctoral dissertation project.

If you have any questions or concerns about the research, please feel to contact Amanda O'Brien at 519-253-3000, ext. 3506 (uofwreadingstudy2017@gmail.com) or Dr. Joseph Casey at 519-253-3000, ext. 2220.

PURPOSE OF THE STUDY

The purpose of the study is to examine reading tendencies in school-aged children (students in Grades 3 to 8) using a computerized program that requires students to distinguish between real words, pseudowords, and consonant strings by pressing a designated button on a keyboard. Performance on this task will then be compared to the student's performance across standardized measures of reading and other related cognitive skills.

PROCEDURES

If you volunteer to participate in this study, you will be asked to:

- Complete an online questionnaire sent via email to provide informed consent and to gather basic demographic and academic information about your child

If you provide consent for your child to participate in the study:

- Your child will meet with the researcher in an office at their school for approximately 75 minutes to complete the following tasks:
    - Two computerized single word reading tasks that require the differentiation of words from pseudowords (15 minutes).
        - Two items will be presented on the screen and your child will need to decide which one is the real word by pressing a specific key on the keyboard.
    - Two verbal comprehension subtests (WISC-V Vocabulary & Information; 10 minutes)
        - Your child will be asked questions related to vocabulary and general information until three consecutive errors are made.
    - Two measures of verbal working memory (WISC-V Digit Span & Sentence Memory test; 10 minutes)
        - Your child will be asked to repeat numbers or sentences of increasing length until two or three consecutive errors are made.
    - A measure of visual working memory (WISC-V Picture Span; 5 minutes)
        - Your child will be asked to indicate the order of pictures that were presented visually for 5 seconds until three consecutive errors are made.
    - A measure of processing speed (WISC-V Coding; 2 minutes)
        - Your child will be asked to copy symbols as quickly as possible.
    - A measure of oral reading fluency and comprehension (GORT-5; 20 minutes)
        - Your child will be asked to read passages out loud and answer related questions.
    - A measure of single word reading ability (WIAT-III Word Reading subtest; 2 minutes)
        - Your child will be asked to read words from a list until four consecutive errors are made.
    - A measure of pseudoword decoding ability (WIAT-III Pseudoword Decoding; 2 minutes)
        - Your child will be asked to read fake words from a list until four consecutive errors are made.
    - A measure of single word spelling ability (WIAT-III Spelling; 5 minutes)
        - Your child will be asked to spell single words until four consecutive errors are made.
    - Three subtests assessing phonological awareness (CTOPP-2; 10 minutes)
        - Your child will be asked to remove sound segments of words to form new words, blend sounds together to form words, and isolate sounds within words.

Please note that your child will be providing their own assent to participate in the study at the time of participation and may choose to not participate despite your consent. Your child is free to withdraw from the study at any time despite your consent.

POTENTIAL RISKS AND DISCOMFORTS

There is no foreseeable risk or discomfort associated with your participating in this study. Although unlikely to occur, if you experience any distress while completing the online survey, please discuss your concerns with Dr. Joseph Casey, C.Psych., (519-253-3000, ext. 2220).

There is no foreseeable risk or discomfort associated with your child participating in this study. Most children will find these tasks similar to ones they complete in school (e.g., reading, spelling, remembering, writing), and therefore should be familiar with the task requirements. They may find the computerized task as more novel, and may enjoy completing these tasks. Most children enjoy interacting with computers, and there is no foreseeable risk or discomfort in the use of this device. If your child refuses to participate on the day of the assessment, they can withdraw their participation or the appointment can be rescheduled.

POTENTIAL BENEFITS TO PARTICIPANTS AND/OR TO SOCIETY

The main purpose of the study is to gain a better understanding of the underlying reading approaches in elementary school-aged children. Completion of the tasks will allow us to explore a child's approach to single word reading and any relationships with reading fluency and related cognitive skills. Clinicians, educators, and parents of children may benefit from the results of this study in that intervention efforts may be better targeted for children with specific reading deficits (i.e., underutilization of a reading approach). Society in general may benefit if we better understand the types of reading approaches and deficits in children. Lastly, participants interested in scientific research may gain useful information about different methods used to conduct research and may also feel intrinsic rewards for contributing to scientific knowledge to benefit others.

COMPENSATION FOR PARTICIPATION

Child participants will be entered into a draw for the opportunity to win 1 of 4 giftcards to Indigo/Chapters worth $50. Parents will be sent an email following the completion of data collection to inform them whether or not their child was the successful winner. Electronic giftcards will then be sent via email to the email address provided by the child's parent.

CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with you and your child will remain confidential and will be disclosed only with your permission. Classroom teachers and peers will know which students participated when your child leaves class to complete the study Otherwise, all demographic and research data collected will be de-identified, meaning that it will be coded with a randomly assigned identification number rather than displaying your name. If this study results in publication within a scientific journal, only aggregated data will be presented and your individual information will not be identified. All of your identifying, demographic, and research data will be stored in separate encrypted files and physically stored within a secure (locked) location. Only Dr. Casey will have access to your personal identifying information once it is stored. In the event these data are ever to be destroyed, their destruction will be carried out in a manner to preserve your confidentiality.

PARTICIPATION AND WITHDRAWAL

You and your child can choose whether to be in this study or not. If you volunteer to be in this study, you may withdraw at any time during the experiment without consequences of any kind. You may also refuse to answer any questions you don't want to answer or your child may refuse to perform any tasks they don't want to perform and still remain in the study. The investigator may withdraw you from this research if circumstances arise that warrant doing so. Your child will be eligible for the draw even if withdrawal occurs. After your child has participated in the study, data may still be withdrawn following written instructions from a parent or guardian. Data can no longer be withdrawn after March 1, 2018 once data analysis has occurred.

FEEDBACK OF THE RESULTS OF THIS STUDY TO THE PARTICIPANTS

When this study is finished, it is the aim of the research team to publish the results in a peer-reviewed scientific journal so that other researchers and clinicians may benefit from its findings. Results of the present study will be posted on the Child Neuropsychology Research Group website. Results will be available by June 2018.

Web address: ____www.uwindsor.ca/cnrg___________________________

Date when results are available: ___June 2018____________

SUBSEQUENT USE OF DATA

These data may be used in subsequent studies, in publications and in presentations.

RIGHTS OF RESEARCH PARTICIPANTS

If you have questions regarding your rights as a research participant, contact: Research Ethics Coordinator, University of Windsor, Windsor, Ontario, N9B 3P4; Telephone: 519-253-3000, ext. 3948; e-mail: ethics@uwindsor.ca

SIGNATURE OF RESEARCH PARTICIPANT/LEGAL REPRESENTATIVE

I understand the information provided for the study **"**Validation of the Reading Tendency Index in school-aged children: A pilot study" as described herein. My questions have been answered to my satisfaction, and I agree to allow my child to participate in this study. I have been given a copy of this form.

______________________________________ ______________________________________
Name of Parent Name of Participant (child)

______________________________________ ___________________
Signature of Parent Date

SIGNATURE OF INVESTIGATOR

These are the terms under which I will conduct research.

_____________________________________ ____________________
Signature of Investigator Date

Appendix C: Child Consent Form

I am a student researcher, and I am doing a project on reading in kids. I would like to ask you to complete two activities on a computer related to word reading. Then, I would like you to complete a number of other tasks with me that involve reading and writing words, repeating numbers and sentences, looking at pictures, and answering questions.

When I am finished working with all the kids who agree to be in my study, I will write a report on what I have learned. My teachers will read it, and it might be put in a book, but no one will know who the kids are that completed my activities.

I want you to know that I will not be telling your teachers or parents or any other kids how you do. Your mom and/or dad have said it is okay for you to complete my activities. Do you think that you would like to do them? You won't get into any trouble if you say no. If you decide to start the activities you can stop them at any time, and you don't have to answer any question you do not want to answer. It's entirely up to you. As a thank-you for participating, you will be entered into a draw to win 1 of 4 giftcards to Indigo/Chapters worth $50. You will be entered into the draw even if you decide not to finish all of my activities. Would you like to help with my project and try completing the activities?

I understand what I am being asked to do to be in this study, and I agree to be in this study.

______________________________ ______________________

Print Name Date

______________________________ ______________________

Signature Witness

Appendix D: Recruitment Poster

WINDSOR-ESSEX CATHOLIC DISTRICT SCHOOL BOARD

University of Windsor

RECRUITING STUDENTS IN GRADES 2 TO 8

FOR A READING STUDY

We are seeking students between the age of 7 and 14 years

to participate in a research study about reading.

All research will occur at the student's school during school hours!

If you choose to participate, you, the parent, would be asked to complete the following:

1. Electronic consent form
2. Brief electronic demographic questionnaire regarding your child's history

Your child will be asked to do the following:

1. Complete approximately 75 minutes of activities related to reading ability, some of which are administered on a computer and/or tablet.

As compensation for participating, your child will be entered in a draw to win 1 of 4 giftcards to Indigo/Chapters worth $50 each.

If you are interested in participating, or would like some more information,

please contact **Amanda O'Brien by email (uofwreadingstudy2017@gmail.com) or phone (519-253-3000 ext. 3506).**

**This study has been approved by the University of Windsor Research Ethics Board*

Appendix E: Participant Demographic Questionnaire

Parent's First Name ____

Parent's Email Address ____

Your Relationship to Child

- ◯ Mother
- ◯ Father
- ◯ Legal Guardian
- ◯ Other

If other was selected, please specify... ____

Child's First & Last Name ____
Child's Grade

- ◯ Grade 3
- ◯ Grade 4
- ◯ Grade 5
- ◯ Grade 6
- ◯ Grade 7
- ◯ Grade 8
- ◯ Grade 2

Name of Child's School ____

Name of Child's Classroom Teacher____

Child's Gender ____

Child's Date of Birth ____

Child's Racial / Ethnic Background (please select all that apply)

- Aboriginal/First Nations
- Asian descent
- Black/African descent
- Hispanic/Latina
- Middle Eastern/Arab descent
- White/Caucasian
- Other

If other was selected, please specify....____

Child's First Language

- English
- French
- Other

If other was selected, please specify....____

Mother's First Language

- English
- French
- Other

If other was selected, please specify....____

Father's First Language

○ English

○ French

○ Other

If other was selected, please specify....

Child's Primary Language Spoken at Home

○ English

○ French

○ Other

If other was selected, please specify..______________________________

Highest Level of Education Completed by Parent #1

○ Did not complete high school

○ High school graduate

○ Attended some college

○ College graduate

○ Attended some university

○ University graduate

○ Graduate/Professional Degree

Highest Level of Education Completed by Parent #2

- Did not complete high school
- High school graduate
- Attended some college
- College graduate
- Attended some university
- University graduate
- Graduate/Professional Degree

Has your child ever been diagnosed with one of the following... (select all that apply)

- Attention problems (e.g., ADHD)
- Autism-spectrum disorder
- Hearing problems
- Speech-language disorder
- Oppositional defiance disorder (ODD) and/or Conduct disorder
- Vision problems
- NO - none apply
- Other ____

Please elaborate on your selections, if applicable_______________________________________

Has your child ever been diagnosed with a learning disability?

- Yes
- No

If yes, what type? (please select all that apply)

- Reading
- Mathematics
- Written Expression
- Learning skills (or Executive Dysfunction)

If yes, was this diagnosis based on a psychological assessment?

- Yes
- No

Has an extended family member of the child *ever* been diagnosed with a *reading* disability? (sometimes referred to as *dyslexia*)

- Yes
- No

If yes, please select all that apply...

- Sibling
- Parent
- Grandparent
- Aunt/Uncle
- Cousin

Has the child ever been identified by the school system as having an *exceptionality*?

- Yes
- No

Does the child have an Individualized Education Plan (IEP)?

- ○ Yes
- ○ No

If yes, what is it for? (please select all that apply)

- ● Reading
- ● Writing
- ● Math
- ● Learning skills
- ● Behaviour

Has the child ever received any special help at school? (e.g., special class placement, tutoring, speech-language therapy, etc).

- ○ Yes
- ○ No

If yes, please elaborate as you see necessary.____

Has the child ever received any additional (outside school) ***reading*** instruction, tutoring, or extra help? (e.g., Kumon, Oxford, Sylvan)

- ○ Yes
- ○ No

If yes, please elaborate as you see necessary.____

Appendix F: LDT Stimuli

Stimuli for pLDT

sweat	soap	mogey	guhs	ners
spare	dumb	bofty	basu	forry
swim	globe	sunch	nired	kound
lung	kneel	kooms	ferbs	maifs
boost	roar	gemp	thard	delp
straw	lawn	erms	aifs	toofs
plea	rail	blans	banf	jurp
pong	shelf	boup	pige	gaik
steam	broup	thant	corth	pafed
graph	cangs	ipon	bunj	maip
slope	kump	oited	gewer	ohal
loud	sech	lugh	vops	huilt
rake	vould	parg	loik	thal
leap	puels	sont	thot	corg
drain	coogs	chost	vunks	shof
dough	wauts	taru	keams	dros
soup	vuff	jeads	lenk	nires
crawl	kest	gises	baves	vuds
crisp	mesp	guilm	zents	croik
mild	halg	gever	chred	noot

Stimuli for oLDT

htwq	pkvqs	coast	check	long	track	worth
dgfk	swpls	going	pass	shape	need	with
vbcnq	nfghv	done	spend	work	made	most
dvbw	swnr	late	when	board	green	floor
fspq	hgtb	crime	serve	were	yours	just
nhwmx	ksld	much	face	then	worst	next
ljhn	left	guess	guide	room	this	hard
qplwp	stock	half	what	march	drive	stuff
pbvgt	well	grant	great	said	loose	here
ntbtg	plain	felt	take	some	catch	must
wxtrm	black	grand	fight	each	last	phone
ntcqr	waste	block	space	give	than	being
tgrw	doubt	come	frame	known	more	press
psghr	north	touch	faith	good	shown	best
kfgd	them	head	wrong	sense	there	tried
lqmwf	once	such	point	week	brain	prove
vsxtg	live	thank	blood	down	gone	home
jnth	place	whole	told	girl	both	
jnmw	cheap	went	call	like	throw	
lpqd	built	tell	twice	mean	will	

Appendix G: RA Training Manual

I. Roles, Responsibilities, & Expectations

Combined Roles and Responsibilities

- Working with participants at WECDSB schools
- Scoring, data entry, and data transmission
- Ensuring secure handoff of materials to other RAs
- Duration of study: December 1, 2017 – May 31, 2018

Research Assistant Roles and Responsibilities

- Communicating schedule and availability problems/issues to AO
- Keep the Gmail calendar updated with monthly availability (posted by last Sunday in month)

Expectations

- Complete TCPS2 training and/or submit a copy of your TCPS2 certificate
  - http://www1.uwindsor.ca/reb/tri-council-policy-statement-2-now-released-tcps2
- Arriving to appointments with sufficient time to park, set up, and assess student (≈ 1.5 hours)
- Meeting time and appointment commitments
- Open communication among research team members
  - Providing at least 48 hour notice if you can't make an appointment (to the best of your ability)
  - Finding replacements if appointments cannot be kept (to the best of your ability)
  - Letting one another know of complications
  - Asking questions
  - Using Dropbox to access project documents (recommended to download free program onto your computer so it acts as a 'folder')
- Professionalism, especially when working within the schools.
- At the schools:
  - Ring doorbell at front door to gain access
  - Sign in using the visitor's log at office door (purpose of visit = research)
  - Check-in with secretary; introduce yourself as one of AO's research assistants and that you are "here for the reading study".
  - Once set up in room, the secretary will call the student down to the office for you. You must provide student's name and grade (found in Participant ID & Scheduling spreadsheet).
  - Upon finishing, leave room in same condition as you found it.

II. Scheduling

General Procedures

- ***Participants to be scheduled using the @gmail.com calendar***
- **Standard color coding**:
  - Grey ( ) = Available Timeslot;
  - Red ( ) = Scheduled appointment
    - In the "What" field, use standard naming: School Name – DIS000
  - Green ( ) = RA is available

        - In the "What" field, use standard naming: Name – Available
    - Edit "AVAIL" entries to "DISXXX" with appropriate color coding, when a participant is added to the schedule
- ***Once the participant is scheduled, contact the RAs to let them know they have a participant on the calendar***

Participant ID & Scheduling Spreadsheet

- Directory of lab's shared folder after you have installed Dropbox onto your computer:
- **ID Assignment and Spreadsheet Data Entry**:
    - ***Participant information will be entered into the appropriate fields once parent provides consent and completes demographic survey***
    - ***English = DIS0XX (001-099)***
      French = DIS1XX (101-199)
- **Access scheduling spreadsheet to determine participant's name, grade, and teacher for that day in order to communicate with secretary (e.g., who will call participant to office to participate).**

III. Consent Process

Informed Consent and Assent

- Parents will have already provided informed consent (via Qualtrics survey) before the child's participation date.
- ***Obtain assent from the child/adolescent participant by reading the assent form. Answer any questions that the participant has before proceeding.*** *You will sign as witness. Encourage child to sign name if they have a signature. Have child print first and last name (or last initial if unable to spell last name).*

IV. Assessment Administration and Scoring

General Recording Procedures for Assessment

- ***Place the "DO NOT DISTURB Testing in Progress" signs on the outsides of the doors*** *(handle and tape on window, if necessary).*
- ***Write the participant ID on each of the scoring protocols in place of NAME***
    - **Do NOT record any names on any of the research protocols**
- Even though the participant's birthdate was provided in the demographic survey, it is recommended to record the birth date and assessment date on each of the protocols. This will make using the scoring easier by having that information at hand.

Overall Order of Administration

- Child/adolescent assessment will occur in a room to be determined by school principal (AO will update RA if known before assessment)
- **Counterbalancing the order of administration is as follows:**
    - For **odd** number participant IDs, administer in the following order: **NP Ax** → **RTI task**
    - For **even** number participant IDs, administer in the following order: **RTI task** → **NP Ax**

Neuropsychological Assessment

- **WISC-V subtests (via iPad Q-Interactive)**:
  - Provide the introductory verbiage for administering the WISC-V
  - Administer the Vocabulary (VC) subtest per standardized administration
  - Administer the Digit Span (DS) subtest per standardized administration
  - Administer the Coding (CD) subtest per standardized administration
  - Administer the Information (IN) subtest per standardized administration
  - Administer the Picture Span (PS) subtest per standardized administration
  - *Software will automatically score/norm subtests as long as you score items as you go.*
  - *If student does or says anything interesting during the tasks, feel free to provide notes on the subtest (either using iPad note system or pad of paper provided to then be placed in file)*.
- **WIAT-III subtests (via iPad Q-interactive)**:
  - WIAT subtests will automatically follow PS on iPad.
  - Administer the Word Reading, Pseudoword Decoding, and Spelling subtests per standardized administration
- **Sentence Memory test**:
  - Administer the Sentence Memory test using instructions on the scoring sheet
  - Discontinue after 3 consecutive failures.
- **CTOPP-2 Phonological Awareness Composite subtests (3)**:
  - Administer the test using instructions on the Examiner Record Booklet.
  - Discontinue after 3 consecutive failures for each subtest.
  - Elision – no additional materials needed
  - Blending Words – audio files on laptop
  - Phoneme Isolation – no additional materials needed
- **GORT-5 (Student Book required)**:
  - ***Administer the test using instructions in the Examiner Record Booklet***.
    - Turn to appropriate entry story in Examiner Record Booklet & Student Book Grade 3 = Story 1; Grades 4, 5 = Story 2; Grade 6, 7, 8 = Story 3
    - Say: *Begin*, and start the timer. Mark deviations from print as the student reads the story using slash method (see Chapter 2 in Examiner Manual for more info).
    - When finished reading, stop timer, record time, and count number of deviations.
    - Read comprehension questions to student
      - *NOT allowed to return to story to scan for answers*
  - ***Score immediately to determine <u>Fluency Score</u>***
    - *Convert time in seconds to Rate Score using table*
    - *Convert deviations to Accuracy Score using table*
    - *Add together for Fluency*
  - ***Discontinue once ceiling is reached (i.e., Fluency of 2 or less for 2 consecutive stories)***
    - *If Fluency score is NOT 9 or 10 for the first 2 consecutive stories based on grade entry story (i.e., basal not reached), after ceiling is reached but before discontinuing, return to the story preceding the entry-level story and administer in reverse order until basal is obtained (2 consecutive stories with score of 9 or 10) or Story 1 administered.*

Experimental Reading Tasks

- Computer Password =
- ***LDT shortcuts are located on the desktop (pLDT & oLDT)***

- **Running the experiment**:
  - The RTI experiments consists of 2 experimental tasks. In Psychopy, they are labeled as follows and their names are self-explanatory (I hope):
    - Phonologic lexical decision task (pLDT)
    - Orthographic lexical decision task (oLDT)
  - **RTI Task Order of Administration**:
    - The pLDT and oLDT tasks must also be counterbalanced. This is a little trickier because of how the overall order of administration works (i.e., you can't just go pLDT/oLDT for odd/even because then it would always be [pLDT/oLDT → NP/Reading] and [oLDT/pLDT → Reading/NP]).
    - Beginning with participant DIS001, the order should be: pLDT → oLDT, oLDT → pLDT; oLDT → pLDT, pLDT → oLDT. See the below table that indicates what order should be used for each participant (table is also printed & included in purple folder)

pLDT → oLDT	oLDT → pLDT	oLDT → pLDT	pLDT → oLDT
DIS001	DIS002	DIS003	DIS004
DIS005	DIS006	DIS007	DIS008
DIS009	DIS010	DIS011	DIS012
DIS013	DIS014	DIS015	DIS016
DIS017	DIS018	DIS019	DIS020
DIS021	DIS022	DIS023	DIS024
DIS025	DIS026	DIS027	DIS028
DIS029	DIS030	DIS031	DIS032
DIS033	DIS034	DIS035	DIS036
DIS037	DIS038	DIS039	DIS040
DIS041	DIS042	DIS043	DIS044
DIS045	DIS046	DIS047	DIS048
DIS049	DIS050	DIS051	DIS052
DIS053	DIS054	DIS055	DIS056
DIS057	DIS058	DIS059	DIS060
DIS061	DIS062	DIS063	DIS064
DIS065	DIS066	DIS067	DIS068
DIS069	DIS070	DIS071	DIS072
DIS073	DIS074	DIS075	DIS076
DIS077	DIS078	DIS079	DIS080
DIS081	DIS082	DIS083	DIS084
DIS085	DIS086	DIS087	DIS088
DIS089	DIS090	DIS091	DIS092
DIS093	DIS094	DIS095	DIS096
DIS097	DIS098	DIS099	DIS0100

  - ***Instructions for RTI tasks***:
    - Load first task (open shortcut, click green running man, input participant ID [DIS###])
    - Introduce tasks: "***We will now be completing the two computerized word reading tasks. For both tasks, words will appear on the screen quickly and you need to decide if the word presented is a REAL word or not a real word. If you***

think 'yes, it is a real word', you will press Z. If you think 'no, it is a fake word', you will press M."

  - Allow them to proceed through practice trial (press space bar twice).
  - Before starting real experiment, say "***Before the first word appears, you will see a + (plus) sign. Eventually 4 number signs (or hashtags) [####] will appear on the screen, this is your 15s break to rest your eyes, fingers, and brain. The + sign will come back before the first word after the break. Just so you know, the word may disappear before you make your decision and that's okay! The next word won't show up until you press either 'Z' or 'M', so be sure to make your best decision based on what word you saw. Do you have any questions before we start?*** [Answer questions]. ***Remember, press Z if yes it is a real word or press M if no it is not a real word.***
- **How to run each experiment**:
  - After you press the green running man and input their participant ID, the experiment should run and save itself.
- ***Instructions for 2nd RTI task:***
  - Once finished the first task, load the second task the same way. To introduce to student, say "***This task is similar to the first one, except the words and timing may be different. You will still press 'Z' for a real word and 'M' for not a real word."*** Allow to do practice trials, then answer any questions before starting real experiment.

After data collection is complete:

- Ensure all forms are filled out with participant ID, birthday, date of assessment, and examiner initials.
- Placed completed files in appropriate place in the lab for access to scoring, data entry & storage.
- At this time, graduate students will complete all scoring and data entry.

Appendix H: Administration Order

ODD # = NP tests → RTI tasks

EVEN # = RTI tasks → NP tests

ENGLISH SCHOOLS

pLDT → oLDT	oLDT → pLDT	oLDT → pLDT	pLDT → oLDT
DIS001	DIS002	DIS003	DIS004
DIS005	DIS006	DIS007	DIS008
DIS009	DIS010	DIS011	DIS012
DIS013	DIS014	DIS015	DIS016
DIS017	DIS018	DIS019	DIS020
DIS021	DIS022	DIS023	DIS024
DIS025	DIS026	DIS027	DIS028
DIS029	DIS030	DIS031	DIS032
DIS033	DIS034	DIS035	DIS036
DIS037	DIS038	DIS039	DIS040
DIS041	DIS042	DIS043	DIS044
DIS045	DIS046	DIS047	DIS048
DIS049	DIS050	DIS051	DIS052
DIS053	DIS054	DIS055	DIS056
DIS057	DIS058	DIS059	DIS060
DIS061	DIS062	DIS063	DIS064
DIS065	DIS066	DIS067	DIS068
DIS069	DIS070	DIS071	DIS072
DIS073	DIS074	DIS075	DIS076
DIS077	DIS078	DIS079	DIS080
DIS081	DIS082	DIS083	DIS084
DIS085	DIS086	DIS087	DIS088
DIS089	DIS090	DIS091	DIS092
DIS093	DIS094	DIS095	DIS096
DIS097	DIS098	DIS099	DIS0100

ODD # = NP tests → RTI tasks

EVEN # = RTI tasks → NP tests

FRENCH SCHOOLS

pLDT → oLDT	oLDT → pLDT	oLDT → pLDT	pLDT → oLDT
DIS101	DIS102	DIS103	DIS104
DIS105	DIS106	DIS107	DIS108
DIS109	DIS110	DIS111	DIS112
DIS113	DIS114	DIS115	DIS116
DIS117	DIS118	DIS119	DIS120
DIS121	DIS122	DIS123	DIS124
DIS125	DIS126	DIS127	DIS128
DIS129	DIS130	DIS131	DIS132
DIS133	DIS134	DIS135	DIS136
DIS137	DIS138	DIS139	DIS140
DIS141	DIS142	DIS143	DIS144
DIS145	DIS146	DIS147	DIS148
DIS149	DIS150	DIS151	DIS152
DIS153	DIS154	DIS155	DIS156
DIS157	DIS158	DIS159	DIS160
DIS161	DIS162	DIS163	DIS164
DIS165	DIS166	DIS167	DIS168
DIS169	DIS170	DIS171	DIS172
DIS173	DIS174	DIS175	DIS176
DIS177	DIS178	DIS179	DIS180
DIS181	DIS182	DIS183	DIS184
DIS185	DIS186	DIS187	DIS188
DIS189	DIS190	DIS191	DIS192
DIS193	DIS194	DIS195	DIS196
DIS197	DIS198	DIS199	DIS200

Appendix I: Supplemental Analyses – Tables & Figures

Supplemental #1: Liberal Cut-off Scores

Table I1

Chi-squared Contingency Table for RTI Dichotomy by Age Group (Liberal Cut-offs)

		Young	Old	Total
Non-balanced	Count	13	12	25
	% within B vs. NB	52	48	100
	% within Y vs. O	61.9	48.0	54.3
	% of Total	28.3	26.1	54.3
Balanced	Count	8	13	21
	% within B vs. NB	38.1	61.9	100
	% within Y vs. O	38.1	52.0	45.7
	% of Total	17.4	28.3	45.7

Table I2

Means and Standard Deviations of Dependent Variables across Reading Tendency Groups

	Reading Tendency Group		
Variables	Decoder (n = 21)	Balanced (n = 28)	Sightword (n = 21)
Age (yrs)[a]	10.1 (1.7)	10.2 (1.9)	9.8 (1.5)
SFIQ[b]	107.8 (11.7)	107.9 (12.2)	100.9 (7.9)
Vocabulary [a]	12.1 (1.9)	11.6 (2.4)	10.5 (1.7)
Information [a]	10.8 (3)	11.3 (2.6)	9.9 (1.9)
Word Reading[b]	111 (11.4)	108.8 (14.6)	101.6 (17.1)
Pseudoword Decoding[b]	105.6 (11.9)	103.9 (17.1)	97.4 (15.6)
Spelling[b]	104.4 (12.4)	102.8 (15.1)	94.8 (13.4)
Reading Fluency [a]	10 (2.3)	9.9 (2.3)	7.9 (2.4)
Reading Accuracy [a]	8.8 (2.3)	9.0 (2.2)	7.4 (2.7)
Reading Rate [a]	11.4 (2.6)	10.8 (2.4)	8.7 (2.3)
Reading Comprehension [a]	9.7 (2.4)	10.2 (1.8)	8.2 (1.6)
Phonological Awareness[b]	99 (17.5)	98.5 (15.9)	94.7 (9.7)
Elision [a]	11.2 (1.7)	9.9 (2.9)	9.4 (1.8)
Blending Words [a]	10.2 (3.2)	9.9 (3)	8.3 (2.3)
Phoneme Isolation [a]	9.4 (1.4)	9.1 (2.7)	9.4 (2.6)
Auditory Working Memory[c]	53.5 (7.5)	52.5 (8.5)	49.3 (6.7)
Digit Span [a]	11.7 (3.2)	11.3 (3.1)	10.5 (2.6)
Sentence Memory[c]	51.4 (7.1)	50.8 (9.8)	47.1 (8.2)
Visual Working Memory [a]	12.7 (2.6)	13.5 (2.4)	11.6 (2.1)
Processing Speed [a]	13.1 (2.3)	13.2 (3.4)	12.8 (2.7)

[a] scaled score (*M*=10, SD=3); [b] standard score (*M*=100, SD=15); [c] T score (*M*=50, SD=10)

Table I3

Tests of Equality of Group Means for Predictor Variables

	F (2, 67)	Sig.	Partial eta
WIAT Word Reading	2.42	.096	.067
WIAT Pseudoword Decoding	1.72	.188	.049
WIAT Spelling	3.01	.056	.082
WISC Picture Span	**3.86**	**.026**	**.103**
WISC Coding	.152	.860	.005
Auditory Working Memory Composite	1.69	.192	.048
CTOPP Phonological Awareness Composite	.557	.576	.016
GORT Reading Fluency	**5.30**	**.007**	**.137**
GORT Reading Comprehension	**6.83**	**.002**	**.169**

Table I4

Bonferroni Post-hoc Multiple Comparisons of Mean Group Differences

Dependent Variable	RTI groups		$M_{difference}$	Std. Error	p
WIAT Word Reading	*Decoder*	*Balanced*	2.25	4.2	1.0
	Sightword	*Decoder*	-9.38	4.5	.121
	Sightword	*Balanced*	-7.13	4.2	.282
WIAT Pseudoword Decoding	*Decoder*	*Balanced*	1.71	4.4	1.0
	Sightword	*Decoder*	-8.19	4.7	.260
	Sightword	*Balanced*	-6.48	4.4	.439
WIAT Spelling	*Decoder*	*Balanced*	1.64	4.0	1.0
	Sightword	*Decoder*	-9.67	4.3	.081
	Sightword	*Balanced*	-8.02	4.0	.146
GORT Reading Fluency	*Decoder*	*Balanced*	.143	0.67	1.0
	Sightword	***Decoder***	**-2.05**	**0.72**	**.017**
	Sightword	***Balanced***	**-1.91**	**0.67**	**.018**
GORT Reading Comprehension	*Decoder*	*Balanced*	-.548	0.56	.985
	Sightword	***Decoder***	**-1.48**	**0.59**	**.047**
	Sightword	***Balanced***	**-2.02**	**0.56**	**.002**
WISC Picture Span	*Decoder*	*Balanced*	-.821	0.69	.713
	Sightword	*Decoder*	-1.09	0.74	.426
	Sightword	***Balanced***	**-1.92**	**0.69**	**.021**
WISC Coding	*Decoder*	*Balanced*	-.119	0.83	1.0
	Sightword	*Decoder*	-.333	0.89	1.0
	Sightword	*Balanced*	-.452	0.83	1.0
Auditory Working Memory Composite	*Decoder*	*Balanced*	1.00	2.23	1.0
	Sightword	*Decoder*	-4.16	2.38	.255
	Sightword	*Balanced*	-3.16	2.23	.481
CTOPP Phonological Awareness Composite	*Decoder*	*Balanced*	.464	4.29	1.0
	Sightword	*Decoder*	-4.33	4.58	1.0
	Sightword	*Balanced*	-3.87	4.29	1.0

Table I5

Summary of Discriminant Function Analysis

LC	Eigenvalue	Canonical Correlation	Wilks' λ	χ^2	df	Sig.
1	.253	.450	.762	17.96	6	.006
2	.047	.213	.955	3.05	2	.217

Table I6

Summary of Discriminant Function Coefficients

	Standardized Discriminant Function Coefficients		Structure Coefficients	
Predictors	1	2	1	2
WISC Picture Span	.456	-.368	.669	-.208
GORT Reading Fluency	.052	1.495	.736	.670
GORT Reading Comprehension	**.733**	-.953	**.896**	.082

Note. Standardized coefficients = variable weights; structure coefficients = correlations

Table H7

Functions at Group Centroids

	Function	
RTI group	1	2
Decoder	.100	.322
Balanced	.462	-.167
Sightword	-.717	-.099

Table I8

Cross-Validated Classification Results of Model (%)

	Predicted Group Membership			
RTI group	Decoder	Balanced	Sightword	Total
Decoder	**23.8**	42.9	33.3	100
Balanced	28.6	**53.6**	17.9	100
Sightword	19.0	9.5	**71.4**	100

Note: Bold-face indicate correct classifications.

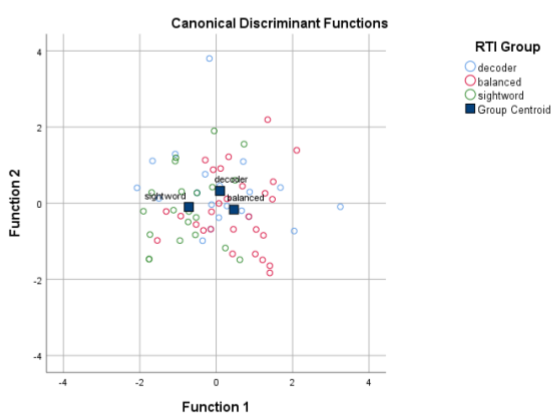

Figure I1. Spread of scores on discriminant functions for the model, including group centroids.

Supplemental #2: Restricted (non-tertile) Sample

Table I9

Means and Standard Deviations of Dependent Variables across Reading Tendency Groups

	Reading Tendency Group		
Variables	Decoder (n = 19)	Balanced (n = 23)	Sightword (n = 19)
Age (yrs)[a]	9.8 (1.8)	10.4 (1.9)	9.6 (1.4)
SFIQ[b]	107.6 (12.3)	108.2 (11.4)	101.6 (6.6)
Vocabulary [a]	12.0 (2.1)	11.8 (2.1)	10.5 (2.0)
Information [a]	10.8 (3.1)	11.3 (2.5)	10.1 (1.7)
Word Reading[b]	110.1 (12.4)	111.2 (13.2)	102.8 (17.8)
Pseudoword Decoding[b]	105.7 (11.8)	105.6 (15.9)	97.5 (16.9)
Spelling[b]	105.9 (12.4)	104.2 (14.3)	94.3 (13.0)
Reading Fluency [a]	9.8 (2.5)	10.0 (2.3)	7.9 (2.4)
Reading Accuracy [a]	8.6 (2.6)	9.1 (2.2)	7.4 (2.7)
Reading Rate [a]	11.3 (2.7)	11.0 (2.4)	8.6 (2.4)
Reading Comprehension [a]	9.6 (2.1)	10.6 (1.4)	8.1 (1.6)
Phonological Awareness[b]	101.4 (10.0)	98.1 (14.4)	94.6 (10.2)
Elision [a]	11.3 (1.7)	9.9 (2.7)	9.6 (2.1)
Blending Words [a]	9.6 (3.1)	9.7 (2.8)	8.4 (2.2)
Phoneme Isolation [a]	9.4 (1.5)	9.1 (2.6)	9.4 (2.8)
Auditory Working Memory[c]	54.3 (7.3)	51.7 (8.6)	49.8 (6.9)
Digit Span [a]	11.6 (3.5)	11.2 (3.3)	10.7 (2.6)
Sentence Memory[c]	51.9 (7.0)	49.3 (9.1)	47.3 (8.4)
Visual Working Memory [a]	12.4 (2.9)	13.3 (2.2)	11.8 (1.5)
Processing Speed [a]	12.8 (2.4)	13.0 (3.3)	12.7 (2.6)

[a] scaled score (*M*=10, SD=3); [b] standard score (*M*=100, SD=15); [c] T score (*M*=50, SD=10)

Table I10

Chi-squared Contingency Table for RTI Dichotomy by Age Group (Reduced Sample)

		Young	Old	Total
Non-balanced	Count	13	8	21
	% within B vs. NB	61.9	38.1	100
	% within Y vs. O	72.2	42.1	56.8
	% of Total	35.1	21.6	56.8
Balanced	Count	5	11	16
	% within B vs. NB	31.3	68.8	100
	% within Y vs. O	27.8	57.9	43.2
	% of Total	13.5	29.7	43.2

Table I11

Tests of Equality of Group Means for Predictor Variables (Reduced Sample)

	F (2, 58)	Sig.	Partial eta
WIAT Word Reading	1.97	.149	.064
WIAT Pseudoword Decoding	1.93	.155	.062
WIAT Spelling	**4.32**	**.018**	**.130**
GORT Reading Fluency	**4.80**	**.012**	**.142**
GORT Reading Comprehension	**10.82**	**.000**	**.272**

Table I12

Bonferroni Post-hoc Multiple Comparisons of Mean Group Differences (Reduced Sample)

Dependent Variable	RTI groups		$M_{difference}$	Std. Error	*p*
WIAT Word Reading	*Decoder*	*Balanced*	-1.11	4.5	1.0
	Sightword	*Decoder*	-7.32	4.7	.381
	Sightword	*Balanced*	-8.43	4.5	.201
WIAT Pseudoword Decoding	*Decoder*	*Balanced*	.128	4.7	1.0
	Sightword	*Decoder*	-8.26	4.9	.291
	Sightword	*Balanced*	-8.14	4.7	.262
WIAT Spelling	*Decoder*	*Balanced*	1.73	4.1	1.0
	Sightword	***Decoder***	**-11.68**	**4.3**	**.027**
	Sightword	*Balanced*	-9.95	4.1	.058
GORT Reading Fluency	*Decoder*	*Balanced*	-.158	0.74	1.0
	Sightword	***Decoder***	**-1.95**	**0.77**	**.043**
	Sightword	***Balanced***	**-2.11**	**0.74**	**.018**
GORT Reading Comprehension	*Decoder*	*Balanced*	-.934	0.53	.251
	Sightword	***Decoder***	**-1.53**	**0.55**	**.024**
	Sightword	***Balanced***	**-2.46**	**0.53**	**.000**

Table I13

Summary of Discriminant Function Analysis(Reduced Sample)

LC	Eigenvalue	Canonical Correlation	Wilks' λ	χ^2	df	Sig.
1	.399	.534	.670	22.79	6	.001
2	.066	.249	.938	3.65	2	.161

Table I14

Summary of Discriminant Function Coefficients (Reduced Sample)

	Standardized Discriminant Function Coefficients		Structure Coefficients	
Predictors	1	2	1	2
WIAT Spelling	.075	.921	.504	.849
GORT Reading Fluency	-.465	.601	.596	.601
GORT Reading Comprehension	**1.285**	-.853	**.965**	.168

Note. Standardized coefficients = variable weights; structure coefficients = correlations

Table I15

Functions at Group Centroids (Reduced Sample)

	Function	
RTI group	1	2
Decoder	.010	.373
Balanced	.670	-.172
Sightword	-.821	-.165

Table I16

Cross-Validated Classification Results of Model (%; Reduced Sample)

	Predicted Group Membership			
RTI group	Decoder	Balanced	Sightword	Total
Decoder	**52.6**	21.1	26.3	100
Balanced	8.7	**78.3**	13.0	100
Sightword	26.3	15.8	**57.9**	100

Note: Bold-face indicate correct classifications.

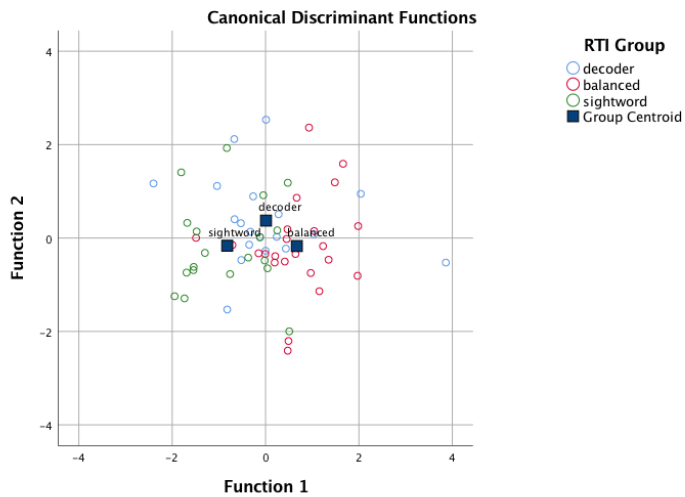

Figure I2. Spread of scores on discriminant functions for the model, including group centroids

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