

**A Longitudinal Examination of the Development of Reading Comprehension
in Children with Spina Bifida Myelomeningocele and Typically Developing
Children**

by

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Abstract

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Reading comprehension is a crucial skill for success across several academic domains and for everyday functioning, yet compared to word reading, longitudinal studies examining the typical and atypical development of this skill are scarce. This dissertation is comprised of two studies that explore reading skill development, with an emphasis on reading comprehension, in a sample of children with Spina Bifida Myelomeningocele (SBM) and a typically developing group. Participants were recruited in infancy to participate in a larger study on the impact of SBM on learning and tested at several timepoints across the first ten years of life. In study one, outcome and growth in word reading, reading fluency, and reading comprehension were explored across three time points at school-age (age 7.5, 8.5 & 9.5). This was followed by analyses to test the relation of preschool oral language and kindergarten phonological processing skills to later outcomes in reading. Results were consistent with hypotheses that suggest a causal relation between early oral language skills and later reading comprehension, while also incorporating the roles of phonological awareness and word reading into the model. Study two is an examination of the cognitive-developmental origins of an important text-level skill, bridging inference making, and its connections to reading comprehension. Results provided evidence that three preschool cognitive abilities (working memory/inhibitory control, oral comprehension, and narrative recall), could partially explain the relation between group and bridging inference skill and that each of these abilities at 36-months had an indirect effect on reading comprehension at age 9.5 through bridging inference skill. Findings from both studies contribute to an understanding of comprehension development, blending theories from the developmental, cognitive, and neuropsychological literatures. Overarching theoretical and clinical implications are discussed in the final chapter.

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Chapter 1

General Introduction

The ultimate goal of reading, whether for learning or for pleasure, is for understanding. Difficulties with reading comprehension have lifelong implications for individuals across domains, including in school, the workplace, and community. Understanding the processes that lead to successful reading comprehension and the ways in which these processes develop, or fail to develop, is crucial for informing educational practice including curriculum development, assessment, and intervention.

In contrast to the development of word reading skill, the literature on the development of reading comprehension is more limited. The development of word identification skill (ability to translate print into words) has been examined extensively in the literature and has been the focus of numerous longitudinal studies that have been successful at delineating the relation of early skills to the typical and atypical development of this skill (e.g., Lonigan, Burgess, & Anthony, 2000; Phillips & Torgesen, 2006; Scarborough, 1998; Wagner et al., 1997). In contrast, much less is known about the factors and processes that underlie and predict success or failure in reading comprehension. The majority of work in this area has been completed by testing concurrent predictors of reading comprehension, making it difficult to draw conclusions regarding causality.

One of the reasons the literature has historically placed a greater emphasis on word reading development is because it was assumed that poor word identification was preventing comprehension via a bottleneck effect; thus, once the child learned to fluently identify the words, comprehension would follow automatically (Wagner, Schatschneider, & Phythian-Sence, 2009). This is no longer thought to be the case. More recent studies typically conceptualize the relation

between word identification and comprehension as word identification being necessary but not sufficient for successful comprehension (Wagner et al., 2009).

Although difficulty with word identification is the most common source of reading comprehension failure, there is a subset of children who are adequate word decoders but have below average reading comprehension skills. In the literature, children with this profile are described as poor comprehenders. In unselected samples from the general school-age population, estimates of the number of children with this profile range from approximately 3% to 10% (e.g., Catts, Fey, Zhang, & Tomblin, 1999; Yuill & Oakhill, 1991). In selected samples of children who have difficulty in some aspect of reading, approximately 10% to 25% of them fit this profile (e.g., are good decoders/poor comprehenders; Cutting & Scarborough, 2006; Leach, Scarborough, & Rescorla, 2003). This profile is particularly prominent in the upper elementary school grades and beyond (Cutting & Scarborough, 2006).

Studying this population from a longitudinal perspective is challenging because reading comprehension skills are not easily measurable until the child has already been in school for some years. As adequate word identification is a prerequisite for reading comprehension, specific reading comprehension disabilities are not typically diagnosed until after third grade when word recognition and reading fluency skills have become more consolidated (Leach et al., 2003). In order to determine whether a student fits the profile of good decoder/poor comprehender, researchers must wait until the time when the student has been given ample opportunity to develop and strengthen word identification skills so that they do not confound the study of comprehension processes.

One way to work around this difficulty is with longitudinal work in clinical populations that have well-documented sequela of good word identification/poor comprehension skill

development at school age. One population that has been considered in this regard is children with Spina Bifida Myelomeningocele (SBM). The cognitive and academic profile of school age children with SBM has been described in the literature as including good word identification/less skilled comprehension. This, taken together with the fact that the diagnosis of SBM is known at or before birth, means that studying this population over time has potential for informing the development of impairments in reading comprehension.

SBM is a neural tube defect that affects the development of motor, cognitive, and academic skills. It occurs in approximately 0.3-0.5 of every 1000 births and represents the most prevalent cause of congenital brain and spine malformations in North American children (Williams, Rasmussen, Flores, Kirby, & Edmonds, 2005). Further damage often arises from hydrocephalus, an obstruction of cerebral spinal fluid flow due to malformation in the cerebellum and hindbrain (Reigel & Rotenstein, 1994). Hydrocephalus affects most children with SBM, necessitating shunt treatment in 80-90% of cases and is associated with a range of effects on brain development (Reigel & Rotenstein, 1994).

Comparing reading comprehension skill between groups of children with SBM and their typically developing peers has been the focus of numerous studies (see Barnes, Johnston, & Dennis, 2007 for a review). Using a low achievement definition of learning disabilities (skill performance below the 25th percentile with an absence of intellectual disability) to identify disability, it has been estimated that up to one-third of children with SBM have a disability in reading comprehension (Barnes et al., 2007). Moreover, even when children with SBM do not meet stipulated criteria for the diagnosis of a reading comprehension disability per se, their reading comprehension skill is typically significantly lower than their word identification skill, a

pattern not observed in typically developing controls (Barnes, Dennis & Hetherington, 2004; Barnes, Faulkner, Wilkinson, & Dennis, 2004).

Because children with SBM often read as accurately as typically developing children (Barnes, Faulkner, & Dennis, 2001), but demonstrate a more specific difficulty with comprehension, they are a potentially informative population for understanding reading comprehension. The likelihood that they will develop a good decoder/poor comprehender profile at school age means that studying this population longitudinally has the potential to be an efficient means of studying the developmental origins of poor comprehension development.

Although numerous studies have described the cognitive processes involved in accessing and constructing meaning from text, it is only recently that developmental considerations have begun to be incorporated into this work. Researchers are beginning to gain a more comprehensive understanding of the cognitive skills, processes, and knowledge required for good comprehension, and to recognize that the relative contribution of each of these predictors may differ depending on age, however, the developmental origins of these processes remains unclear. The most methodologically sound approach for understanding the development of these processes is via longitudinal studies, which are rare in the literature. Because the school-age cognitive and academic profile of children with SBM has been well documented and typically includes a pattern of adequate word identification and poor comprehension, this special population may be particularly informative for examining atypical comprehension development from a longitudinal perspective.

The overarching objective of the following two studies that comprise this dissertation is to study the development of reading comprehension from a longitudinal perspective in children with SBM and in typically developing children. A sample comprised of children with SBM and

typically developing controls were recruited in infancy as part of a larger study on SBM and learning. This sample has been tested regularly on a variety of cognitive and achievement outcome measures, including reading comprehension across the early school years (age seven to nine), allowing for the testing of earlier skills and abilities at predicting not only later outcomes, but also later growth in reading skills. A variety of early cognitive abilities and achievement skills can be theoretically linked to later development in reading comprehension, but this can only be empirically tested by studying these relations in a single sample followed over time.

Study one is a more general exploration of reading skill development across school-age, including a comparison of the relation of early language and phonological skills to reading development in addition to an investigation of the developmental trajectory of these skills.

Study two is a more specific examination of the ability to make bridging inferences, an important component skill of reading comprehension, and draws links between preschool cognitive and language abilities, later inferencing ability, and reading comprehension. Broader theoretical and clinical implications from both studies are discussed in the final section, the general discussion.

Chapter 2

Study One: Exploring the Developmental Trajectory of Reading Skill Development

Reading can be broadly conceptualized into three skills: (1) word identification (the ability to translate print into sounds and words); (2) fluency (the rate of reading when word identification is accurate); and (3) what is considered the ultimate goal of reading, comprehension of the information in the text. In general, studies of reading development in children with SBM without social and economic disadvantage have revealed a pattern of good word identification accuracy and speed of lexical access in the pronunciation of single words (when presented individually), but poorer text-level reading fluency and reading comprehension (Barnes, et al., 2001; English, Barnes, Fletcher, Dennis, & Raghobar, 2010; Fletcher et al., 2004).

The simple view of reading (Gough & Tunmer, 1986; Hoover & Gough, 1990) purports that reading comprehension is the product of word identification skill and oral language comprehension, and that if each of these skills is adequately developed, good comprehension will result. Indeed, a strong association between oral language and reading comprehension has been well-documented in the literature. For example, a review by Tannenbaum, Torgesen, and Wagner (2006) reported that the correlation between reading comprehension and vocabulary knowledge varies between approximately 0.3 to 0.8 and poor comprehenders are consistently found to have weaker oral language skills when tested concurrently (e.g., Nation, Clarke, Marschall, & Durand, 2004; Cain & Oakhill, 2007). It is not clear, however, how the association between oral language and reading comprehension is most accurately interpreted. Although language comprehension, in particular vocabulary knowledge, is often considered an important prerequisite skill for reading comprehension because of its role in accessing meaning, it is also

plausible to conceptualize the relation in reverse, or as an iterative relation, because one of the ways children are exposed to new vocabulary and more complex syntactic structures is through reading. Children who are poor comprehenders read less which in turn reduces language development. A handful of recent longitudinal investigations have examined the unique contribution of oral language and early word identification skills to reading outcomes, including reading comprehension, in young children.

Storch and Whitehurst (2002) followed a group of children over six years (preschool through grade four). They found that in the early grades word identification was the strongest predictor of reading comprehension whereas by grades 3 and 4, oral language skills were more predictive of comprehension. Similar findings were reported by Kendeou, van den Broek, White and Lynch (2009) who followed two groups of children (age 4 and 6) for two years. While oral comprehension and word identification were positively related in the youngest group of children, this relation diminished with age. They also found that oral comprehension and word identification skill at age 6 each made a unique contribution to reading comprehension at age 8. Oakhill and Cain (2012) studied word reading and reading comprehension in children for four years beginning at age 7, and found that the skills that underpin each continue to become increasingly separate with age. Specifically, they found that at age 11, specific discourse skills, but not word reading, measured at earlier timepoints predicted comprehension whereas phonological awareness skills (also measured at earlier timepoints) predicted later word reading but not comprehension. Taken together, these findings suggest that in typically developing samples, reading comprehension and word identification skills are highly correlated in young children, but this relation decreases with age. In contrast, the correlation between reading comprehension and language comprehension skills increases with age. This commonly reported

finding may be a result of the fact that the content of the assessment measures used to test oral and reading comprehension becomes increasingly similar with age. When children begin formal schooling, their language skills are typically much more advanced than what is needed to understand the types of curriculum materials used to teach early word identification and fluent reading skills. As word identification and fluency skills consolidate, reading materials become more complex and language comprehension becomes more important for understanding of the text.

While findings from these studies of typically developing readers begin to disentangle the development of these skills in relation to the typical development of reading comprehension, they do not completely inform our understanding for poor comprehenders. To date, it appears that only two longitudinal studies have been completed that have examined the development of reading comprehension in *poor* comprehenders.

Catts, Adolf, and Weismer (2006) identified 57 children in grade 8 who presented with poor reading comprehension but normal word recognition scores. This subsample was selected from a larger sample of youth who had been participating in a large scale epidemiological study and were assessed in kindergarten, grade two, and grade four. This allowed for retrospective analyses of students who had developed specific comprehension difficulties. While there was no difference in phonological awareness skills between the good and poor comprehenders in grades two, four, or eight, the poor comprehender group had weaker phonological awareness skills in kindergarten compared to the controls. This suggests that children who go on to become poor comprehenders are slower to develop phonological awareness and word reading skills. Although this weakness compared to controls diminished over time (no differences in phonological awareness or word-level reading by grade 2), it may be indicative of a processing bottleneck in

early reading acquisition that contributes to reading comprehension impairments (Catts et al., 2006).

Using a similar retrospective methodology that involved testing a large sample of children at age 5, 5.5, 6, 7 and 8 years of age, Nation, Cocksey, Taylor, and Bishop (2010) were able to identify fifteen of the children as poor comprehenders at age 8. A control group of good comprehenders was also selected from this sample. In general, poor comprehenders did not show early deficits in the areas of word reading accuracy or fluency. Both groups achieved age-appropriate levels of letter knowledge, early word reading, and reading fluency at all time points, including kindergarten. In contrast to Catts et al. (2006) there were no statistical differences on most measures of phonological awareness at any of the time points, with the exception of the sound-matching task at age 5. However some moderate effect sizes did emerge when comparing early phonological awareness skills between these two groups, which in light of their small sample size suggests that poor comprehenders may have some difficulty with this skill earlier in their development (i.e., this weakness may be detected with increased statistical power).

Phonological tasks also draw upon language skills that may have implications for later comprehension development (Cooper, Roth, Speece, & Schatschneider, 2002; Metsala & Walley, 1998; Metsala, Stavrinos, & Walley, 2009). For example, a longitudinal study by Cooper et al. (2002) found that oral language in kindergarten predicted significant variance in phonological awareness concurrently, as well as at two later timepoints (grades one and two), even when letter and word knowledge were controlled for at each timepoint. They used a general oral language measure which was a composite score comprised of semantic, syntactic, and morphological tasks. Metsala and colleagues have specifically highlighted the role of vocabulary growth in prereaders as important for the development phonological awareness (Metsala &

Walley, 1998). Their lexical restructuring hypothesis suggests that initially, representations of spoken words in memory are holistic (i.e., represented as “whole words”) but become segmental with development, and that increases in vocabulary knowledge play an important role in this transition (Metsala et al., 2009). Other studies have highlighted the importance of literacy exposure for emerging phonological awareness skills (Mann & Wimmer, 2002), although is noteworthy that the studies by Cooper et al. (2002) and Metsala et al. (2009) were with samples of young children, who would have had limited literacy instruction at this point. These findings provide further evidence that oral language makes an independent contribution to the development of phonological awareness. Additional research is required to determine if and how this relation impacts reading comprehension, either directly or indirectly.

In addition to phonological awareness, the ability to quickly access lexical information has also been identified in the literature as important for reading across domains (Kirby, Georgieue, Martinussen, & Parilla, 2010). This ability is often assessed by rapid automatized naming tasks, which involve the speeded naming of overlearned visual stimuli (e.g., colours, simple objects, letters, digits; Kirby et al., 2010; Lervag & Hulme, 2009; Parilla, Kirby, & MacQuarrie, 2004; Torgesen, Wagner, Rashotte, Burgess & Hecht, 1997). Findings from Lervag and Hulme (2009) suggest that rapid automatized naming tasks tap the same neural circuits involved in visual word recognition and they have speculated that this is why rapid naming has been so strongly implicated in reading development. Difficulty with rapid naming is considered a core difficulty among children with reading disabilities and has been specifically linked to reading fluency (Wolf et al., 2003). Good reading fluency allows attention to be directed toward comprehension because as word reading becomes more automatic, attentional resources can be allocated for the construction of meaning (Wolf & Katzir-Cohen, 2001).

Children with SBM are less fluent and slower than their peers on rapid naming tasks (Dennis, Hendrick, Hoffman, & Humphreys, 1987). Difficulty with these tasks, however, is likely due to more general difficulties with pacing their speech production in a smooth and regulated manner rather than naming the stimuli (i.e., visual word recognition; Lervag & Hulme, 2009) per se (Dennis et al., 1987). The speech of children with SBM is often dysfluent and slower than typically developing children (Dennis et al., 2008; Huber-Okraïnec, Dennis, Brettschneider, & Speigler, 2002) and their difficulties with speech production have been attributed to congenital malformation of the cerebellum, which is common in SBM (Dennis et al., 2008; Dennis, Salman, Juranek, & Fletcher, 2010; Huber-Okraïnec et al., 2002).

Although the longitudinal studies described above lay some foundation for understanding the trajectory of atypical comprehension, more research is required. In particular, these studies have not included reading fluency and early predictors of this skill such as rapid automatized naming in their investigations. In contrast to retrospective analyses (e.g., Catts et al., 2006; Nation et al., 2010), a study design that includes children with SBM increases the likelihood that there will be a higher number of children in the sample who have a good word identification/weaker comprehension profile. This increases statistical power and allows for a more comprehensive prospective investigation of these relations in poor comprehenders.

In the current study, a sample comprised of children with SBM and typically developing controls were recruited in infancy as part of a larger study on the effects of SBM on learning. This sample has been tested regularly on a variety of cognitive and achievement outcome measures, including word identification, fluency, and comprehension across the early school-age years (age 7 to 9), and in early oral comprehension, phonological awareness, and naming speed. This allows for the testing of these abilities at predicting not only later outcomes in each of the

three reading skills, but also later growth in these skills, in a sample that includes children with a higher likelihood of meeting the criteria for poor comprehenders.

The overall purpose of current study was to explore the nature of school-age growth in reading skills in an SBM population compared to typically developing children. Specific study aims were to (1) examine the growth in three aspects of reading (word identification, fluency, and reading comprehension) at three time points across the early school years (age 7.5, 8.5, and 9.5); (2) to compare outcome and growth in these reading skills between groups (i.e., SBM vs. normal controls); (3) to determine whether early oral comprehension, phonological awareness, and/or rapid automatized naming relate to outcome and/or growth in each of these three reading skills; and (4) to clarify the developmental relation of early oral language (at 36 months) to later phonological awareness (at 60 months), and to examine this relation with regard to later outcome in reading comprehension skill.

Methods

Participants

Participants were recruited from Houston, Texas and Toronto, Ontario to participate in a larger longitudinal study on the impact of SBM on learning. Recruited in infancy through treating neurosurgeons and pediatricians (SBM sample) and well-baby clinic advertisements (TD sample), all children participating in the study had to have a normal birth weight, and an APGAR score of eight or higher. Exclusionary criteria included the presence of an uncontrollable seizure disorder, known congenital abnormalities, significant sensory impairments, or if the child's mother was under the age of 17 at the time of birth. In addition, the typically developing group had to be free of motor abnormalities (Lomax-Bream, Barnes, Copeland, Taylor, & Landry, 2007).

In the current study, children who did not attend at least two of the three school-age time points were excluded from the analyses. Therefore the final sample reported on in the current study consisted of 106 participants ($n = 53$ in each group). Demographic information is reported in Table 1. The group with SBM had more female participants than the TD group, $\chi^2(1) = 3.79$, $p = 0.05$, however sex was not related to any outcome measures and therefore not included as a covariate in subsequent analyses. The TD group had a significantly higher SES than the group with SBM, $F(1, 104) = 9.35$, $p < 0.01$, which reflects the greater number of economically disadvantaged Hispanic families in the group with SBM in Texas (Au et al., 2008; Northrup & Volcik, 2000). SES was significantly correlated with several of the outcome measures and therefore included as a covariate in subsequent analyses. Most of the children in the group with SBM had hydrocephalus treated with a diversionary shunt ($n = 47$); six had arrested hydrocephalus and no shunt. The majority had lower spinal lesions below L1 ($n = 46$).

Procedure

Children and their caregivers participated in numerous laboratory or home visits over the first ten years of life. Data for the current study are taken from 36 month, 60 month and age 7.5, 8.5, and 9.5 year assessment timepoints. Written consent was obtained from parents at all time points and children at school-age (e.g., from age 7.5 on) in accordance with the institutional review boards at the University of Texas Health Science Center at Houston and the Hospital for Sick Children in Toronto. In general, testing at each timepoint took approximately three to five hours, depending on the focus of the child and how quickly ceilings were reached. Parents received written reports after each assessment which gave the standard scores, age equivalents and percentile ranks for the standardized tests.

Materials

Given that the overall purpose of the study was related to exploring skills within the reading domain, measures of word reading, fluency, and comprehension were administered at three timepoints across school-age (age 7.5, 8.5, and 9.5). The early preschool and kindergarten predictors were chosen based on the rationale and study goals outlined earlier. Specifically, a preschool measure of early oral comprehension skill and kindergarten measures of phonological awareness and rapid automatized naming were selected in order to determine the relations of these variables to later outcome and growth in each of these three reading skills. The specific measures are described below according to the order of administration (timepoint).

Oral Comprehension

Preschool Language Scale: 3rd Edition - Auditory Comprehension Subtest (PLS-AC; Zimmerman, Steiner, & Pond, 1992). This task was administered at the 36-month timepoint. This test measures receptive language development through picture-word and picture-phrase matching tasks and requiring the child to follow directions (e.g., "point to the toy that is not red"). There are also items that assess the child's ability to make connections between concepts, to make basic inferences, and that require syntactic knowledge. This subtest reports a test-retest reliability of 0.90.

Phonological Awareness

Comprehensive Test of Phonological Processing - Sound Matching and Elision Subtests (Wagner, Torgesen, & Rashotte, 1999). These subtests were administered at the age 60-month timepoint. The scaled scores from these two subtests were combined to create a composite measure of phonological awareness. The Sound Matching subtest measures the child's ability to choose the word that contains a target sound. Words are presented orally and the child is shown a

card containing pictures of the four words. The child must indicate which word contains the sound. The target sound is tested in both the initial and final positions in the word. The Elision subtest is a sound deletion task measuring the child's ability to segment and manipulate different sound units within words. Earlier items require the child to delete part of a compound word such as 'butter' in 'butterfly'. As items increase in linguistic complexity, students must delete smaller phoneme units to pronounce the word (e.g., say "cup" then it again without saying /k/). The Sound Matching subtest reports an internal consistency of 0.93 and a test-retest reliability of 0.83. The Elision subtest reports an internal consistency of 0.90 and a test-retest reliability of 0.88.

Rapid Automatized Naming

Comprehensive Test of Phonological Processing – Rapid Colour Naming and Rapid Object Naming Subtests (Wagner et al., 1999). These subtests were both administered at the age 60-month timepoint. These tasks measure the speed with which the child can name a series of colours or objects. Six items (colours or objects) are arranged randomly across two pages for a total of 72 items to name. An individual's score is the total number of seconds it takes for them to name all items. The majority of children who completed the rapid naming tasks completed both subtests. For these children, the average of the two scores were used in the analyses. However, in cases where children had a score for rapid colour naming only ($n = 8$) or rapid object naming only ($n = 15$), their scaled score from just this subtest was used in order to minimize the loss of data from these participants¹. The rapid colour naming subtest reports an

¹ A confirmatory factor analysis reported in the CTOPP's technical manual reports high factor loadings (i.e., > 0.70) of the rapid colour and rapid object subtests onto a single 'rapid naming' construct, indicating that in the norming sample the two subtests were found to share a high amount of variance (Wagner et al., 1999). These results support the decision to use one or the other in cases where the child only completed one of the subtests.

internal consistency of 0.74 and test-retest reliability of 0.78. The rapid object naming subtest reports and internal consistency of 0.82 and a test-retest reliability of 0.77.

Reading Achievement

All of the following subtests are part of the Woodcock-Johnson III Tests of Achievement (WJ-III; Woodcock, McGrew, & Mather, 2001). Each of the following subtests was administered at ages 7.5, 8.5, and 9.5.

Letter-Word Identification Subtest. This untimed measure of word reading ability assesses how many real words a child can read. This subtest reports an internal consistency of 0.94.

Reading Fluency Subtest. This task requires the child to silently read simple sentences, decide if the statement is true, and then circle yes or no accordingly. The reading fluency score is based on how many correct responses they can produce in three minutes. This subtest reports an internal consistency of 0.90.

Passage Comprehension Subtest. This measure requires the child to read sentences and passages of increasing length and to then orally generate a missing word to make a passage complete and coherent. Items become progressively more difficult as passages increase in length and vocabulary and syntax become more sophisticated. This subtest reports an internal consistency of 0.88.

Results

Results for the current study are divided into four subsections which correspond to the four study goals listed at the end of the introduction. First, latent growth curve modelling (LGCM) was employed to examine growth in each reading skill (word identification, fluency, and comprehension) between ages 7.5, 8.5, and 9.5. This method was chosen because it allows

for the inclusion of predictor variables, which was required to address the second and third goals of the study, to compare outcome and growth in these reading skills between groups (i.e., SBM vs. normal controls) and to determine whether early oral comprehension, phonological awareness, and/or rapid automatized naming relate to outcome and/or growth in each of these three reading skills. In addition to LGCM, multiple mediation models were used to test the second and third goals of the study. Finally, a path analysis model was conducted to further clarify the relation of early oral language to later phonological awareness, and to examine the effect of this relation on later outcomes in word reading and reading comprehension. More detailed rationale and background information for each of these statistical procedures is provided in their respective sections below. The means, standard deviations, and group comparisons for all measures are presented in Table 2.

Latent Growth Curve Modelling

LGCM is a statistical technique used to model longitudinal data in which repeated measurements are observed for an outcome variable on more than two occasions. LGCM has numerous advantages over traditional techniques such as repeated measures ANOVAs, including allowing for enhanced statistical power through an examination of both intra (within) and inter (between) individual variability in change over time (Preacher, Wichman, MacCallum, & Briggs, 2008).²

² Latent growth curve models are considered a special case of structural equation modelling (SEM; Preacher et al., 2008). SEM is an approach for specifying and testing hypothesized patterns of relations between measured (observed) and latent (unobserved) sets of variables. In LGCM, the measured (observed) variables are repeated measures of the same variable (i.e., word identification, fluency, and comprehension in the current study). Unlike traditional SEM frameworks, the latent variables of primary importance in LGCMs are not psychological constructs, but instead represent aspects of change in the measured variable (i.e., reading skill at each time point). In a basic LGCM, the most commonly examined factors that are specified to represent patterns of change are the intercept factor, which represents the level of the outcome measure when time = 0, and the slope factor, which represents the linear rate at which the outcome measure changes (Preacher et al., 2008). This approach assumes the existence of a continuous

In the current study, LGCM was used within a structural equation modeling (SEM) approach to model change in three school-age reading skills (comprehension, word identification, and fluency), each measured at three timepoints (age 7.5, 8.5, and 9.5). In these models, the intercept was conceptualized as the earliest timepoint when reading skills were measured and therefore represents the mean performance on each of the reading measures at 7.5 years. The intercept mean corresponds to the group mean intercept and the intercept variance corresponds to individual variability in the intercepts. Models also estimated the slope, or the rate of change in the reading skill over time (i.e., the mean rate of growth). The slope mean is an estimate of the best-fitting line that explains linear change across time, and the slope variance represents the variability in individual trajectories. These analyses were conducted using Mplus Version 6 (Muthén & Muthén, 2010).

Figure 1 depicts the basic growth curve model that was fit for each of the three reading skills (word identification, fluency, and comprehension). In SEM depictions, circles represent the latent variables, rectangles represent the observed variables, single-headed arrows represent the impact of one variable on another, and double-headed arrows represent correlations between variables. Loadings on the slope factor were constrained at 0, 1, and 2, which correspond to the change in years between the timepoints that reading achievement was tested (i.e., age 7.5 = 0; age 8.5 = 1; age 9.5 = 2) and create a linear growth trajectory. The mean and variance of both the intercept and slope were unconstrained and both of these latent variables were allowed to correlate (Bryne, 2010; Kenny, 2011).

underlying trajectory and the pattern of change in the observed repeated measures provides information about this trajectory. Because the trajectory process is observed only through use of the repeated administration of the observed task (i.e., reading skill), it is considered latent. More detailed mathematical and theoretical explanations of LGCM can be found in the following texts: Duncan, Duncan, & Strycker (2006); Bollen and Curran (2006), and Preacher et al. (2008).

First, model fit for growth in each of the three reading skills (word identification, fluency, and comprehension) was examined in separate unconditional models. Unconditional latent growth curve models are completed as a first step in modeling change over time and do not include any explanatory variables or covariates (Bollen & Curran, 2006).

The unconditional growth model for performance on the word identification task revealed that both the intercept ($M = 31.74, SE = 1.34$) and slope ($b = 4.81, SE = 0.36$) differed significantly from 0, $p < 0.001$. Significant individual variability was found for the intercept ($\sigma^2 = 94.89, SE = 19.41, p < 0.001$), but not for the slope ($\sigma^2 = 1.78, SE = 5.58, ns$). Examining the chi-square statistic for the model indicated that this model fit the data well, $\chi^2(1) = 0.591, ns$.³

The unconditional growth model for performance on the reading fluency task found that both the intercept ($M = 21.99, SE = 1.36$) and slope ($b = 7.69, SE = 0.42$) differed significantly from 0, $p < 0.001$. Significant individual variability was found for the intercept ($\sigma^2 = 128.15, SE = 28.27, p < 0.001$), but not for the slope ($\sigma^2 = 4.72, SE = 10.37, ns$). Examining the chi-square statistic for the model indicated that this model fit the data well, $\chi^2(1) = 2.09, ns$.

Finally, the unconditional growth model for performance on the reading comprehension task also indicated that both the intercept ($M = 15.31, SE = 0.77$) and slope ($b = 3.38, SE = 0.21$) differed significantly from 0, $p < 0.001$. Significant individual variability was found for the intercept ($\sigma^2 = 42.48, SE = 8.06, p < 0.001$), but not for the slope ($\sigma^2 = 1.14, SE = 2.29, ns$). The chi-square statistic indicated that model fit was acceptable $\chi^2(1) = 4.21, p = 0.04$.

³ Model fit is a statistic that indicates how well the data correspond to the theorized relations between the variables in the model. Although there are several fit indices to choose from, the chi-square statistic was reported following recommendations by Hayduk, Cummings, Boadu, Pazderka-Robinson, & Boulianne (2007). A nonsignificant chi-square indicates that the theorized model and the observed model are not significantly different from each other (i.e., “the model fit the data well”).

Results from these models warranted reconsideration of the analysis plan. Specifically, the lack of significant individual variability in the slope for each reading skill indicated that moving forward to assess predictors of growth rates would be futile. There was, however, significant variability in the intercept for each reading skill; given that from the age 7.5 timepoint, participants proceeded to grow at similar rates, an investigation of the relation between reading skills for each group and a comparison of the predictors for each of the reading skills at this timepoint (i.e., intercept = reading skill at age 7.5) was conducted.

Comparison of Reading Skill Between Groups

The first step was to investigate whether there were different patterns of relative strengths and weaknesses within the reading domain for each group at the age 7.5 timepoint. In order to test this, a 2 (group: SBM vs TD) by 3 (reading skill: word identification, fluency, and comprehension standard scores at age 7.5) repeated measures ANOVA was completed.⁴ Results revealed main effect of group, $F(1, 86) = 17.74, p < 0.001, \eta_p^2 = 0.171$, and a main effect of reading skill, $F(2, 172) = 108.6, p < 0.001, \eta_p^2 = 0.558$, which was qualified by significant interaction, $F(2, 172) = 3.04, p = 0.05, \eta_p^2 = 0.036$. Tests of simple main effects (see Figure 2) revealed that for the group with SBM, the mean word identification score ($M = 106.53, SD = 24.78$) was significantly greater than both the comprehension score ($M = 97.98, SD = 20.76$) and the fluency score ($M = 94.17, SD = 15.60$), p 's < 0.01 . The difference between comprehension and fluency in the group with SBM was not significant. In the TD group, there was no difference between word identification ($M = 120.02, SD = 20.20$) and comprehension ($M = 117.11, SD = 16.39$), but both word identification and comprehension were significantly greater than fluency ($M = 108.72, SD = 13.61$), p 's < 0.01 .

⁴ Results from this model revealed a nonsignificant Mauchly's statistic, indicating that the assumption of sphericity (i.e., that the variances of the differences between the scores taken from the same participant are equal) was met.

Predictors of Reading Skill – Multiple Mediation Analyses

Because there were significant group differences between each of the reading skills, multiple mediation analyses were employed to determine if oral comprehension, rapid automatized naming, and/or phonological awareness could explain any or all of the group difference for each reading skill.

Mediation analyses were conducted using models with multiple proposed mediators to simultaneously assess multiple early abilities as potential mediators for the effect of group membership (SBM vs. TD) on age 7.5 reading skill. Bootstrapping procedures as outlined by Preacher and Hayes (2008) and recommended as current best practice in developmental research (Dearing & Hamilton, 2006), were used. Bootstrapping is a nonparametric resampling procedure where a large number of samples are drawn with replacement from the dataset. Approximations of the distribution of the indirect effects, point estimates, and confidence intervals are calculated based on these samples. Bootstrapping also addresses concerns associated with traditional mediation approaches (e.g., Baron & Kenny, 1986; Sobel, 1982) when working with small sample sizes and variables with non-normal distributions while at the same time accounting for the increased probability for Type I error (Preacher & Hayes, 2008).

The Preacher and Hayes (2008) method allows for the inclusion of several variables as potential mediators in the same model. When completed with bootstrapping this allows for the testing of whether an overall indirect effect exists, in addition to testing the significance of the indirect effect of each individual mediator variable while controlling for all other variables in the model. This reduces parameter bias due to omitted variables (e.g., as would be present in multiple simple mediation models; Preacher & Hayes, 2008). Finally, this method allows for the

inclusion of covariates, which are partialled out of the outcome variable and all hypothesized mediators (Hayes, 2011).

In the current study, this procedure was conducted using the SPSS macro provided by Preacher and Hayes (2008). The reported results are based on a 10,000 resample 90% Bias-Corrected confidence intervals (C.I.), which account for the often asymmetric point estimate distribution resulting from bootstrapping. The point estimate for an indirect effect was considered significant if zero was not included in the 90% C.I. (Hayes, 2009).

The same multiple mediation model was conducted three times, once for each dependent variable (i.e., age 7.5 score for word identification, fluency, and comprehension; see Figure 3). The models consisted of group membership as the predictor (SBM, coded as 1, vs. TD, coded as 2), auditory comprehension (36 months), rapid automatized naming (60 months), and phonological awareness (60 months) tasks as mediators, and then either word identification, fluency or comprehension as the outcome variable. In addition, SES was entered as a covariate in each model.

Word Identification. In the model with age 7.5 word identification as the outcome, 40% of the variance was accounted for ($R^2 = 0.40$, $p < 0.001$) and the total indirect effect of all mediators was significant, with a point estimate of 4.36 and 90% bootstrap C.I. of 1.71 to 7.79, indicating that performance on at least one of the mediating variables was a significant mediator in the relation between group and age 7.5 word identification skill. An examination of the specific indirect effects was consistent with a model whereby both auditory comprehension (point estimate = 1.96; 90% C.I. = 0.50 to 4.18) and phonological awareness (point estimate = 2.22; 90% C.I. = 0.92 to 4.03) significantly mediated the effect of group on age 7.5 word identification skill but rapid automatized naming did not (point estimate = 0.21; 90% C.I. = -0.66

to 2.05). With all mediators entered in the model, the direct effect from group to word identification skill was no longer significant, which supports a complete mediation model, $b = 2.17$, $t(68) = 1.03$, *ns*. The path coefficients for this multiple mediation model can be found in Table 3.

Fluency. In the model with age 7.5 fluency as the outcome, 51% of the variance was accounted for ($R^2 = 0.51$, $p < 0.001$) and the the total indirect effect of all mediators was significant, with a point estimate of 4.94 and 90% bootstrap C.I. of 1.81 to 8.69, indicating that performance on at least one of the mediating variables was a significant mediator in the relation between group and age 7.5 fluency skill. An examination of the specific indirect effects was consistent with a model whereby phonological awareness significantly mediated the effect of group on age 7.5 fluency skill (point estimate = 3.55; 90% C.I. = 1.22 to 6.91) but auditory comprehension (point estimate = 0.78; 90% C.I. = -0.39 to 2.98) and rapid automatized naming (point estimate = 0.62; 90% C.I. = -1.31 to 2.76) did not. With all mediators entered in the model, the direct effect from group to fluency skill was not significant. The path coefficients for this multiple mediation model can be found in Table 3.

Comprehension. In the model with age 7.5 comprehension as the outcome 42% of the variance was accounted for ($R^2 = 0.42$, $p < 0.001$) and the total indirect effect of all mediators was significant, with a point estimate of 3.21 and 90% bootstrap C.I. of 1.48 to 5.46, indicating that performance on at least one of the mediating variables was a significant mediator in the relation between group and age 7.5 comprehension skill. An examination of the specific indirect effects was consistent with a model whereby both auditory comprehension (point estimate = 1.17; 90% C.I. = 0.23 to 2.74) and phonological awareness (point estimate = 1.68; 90% C.I. = 0.68 to 3.11) significantly mediated the effect of group on age 7.5 comprehension skill but rapid

automatized naming did not (point estimate = 0.36; 90% C.I. = -0.91 to 1.69). With all mediators entered in the model, the direct effect from group to comprehension skill was no longer significant, which suggests a full mediation model, $b = 1.48$, $t(67) = 1.04$, *ns*. The path coefficients for this multiple mediation model can be found in Table 3.

Developmental Trajectory of Reading Skill Development – Sequential Path Analysis

Finally, because auditory comprehension and phonological awareness both explained significant variance in the relation between group and word identification and group and comprehension and because auditory comprehension has time precedence over phonological awareness (measures conducted at 36-month vs 60-month assessments), a path analysis model was tested to further delineate these relations within the trajectory of the development of these skills (see Figure 4). The path analysis was run in SPSS using macros developed and available in Hayes (2012). This analysis is similar to the multiple mediation models described above, except the mediators are linked consecutively instead of entered simultaneously. The model estimated the total and direct effect of group on passage comprehension, as well as the total and all possible specific indirect effects of group on passage comprehension through auditory comprehension, phonological awareness, and word identification. As described above, the estimate of the indirect effect was considered significant if zero was not included in the 90% C.I. that was generated from 10,000 bootstrap samples. Variables were entered into the path analysis sequentially based on timepoint of administration, with the exception of word identification. Although word identification and comprehension were administered at the same timepoint, word identification precedes comprehension in the path analysis based on theory and previous research which conceptualizes word identification as a prerequisite skill for reading comprehension (e.g., Wagner et al., 2009).

The path analysis model accounted for 74% of the variance in age 7.5 reading comprehension ($R^2 = 0.74$, $p < 0.001$). The structure of this model, a series of five variables entered in succession, resulted in seven indirect paths to the final outcome variable, reading comprehension. The seven paths are listed in Table 4 and are depicted visually in Figure 4. The path analysis tested the indirect effect from each of the seven paths. The total indirect effect from the seven paths included in the analysis was significant (point estimate = 3.72; C.I. = 0.28 to 2.09). Results from all seven specific indirect effects can be found in Table 4; examination of the confidence intervals revealed the indirect effects from two paths were significant: (1) the indirect effect of the path that included all variables was significant (point estimate = 0.69; 90% C.I. = 0.38 to 1.26) and (2) the indirect effect in the path from group to auditory comprehension to reading comprehension was also significant (point estimate = 0.99; 90% C.I. = 0.28 to 2.09). In addition, the direct effect of group on comprehension was not significant. In sum the results from the path analysis revealed that group had an indirect effect on reading comprehension through two significant pathways: (1) the path that included auditory comprehension (36 months), phonological awareness (5 years), and word reading skill (7.5 years), sequentially and (2) through preschool auditory comprehension skill. In addition, even after all indirect effects were controlled for in the same model, the direct effect of group on reading comprehension was significant.

Discussion

The present study afforded the unique opportunity to study reading skill development in a clinical population with documented sequelae of good word identification/poor comprehension skill at school age from a longitudinal perspective. Data from a sample of children with SBM and typically developing controls were taken from several timepoints across a nearly seven year

time period (i.e., age three to ten) in order to add to the literature on the developmental trajectory of atypical reading development, in particular comprehension.

Growth of Reading Skills Across School-Age

As part of a larger study on SBM and learning, participants completed tests of word identification, fluency, and comprehension at three timepoints across school-age (7.5, 8.5, and 9.5) with the aim of exploring group differences and early predictors of both outcome and growth in these skills. Initial explorations of the growth curve models, however, revealed that although there was significant individual variability in the intercept (i.e., age 7.5 reading scores), the individual variability in slope was not significantly different from zero. This pattern was found for all three reading types, indicating that although the current sample consisted of children with a range of abilities in their age 7.5 word identification, fluency, and comprehension scores, on average, their rates of growth were equivalent. This suggests that, at least between these timepoints, children with SBM experience the same amount of growth in reading skill as their typically developing peers. This finding also means that all of the children in the sample maintained their reading status relative to their peers over time: no differences in growth rates implies that the children with high reading scores relative to their peers at age 7.5 remained higher across time and those with lower scores remained lower. That the children with weaker reading scores at the age 7.5 timepoint did not catch-up with their peers over time supports the conceptualization of a deficiency in skill development, rather than a delay.

Given the lack of individual variability in growth rates for all three reading skills, analyses were directed toward an investigation of predictors of each of the reading skills at the age 7.5 timepoint. From this age, participants proceeded to develop reading skills at a constant rate across time. Therefore, determining what early predictors and developmental pathways

accounted for variance in age 7.5 skills has implications for later reading outcomes as well. The remainder of this paper is a discussion of the differing pattern of strengths and weaknesses between reading skills in each group at this timepoint, followed by a comparison of early predictors for each reading skill and the relation between them across development.

Reading Profile of Children with SBM

Comparing outcomes in word identification, fluency, and comprehension between groups at age 7.5 revealed a different pattern for each group. Although the TD group outperformed the group with SBM in all reading skills, the unevenness between reading skills was more apparent for children with SBM who, as a group, had significantly lower fluency and comprehension scores than word reading scores, which were age-appropriate. This pattern is consistent with previous literature identifying a significant discrepancy between word identification and comprehension in SBM, compared to equal performance between these two skills in the control group (Barnes & Dennis, 1992; Barnes et al., 2004a; Barnes et al., 2004b).

Moreover, the inclusion of the reading fluency measure in this analysis contributes to an understanding of the group with SBM's variability in skill development within the reading domain. Previous research has shown that children with SBM are fluent in their ability to read single words and pseudowords (presented individually; Barnes & Dennis, 1992; Barnes et al., 2001), but are significantly slower when reading words in text (e.g., short stories; English et al., 2010). Results from the current study add to these findings by providing additional evidence that children with SBM have difficulty with reading fluency, however more research is required to determine the exact nature and correlates of this weakness.

Mediators of Reading Skill Outcome

Next, three multiple mediation models were conducted to test whether early oral language comprehension, phonological awareness, and/or rapid automatized naming explained part or all of the relation between group and reading skill outcome. Entering all three early predictors in the same model for each reading skill tests the significance of the indirect effects while holding all other variables in the model constant. Results from these analyses supported models whereby auditory comprehension and phonological awareness both significantly mediated the relation between group and age 7.5 outcomes for both word identification and passage comprehension, but only the indirect effect through phonological awareness was significant for fluency. Rapid automatized naming did not mediate the relation in any of the models, and while this might be somewhat unexpected particularly in the case of reading fluency, previous studies have shown that rapid automatized naming may be more important for early-literacy skill, and exerts less predictive power over time (Torgesen et al., 1997). Moreover, the current study only tested rapid object and rapid colour naming and there is evidence that letter and digit naming is more predictive of reading skill than picture naming (Compton, 2003; Manis, Doi, & Bhadha, 2000), however given the age of participants when they completed these tasks (60 months), these subtests were not possible because the norms for these tasks do not begin until age 7.

Developmental Trajectory of Reading Comprehension

In particular, the results from the word identification and comprehension multiple mediation models were intriguing because both auditory comprehension and phonological awareness were unique mediators in both models. In order to further understand the associations between these abilities, variables from these two models were combined into a single sequential

path analysis. The decision regarding sequence was based on a combination of timepoint precedence and theoretical rationale. Findings from this model allow for a deeper discussion of the developmental trajectory of reading development, in particular comprehension, in children with SBM. A compelling aspect of this model is the wide time range that was part of the longitudinal study design, which allows for stronger, though not definitive, assumptions regarding causal relations.

The path analysis model simultaneously tested the indirect effect of group on reading comprehension through seven different paths; each indirect effect was tested while controlling for the effects of all other indirect effects (Hayes, 2012). Results from this analysis revealed that group exerted an indirect effect on reading comprehension through two significant pathways. The first indirect effect that was significant in explaining the relation between group and passage comprehension was the path that included auditory comprehension (36 months), phonological awareness (5 years), and word reading skill (7.5 years), sequentially. The second significant indirect effect was through preschool auditory comprehension skill. Conceptualizing this path is akin to a simple mediation model, whereby auditory comprehension explained additional variance in the relation between group and passage comprehension. Even after all indirect effects were controlled for in the same model, there remained a trend toward a significant direct effect of group on comprehension.

As demonstrated in the multiple mediation model predicting word identification, auditory comprehension and phonological awareness each accounted for unique variance. Including them in the subsequent the path analysis according to assessment timepoint, however, revealed that auditory comprehension had an indirect effect on word identification (and in turn comprehension) through phonological awareness over time. The indirect effect of oral language

on word identification through phonological awareness has been found previously in a sample of typical readers (Storch & Whitehurst, 2002) and speculated about in findings from a sample of poor comprehenders (Catts et al., 2006). Nation et al. (2010) reported a trend toward this finding in poor comprehenders, and noted the substantial demands that phonological tasks place on general language ability. The significant relation between auditory comprehension and phonological awareness in the current study adds to the evidence that early oral language contributes to later phonological awareness development (Metsala et al., 2009). In particular, because the measure of preschool oral language used in the current study involves a significant receptive vocabulary component, it is possible that this may have been the major factor accounting for this relation, which fits with the lexical restructuring hypothesis (Metsala & Walley, 1998). Other important influences on the development of phonological awareness, namely exposure to early literacy instruction, were not included in this study but also likely play an important role in the development of this skill (Mann & Wimmer, 2002).

Catts et al. (2006) argued that if a deficit in early oral language was, in part, the cause of their poor comprehender sample having low phonological awareness scores in kindergarten, the fact that their phonological skills were indistinguishable from the control group at later timepoints was evidence that the influence of difficulties with early oral language on phonological awareness did not persist over time. Although the current study had a notably distinct sample (i.e., SBM), and did not include measures of phonological awareness at later timepoints, results suggest that the influence of a deficit in early oral comprehension on phonological awareness does persist over time with regard to its lingering effect on later reading skills. Specifically, findings support a model of skill development whereby a deficit in early oral language exerts an effect on phonological awareness at 60 months, which in turn relates to word

identification and then reading comprehension at age 7.5 years. Therefore, although deficits in phonological awareness may resolve quickly for poor comprehenders (both Catts et al., 2006 and Nation et al., 2010 found no differences between groups after kindergarten), the current study provides evidence that early difficulties with phonological awareness may have an indirect effect on reading comprehension over time. This supports the hypothesis that there is a causal link between these abilities across development, even if differences in phonological awareness are no longer present in older groups of children. It also extends previous findings (e.g., Kendeou et al., 2009) by increasing the range between timepoints, most notably with the inclusion of an oral language measure from 36 months, and by demonstrating this pattern in a sample from a special population. Results from the path analyses suggest that early phonological awareness only impacts later reading comprehension because of its relations with word reading development, as the path from phonological awareness to comprehension which excluded word identification was not significant. Similar results were reported by Oakhill and Cain (2012).

Further support that a deficit in early oral language skills plays a causal role in reading comprehension difficulties came from the second indirect effect that was significant in the path analysis model, namely, the finding that auditory comprehension mediated the relation between group and passage comprehension. That this effect was significant even after numerous other important variables and effects were controlled for in the model, further emphasizes the unique role of early oral language skills in comprehension development. This finding is consistent with other studies, which also found that poor comprehenders had a deficit in oral language that preceded their difficulties in reading comprehension (e.g., Nation et al., 2010), and extends the literature on this topic by replicating this finding at a timepoint before children have started any formal schooling in reading. This evidence is inconsistent with the hypothesis that the

weaknesses in oral language reported frequently in cross-sectional studies of poor comprehenders are primarily a consequence of poor reading comprehension itself (although some degree of reciprocity likely exists; Cain & Oakhill, 2007; Nation et al., 2010).

One important caveat for interpreting the results from the path analysis model, in particular when comparing the findings to previous studies, is the co-occurring weakness in reading fluency in the group with SBM. Reading fluency is often not explicitly mentioned in the literature describing atypical comprehension development, however it is usually implied that by definition, poor comprehenders have both accurate and fluent text-reading skills. That being said, the majority of the longitudinal studies described in this paper did not measure reading fluency at all, and the one exception to this (Nation et al., 2010) only measured fluency for reading lists of words. More research is required to clarify the role of text-level fluency in this and other samples of poor comprehenders.

Conclusion

Results from the current study contribute to an understanding of both typical and atypical reading skill development, with a particular emphasis on reading comprehension. Very few studies have explored the developmental trajectory of reading comprehension longitudinally and even fewer with samples who have particular difficulty with comprehension, such as SBM. Findings are consistent with the discrepancy between word reading and reading comprehension skill for school-age children with SBM, and add to knowledge about the unevenness in their reading profile by demonstrating that they also have weaknesses related to reading fluency. The longitudinal design of the study adds to the evidence suggesting a causal relation between an early deficit in oral language and later reading comprehension problems. In addition, it highlights the role of an early oral language deficit on later phonological awareness and then word reading

skills. Although examining the specific relations between early predictors and reading outcomes at ages 8.5 and 9.5 was beyond the scope of the current study, because there were no individual differences in growth rate in the current sample for any of the three reading skills tested, the models which explain the relation between group and age 7.5 reading skill have implications for later reading outcomes (through ages 8.5 and 9.5) as well.

Chapter 3

Study Two: Effect of Preschool Working Memory, Language, and Narrative Abilities on Inferential Comprehension at School-Age

The development of a mental representation of the situation described by the text is an element that is common to all major theories of reading comprehension (Oakhill & Cain, 2007). Kintsch's (1988) model describes two primary processes that operate cyclically to build the situational (mental) model: construction and integration. First, all prior knowledge associated with the incoming information is activated (construction), resulting in a large amount of activated information, much of which is unnecessary for understanding the text. The relevant parts are identified and incorporated into the current model to form a coherent representation (integration). This results in a cognitive representation that reflects the interaction between information provided by the text and the reader's prior knowledge. Similarly, Johnson-Laird (1983) proposed that the development of the mental representation of the text goes beyond the literal meaning to embody spatial, temporal, causal, motivational, and person and object related information in what is called a mental model. As the reader progresses through the text, the mental model is continuously updated as new information is read and interpreted (Zwaan & Madden, 2004).

These models describe the access of meaning from three levels of text (Clifton & Duffy, 2001; Kintsch, 1988; Schmalhofer, McDaniel, & Keefe, 2002). The surface-code (i.e., vocabulary, syntax knowledge and interpreting information from sentences), text-base (i.e., literal interpretation of the text that unfolds via integration of various sources of information from within the text), and situation model (i.e., construction of the mental models that represent an integration of information provided by the text with readers' goals and world knowledge;

Kintsch, 2005). Accessing meaning from each of these levels is considered to occur cyclically, with each of these processes occurring simultaneously and repeatedly as the reader progresses through the text.

Studies of how reading comprehension unfolds in children with SBM have been informed through experiments that examine this population's strengths and weaknesses at accessing meaning from these three levels of text (Barnes, Huber, Johnston, & Dennis, 2007). In general, children with SBM are able to access surface level representations of written text as well as their TD peers. They have been found to have intact vocabulary knowledge, grammatical skills, and ability to understand figurative language (Barnes & Dennis, 1998; Dennis, Jacennik, & Barnes, 1994). Assembling this information into a text-based representation, however, is more difficult for children with SBM (Barnes et al., 2007). Specifically, they have been found to have difficulty with a skill that has been highlighted in the literature as particularly important for the construction of text-based representations: bridging inferences (Barnes et al., 2007; Clifton & Duffy, 2001). Bridging inferences, which require the reader to integrate two pieces of explicitly stated information from within the text, are considered essential for developing and maintaining a coherent understanding (Kintsch, 1994). Barnes et al. (2004b) found that while children with SBM were accurate at making bridging inferences, they were slower than the control group at making them when required to integrate two pieces of information separated by longer chunks of text.

The aim of the current study is to understand the developmental pathways that result in the difficulties that children with SBM have in making the inferences that are necessary for the formation of an accurate, coherent representation of the text (i.e., bridging inferences). The

hypothesized predictors of difficulties in inferential comprehension specifically and in reading comprehension more generally are as follows:

Working Memory/Inhibitory Control

Working memory and inhibitory control are two executive functioning processes that are considered important for comprehension (Christopher et al., 2012; Swanson, Howard, & Saez, 2007; Miyake et al., 2000). Working memory can be thought of as the “work space” where information is processed, stored, and integrated and therefore limited working memory capacity has consequences for reading comprehension (Cain, Oakhill, & Bryant, 2004). As new information is read, the mental model is continually updated so that the information that remains activated is relevant to the unfolding situation described by the text (Kintsch, 1988). The updating of the model involves the reactivation of information from previous cycles and subsequent integration of that information with the material in working memory.

Cognitive theories of reading comprehension also emphasize inhibitory processes such as suppression (Gernsbacher, 1990). Suppression of information that is not relevant for ongoing comprehension is important to free up the cognitive resources required to process the increasing input of information as the reader progresses through the text (Gernsbacher, 1990; Gernsbacher & Faust, 1991). Failure to suppress irrelevant information overloads cognitive capacity, which then interferes with meaning construction (Palladino, Cornoldi, DeBeni, & Passaglia, 2001).

Working memory and suppression have been consistently found to be impaired in poor comprehenders, including children with SBM (Barnes et al., 2004b; DeBeni & Palladino, 2000; Gernsbacher, 1993; Swanson, Howard, & Sáez, 2007). Some research has demonstrated that the ability to make inferences is associated with working memory ability (e.g., Barnes et al., 2007;

Cain et al., 2004; Pike, Barnes, & Barron, 2010), however, these relations have been studied concurrently, which precludes the examination of causal relations.

Oral Language

Oral language skills have been linked to reading comprehension ability in numerous studies, with samples of children at various ages (Oakhill & Cain, 2007). Early abilities in this area have also been identified as important predictors of later comprehension skill in longitudinal studies (e.g., Catts et al., 1999; Kendeou et al., 2009; Storch & Whitehurst, 2002). Consistent with the ‘Simple View of Reading’, Hulme and Snowling (2011) argue that oral language problems produce deficits in reading comprehension based on several studies showing that poor comprehenders have early difficulties across a range of oral language skills (e.g., Catts, Adlof, & Ellis-Weismer, 2006; Nation et al., 2004).

The term ‘early oral language skills’ is broad and can be further broken down into more distinct language skills, such as comprehension and expressive abilities. Comprehension of oral language (e.g., receptive language) involves the understanding of spoken language and is often considered a prerequisite skill for reading comprehension because of its role in accessing meaning from the surface code. Vocabulary knowledge in particular has been identified as a strong predictor of reading comprehension (Tannenbaum, et al., 2006). Expressive language is frequently studied in the comprehension literature through narrative recall tasks because the ability to retell narratives is considered, in part, a function of how well the child understood the story and reflects memory for story content and knowledge of narrative structure (Catts et al., 1999; van den Broek, 1997). A reader’s ability to construct a coherent mental model of the text is dependent, in part, on the ability to recall relevant information from the text (van den Broek, White, Kendeou, & Carlson, 1999).

Oral comprehension and narrative retell are partially overlapping, but also somewhat separate abilities; however, most previous longitudinal studies linking them to later outcomes in reading comprehension have combined them into an oral language composite, making their relative contributions unknown (e.g., Catts et al., 1999; Kendeou et al., 2009; Storch & Whitehurst, 2002). In addition to examining them separately, testing their impact on later inferencing ability, and in a sample of children with SBM, will add significantly to the current literature.

The Present Study

Although some studies have begun to investigate the cognitive processes that may limit reading comprehension skill in children with SBM (Barnes et al., 2007), the developmental origins of these processes in both neurodevelopmental disorders and in typical development remains unclear. An empirical examination of this requires longitudinal studies, which are rare in studies of inferential comprehension, and in the literature on cognitive and academic outcomes in neurodevelopmental disorders such as SBM.

The goal of the current study was to examine the relation between preschool cognitive abilities and school-age ability on an important component skill of comprehension, the ability to make bridging inferences. Specifically, working memory/inhibitory control, oral comprehension, and narrative recall at 36 months of age were tested as mediators of the effect of group (SBM vs. TD) on bridging inference making at 9 years of age. The relation of these preschool abilities to achievement in reading comprehension was also tested.

Methods

Participants

Participants from the current study came from the same sample as study one. Therefore, details regarding recruitment and exclusionary criteria can be found earlier in this document. For the current study, children who did not complete all tasks were excluded from the analyses. Therefore the final sample reported on in the current study consisted of 78 participants ($n = 35$ for group with SBM). Demographic information for this sample is reported in Table 5. The group with SBM had more female participants than the TD group, $\chi^2(1) = 3.82, p = 0.05$, however sex was not related to any outcome measures and therefore not included as a covariate in subsequent analyses. The TD group had a significantly higher SES than the group with SBM, $F(1, 76) = 6.13, p = 0.02$, which, as in study one, reflects to the greater number of economically disadvantaged Hispanic families in the group with SBM in Texas. Again, because SES was significantly correlated with many of the outcome measures and it was included as a covariate in all analyses. Most of the children in the group with SBM had hydrocephalus treated with a diversionary shunt ($n = 32$); three had arrested hydrocephalus and no shunt. The majority had lower spinal lesions below L1 ($n = 31$).

Procedure

As in study one, children and their caregivers attended several laboratory visits or had testing completed in their home. Data for the current study are taken from 36 month and 9.5 year assessments.

Materials

Tasks Administered at 36 months

Six Boxes Task. This is an adapted self-ordered pointing task (Diamond, Prevor, Callender, & Druin, 1997; Petrides & Milner, 1982) that was modified to be suitable for preschool children. The child and examiner sit across from each other at a table with six boxes on it. First, the child watches the examiner hide a reward (a cheerio) under each box. Next, a screen is held up to cover the boxes from the child's view for five seconds. The screen is removed and the child is then asked to find one cheerio, representing one trial. Once the child finds a cheerio, it is removed from the box and given to the child. The screen is again held up to block the child's view of the boxes. After five seconds, the screen is removed and the child is then asked to find another cheerio. In order to do so, the child has to remember where they previously located the cheerio and not look under the same box again (i.e., they have to inhibit looking under a box in which they previously located a reward). Trials proceed to a maximum of 20. The child's score on this is the total number of searches the child required to locate all of the rewards. This task requires the child to keep track of his or her history of searching multiple boxes for rewards (working memory) and to inhibit return to a previously rewarded location (inhibitory control; Ewing-Cobbs, Prasad, Landry, Kramer, & DeLeon, 2004). This is an experimental task and as such reliability scores are not available.

Preschool Language Scale: 3rd Edition - Auditory Comprehension Subtest (Zimmerman, Steiner, & Pond, 1992). This task was administered at the 36-month timepoint. This test measures receptive language development through picture-word and picture-phrase matching tasks and requiring the child to follow directions (e.g., "point to the toy that is not red"). There are also items that assess the child's ability to make connections between concepts, to make basic

inferences, and that require syntactic knowledge. This subtest reports a test–retest reliability of 0.90.

Story Retell Task. In this experimental task, children are read a simple story about Winnie the Pooh while the researcher simultaneously acts out events in the story using toy figures. The child is then asked to tell the same story back to the examiner. The child’s score on this task is comprised of the number of story elements the child is able to recall, either verbally or nonverbally (e.g., acted out using the toy figures). This is an experimental task and as such reliability scores are not available.

School-Age Inferencing and Reading Achievement Measures

Bridging Inferences Task (Bridge-IT; Davis, Johnston, Barnes, & Desrochers, 2007; Pike et al., 2010). The Bridge-IT measures the ability to integrate information presented within text in order to make inferences when the text needing integration is in close proximity (i.e., continuous sentences; near condition) or farther apart (i.e., separated by three sentences; far condition). The child is asked to read four sentence stories and then to choose “the best sentence” from three possible answers to complete the story (see Table 6 for an example item). The child is not allowed to refer to the original story when considering their response. Choosing the best of the three possible answers demonstrated that the child made the correct inference. Of the 20 items, 10 were in the near condition and 10 in the far. Children received a raw score comprised of the total number of correct inferences made (out of 20). A previous study that included this task reported a reliability coefficient of 0.73 between parallel versions of the task (Davis et al., 2007).

Passage Comprehension Subtest, Woodcock-Johnson (WJ-III; Woodcock et al., 2001).

This measure requires the child to read sentences and passages of increasing length and to then generate a missing word to make a passage complete and coherent. Items become progressively

more difficult as passages increase in length and vocabulary and syntax become more sophisticated. This subtest reports an internal consistency of 0.88.

Letter-Word Identification Subtest, Woodcock-Johnson (WJ-III; Woodcock et al., 2001).

This untimed measure of word reading ability assesses how many real words a child can read.

This subtest reports an internal consistency of 0.94.

Results

Group comparisons of the hypothesized mediators, covariates, and outcome measures revealed that the TD group significantly outperformed the group with SBM on each measure (see Table 7). Statistical analyses were conducted as follows. First, a repeated measures ANOVA was completed to compare the pattern of word identification and comprehension performance between groups. Next, multiple mediation models were employed to determine if performance on the six boxes task, auditory comprehension test, and/or story retell were mediators of the effect of group (SBM vs. TD) on bridging inference making at 9 years of age. Finally, a second mediation model was tested to determine relation of the preschool abilities to achievement in reading comprehension.

A 2 (group) by 2 (reading measure: word identification and comprehension) repeated measures ANOVA revealed a main effect of group, $F(1, 98)=22.7, p < 0.001, \eta_p^2 = 0.151$, and a main effect of reading measure, $F(1, 98)=14.42, p < 0.001, \eta_p^2 = 0.107$, which was qualified by a significant interaction, $F(1, 98)=6.24, p = 0.014, \eta_p^2 = 0.056$. Tests of simple main effects revealed that for the group with SBM, the mean word identification score ($M = 100.04, SD = 24.21$) was significantly greater than their comprehension score ($M = 92.56, SD = 20.76$), $p = 0.003$, but that in the TD group there was no difference between word identification ($M = 115.21, SD = 15.09$) and comprehension ($M = 114.04, SD = 13.74$).

Mediation analyses were conducted using procedures outlined by Preacher and Hayes (2008). This method, described in detail in study one, permitted the inclusion of all the preschool predictors to be included together in the same models, thereby testing their individual effects while at the same time controlling for the effects of all variables in the models. As in study one, bootstrapping procedures were used and the point estimate for an indirect effect was considered significant if zero was not included in the 90% confidence interval (Hayes, 2009).

The first model that was tested was a multiple mediator model that consisted of group membership (SBM vs. TD) as the predictor and 36-month performance on the 6 boxes task (measure of working memory/inhibitory control), the auditory comprehension subtest of the PLS, and number of elements recalled on the story retell task as mediators. Performance on the Bridge-IT was the outcome measure and SES and word identification skill were entered as covariates.

Path coefficients from this model can be seen in Figure 5. The total indirect effect for this set of mediators was significant, with a point estimate of 1.77 and 90% bootstrap C.I. of 0.874 to 2.959, suggesting that performance on at least one of the mediating variables was a significant mediator in the relation between group and inferencing ability. An examination of the specific indirect effects was consistent with the model whereby the 6 boxes task, auditory comprehension, and story retell all significantly mediated the effect of group on bridging inferences with point estimates of 0.38, 0.91, and 0.48 and 90% C.I.s of 0.037 to 1.12, 0.34 to 1.67, and 0.06 to 1.14, respectively. The exclusion of zero from the confidence intervals suggests significant mediation (Hayes, 2011). With all mediators entered in the model, the direct effect from group to inferencing skill remained significant, $b = 1.84$, $t(77) = 2.72$, $p = 0.008$, which supports a partial mediation model.

Second, analyses were completed to extend these findings to include reading comprehension achievement. Bridging inferences has been identified in previous studies as a variable that can predict performance in reading comprehension ability above and beyond many other known predictors of the skill (e.g., Pike et al., 2010). Although none of the 36-month variables were directly related to paragraph comprehension after group, SES, and word identification were accounted for (see Figure 6, Model a), a second mediation model was run to test whether the 36-month variables exerted an indirect effect on paragraph comprehension via bridging inferences skill. Proceeding to test indirect effects in the absence of a significant total effect is recommended in models with multiple independent variables and small sample sizes (Hayes, 2009; MacKinnon, Krull, & Lockwood, 2000; Shrout & Bolger, 2002).

As shown in Figure 6, the second mediation model consisted of three independent variables (36-month performance on the 6 boxes task, auditory comprehension, and story retell), performance on the Bridge-IT as the mediator, and performance on the reading comprehension task as the outcome variable. Group, SES, and word skill were all included as covariates. Results indicated a significant indirect effect between all three independent variables and reading comprehension, via bridging inferences. Specifically, the point estimates of the indirect effects through the Bridge-IT task to reading comprehension for the 6 boxes task, auditory comprehension, and story retell were -0.10 (90% C.I. = -0.20 to -0.02), 0.10 (90% C.I. = 0.04 to 0.16), and 0.10 (90% C.I. = 0.002 to 0.23), respectively. As noted previously, the exclusion of zero from the confidence intervals is indicative of significant indirect effects (Hayes, 2011). In this model, the direct effects from each of the 36-month variables to reading comprehension were all nonsignificant, which is supportive of a complete mediation model.

Discussion

As part of a larger study on SBM and learning, the current study allowed for a longitudinal examination of the developmental trajectory of comprehension skill in children with SBM and their TD peers. Specifically, the ability of early cognitive abilities at preschool age to mediate the relation between group (SBM vs. TD) and later performance on bridging inferences ability at school-age was tested and these findings were then linked to a measure of reading comprehension achievement.

In terms of group comparisons, the group with SBM had lower performance on all of the variables included in the model. Although the group with SBM had a significantly lower word identification score than the control group, it was nonetheless age-appropriate (50th %ile). In addition, the reading comprehension score of the group with SBM was significantly lower than their word identification score. This difference was not present in the control group, which is consistent with the pattern often reported in the literature (Barnes & Dennis, 1992; Barnes et al., 2004a).

Mediation analyses allow for the inclusion of variables that are hypothesized to explain the relation between two other variables or sets of variables. The longitudinal design of the current study allowed for the testing of preschool abilities that were hypothesized to explain the relation between SBM status, a condition known at birth, and inferencing skill at age 9.5 years. The multiple mediation analyses were supportive of a model whereby the three early cognitive abilities (working memory/inhibitory control, oral comprehension, and narrative recall, all at 36 months), each explained a significant part of the relation between group and inferencing ability. In addition, even when the effect of the mediators was partialled out, the direct effect of group on inferencing ability remained significant.

Working Memory/Inhibitory Control

Working memory and inhibitory control are related constructs often conceptualized within the broader category of executive functions (Miyake et al., 2000). Each of these abilities has been implicated in reading comprehension for their role in supporting the integration of incoming information during reading (Swanson et al., 2007). Monitoring incoming information in order to appropriately update the mental model and actively inhibiting irrelevant information from entering working memory are examples of the role of executive functions in comprehension (Kintsch, 1994; Swanson et al., 2007). Recent studies suggest that executive processing may be particularly important for making bridging inferences, where the reader must reactivate previously read information, and connect relevant material with incoming information while simultaneously suppressing previously activated semantic information that is irrelevant to the current context (Cain et al., 2004; Gernsbacher, 1990; Pike et al., 2010).

Results from the current study extend previous work in this area, which has mostly examined the relation between executive functioning and inferencing and/or reading comprehension concurrently and has used verbal working memory and inhibitory control tasks. Measuring these skills in preschool necessitated an age-appropriate task that is less reliant on language processing. The adapted self-ordered pointing task used required the child to keep track of his or her history of searching multiple boxes for rewards and to inhibit return to a previously rewarded location (Ewing-Cobbs, et al., 2004; Petrides & Milner, 1982). Thus, performance on this task requires both working memory and inhibitory control ability in concert and is considered a measure of early executive functioning ability.

At age 36 months, the group with SBM required significantly more searches than the control group to locate all of the rewards, meaning that they chose already searched boxes

significantly more than the control group, suggesting weaker executive processing ability at this age (Ewing-Cobbs, et al., 2004). Importantly, the deficit in working memory/inhibitory control that children with SBM have compared to their TD peers at preschool age had a significant impact on inferencing ability at school age. This finding is compatible with models of reading comprehension that implicate weak working memory and inhibitory control in poor comprehenders (Barnes et al., 2007; DeBeni & Palladino, 2000; Gernsbacher & Faust, 1991) and provides stronger support for the hypothesis that early deficits in this area play a causal role in later comprehension difficulties.

Oral Language

Early oral language abilities have been linked to later reading comprehension in several longitudinal studies (e.g, Catts et al., 1999; Kendeou et al., 2009; Storch & Whitehurst, 2002), but the relative contributions of preschool receptive language and narrative retell abilities to later outcomes in bridging inference skill have not been examined, in particular in a sample of children with SBM who have known difficulty with this skill.

In the current study, the measure of preschool receptive language was a significant mediator between group and bridging inferences. This task purports to measure receptive language comprehension and in doing so, relies heavily on receptive vocabulary knowledge, which consistently emerges in the literature as one of the strongest predictors of reading comprehension (Tannenbaum et al., 2006). Vocabulary knowledge and language comprehension skills are often considered important prerequisites for reading comprehension because of their role in accessing meaning from the surface code. In addition to measuring receptive vocabulary skill, the PLS includes items that require the child to follow directions and make basic inferences. These items implicate higher-order cognitive processes, such as the integration and

assembly of information, which are known to be weaker in children with SBM (Barnes et al., 2007). It follows, then, that this would in turn impact later bridging inference skill, which also relies more heavily on these processes. Taken together, the current study suggests that deficits in oral language comprehension are present in children with SBM in preschool and these have a significant impact on the later development of bridging inferences skill.

Children with SBM also performed more poorly at 36 months on their ability to retell a story that was read and acted out to them using toys, and this narrative retell ability was also found to be a unique mediator of the relation between group and inferencing ability. Although narrative retell ability depends on how well the child can encode and retain story content, and their oral comprehension skills, such as vocabulary and syntactic knowledge, this component of oral language emerged as a unique mediator in addition to auditory language comprehension and working memory simultaneously entered into the multiple mediation model. This suggests that there is something unique about the ability to recall and/or express story content that is important for later inferencing skill.

Several variations of early narrative comprehension tasks have emerged as important predictors of reading comprehension in school-age children (e.g., Kendeou et al., 2009; Lynch et al., 2008; Roth, Speece, & Cooper, 2002). Work by van den Broek and colleagues indicates that for young children, narrative recall performance is dependent on the causal structure of the story; younger children are able to recall more when there are a higher number of meaningful connections between elements in the narrative (van den Broek, 1997). Their research suggests that even children as young as preschool age make causal connections (i.e., inferences) between concrete information from presented narratives, and children who make more of these connections have a better understanding of the narrative and thus are better able to recall more of

the core elements of the story. With age, children become increasingly able to make more complex inferences (e.g., between underlying goals of characters or related to emotions of characters; Oakhill & Cain, 2007; van den Broek, 1997). The current findings add to the literature of how this skill develops, by identifying narrative recall ability at 36 months as a significant mediator of later, more complex, inferencing skill. Narrative recall and bridging inferences have been highlighted in the literature as important skills contributing to mental model construction, which is a weakness for children with SBM (Barnes et al., 2007).

Bridging Inferences and Reading Comprehension

In order to connect the findings from the first model to more general comprehension skill, a second mediation model was run. Interestingly, this model implied that although the 36-month predictors did not exert a direct effect on paragraph comprehension skill at age 9.5 years, they each had a significant indirect effect on comprehension through bridging inferences skill.

The ability to make bridging inferences has been theorized as a component skill of reading comprehension and has been found in previous studies as a variable that can predict performance in reading comprehension ability above and beyond many other known predictors of the skill (e.g., Cain et al., 2004; Pike et al., 2010). This finding was replicated and extended in the current study by a model which suggests that in the early preschool years, abilities which have been noted to be important for reading comprehension in adult and school-age populations (i.e., working memory/inhibitory control, oral language comprehension, and narrative recall), indirectly affect comprehension some six years later through bridging inference skill. This relation was found even when group, SES, and word identification skill were controlled for in the model. This suggests that inferencing ability is an important part of the developmental

pathway that leads to comprehension skill by connecting early cognitive abilities to later reading comprehension.

In addition to providing further evidence that inferencing ability is an important skill for successful reading comprehension (Cain et al., 2004; Kintsch, 2005), it also broadens the populations for which this is the case. Children with SBM had poorer performance in working memory/inhibitory control, oral language comprehension, and narrative recall at 36 months – all abilities that analyses from the current study suggest relate to poorer bridging inference skill, which in turn affects reading comprehension.

Conclusion

The current study is unique in its ability to contribute to an understanding of both typical and atypical reading comprehension, blending theories from the developmental, cognitive, and neuropsychological literature. Very few studies have explored the developmental trajectory of reading comprehension longitudinally and even fewer with samples who have particular difficulty with comprehension, such as SBM. The finding that preschool cognitive abilities impact inferencing skill over six years later adds to evidence that is suggestive of a causal relation. From a very early age, children with SBM are disadvantaged in terms of important precursors to reading comprehension, which in turn continue to affect inferencing and general comprehension skill through school-age.

Chapter 4

General Discussion

Taken together, the two studies in this dissertation provide unique findings pertinent to general reading development, and to reading comprehension, in particular. In contrast to the large volume of literature on normal and deficient word reading, relatively little is known about the development of reading comprehension. Given that the existence of a specific learning disability in reading comprehension is now largely accepted by researchers and clinicians (Cain & Oakhill, 2007; Fletcher et al., 2007), longitudinal studies that endeavor to delineate the cognitive underpinnings of typical and atypical comprehension development are imperative for informing clinical applications, namely prevention, and remediation.

In addition to contributing to knowledge of the reading profile of children with a specific neurodevelopmental disorder, SBM, results from the current set of studies have theoretical implications for both typical and atypical development of reading comprehension skill. Results also have practical implications related to curriculum development and clinical assessment and intervention, which are discussed below.

Reading Profile of Children with SBM

Within the reading domain, children with SBM have been found in the literature to have a good word identification/poor comprehension profile (Barnes et al., 2007). Uneven skill development has also been found more specifically within the comprehension domain, in that children with SBM can access the surface code of the text as well their peers but when the construction of meaning involves the integration or assembly of information their comprehension is weaker (Barnes et al., 2007). Results from the current set of studies expand the knowledge of children with SBM's relative strengths and weaknesses within the reading domain by (1)

replicating the word identification-comprehension discrepancy not found in the control group; (2) clarifying that their reading fluency is also impaired and (3) demonstrating that an important component skill of comprehension, bridging inferences, is weak in this group and contributes to their difficulties with reading comprehension.

Theoretical Implications for Reading Comprehension

The role of preschool language comprehension for later outcomes in reading comprehension emerged as a major finding in both studies. The group with SBM had clear deficits in language comprehension at 36 months, which not only went on to directly affect later outcomes in reading comprehension, but also had indirect effects through phonological awareness and then word identification. Moreover, results from study two highlight the role of early language comprehension in bridging inferences, an important component skill of reading comprehension. Taken together, this is compelling evidence that fits with the simple view of reading (Hoover & Gough, 1990), which contends that when word identification is intact, comprehension failure arises from general difficulty with language comprehension.

While this view offers a parsimonious explanation, and has a considerable amount of support in the literature, it fails to take into account the potentially important cognitive underpinnings of language comprehension. Furthermore, there is substantial evidence (including findings from the current study) that suggests there is room for increased specificity concerning the exact types of language difficulties that lead to poor comprehension.

Collectively, findings from study one and study two suggest that some degree of theoretical integration is required in order to capture the full extent of reading comprehension development and why it breaks down for some children. As is often the case in developmental research, there seems to be value in drawing on the adult literature for this. Cognitive theories

from research with adults emphasize individual differences in both the component skills of comprehension, such as inferencing (Kintsch, 1988), as well as cognitive processes, such as working memory (Gernsbacher, 1993), in constructing a coherent and integrated mental model (Johnson-Laird, 1983).

Gernsbacher's work in particular endorses the view that successful language comprehension is dependent on cognitive resources such as working memory and inhibitory control (Gernsbacher, 1990). There is evidence that these variables play a unique role in comprehension skill for children as well (Barnes et al., 2004b; Cain et al., 2004; Palladino et al., 2001; Pike et al., 2010). In addition to language comprehension, findings from study two also implicate early working memory/inhibitory control and inferencing skill in school-age comprehension ability. It seems plausible that difficulties in cognitive processes such as working memory precede difficulties in early oral language comprehension, although a recent review paper by Hulme and Snowling (2011) argued that the cognitive deficits found in poor comprehenders are secondary to their limitations in oral language comprehension. Whether a causal (or reciprocal) relation exists between these cognitive process and oral language in young children and poor comprehenders, and if so, what the connection of this relation might be to reading comprehension development is remains to be tested. These findings speak to the complexity of the processes involved in reading comprehension and the extent of research that is still required.

Clinical Implications

The results from both of these studies have clinical implications for general reading instruction and curriculum development as well as preventive and remediation intervention for atypical reading development, particularly with regard to reading comprehension.

The literature review presented in this dissertation combined with current findings clearly point toward the importance of not focusing solely on word reading skills in early reading instruction. Although word identification and its precursors are a crucial component, it is now known that comprehension skills will not necessarily develop automatically once fluent word reading is mastered. Therefore, a focus on teaching the skills that support later comprehension should be integrated into mainstream instruction, and importantly, findings suggest that educators should not wait until after word reading skills have consolidated before introducing explicit instruction in these skills. Supporting oral language skills such as vocabulary knowledge, syntax as well as more comprehension specific strategies such as the identification of main themes and ideas and drawing connections between ideas should be an integral part of reading instruction beginning as early as preschool and continue throughout elementary school (Kendeou, van den Broek, White, & Lynch, 2007).

For those children who present with a good word identification/poor comprehension profile, including but not limited to those with SBM, research suggests that intervention should focus on teaching language skills and comprehension strategies. A recent randomized control trial focusing on poor comprehenders oral language skills led to significant improvements in reading comprehension (Clarke, Snowling, Truelove, & Hulme, 2010). Effects were larger and maintained longer for those who received this intervention compared to one focusing on text comprehension strategies. Although not necessarily addressing the root cause of comprehension difficulties, there is likely some utility in the explicit teaching of comprehension strategies that may help poor comprehenders compensate for their deficits (Barnes et al., 2007), particularly for children with SBM whose metacognitive strategies may be better developed than more basic text comprehension processes such as inferencing (English et al., 2010; Dennis & Barnes, 2010).

Study Limitations

It is first important to emphasize that while using longitudinal data is stronger than using cross-sectional data for testing causal relations, they are not as strong as experimental manipulations and it is possible other unmeasured variables could be accounting for some findings. Therefore, although many of the results are discussed in terms of being consistent with causal hypotheses, no definitive statements regarding causality can be made based on the current results. In addition, a common difficulty with longitudinal research is managing missing data from between or within timepoints. In study one, the software for modelling the growth curves was able to retain the majority of the participants by taking a full information maximum likelihood approach (Muthén & Muthén, 2010), however the mediation models and path analysis included in both studies were conducted using software that excluded participants with missing data on any of the variables entered into the analysis (i.e., listwise deletion; Hayes, 2012). Although bootstrapping procedures were employed to manage this problem, the sample size was reduced in some analyses.

The generalizability of the current study, in particular the findings from study one related to growth rates, is limited by the age range for which reading skill was tested. There may indeed be variability in reading skill growth rate when comparing children with SBM to control groups across different age ranges. It is also important to consider potential task limitations related to the assessment of reading skill at each timepoint. With only a single measure each of word identification, fluency, and comprehension, it is possible that more specific components of these skills were missed, in particular for comprehension (e.g., see Cutting & Scarborough, 2006). The Bridge-IT, story retell, and 6 boxes tasks employed in study two are experimental tasks that lack comprehensive indicators of reliability and validity. Furthermore, performance on the 6 boxes

task provides a score that reflects both working memory and inhibitory control, meaning it was impossible to parse out whether there are separate effects of each.

Finally, it is important to note that the control group performed above age-expectations on the word identification and passage comprehension tasks, warranting some caution related to the interpretation of results and group differences.

Final Thoughts and Future Directions

A 2001 review paper by the Snow and the RAND Reading Study Group, a panel of experts in reading research, described the current knowledge base on reading comprehension as “sketchy, unfocused, and inadequate as a basis for reform in reading comprehension instruction” (p. xii). Although there has been significant progress since this review was published, the reading comprehension literature as a whole is in need of longitudinal studies with the aim of continuing to work towards models of comprehension development and disability. As noted by Cain and Oakhill (2007), a general issue with longitudinal studies is that the pattern of results can depend on what variables are entered and how they are measured. These two issues have particularly plagued the reading comprehension literature in that studies differ significantly with regard to the skills tested and the ages, characteristics, or conditions of the participants. Research that works towards creating more appropriate assessment tools, such as the Bridging Inferences Task used in study two, is essential. In addition, more consistency and replication across studies is required. Specific questions that remain unanswered by the current study are whether differences in growth rates exist outside of the age range that was tested in study one and how the trajectory of comprehension skill continues to develop through the middle-school years and adolescence. In addition, further clarification of the roles of specific early language skills in later component skills of comprehension, and their cognitive underpinnings, is required.

The word reading/word identification literature has benefited significantly from research spanning different disciplines such as cognitive functioning, typical development, neuropsychology, and education. Findings from the current study are unique in their ability to contribute to an understanding of both typical and atypical reading comprehension, integrating theories from a range of disciplines, which in turn leads to equally widespread practical implications. Research that continues to build upon and integrate knowledge from a wide range of disciplines will also prove useful in understanding how children acquire comprehension skills, why it fails for some, and what can be done to prevent and remediate difficulties in what is the ultimate goal of reading.

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Table 1

Demographic Information for SBM and TD groups (Study One)

	SBM (N = 53)	TD (N = 53)
Houston	32	28
Toronto	21	25
Ethnicity		
Caucasian	22	30
Hispanic	23	13
African American	4	1
Other	4	9
Sex		
Male	20	30
Female	33	23
Mean (SD) Hollingshead SES Score	29.40 (16.65)	39.26 (16.57)

Table 2

Means and Standard Deviations for Variables by Group (Study One)

	TD Group		SBM Group	
	M	SD	M	SD
PLS3-AC **	110.49	17.54	87.22	20.77
CTOPP – PA *	99.02	9.76	90.55	9.76
WJ-III-LWI				
7.5 **	120.02	20.20	106.53	24.78
8.5 **	115.62	17.33	103.13	25.76
9.5 **	115.21	15.10	101.04	24.21
WJ-III-RF				
7.5 **	108.72	13.61	94.17	15.60
8.5 **	106.18	15.52	92.71	11.69
9.5 **	106.44	18.17	92.32	11.67
WJ-III-PC				
7.5 **	117.11	16.39	97.98	16.19
8.5 **	116.10	14.08	95.47	22.64
9.5 **	114.04	13.74	92.32	20.76

Note. PLS3-AC = Preschool Language Scale – Auditory Comprehension Subtest (standard score); CTOPP-PA = CTOPP Phonological Awareness Composite (standard score); WJ-III-LWI = Woodcock Johnson Letter-Word ID Subtest (standard score); WJ-III-RF = Woodcock Johnson Reading Fluency Subtest (standard score). WJ-III-PC = Woodcock Johnson Passage Comprehension Subtest (standard score); Group comparisons, with SES as a covariate, * = $p < 0.05$; ** = $p < 0.01$.

Table 3

Unstandardized path coefficients of multiple mediation models from group to reading outcome at age 7.5.

Model Outcome: Age 7.5 reading skill	Total effect of group (c path)	Direct effect of group (c' path)	Mediation by AC			Mediation by PA			Mediation by RAN		
			(a1 path)	(b1 path)	(a1xb1)	(a2 path)	(b2 path)	(a2xb2)	(a3 path)	(b3 path)	(a3 x b3)
Word ID	6.56**	2.17	5.55**	0.36*	1.96 ⁺	5.32**	0.42*	2.19 ⁺	2.19**	0.09	0.17
Fluency	9.51**	4.57	4.13*	0.19	0.78	4.51*	0.79**	3.55 ⁺	1.93**	0.32	0.62
Comprehension	4.69**	1.48	5.44**	0.22*	1.17 ⁺	5.24**	0.32**	1.67 ⁺	2.16**	0.17	0.36

Note. AC = Preschool Language Scales - Auditory Comprehension Subtest; PA = CTOPP Phonological Awareness Score; RAN = CTOPP Rapid automatized naming; SES entered as covariate in all models. * = $p < 0.05$; ** = $p < 0.01$; ⁺ = 0 excluded from 90% C.I., indicating significant mediation.

Table 4

Indirect effects from each path tested in sequential path analysis

Path	Indirect effect	Lower Limit C.I.	Upper Limit C.I.
Group → AC → PC	1.00 *	0.28	2.09
Group → AC → PA → PC	0.29	-0.06	0.78
Group → AC → LWI → PC	0.20	-0.64	1.24
Group → AC → PA → LWI → PC	0.69 *	0.38	1.26
Group → PA → PC	0.16	-0.04	0.66
Group → PA → LWI → PC	0.39	-0.01	1.02
Group → LWI → PC	0.99	-0.49	2.51

Note. Group = SBM vs. TD; AC = Preschool Language Scales - Auditory Comprehension Subtest; PA = CTOPP Phonological Awareness Score; LWI = Woodcock Johnson Letter-Word ID; PC = Woodcock Johnson Passage Comprehension. * = 0 excluded from confidence interval, indicating the indirect effect is significant.

Table 5

Demographic Information for SBM and TD groups (Study Two)

	SBM (<i>N</i> = 35)	TD (<i>N</i> = 43)
Houston	16	18
Toronto	19	25
Ethnicity		
Caucasian	19	26
Hispanic	13	10
African American	3	1
Other	0	6
Sex		
Male	11	23
Female	24	20
Mean (SD) Hollingshead SES Score	30.06 (14.79)	39.08 (16.94)

Table 6

Example item from the Bridging Inferences Task (Bridge-IT).

Near condition:

It was the day of the big bike race at Emily's school.
 All of her friends were fastening ribbons to their handlebars.
 Emily always wants to win and be the best.

Emily had never ridden a bike before and was scared to learn.

- a) Emily jumped her bike across a wide canyon.
- b) Emily was so fast she won the gold ribbon.
- c) *Emily was slower than most but she finished the race.*

Far condition:

Emily had never ridden a bike before and was scared to learn.

It was the day of the big bike race at Emily's school.
 The bike race was a fundraiser for the local hospital.
 All of her friends were fastening ribbons to their handlebars.
 Emily always wants to win and be the best.

- a) Emily jumped her bike across a wide canyon.
- b) Emily was so fast she won the gold ribbon.
- c) *Emily was slower than most but she finished the race.*

Note. Target sentences are in bolded font; correct answers are in italicized font.

Table 7

Means and Standard Deviations for Mediators and Outcome Variables by Group

	TD Group		SBM Group	
	M	SD	M	SD
<i>Mediators (age 36 months)</i>				
6 Boxes Task**	7.65	3.22	10.62	4.43
PLS-AC**	110.43	17.32	87.28	20.83
Story Retell Task*	5.86	2.23	3.49	1.96
<i>Outcome Variables (age 9.5 years)</i>				
Bridging-Inferences Task**	16.28	2.94	11.71	3.54
WJ-III-PC **	114.04	13.74	92.56	20.76
<i>Covariates</i>				
WJ-III LWI (9.5 years)**	115.21	15.09	100.04	24.21
SES*	39.08	16.94	30.06	14.79

Note. 6 Boxes Task = number of searches required; PLS-AC = Preschool Language Scale – Auditory Comprehension Subtest (standard score); Story Retell Task = total number of elements recalled from story; Bridging-Inferences Task = total number of correct inferences made; WJ-III-PC = Woodcock Johnson Paragraph Comprehension Subtest (standard score). WJ-III-LWI = Woodcock Johnson Letter-Word ID Subtest (standard score). Group comparisons, with SES as a covariate.* = $p < 0.05$; ** = $p < 0.01$.

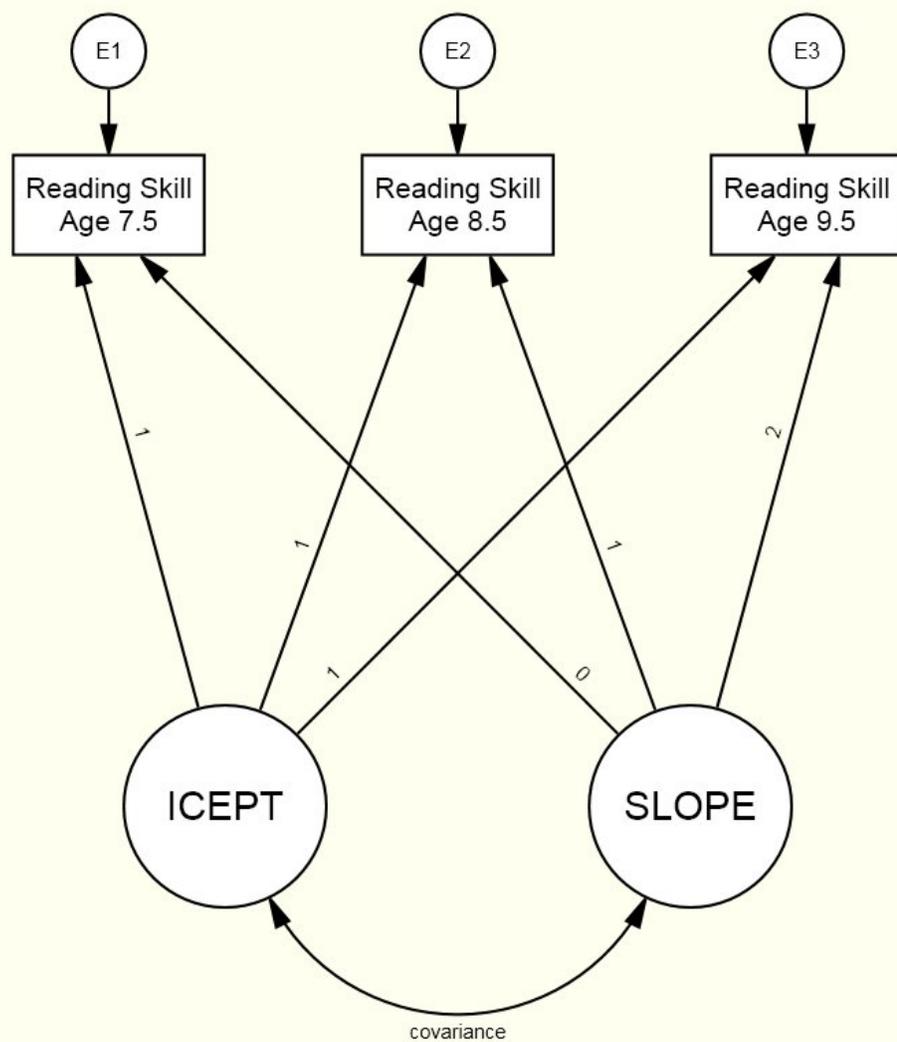


Figure 1. Unconditional latent growth curve model depicting change in reading skill over time.

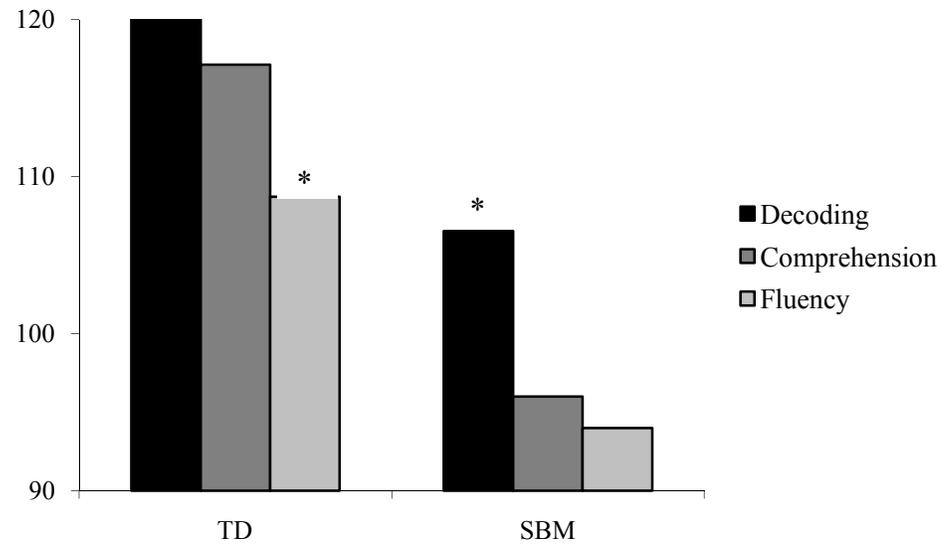


Figure 2. Bar graph depicting the different pattern of relative strengths and weaknesses in reading skill between groups.

*Note.** = Reading skill is significantly different from others within group.

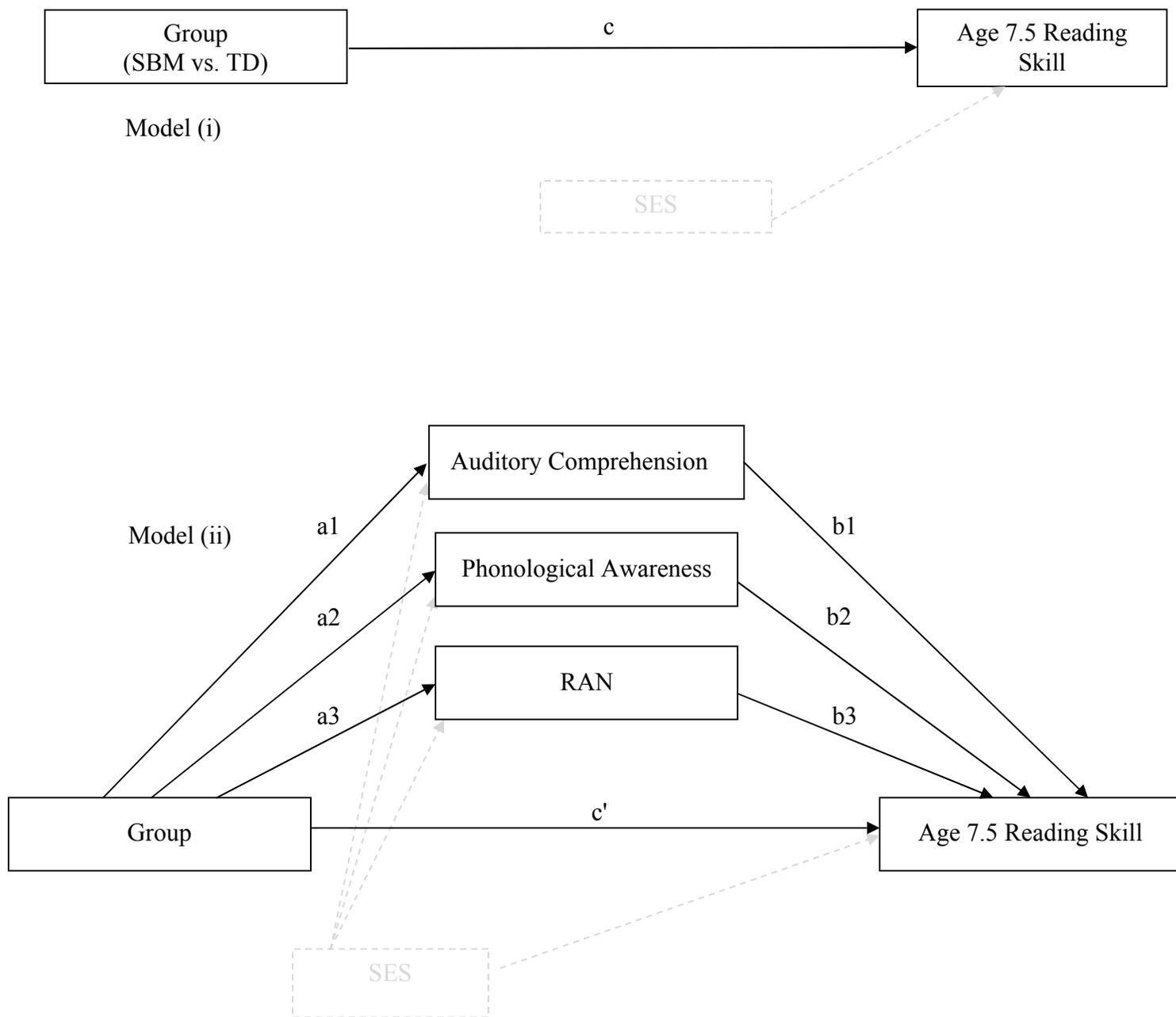


Figure 3. Multiple mediation model of age 7.5 reading skill. (i) unstandardized path estimates for the total effect of group on reading skill (path c) and (ii) unstandardized path estimates for the indirect effects of group on reading skill.

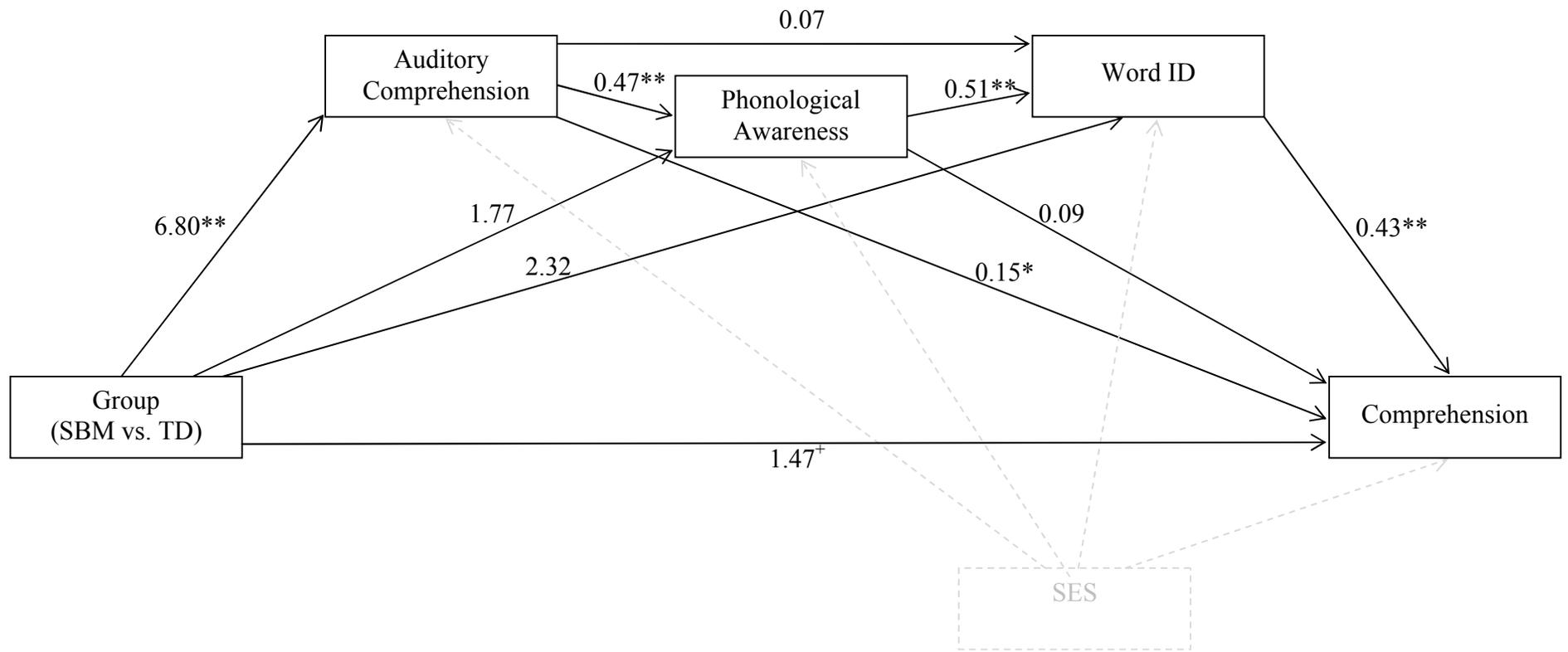


Figure 4. Sequential path analysis from group to age 7.5 passage comprehension (unstandardized coefficients).
 * = $p < 0.05$; ** = $p < 0.01$; + = $p < 0.10$.

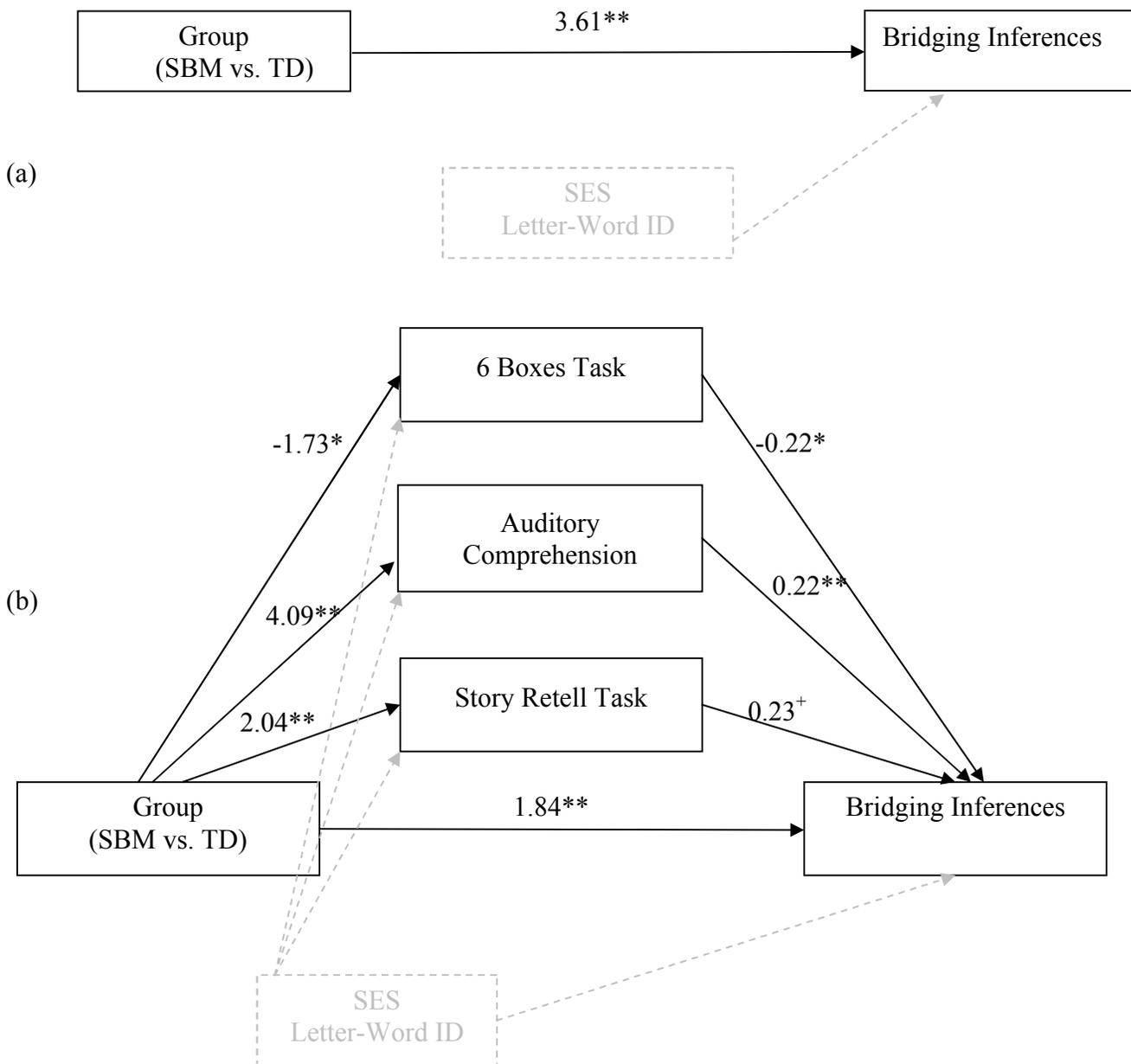
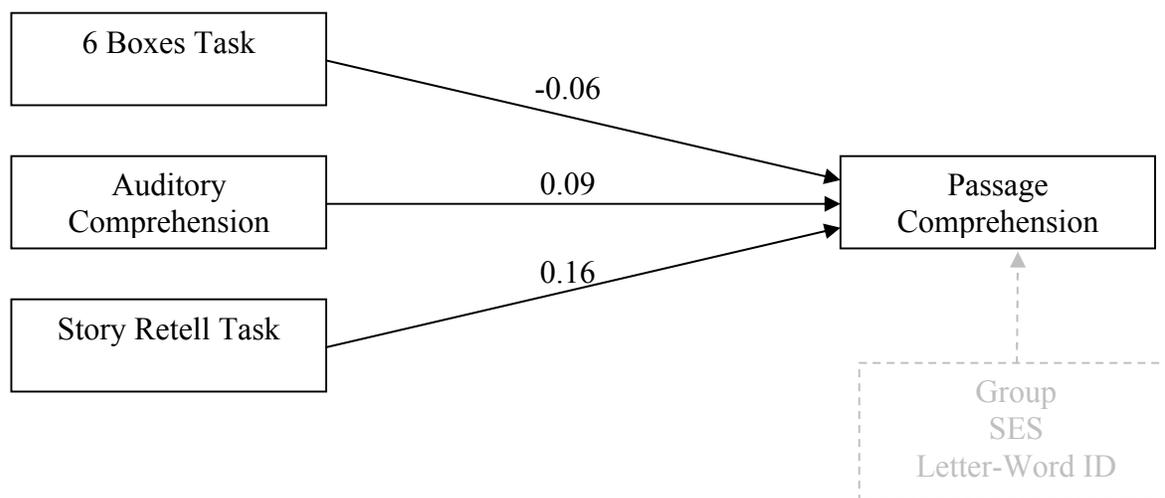


Figure 5. Multiple mediation model of bridging inferences skill. (a) unstandardized path estimates for the total effect of group on bridging inferences skill (controlling for SES and word identification skill) and (b) unstandardized path estimates for the indirect effects of group on bridging inferences skill (controlling for SES and word identification skill. $^+ = p < 0.10$; $** = p < 0.05$; $*** = p < 0.00$).

(a)



(b)

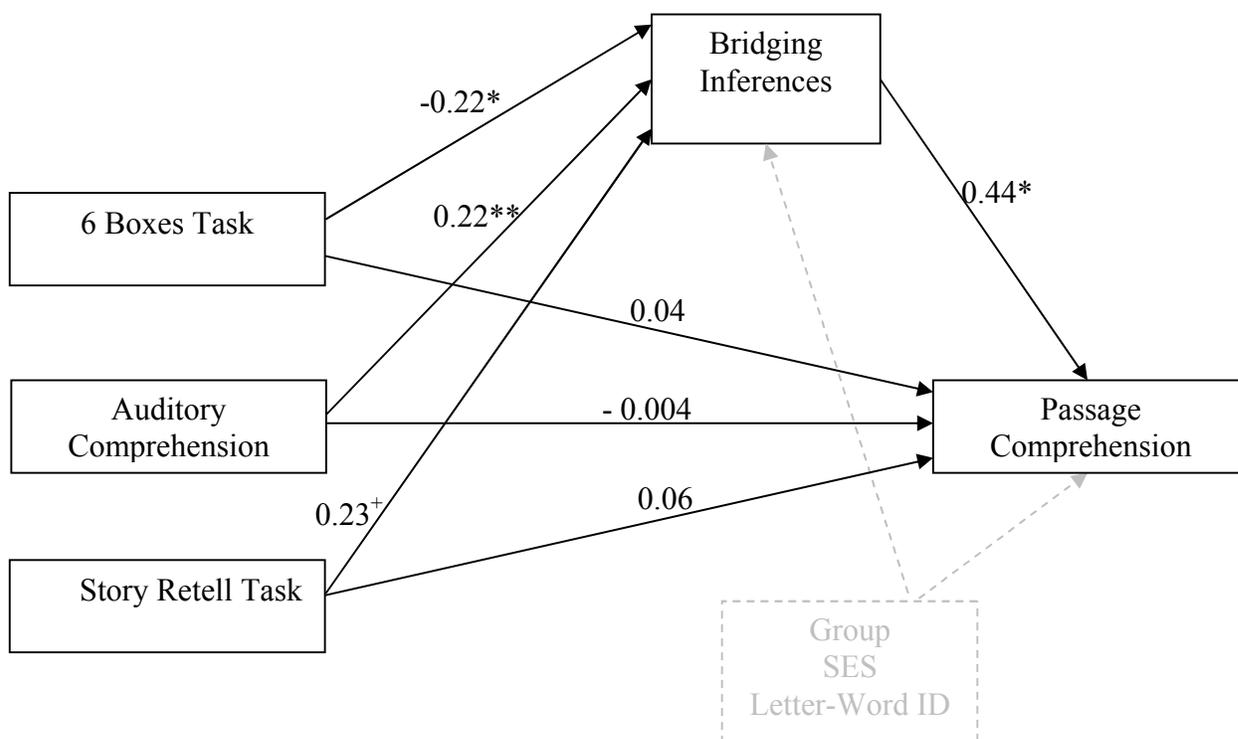


Figure 6. Mediation model of paragraph comprehension with multiple IVs (a) unstandardized path estimates for the total effect of preschool predictors on paragraph comprehension (controlling for group, SES, and word identification skill) and (b) unstandardized path estimates for the indirect effects of preschool predictors on paragraph comprehension (controlling for group, SES, and word identification skill). ⁺ = $p < 0.10$; * = $p < 0.05$; ** = $p < 0.001$

APPENDIX

Table A1

Bivariate Correlations Between Variables in Study One

Variable	1	2	3	4	5	6	7	8	9	10	11
1. PLS-AC											
2. PA	0.673*										
3. RAN	0.401*	0.439*									
4. WJ-LWI 7	0.487*	0.564*	0.356*								
5. WJ-RF 7	0.434*	0.681*	0.375*	0.701*							
6. WJ-PC 7	0.663*	0.691*	0.353*	0.761*	0.755*						
7. WJ-LWI 8	0.537*	0.612*	0.485*	0.896*	0.708*	0.727*					
8. WJ-RF 8	0.559*	0.626*	0.502*	0.679*	0.811*	0.765*	0.747*				
9. WJ-PC 8	0.684*	0.657*	0.488*	0.734*	0.705*	0.801*	0.798*	0.739*			
10. WJ-LWI 9	0.509*	0.617*	0.390*	0.893*	0.728*	0.698*	0.933*	0.703*	0.755*		
11. WJ.RF 9	0.562*	0.651*	0.499*	0.650*	0.850*	0.734*	0.693*	0.875*	0.710*	0.688*	
12. WJ.PC 9	0.641*	0.621*	0.456*	0.699*	0.738*	0.801*	0.766*	0.751*	0.854*	0.764*	0.752*

Note. PLS-AC = Preschool Language Scales 3rd Edition, Auditory Comprehension Subtest; PA = Phonological Awareness; RAN = Rapid Automatized Naming; WJ = Woodcock-Johnson Test of Academic Achievement, 3rd Edition; LWI = Letter-Word ID subtest; RF = Reading Fluency Subtest; PC = Passage Comprehension Subtest; 7 = administered at age 7.5 timepoint; 8 = administered at age 8.5 timepoint; 9 = administered at age 9.5 timepoint.

*= $p < 0.01$

Table A2

Bivariate Correlations Between Variables in Study Two

Variable	1	2	3	4	5	6	7
1. SES							
2. Sex	0.094						
3. 6 Boxes	-0.070	0.176					
4. PLS-AC	0.353**	0.012	-0.162				
5. Story Retell	0.271*	-0.118	-0.328**	0.408**			
6. Bridge-IT	0.386**	-0.027	-0.391**	0.652**	0.541**		
7. WJ-PC 9	0.295**	0.016	-0.306**	0.565**	0.473**	0.711**	
8. WJ-LWI 9	0.126	0.050	-0.226*	0.364**	0.272*	0.412**	0.712**

Note. 6 Boxes = total number of searches on 6 boxes task; PLS-AC = Preschool Language Scales, 3rd Edition – Auditory Comprehension Subtest; Story Retell = total number of elements recalled; Bridge-IT = total number of inferences made; WJ-PC 9 = Woodcock Johnson III Tests of Achievement, Passage Comprehension Subtest (administered at age 9.5); WJ-LWI 9 = Woodcock Johnson III Tests of Achievement, Letter-Word ID Subtest (administered at age 9.5).

* = $p < 0.05$; ** = $p < 0.01$.