COGNITIVE PROCESSES RELATED TO READING AND ARITHMETIC

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ABSTRACT

This study explored the robustness of the low achievement approach for diagnosing learning difficulties in a group of one hundred and twenty-one grade 3 children in two inner city schools. The children were tested using standardized tests of achievement and experimental cognitive measures. The cognitive profiles of the low achievers, the children with difficulties in reading and/or arithmetic, were examined and the results showed that the defining feature in these low achievers was a phonological deficit. The Chi square tests in this study contributed to providing important information that was particularly useful for individual diagnosis. The pattern of association between low reading achievement and the measures tapping into phonological processing showed that there was little or no likelihood of being normally achieving in reading when the phonological processing skills were low. Three different cutoff points for low achievement were used reflecting differing levels of stringency. Children in the low groups, regardless of the cutoff points used, exhibited similar characteristics in terms of their cognitive deficits. Hierarchical regression analyses of the predictor variables related to reading and arithmetic revealed that phonological processing contributed to accounting for large proportions of unique variance in both reading and arithmetic.

The findings in this study suggests that the phonological core deficit model for understanding reading difficulties is robust even in a population where there are confounding social variables associated with the children (e.g., low SES and ESL home background). As well, phonological processing also emerged as being important in contributing to children's achievement in arithmetic. The efficacy of the low achievement approach was affirmed in this study: children with cognitive processing deficits related to reading or arithmetic were identified using a low cutoff of somewhere around or below the 25th percentile in standardized achievement tests. Furthermore, using the low achievement approach had the benefit of avoiding biases previously identified in IQ-achievement discrepancy definitions of learning disability.

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who have achieved academic success despite great challenges.

Well done, gentlemen!

1. INTRODUCTION

1.1 Differential treatment of children with low achievement

Low achievement is a serious problem in our society today. Usually, poor academic achievement is a strong predictor of dropping out before high school completion (Battin-Pearson et al., 2000). Substance abuse, suicide, and social maladjustment, have been found to be linked with low achievement in school (e.g., Barwick & Siegel, 1996; Karacostas & Fisher, 1993; Maag, Irvin, Reid, & Vasa, 1994: McBride & Siegel, 1997). General social maladjustment, as a risk factor, increases with age as a child accumulates negative experiences of learning failures and develops a growing loss of self-esteem (e.g., Beitchman, Wilson, Douglas, Young, & Adlaf, 2001). Low achievement related to learning disabilities (LD) or other causes, if not identified in a timely way, can have devastating effects. Here is the story of a former UBC Education student, Spencer (not his real name), which has captured the universal experience of many children who faced severe learning difficulties in their early years:

> I spent two years in grade 3 and can say to this day I still don't have a good grip on basic spelling and math. It was during those early years between grades three and four that I visited a number of specialists, from neurologists to reading specialists and everyone in between. I can't say if anything came of it. One told my mother I would never learn to read or write. I've read the reports…I began using drugs and alcohol in grade eight or nine. They helped me to fit in and deal with the stress of life. I quit nineteen years later with the help of Narcotics Anonymous and enrolled in university to get a degree.

Spencer shared his story in a class paper on Inclusion while taking a course on teaching students with special needs. He was able to compensate for his learning disabilities with a great deal of hard work while at UBC and had graduated successfully. He now teaches in a secondary school in British Columbia. This was a rare story with a happy ending.

Differential treatment of children with low achievement – that is, providing intervention for some and leaving others to struggle – based on a set of assumptions rooted in the discrepancy-based tradition of defining learning disability (LD) have produced some devastating consequences in the past. The discrepancy-based definition of learning disability stipulates that children whose achievement scores are consistent with their IQ scores are regarded as ordinary low achievers (LA). At the same time, learning disabled (LD) children are those whose achievement scores are not consistent with their average to above average IQ scores; these children are considered "underachievers" whose low achievement is "unexpected" because their achievement scores are not consistent with their average to above intelligence (IQ) scores in regression-based statistical procedures (e.g., Rutter & Yule, 1975: see also Fletcher et al., 1994). For a long time, the field of learning disabilities operated under the assumption that there are two distinctive types of low achieving children (e.g., Rutter & Yule, 1975): the learning disabled (LD) who can benefit from intervention because they are more intelligent and have learning potential; and the low achievers (LA), sometimes referred to as "garden-variety" low achievers (e.g., Stanovich, 1988) or poor readers, who cannot benefit from intervention because they are limited by their low intelligence and lack of learning potential. In the discrepancy-based definition of LD, IQ test scores are used as a proxy for intelligence or learning potential.

Implicit in the discrepancy-based definition of LD is the notion that unexpected low achievement (Kavale & Forness, 2000) is the defining feature of LD. Children with a discrepancy between their IQ scores and their achievement scores would be considered as children with learning disability (LD); that is, these children's performance in the standardized test is regarded as not consistent with their average to above average IQ scores. As for the children with low IQ test scores and low standardized achievement test scores, their low achievement is considered as a reasonable and therefore an "expected" outcome of their low intelligence. Children in this category are the LA children who generally do not get additional educational assistance in school whereas LD children do (Siegel, 1989a).

Although the discrepancy-based tradition has deep roots in the field of learning disabilities (Swanson, 2000), there are compelling reasons for not using a discrepancy-based approach to differentiate low achieving children (e.g., Aaron, 1997; Fletcher et al., 2001; Siegel, 1989a). The discrepancy-based formulae rely heavily on IQ tests scores for measuring intelligence. Children who fit one or more of these descriptions, for example, the learning disabled (LD), children of low SES background, and children from an ESL background, are more likely to obtain spuriously low IQ tests scores (e.g., Sacks, 2000; Siegel, 1992; Gunderson & Siegel, 2001; Siegel & Himel, 1998); and, if a discrepancy-based formula is used for LD identification, some children may be identified as low achievers (LA) even though they have similar cognitive processing deficits related to reading and arithmetic as those who are LD (e.g., Fletcher et al., 1994; Geary, 2004). The consequence is that, based on a faulty LD identification process, some children will not receive the help they need to succeed academically.

In recent years, the inequity created by the IQ-discrepancy based model of LD diagnosis has attracted a great deal of attention and criticism (e.g., Aaron, 1997; Fletcher, Coulter, Reschly, & Vaughn, 2004; Lyon, 1997; Siegel, 1998; Gunderson & Siegel, 2001; Stuebing et al., 2002; Swanson, 2000; Vellutino, Scanlon, & Lyon, 2000). Clearly, there is a need to develop alternative ways to effectively diagnose the learning problems of low achieving children and to provide meaningful intervention for them to succeed academically. Based on scientific advances in the last thirty years of research on reading and arithmetic development in children, the field of learning disability is now ready to move towards adopting a new paradigm in the identification of learning problems in children with low academic achievement (e.g., Fletcher et al. 2001; Siegel, 1999; Siegel & Ladyman, 2000; Torgesen, 2001). The definition of learning disability (LD) as "unexpected" low academic achievement (Lerner, 2006) is no longer acceptable. Considering that very little was known about the cognitive processes related to reading and arithmetic at the turn of the 20th century when reports of reading disability first appeared (e.g., Orton, 1966; Torgesen, 1998), finding children who seemed to be normal in every way except that they were not able to read was indeed surprising or "unexpected." However, as research findings expand current understanding of the cognitive processes related to reading and arithmetic, hopefully, teachers and parents will view low achievement from a more scientific perspective and see it as the logical and hence "to be expected" outcome of constitutional cognitive deficits interacting with the environment (e.g., Spear-Swerling & Sternberg, 1996). In fact, based on current knowledge about the cognitive processes related to reading and arithmetic, educators can now take a proactive role in early identification and intervention; they now have the tools to identify at-risk children, to "expect" learning difficulties in certain children based on their cognitive deficits and provide intervention before they become victims of long-termed academic failure (e.g., Lesaux, 2001).

The ideal of realizing widespread early identification and intervention depends on the availability of education professionals trained in using systematic assessment for diagnosing low achievement. Given that a child has been administered a battery of standardized tests in reading, spelling, and arithmetic, it should be possible for a teacher familiar with how children develop reading and arithmetic skills to infer where the learning problems are. Children who perform significantly low in standardized tests of reading and/or arithmetic should receive some additional attention in their schools without having to wait for expensive formal psycho-educational assessments (refer to Siegel & Ladyman, 2000, p.28 for discussion on classroom based assessment). IQ scores that place a child in the "normal" or "above average" category to qualify for a LD diagnosis may be useful for special education funding purposes, but they are not particularly relevant for identifying the source of the learning problems.

The pattern of low achievement revealed in the standardized tests can provide a great deal of information about the nature of a child's low academic achievement (e.g., D"Angiulli & Siegel, 2003); for example, a child who is normally achieving in the reading sub-skill tests (e.g., phonics and word recognition) but scored extremely low in the reading comprehension test may have a very different type of reading problem from a child who scored low on all the reading sub-tests as well as the reading comprehension. It is now fairly well established that reading disability is characterized by a deficit in phonological processing (e.g., Blackman, 1991; Brady & Shankweiler, 1991; Catts & Hogan, 2003; Ehri, 1998; Gathercole & Baddeley, 1993a; Liberman, Brady, & Shankweiler, 1991; Shankweiler, Crain, Katz, & Fowler, 1995; Siegel, 1993a, 1993b, 1998) and this deficit has implications for other cognitive processes related to reading (see Stanovich, 1998 for discussion on phonological core deficit theory). In the arithmetic domain, although no "core deficit theory" has emerged as yet (Chiappe, 2005), significant advances have also been made in recent years on how children develop arithmetic skills by researchers examining the cognitive processes related to arithmetic. Attention problems (Lindsay, 2001; Siegel & Heaven, 1986) and impaired executive functioning (McLean & Hitch, 1999) have been linked to problems in arithmetic performance. Working memory deficits, both in the verbal domain (Wilson, & Swanson, 2001) and the visual-spatial domain (McLean & Hitch, 1999), also appeared to be important in arithmetic (see also Siegel & Feldman, 1983; Siegel & Heaven, 1986 on written work-arithemtic disability; Siegel & Linder, 1984; Siegel & Ryan, 1989). The inability to retain numerical information in working memory during computation has been identified as a persistent problem in arithmetic disability (Geary, Hoard, & Hamson, 1999; Passolunghi & Siegel, 2001; 2004; Siegel & Ryan, 1989). Counting, which assumes a number of cognitive skills critical for success in arithmetic, has emerged as a good indicator of arithmetic performance (Geary & Hoard, 2001; Siegel, 1982).

Applying existing knowledge on the cognitive processes related to reading and arithmetic in diagnostic situation will reduce unnecessary dependency on IQ-achievement discrepancy formulas; low achieving children do not need to show a discrepancy between learning potential and actual achievement in order to have educational support (e.g., Siegel, 1992); furthermore, they do not need a composite IQ score that has little diagnostic value (e.g., Siegel, 1989a). Amongst educational professionals, the concern about differentiating experiential deficits from cognitive deficits can be addressed, at least in part, by giving low achieving children standardized academic achievement tests as well as tests tapping into their cognitive processes which are known to be related to reading and arithmetic (e.g., Gathercole, Pickering, Knight & Stegmann, 2004b; Siegel, 1999; Torgesen, 1998). The scores from such tests, together with family histories and teachers' observations related to the social-behavioral aspects, should enable the teachers to form a comprehensive understanding of the possible causes for the low academic achievement. For example, if a child is low in reading and/or arithmetic according to the standardized achievement tests, but the scores from tests tapping into the related cognitive processes are high, then perhaps this is an indication that the problem in the academic domain may be linked to other factors (e.g., stressful family circumstances) which are not of a cognitive nature. Of course, in any diagnosis of learning problems, there is always an element of "detective" work involved; diagnosticians have to be open to the possibility that the child's learning problem, though of a cognitive nature, may not be readily identified because the battery of tests given was not sensitive enough to detect certain deficits in the cognitive domain.

This study was motivated by a desire to improve current diagnostic practice. The relevant question to ask when trying to diagnose low achievement is not whether the low achievement is "expected" or "unexpected," but rather, whether the cognitive processes related to academic learning such as reading and arithmetic are impaired. The answer to this question will determine what course intervention should take; for example, children with cognitive deficits generally respond well to direct instruction (e.g., Foorman, Francis, Fletcher, Schatschneider, & Mehta, 1998; Swanson, 1999) whereas children with motivation problems or family issues affecting learning may require other types of support. Meaningful diagnosis and purposeful intervention should be based on the pattern of cognitive deficits revealed in the assessment using standardized achievement tests and measures tapping into the cognitive processes related to reading, spelling, and arithmetic (e.g., Siegel & Ladyman, 2000; Spear-Swerling & Sternberg, 1996; Torgesen, 2001). This is the low achievement approach to diagnosing learning problems in children struggling in academic domains.

The low achievement approach is anchored on evidence that low achievers of various types, those who are low in reading and/or arithmetic, have cognitive profiles that are similar to those who are learning disabled in reading and/or arithmetic (e.g., Siegel & Ryan, 1988; Siegel & Ryan, 1989). The IQ-discrepancy approach to identifying learning disability, on the other hand, is based on an implicit assumption that IQ scores, used as a proxy for learning potential, correlate with academic achievement measures such as reading and arithmetic, and have the capacity to set the limit on how much children can achieve in these areas (Lerner, 2006). This assumption has been critically examined and discredited by researchers such as Fletcher et al. (2001), Siegel (1989a), and (Torgesen, 2001). The credibility of the low achievement approach to identifying LD can only be supported if there is a critical mass of research showing that low achievers are similar to LD children. If the cognitive profiles of low achieving children are similar to that of the learning disabled (LD), then there is no need to show that someone is LD using methods that are tied to a discrepancy-based definition of LD. This way, the defining features of children with LD, whether it is reading disability (RD), arithmetic disability (AD), or reading and arithmetic disability (RAD), would be the specific cognitive profiles related to each of these learning problems and not the "unexpected" low achievement determined by a discrepancy formula.

The approach taken in this study departs from the traditional achievement-aptitude discrepancy (e.g., IQ-achievement) discrepancy model of LD. Standardized achievement tests were used to identify those which low achievement and IQ tests were not used at all. "Unexpected low achievement" is not regarded as a meaningful descriptor for LD here; given what is known about the development of reading and arithmetic (e.g., Mather & Gregg, 2006), low achievement in these areas are more predictable than unexpected. Many in the field of LD, however, continue to regard "unexpected low achievement" as a defining feature of LD and much attention is still focused on operationalizing it (e.g., Fletcher, Denton, & Francis, 2005). In fact, the response to instruction model (e.g., Gresham, 2001) is an attempt to show some form of "unexpected" low achievement to satisfy the commonly accepted LD definition. The response to instruction model is based on curriculum-based assessments of the same core areas (e.g., reading and/or arithmetic); the student is given quality instruction and is expected to improve and non-responsiveness to instruction would be considered as "unexpected" low achievement. Curriculum-based assessments are very helpful monitoring tools for treatment in the sense that the teacher can refine and customize teaching methods to suit individual children based on observed responses. The response to instruction model provides a great deal of information for intervention purposes, it is not necessarily the most effective tool for LD diagnosis compared to the low achievement approach. Essentially, when the predictors of different areas of academic achievement (e.g., reading and arithmetic) are available, LD identification can make use of them (e.g., Mather & Gregg, 2006). At the same time, RIT can support the ongoing process of refining the individual intervention design based on the initial diagnosis; additional information obtained from one-on-one interaction between teacher and student will be extremely helpful.

There is also the intraindivial differences model of LD (e.g., Toregesen, 2001) which takes into account the cognitive profiles of individual students uspected of having LD. Here, LD is conceptualized as a kind of uneven pattern in the cognitive profiles. Children with a flat profile (e.g., low in all the cognitive areas measured) are considred as having "expected underachievement" and those with uneven cognitive profiles (e.g., show strength in some cogniive areas and low functioning in others) are deemed "unexpected underachievers." The criticism of this approach is that flatness in a profile in unrelated to LD (e.g., Fletcher, Denton, Francis, 2005). Children with severe academic problems (e.g., reading and arithmetic disabled) will be low in a number of cognitive measures and are more likely to have an overall flat cognitive profile. Directly assessing the cognitive functioning of low achieving children without considering the pattern of academic achievement may not be a reliable way of identifying LD.

This study recognized the importance of utilizing cognitive profiles, together with the achievement patterns, for LD identification and it was an attempt to refine the low achievement approach by further exploring the relationship between academic achievement variables (e.g., reading and arithmetic) and related cognitive variables in novel ways described below.

The focus of this study is on whether the children identified by a low achievement definition share similar cognitive profiles with the reading and/or arithmetic disabled children from the research literature. In addition, the present study is also interested in the pattern of cognitive deficits associated with the various forms of low achievement. For example, low achievement in reading, spelling, and arithmetic was examined in relation to low and normal performance in the cognitive measures. These findings will contribute to informing clinical diagnoses in meaningful ways. For example, children with low achievement in certain reading sub-skills have a tendency to show a higher chance of having problems in other academic areas (e.g., low word decoding skills are associated with low word reading skills and poor reading comprehension); knowing what these risks are will lead to more effective intervention. A child with low word attack skills who is able to receive intensive direct instruction at an early age may have a better chance of overcoming word recognition difficulties which otherwise will impede future progress in reading development.

The next section will be an overview of some of the issues related to the discrepancy-based approach to diagnosing low achievement; as well, the cognitive processes related to reading and arithmetic will be discussed and explained.

1.2 Discrepancy-based definition of learning disability (LD)

Identifying the source of low achievement in children, whether it is one single cause or a cluster of causes, can be a difficult task. Diagnosing the underlying cause or causes for a learning problem often requires navigating through a number of confounding variables to arrive at the answer. Even professionals such as teachers and diagnosticians find it hard to differentiate learning disabilities (LD), mild mental retardation (MMR), and emotional and behavioral disorder (EBD) from one another at times (e.g., Gresham, MacMillan & Bacian, 1996; Kauffman, Hallahan & Lloyd, 1998; Merrell, 1990). In some situations, it is difficult to determine whether the low achievement is from a cognitive deficit or an experiential deficit (e.g., Vellutino, Scanlon & Sipay, 1997). Low achieving children from disadvantaged backgrounds are sometimes placed in special education classes by eager teachers willing to disregard LD definition rules; these low achieving children do not necessarily have cognitive deficits but they do require extra educational input which otherwise would not be available to them (e.g., see Fuchs, Fuchs, Mathes, Lipsey, & Roberts, 2001; Vaughn, Linan-Thompson, & Hickman, 2003). At the other end of the spectrum, there are low achieving children who genuinely have LD and are not properly identified as such (Siegel & Himel, 1998). One of the reasons for this to happen is the use of a problematic LD definition, the discrepancy-based definition of learning disability.

Children with persistent low persistent low academic achievement are most likely to be suspected of having a learning disability. Learning disabilities (LD) are generally understood to be learning difficulties in academic domains such as language (e.g., Catts & Kamhi, 1999) and arithmetic (e.g., Geary, 2004). The most commonly known LD is reading disability (RD), and the other is arithmetic disability (AD). It is possible to have RD or AD, or a combination of both in the form a reading and arithmetic disability (RAD).

The term, "learning disability," is often used loosely to define those having significant difficulties in reading, spelling, arithmetic, and/or written language in spite of average or above average intelligence (see Lerner & Kline, 2006 for examples of LD definitions). Currently, the British Columbia Ministry of Education (2002) defines learning disabilities as "a number of disorders" which "affect learning in individuals who otherwise demonstrate at least average abilities essential for thinking and/or reasoning." Children who qualify for an LD diagnosis must "demonstrate a significant discrepancy between estimated learning potential and academic achievement as measured by norm-referenced achievement instruments in Grades 4-12" (refer to Section E, E.3). What is worth noting here is that, based on the above descriptions, a child who has LD must: (1) have at least average abilities for thinking and reasoning; (2) have a significant discrepancy between estimated learning potential and academic achievement; and (3) wait until grade 4 to be considered for LD diagnosis and intervention. The implications of these three points found in the above specification will be discussed in more details in the following sections.

1.2.1 Average abilities for thinking and reasoning

In practically all of the discrepancy-based definitions, there is the emphasis on "at least average intelligence" which is typically measured by IQ tests; what is implied here is that the IQ tests are able to test for abilities to think and reason. The concept of a discrepancy-based definition of LD had its origin in the expectancy formulas found in the reading literature at the turn of the 20th Century (e.g., see Monroe, 1932); and it was intended to distinguish learning disabilities (LD) from mental retardation (Siegel, 1989a). However, what had resulted with the use of discrepancy-based formulas for determining LD is the creation of an artificial category of low achievers (LA) who have similar academic challenges as the learning disabled (LD) except they do not receive any educational assistance (e.g., Rutter & Rule, 1975; Siegel, 1989b); the reason is because their IQ scores are lower than whatever the discrepancy formula being used dictates. On logical grounds, the discrepancy-based definition of learning disability can only be defended if evidence exists to demonstrate that low academic achievers of different IQ levels are actually different. Presently, there are indications suggesting otherwise; that is, low achievers (LA) and the learning disabled (LD) identified according to discrepancy-based formulas are more similar than different (e.g., Fletcher, et al., 1994; Siegel, 1992; Stanovich & Siegel, 1994).

The use of IQ test scores to determine "intelligence," and hence, learning potential, actually works to discredit the IQ-discrepancy definition of LD. The nature of human intelligence is such that it defies being captured and described with a composite IQ test score (Siegel, 1995); any claim suggesting that it is possible to measure human intelligence in absolute quantitative terms is suspect. Furthermore, to rely on an IQ test score to make important decisions such as determining if a child has a learning disability does not always do the child justice. Examining one of the earliest documented cases of "unexpected" low reading achievement (see Orton, 1925) serves to illustrate important reasons why intelligence cannot be assessed reliably by IQ tests. Here is a case of "IQ-clinical observation discrepancy" (i.e., an individual with low IQ scores who appears bright) which, as observed by Orton (1925), was possible because "psychometric tests as ordinarily employed give an entirely erroneous and unfair estimate of the intellectual capacity of these (reading disabled) children." Often, these children are deemed low in intellectual capacity when in fact the problem comes from the inadequacies of the IQ test as an instrument for assessing intellectual abilities. The widely written about case of "M.P.," a sixteen-year-old boy described by Orton (1925) as "bright but couldn't learn how to read," came from a study sample of fifteen children all having reading difficulties in " greater or less degree". Worth noting was the fact that these children with low reading had a range of IQ scores between 70-122 as measured by the Stanford-Binet Intelligence Quotient Test (refer to the table on p.19 in Orton, 1925 showing the grade levels and IQ scores); in other words, reading disability was not restricted to any particular IQ level in that sample of children (e.g., Siegel, 1989a). "M.P." did not have a discrepancy between his IQ and reading achievement as both his IQ scores and reading achievement scores were low; in fact, he would be considered low achieving (LA) if judged by today's discrepancy-based formulas. "M.P." was selected for an intensive case study because Orton had observed that this patient's "apparent" intelligence did not seem to fit his performance in the IQ tests: it was the low IQ score of 71 that caught Orton's attention as being "unexpected." Orton wrote:

> During the clinic, M. P. was tested by the Stanford-Binet method and showed the following rating: Age, 16, 2 months; mental age, 11 years, 4 months; intelligence quotient, 71. During the psychiatric examination which followed, however, I was strongly impressed with the feeling that this estimate did not do justice to the boy's mental equipment, and that the low rating was to be explained by the fact that the test is inadequate to gage the equipment in a case of such a special disability... I asked him, for example, questions concerning the adjustment of bearings in the V type automobile engine which required a good visualizing power for answer, and his replies were prompt and keen. (Orton, 1925, p. 19-20)

What Orton discovered was a measurement problem manifesting itself in a discrepancy between observed intelligence (i.e., clinical observations) and the Stanford-Binet, a psychological assessment test often used in measuring intelligence.

Subsequently, when further tests were given, "M.P." improved in his performance and was able to obtain a higher IQ score of 86 which Orton still felt was an underestimate of the boy's "general intellectual capacity."

> Additional tests given in the psychologic laboratory of the hospital gave the following results: The Stanford-Binet test was repeated, but certain alternative tests were substituted; others, when permissible were given orally, and he was tried by tests higher in the scale. This resulted in a mental age of 13 years, 10 months, and an intelligence quotient of 86 – fifteen points higher than in the initial test, thus placing him in the dull normal instead of the marginal defective group. He still gave the impression, however, to one who had learned to estimate mental defect before the widespread use of mental tests, of a much better equipment than even this second rating indicated (Orton, 1925, p. 21).

In fact, in areas other than reading, "M.P." appeared to be particularly gifted.

> By the Healy pictorial completion test No. 2 his score was 90 out of a possible 100, which is a superior performance for adults. By the Stenquist mechanical assembly test, No. 1, he earned a score of 82, which would place him on a level with the highest 1 per cent. of unselected army draft recruits. He solved the Freeman mechanical puzzle box in 102 seconds on the first trial and 72 seconds on the second, which is a superior performance (Orton, 1925, p. 21).

Hence, in his 1925 paper, *Word-Blindness in School Children*, Orton had devoted a section specifically to raise the issues related to the "erroneous estimates of intelligence" by psychometric tests. He wrote:

> M.P. had by far the most outstanding case of the series, and I have been far from content, after close personal study, that either the original rating of 71 or the revised rating of 86 really estimated his general intellectual capacity. I think we must therefore challenge the competence of the Stanford-Binet method to give us even an approximate rating in these cases. These children fall in a group of an especial nature more closely comparable to those with true sensory deprivations than to the so-called feebleminded...(Orton, 1925, p. 47).

Orton highlighted three important factors for considering the adequacy of the test:

> First, the ratings given are the results of the application of the test to large numbers of children of each chronologic age. In any such group, unless selected on the basis of a reading difficulty, the number of such cases would naturally be small, and we are therefore comparing these handicapped children with an unlike standard. Second, the material of the test itself consists in part of words which are visually presented, and this penalizes their handicap heavily. This factor was an operative one in the change of intelligence quotient in M. P.'s case from 71 on the first examination to 86 on the second. It would seem that a modification of the method might readily be devised to use only auditory presentation except for those parts of the test that deal with images of objects. Such as the ball-in-field test, etc., and that this might readily give a better estimate of their equipment. Third, one path of acquisition of information open to the average child, that of reading, is more or less completely closed to these children. When we realize that M. P.' s disability was so great that practically none of his verbal store had been acquired by vision, we appreciate that his accomplishments in the test are far from establishing as low a capacity as the rating would indicate. This lack of information, however, is not a competent measure of how effectively he can make use of those data which he has garnered by the auditory path (Orton, 1925, p. 48).

In particular, Orton was critical of the practice of using an "unlike standard" to test the children with reading difficulties; the tests were designed for children who do not have reading problems and, if tested by such instruments, the reading disabled children's true intellectual capacity would be underestimated (e.g., see Siegel, 1989a, p.471, on effects of reading disability on IQ scores). Since the pathway of getting information from reading was closed to those with reading problems, Orton suggested that tests should be given orally so that the test results would better reflect the true "intelligence" of the children.

What Orton had concluded about the limited nature of IQ tests as an instrument for tapping into human intelligence is important and many would agree with him (e.g., Francis, Espy, Rourke, & Fletcher, 1991; Gould, 1996; Siegel, 1989a; Sternberg, 1985). In fact, Alfred Binet, the originator of the IQ tests, recognized the limitations of his tests of intelligence quotients and had indicated that case studies, such as the ones done by Orton, may be more informative in some situations (Fancher, 1985). The Stanford-Binet was developed to streamline army recruitment; its original purpose was to provide a quick way of screening individuals for military service (Gould, 1996) and not for diagnosing clinical cases in particular. Instead of indiscriminately using IQ tests known to have some serious limitations, careful clinical observations by trained individuals would be more effective for diagnosing learning problems (e.g., Gunderson & Siegel, 2001). One could argue that better IQ tests should be developed, but the complex nature of human intelligence is such that no IQ tests can be expected to do justice to evaluating ones true "intelligence." Furthermore, the influence of educational background and culture has to be taken into account when IQ tests are used (Siegel, 1989b).

Contrary to what many would expect, IQ tests do not measure "intelligence" in terms of the ability to reason logically, solve problems, and adapt to the environment. IQ tests often require children to have a great deal of specific knowledge, vocabulary, expressive language, and memory skills; as such, they put children with learning disabilities in a disadvantaged position because deficits in language and working memory are typical of LD children (e.g., Siegel & Ryan, 1988; Siegel & Ryan, 1989; Vellutino, 1979). It is also common that IQ tests have tasks that demand fine motor skills and visual-spatial abilities where speed is often emphasized; all of these abilities are especially deficient in some LD children with arithmetic disability (e.g., Rourke, 1993; Rourke & Conway, 1997). Such IQ tests cannot be expected to serve as an effective tool for assessing higher level thinking (e.g., Sternberg, 1985) associated with intelligence. IQ test scores, to be precise, are more of an indicator of how much knowledge a child already has. And this, to a large extent, reflects the quality and quantity of nurturing a child has been given. Thus, this makes IQ tests particularly biased for children from disadvantaged backgrounds who do not have the same resources and exposure to learning as the average middle-class children.

Children of low socioeconomic status (SES) are more at-risk- for low academic achievement and school failure (e.g., Hagans-Murillo, 2000; McLoyd, 1998; Reynolds & Temple, 1998). Generally, socioeconomic status is measured by such variables as ethnicity, occupation, education, and income. Chronic poverty and stressful life circumstances may have a negative impact on the academic achievement of low SES children and hence many of the early childhood intervention programs are designed to minimize the disadvantages that come with low SES (e.g., Ramey & Ramey, 1992; Reynolds & Temple, 1998). The cognitive development of low SES children may be lower because their home environment sometimes cannot provide them with the type of stimulation conducive to cognitive growth which would enable them to compete favorably in traditional intelligence (Hagans-Murillo, 2000). Since IQ scores are significantly correlated with socioeconomic status (Noble, Norman, & Farah, 2005), low achieving children from lower SES backgrounds are less likely to obtain a discrepancy between IQ and achievement scores (e.g., Siegel, 1999). Often, the low IQ scores of low achieving children from a low SES background are the product of an experiential deficit, a lack of exposure to the type of vocabulary and knowledge measured in IQ tests (see Siegel, 1989a; Siegel, 1999; Siegel & Himel, 1998 for discussion). When the achievement of low SES children is generally low, identifying learning disabilities is more difficult if the IQ discrepancy formula is used. Instances where low SES children scored low on the achievement test as well as on the IQ test may be thought of as a situation that is to be expected; in other words, it is a reasonable outcome of these children's disadvantaged circumstances in life. Therefore, many of the low achieving children from a low SES background with LD may be overlooked and not be given appropriate educational intervention. Low achieving students who are not properly diagnosed will be placed in inappropriate special education categories and therefore the effectiveness of intervention may be compromised (Gresham et al., 1996). A learning disabled (LD) child, who is mislabeled as "retarded" based on the IQ discrepancy formula of LD diagnosis, will not likely benefit much from receiving special education instruction designed for a "retarded" child (see Fletcher et al., 1992; Siegel, 1992).

Children who speak English as a second language (ESL) have a high representation in inner-city schools where the SES is low (Chall, Jacobs, & Baldwin, 1990). The dropout rate is high in the ESL population because English proficiency is crucial to achieving academic success (Watt & Roessingh, 1994). Low SES children who come from an ESL background have an increased risk of academic failure. Learning problems of ESL-speaking children are not always properly understood. Determining whether the learning difficulties are related to second language acquisition and acculturation or a learning disability is sometimes difficult.

Genuine learning disabilities of a cognitive nature may be overlooked when the LD diagnosis involves an IQ-achievement discrepancy (Gunderson & Siegel, 2001).

In summary, IQ test scores are inaccurate estimates of intelligence and those who are learning disabled (e.g., Siegel. 1989a), speak English as a second language (e.g., Gunderson & Siegel, 2001), and come from a low SES background (e.g., Siegel & Himel, 1998) are likely to obtain a lower IQ score.

1.2.2 Severe discrepancy between IQ and achievement

The way discrepancy-based definitions of learning disabilities are operationalized as a severe discrepancy between potential and achievement necessitates an LD diagnosis to anchor itself to measurements of potential and achievement as well as to some sort of standard to define what a "severe" discrepancy is. In every discrepancy formula, there has to be a measure of learning potential (IQ score) and a measure of academic achievement (achievement score) to produce a discrepancy score. Diagnosticians often place a great deal of weight on IQ scores as a measure of learning potential and they are central in LD diagnoses. Academic achievement status is usually determined by standardized academic achievement tests; however, these tests are sometimes problematic because there is a great deal of variability in the way the target skills such as reading and arithmetic are measured (see Siegel, 1986, pp. 103-7). The discrepancy between learning potential and achievement is quantified by a discrepancy score derived from the various discrepancy formulas developed specifically for the purpose of LD diagnoses (e.g., see Lerner, 2000, pp. 102-4 for examples). Some of these formulas use a regression equation where achievement, such as reading, is predicted from a child's IQ scores (e.g., Rutter & Yule, 1975) while other formulas would take actual achievement scores and compare them to "expected" achievement scores based on a child's chronological age (Siegel, 1992). For example, to qualify for an LD diagnosis in reading (i.e., reading disability), a child would be required to have reading achievement scores below the predicted level based on his/her IQ scores. Calculating discrepancy between IQ and achievement on standardized test scores is the most common method in use (Swanson, 2000).

In diagnosing learning disability in mathematics, there are no specifically designed measures that are used (Geary, 2004). Most researchers rely on standardized achievement tests, often in combination with measures of IQ. A score lower than the 20th or 25th percentile on a mathematics achievement test combined with a low-to-average or high IQ scores are typical criteria for diagnosing mathematics learning disability (e.g., Geary, Hamson, & Hoard, 2000; González & Espínel, 1999). Similar diagnostic criteria can be expected for determining arithmetic disability (AD) which is subsumed under mathematics learning disability (MLD). Arithmetic disability (AD) refers to difficulties in calculation.

Since LD is defined in terms of a discrepancy between learning potential and achievement, in diagnostic situations, a great deal of resources is directed to finding the illusive "severe discrepancy" specified in the LD definitions. The weak research foundation in the LD discipline (Swanson, 2000) had created an open field for a plethora of discrepancy formulas, all of which are associated with flaws of one kind or another (Lerner, 2000, pp. 102-4). Criteria for LD diagnosis can vary between localities (e.g., Frankenberger & Fronzaglio, 1991); much of the frustration comes from the fact that a child can be diagnosed as LD according to one discrepancy formula and not in another. Some of the existing discrepancy formulae are known to have statistical problems and measurement issues. Comparability of norms across tests is lacking in many cases and grade-level or age-level scores on one test are not comparable to those on another test (e.g., Cone & Wilson, 1981).

Consistency and precision are lacking in methods used for calculating discrepancy scores and often there are difficulties associated with the various IQ tests (e.g., Siegel & Heaven, 1986; Siegel, 1992). For example, a child who has a discrepancy between his/her WISC-R Verbal and achievement score may not have a discrepancy between his/her Performance IQ scores and achievement score. This child is likely to be diagnosed differently, that is, LD or not LD, depending on which of the two tests is used in the calculation formula. Furthermore, "the actual variables entered into the equation are different in each formula, and the formulas use different relationships between achievement and IQ" (Siegel, 1989a. p.471). How much of a discrepancy is meaningful in an LD diagnosis is often difficult to determine. Whether a discrepancy of one or two standard deviations is used, it still remains that the decision is at best an arbitrary one. For example, in the study of Algozzine, Ysseldyke, and Shinn (1982), both LD and non-LD children were just as likely to show a discrepancy whether a severe (1 1/2 standard deviations) or a moderate (1 standard deviation) criterion was used; the diagnoses resulting from these discrepancy-based procedures were at best meaningless. In reviewing LD diagnoses for the *Guckenberger* case in Boston, Siegel (1999) found that there were LD diagnoses made on the basis of a discrepancy between the WAIS-R Verbal and Performance Scale IQ test scores in the absence of any standardized achievement tests. Although this practice has been discredited, it does show that the zeal to obtain a discrepancy in order to qualify for an LD diagnosis can lead to questionable professional practice.

The prevalence of inconsistency in diagnosing LD at the school district level (e.g., Perlmutter & Parus, 1986) has caused major problems for children moving from one locality to another. Since individual school districts have the autonomy to adopt discrepancy formulas of their choice (Morgan, Singer-Harris, Bernstein, & Waber, 2000), multiple standards have resulted and a great deal of confusion exists in special education service delivery. It is possible for a child to be diagnosed as LD in one locality and not in another (Lerner, 2006) and therefore continuity of special education service is threatened.

1.2.3 LD identification after grade 3

The British Columbia Ministry of Education (2002) stipulated that children are not tested for learning disabilities until after grade three. Evidence from research has shown that early identification and intervention is by far the most effective way of reducing the risk of school failure in children (e.g., Felton & Pepper, 1995; Fletcher & Satz, 1979; Hurford et al., 1994; Kame'enui, 2000; Lesaux, 2001; Lesaux & Siegel, 2003, Vellutino, Scanlon, & Tanzman, 1998). In Reynolds and Temple's (1998) early childhood research, there is evidence showing that the intervention beginning early in the lives of at-risk children produced the best effect; the intensive, one-time, "big dosage" intervention that happened in later developmental stages was in comparison less effective. The learning gaps in the early years, if unaddressed, will not disappear; in fact, they will only grow wider with time (Chall, 1983).

Identification and intervention of low achievement theoretically can take place at the classroom level before grade four if there are enough trained teachers in the school system. It is not necessary to wait until grade four for extensive and expensive discrepancy-based LD identification.

For children in elementary school, mastering the foundational academic skills such as reading, spelling, and arithmetic by grade three is very important. The reading "slump" often observed in grade four students (e.g., Chall et al., 1990) can be avoided if at-risk children were identified earlier and given timely and appropriate intervention. Significant learning problems that are not dealt with from earlier grades will likely lead to persistent low academic achievement in school (Chall, 1983).

Low performance in language-intensive academic subjects is usually rooted in reading problems. By grade four, reading for content, the ability to extract information from written text to understand school subjects, becomes a critical element for academic success. The ability to read and the continual cultivation of this ability profoundly influences the development of language, knowledge, and vocabulary skills in children (Siegel, 1999). What is known as the "Matthew effects" described by Stanovich (1986) portrays a phenomenon where a bi-directional relationship exists between reading and cognitive development. The term, "Matthew effects," was originally coined from the Parable of the Talents in the Gospel According to Matthew: "For everyone who has will be given more, and he will have an abundance. Whoever does not have, even what he has will be taken from him." (Matthew 25:29, New International Version.) The educational consequence of the Mathew effects is a cumulative one; good readers capable of taking advantage of reading opportunities will become even better readers while poor readers, unable to profit from reading opportunities, will fall further behind in reading. The implication of the bi-directional nature of reading and cognitive development is such that over time, the poor readers will not only be limited in their ability to read, but they will also lag behind in their cognitive development, the ability to mentally represent information and to process it, compared to their peers who are proficient readers.

The "Matthew effects" are not restricted to the reading domain; the same parallel can exist in arithmetic as well. Early learning difficulties in arithmetic can have far reaching academic consequences. The inability to manage basic arithmetic operations such as adding, subtracting, multiplying, and dividing will have an impact on school performance, especially in science-related subjects which often assume a certain level of proficiency in performing arithmetic calculations. Again, the cumulative nature of mathematical knowledge is such that gaps in basic arithmetic competence may impede learning in mathematics and science beyond the primary grades in elementary school. The cognitive growth that comes from the development of mathematical and scientific thinking is hindered.

Calculation problems related to low achievement in arithmetic can also interact with language-related reading difficulties. In intermediate grades when children are required to do problem solving in arithmetic, they must be able to understand the written language describing the arithmetic problems they have to solve. The inability to understand the language used in arithmetic problems poses a serous obstacle for children to conceptualize a problem dealing with quantities and to express it in accurate numeric terms using arithmetic operations. When poor reading is combined with weak calculation skills, it becomes extremely difficult for a child to master the more complex mathematical problems that require both proficiency in language and a good grasp of basic arithmetic.

1.3 Cognitive processes related to reading and arithmetic

1.3.1 The working memory system

Working memory can be conceptualized as a mental workspace where information is stored and processes for short periods of time in the course of demanding cognitive activities. One of the most influential and widely accepted model of working memory (Baddeley, 1986; Baddeley & Hitch, 1974) conceptualized working memory as having a number of separate but interacting temporary memory systems. In the scheme of Baddeley and Hitch (1974), the central executive, a high-level control system, is served by two domain specific slave systems that temporarily store limited amounts of information for processing, the phonological loop and the visual-spatial sketchpad; the former maintains phonologically coded information while the latter represents information in terms of its visual-spatial features (Gathercole & Baddeley, 1993b) There are possibly other subcomponents within the working memory system that are yet to be discovered (see Baddeley & Logie, 1999) and current understanding of how working memory operates with its subsystems is constantly being revised to accommodate new findings. A subcomponent recently identified by Baddeley (2002) is the episodic buffer; its function is to integrate information from multiple sources in the cognitive system, including long and short-term memory systems, for processing tasks. Some preliminary exploration into the concept of an episodic buffer was attempted by Baddeley and his colleagues using a memory span task, the "constrained sentence" span, which involved the use of sentences of a fixed syntactic structure (see Baddeley, 2002, pp. 93-4). As Willis and Gathercole (2001) have suggested, the episodic buffer may have an essential integrative function in the comprehension of sentences, a task requiring the orchestrating of multi-source or multi-modality processing.

Working memory, as a construct explaining how humans process information, refers to a simultaneous operation where small amounts of quickly decaying domain-specific information is held in temporary storage while other task-relevant information is being retrieved from long-term memory. Complex intellectual processes such as reading and arithmetic require the working memory system to support their operations; however, the way in which the components of working memory function may differ between the two processes. For example, Siegel and Ryan (1989) have found that children with reading disability appear to have a more generalized working memory deficit; they perform poorly in working memory tasks dealing with words as well as those dealing with numbers. The children with arithmetic disability, on the other hand, only performed poorly in the working memory for number task. This perhaps may be attributed to the fact that while there is some verbal information processing involved in arithmetic, it does not make as much demands on working memory for words as reading does, and hence arithmetic disabled children with no reading disability appear to be impaired only in a specific working memory domain, that of numbers (Siegel & Ryan, 1989). Working memory is linked to attention capacities (Baddeley, 1993) and as such, it is important for arithmetic (Lindsay, 2001) and reading comprehension (Gottardo, Stanovich, & Siegel, 1996). Those who have reading disabilities generally have significant difficulties with working memory (Brady, 1991; Siegel, 1994; Siegel & Linder, 1984; Siegel & Ryan, 1988).

The function of the working memory system is critical to the development of academic skills. Verbal working memory deficits (e.g., Brady, 1991; Gottardo, Stanovich, & Siegel, 1996; Willcutt et al., 2001) and a more generalized form of deficiency in the working memory system (e.g., Swanson, 2000; Swanson & Ashbaker, 2000) have been linked with reading problems. The inability to sustain phonological information in working memory in the form of language or numbers may pose serious obstacles for children to acquire literacy (Johnston, 1993) and numeracy (Passolunghi & Siegel, 2001).

1.3.2 The central executive in relation to reading and arithmetic tasks

The central executive is a limited capacity processing system which, as the primary managing processor, has a major function in the working memory model (e.g., Baddeley, 2002), and its role is analogous to that of a symphony conductor: it coordinates access to and retrieval from relevant knowledge systems in long term memory for specific tasks. The flow of information going through working memory is regulated by the central executive which makes decisions about what and how much domain specific information is to be allowed into working memory for a particular task and synchronizes the information processing. In reading and arithmetic, the central executive serves to coordinate modular inputs from the phonological and visual domains and processes them according to task specifications.

The central executive has an important part to play in higher-level processing such as reading comprehension and arithmetic. In reading comprehension or arithmetic, the central executive inhibits irrelevant information from entering working memory, thus preventing its limited capacity from being depleted. Chiappe, Hasher, and Siegel (2000) found that in addition to having lower scores in working memory tasks utilizing the listening span paradigm, those with a reading disability appeared to have deficient inhibitory control. In particular, error analyses showed that disabled readers produced more errors that were indicative of problems in the access and restraint functions of inhibition control. Children with difficulties in arithmetic problem solving also appeared to have deficits in their inhibitory mechanism (Passolunghi & Siegel, 2001; 2004); their scores in dual task processing, the coordination and storage of numeric and visuospatial information, was lower than the normally achieving children. Intrusion errors indicative of inhibitory control problems were more common in children with poor arithmetic problem solving abilities. It appeared that they had difficulty in filtering out irrelevant information while working on their specific tasks. Complex processing tasks such as those related to academic learning and problem solving require the central executive to facilitate multiple cognitive activities which assumes the efficient function of inhibitor controls (e.g., Baddeley, 1998; Jefferies, Lambon, Matthew, & Baddeley, 2004; Baddeley & Logie, 1999).

The influence of the central executive capacity on learning appears to be pervasive; compromised functioning of the central executive has been found to hinder academic learning in a member of ways. Recent studies assessing the central executive within a memory span paradigm by Gathercole, Pickering, Ambridge, et al. (2004) and Gathercole, Pickering, Knight, et al. (2004) have linked poor central executive functioning to poor performance in key scholastic domains such as literacy, arithmetic, vocabulary, and the more general aspects of cognitive capacity. Selected tests from the Working Memory Test Battery for Children (Pickering & Gathercole 2001) were used in both studies. The contribution of the central executive to educational attainment is an important one.

The efficacious functioning of the working memory system necessarily depends on the operating condition of the slave systems serving the central executive. Domain-specific processing tasks require modular inputs, whether it is auditory or visual, to be channeled into the working memory system where the subcomponents operate in relation to one another in an intricate network. Well-defined phonological and visual representations will make the work of the central executive easier and increase the effectiveness of the working memory system. Ambiguous or decayed representations from the phonological loop (e.g., Adams & Hitch, 1998; Hitch, 1978; Hitch & McAuley, 1991) or the visuo-spatial sketchpad (e.g., Bull, Johnston, & Roy, 1999; D'Amico & Guarnera, 2005; Geary, 1993, 2004) will inevitably affect the workings of the central executive and cause the efficacy of the working memory system to be compromised.

1.3.3 Phonological processing and reading

Since much of human learning depends on the auditory domain, the central executive and the phonological loop components of working memory necessarily operate in close relation to facilitate the learning of new knowledge and complex skills through the manipulation of and the retention of auditory inputs. One of the most complex tasks undertaken by the central executive is that of processing language (Liberman, 1997), and language is a medium of thought and learning; hence this is why the phonological loop plays an important role in working memory (Baddeley, Gathercole, & Papagno, 1998). Severe impairments in the phonological loop may contribute to profound language learning problems that can impact learning in general (Gathercole & Baddeley, 1990).

In learning to read an alphabetic language such as English, a child has to have the ability to make sound-symbol relationship. Phonological awareness, the explicit awareness of sound-structure of language, has been widely accepted in recent times as being linked to reading development in important ways. There is a general consensus in the field of reading that phonological processing is the best predictor for reading (e.g., Adams, 1990; Blachman, 1997; Brady & Shankweiler, 1991; Bryant, 1995; Morais & Kolinsky, 1995; Perfetti, 1985; Siegel, 1993b, Stanovich, 2000b).

In the pre-reading stage, children's phonological memory (e.g., Gathercole & Baddeley, 1990; Gathercole, Service, Hitch, Adams, & Martin, 1999), the ability to retain novel speech sound patterns, will help them to successfully engage in phonological encoding, that is, using speech perception (e.g., Chiappe & Chiappe, 2001; Gathercole & Baddeley, 1993a) to form and store phonological representations which they can draw on when they later learn to read (e.g., Coltheart, 1987; Doctor & Coltheart, 1980; Huba, Vellutino, & Scanlon, 1990). Many theorists take the view that inadequate phonological encoding is the root cause of reading difficulties (e.g., Huba et al., 1990; Shankweiler et al., 1999; Snow, Burns, & Griffin, 1998; Vellutino, Fletcher, Snowling, & & Scanlon, 2004). The phonological awareness skills that emerge in the pre-reading phase have been shown to correlate with later success in reading (Burgess & Lonigan, 1998; Muter & Snowling, 1998); children who have a developed phonemic awareness, a sense that individual words are composed of phonemes, will be better able to make a smooth transition to beginning reading and demonstrate proficiency in word attack, work recognition and spelling (e.g., Ehri, 2000; Ehri, Nunes, Stahl, & Willows, 2001; Ehri, Nunes, Willows et al., 2001; Gathercole & Baddeley, 1993a; Goswami, 1999; Morais, Mousty, & Kolinsky, 1998).

When children learn to read, they have to engage in vigorous phonological recoding from the written symbols to access their mental lexicon (e.g., Brady, 1997; Morais, 2003), and at this stage, phonemic awareness becomes extremely important. Children who are unable to develop effective decoding and word recognition skills will be less likely to excel in vocabulary acquisition later on (e.g., Adams, 1990; Brown & Hulme, 1996; Gathercole, Hitch, Service, & Martin, 1997; Gathercole et al., 1999; Snow, Burns, & Griffin, 1998); they will have more difficulties achieving automaticity in reading (Brady, 1991; Stanovich, 2000c), and less reading-related skills are available for facilitating comprehension strategies (e.g., Catts & Hogan, 2003; Ehri, Nunes, Stahl et al., 2001).

1.3.4 Syntactic processing and reading

Beyond phonological processing that is related to word recognition, syntactic awareness and grammatical knowledge are important for reading comprehension (Bryant, 1995; Muter, Hulme, Snowling, & Stevenson, 2004; Siegel, 1993b). In any language, words are ordered according to rules of syntax to convey meaning in the form of sentences. Normally, children's knowledge of syntax will grow with increasing age, and hence their sentences, too, will become longer and more syntactically complex (Chall, 1983). The ability to use syntactic knowledge to make sense of the propositions being presented in sentences is extremely important in reading comprehension. Deficient syntactic processing is linked to poor reading performance and it appeared to be an epiphenomena of deficiencies in phonological processing (Gottardo et al., 1996). In fact, the development of spelling and orthography can be attributed to the acquisition of grammar (Bryant, Nunes, & Bindman, 1997). Explained in the context of the phonological core deficit theory (e.g., Gathercole & Baddeley, 1993a), phonological processing has an all-encompassing impact on language acquisition. Children generally first acquire language as auditory inputs. They gain linguistic information through the phonological route; that is, their knowledge of vocabulary, syntax, and semantics comes from language patterns that have been phonologically coded. Language, with its rules and all, is encoded into the mental lexicon as phonological representations. An impaired phonological memory would impede the language encoding process. The phonological representations in long-term memory would be of a poor quality; syntactic and grammatical knowledge inadequately represented as phonological codes will make the phonological retrieval process challenging and imprecise (Catts & Hogan, 2003). The consequence of this will be evident in reading comprehension when component subsystems in working memory attempt to access phonological representations for reading-specific processing. Poor phonological memory makes inadequate phonological representations and this has negative implications for reading comprehension (Willis & Gathercole, 2001).

1.3.5 Lexical access

Phonological retrieval, also know as name retrieval or phonological recoding in lexical access (Wagner & Torgesen, 1987), is an aspect of phonological processing that is important for word retrieval in reading (Chiappe, Stringer, Siegel, & Stanovich, 2002). Previous studies have found that those with reading disability cannot name pictures, colors, letters and digits as quickly as their non-reading disabled counterparts (e.g., Ackerman, Dykman, & Gardner, 1990; Bowers & Swanson, 1991; Toregesen, Wagner, Rashotte, Burgess, & Hecht, 1997). Rapid naming deficits are likely linked to problems in phonological processing because they involve the retrieval of phonological representations previously coded in memory through the phonological route. Lexical access in naming and lexical access in word reading share similar sub-processes, and as such, deficiency in one will also be reflected in the other (Chiappe et al., 2002). Interestingly, in the arithmetic domain, children who have number fact disorders, that is, difficulties with retrieving task-related arithmetic facts for processing, appeared to have naming deficits in access to lexical items tasks (Temple & Sherwood, 2002).

1.3.6 Phonological processing and arithmetic

The connection between reading and phonological processing is a more obvious one compared to that of arithmetic. In recent years, there is a growing interest in the role that phonological processing abilities play in the development of arithmetic (Hecht, Torgesen, Wagner, & Rashotte, 2001). As a form of information processing, arithmetic operations typically do not require elaborate phonological recoding. For example, the numbers can be recognized simply as symbols when children are presented with, say, the addition operation of 2+3. One form of phonological processing important in arithmetic is probably that of phonological rehearsal. During mental arithmetic operations, children often rehearse phonologically coded information relevant to the arithmetic operation and try to maintain it in short-term memory for as long as possible to support the calculation process (Hitch, 1984; Hitch & Baddeley, 1976; Hitch & McAuley, 1991; Shafrir & Siegel, 1994b). Children who have a phonological processing deficit will be less able to hold phonologically coded information in short-term memory and the decaying of this information disrupts the arithmetic operation. An impaired phonological loop affects short-term memory processing tasks and can pose serious difficulties for both reading and arithmetic; however, if the function of the visual sketchpad is intact, then using visual strategies is one way to circumvent the phonological processing deficit (Shafrir & Siegel, 1994a; Stanovich, 2000a). The contribution of visuo-spatial processing to arithmetic is one that cannot be ignored (Kulak, 1993).

1.3.7 Visual processing in reading and arithmetic

Although the phonological loop component of working memory holds a primary position in learning, visual processing, or the visuo-spatial sketchpad component of the working memory model, also contributes to the development of academic skills in important ways. Reading and working with arithmetic operations require the efficient functioning of the visuo-spatial sketchpad. The ability to visually scan text or symbols and accurately represent them in the visuo-spatial sketchpad for further higher level processing is assumed in efficient reading and arithmetic operations. Visuo-spatial abilities go beyond simply having sharp vision; problems in interpreting visual information accurately stem from the brain. Without a functioning visuo-spatial sketchpad, it is not possible for task specific processing to take place in the working memory system. Visual-spatial deficits, depending on the severity of the impairments, can compromise the reading process and possibly one's ability to perform arithmetic operations. For example, visual confusion is sometimes observed in children with reading problems; the letters b, d, p, q, are often confused and words such as "tea" may be perceived at "eat." A recent theory presented by Lachmann (2002) and his associate (Lachmann & Geyer, 2003) suggests that such phenomenon may be the result of a functional coordination deficit, an inability to orchestrate reading related sub-functions, visual processing and phonological processing, to bear on the target task of reading. Visual processing deficits may affect the children's ability to work with numbers in arithmetic operations; numbers are sometimes erroneously rotated due to faulty visual representations during the mental operation. For example, 24 + 15 may be perceived as 42 + 51 in a horizontal rotation error, and will result in the wrong sum. Often, children with a deficit in one domain will be compensated by strength in another (Siegel, 1993b; Siegel, Share, & Geva, 1995); however, when a co-morbidity diagnosis exists where there is both a phonological and a visual-spatial processing deficit, the resulting learning problem can be very severe (Shafrir & Siegel, 1994b). There is a growing consensus that arithmetic disability is linked with visual-spatial deficits (Assel, Landry, Swank, Smith, & Steelman, 2003; Kulak, 1993; Shafrir & Siegel, 1994b; Silver, Pennett, Black, Fair, & Balise, 1999).

1.4 Statement of the problem and overview of the study

In certain educational settings where most children are from a low SES and/or non-English speaking background, the risk for academic failure is higher than that of the general population. The confounding variables of social status and language background make it more difficult to identify the source of learning problems in many cases. The widely used IQ-achievement discrepancy definition of LD appeared to be particularly biased against some children. Three types of children are particularly vulnerable to being marginalized within the educational system and being misidentified as low achievers (LA) and not as the learning disabled (LD): children from a low socioeconomic (SES) background; children who speak English as a second language (ESL); and children who are genuinely learning disabled (LD). For this reason, there is a need to fill the gap in current LD identification practice and to develop a viable alternative diagnostic approach that is robust even in populations where there are confounding variables; at present, the low achievement approach to identifying learning disabilities appears to be a promising alternative that would not be biased against low achievers who are likely to be excluded from receiving appropriate special education intervention based on their background characteristics.

This study had attempted to do what many in the field of learning disability have been advocating for a long time, that is, to abandon the use of IQ tests in diagnosing low academic achievement and focus on the underlying cognitive processes in reading and arithmetic (e.g., Siegel, 1989a, 1989b; Siegel, 1999; Siegel & Ladyman, 2000; Torgesen, 1998); the learning problems were diagnosed by examining the pattern of low achievement together with known predictors variables associated with these academic domains (e.g., Torgesen, 2001). The current research was driven by the phonological core deficit theory in reading research (e.g., Stanovich, 1998; 2000a) as well as by some of the emerging theoretical consensus in mathematics research (e.g., Baddeley & Hitch, 1974; Assel et al., 2003). The universality of these theories was tested in this sample specific study of children from a low socioeconomic (SES) and predominantly ESL language background. The assumption was that the cognitive processes identified as important to children learning to master the English language and to do arithmetic would be applicable across home language background and socioeconomic status: deficits in these cognitive processes will lead to low academic achievement. The hypothesis was that previously identified patterns of relationship in studies of L1 children from middle-class backgrounds (e.g., Gottardo et al., 1996; Stanovich & Siegel, 1994) will emerge and that low achievers in this study will have similar cognitive profiles as the reading disabled (RD), the arithmetic disabled (AD), and the reading and arithmetic disabled (RAD) from the research literature on reading and arithmetic development in children (e.g., Fletcher et al., 1994; Stanovich & Siegel, 1994; Vellutino, Scanlon, Sipay, et al., 1996). It was also predicted that the normally achieving and low achieving children would be differentiated on variables associated with the core deficits referred to in the working theories for this study.

The current research investigated the pattern of low achievement in children having academic difficulties in reading and arithmetic. Specifically, the following questions were addressed: (1) Were the low achieving children and normally achieving children differentiated by their cognitive profiles? (2) Were the L1 and ESL children differentiated by their cognitive profiles? (3) What was the relationship between reading achievement and the measures of phonological processing, working memory, and syntactic awareness? (4) What was the relationship between arithmetic achievement and measures of phonological processing, working memory, and RAN?

2 Method

2.1. Participants

This research was approved by the Behavioural Research Ethics Board of the University of British Columbia (see Appendix A for certificate of approval). One hundred and twenty-one grade three children were recruited from two inner city schools. The schools in this study were in close proximity to one another and hence they were fairly similar in terms of demographics. The grade three students in this study were what social scientists would label as children of low socioeconomic status (SES). Information obtained from the schools indicated that the parental occupations were mostly associated with blue-collar jobs, service industry, and trade. According to figures provided by the principals, 45.8% of the parents did not have a high school diploma; 38.2% of the families were in the "working poor" class with an annual family income of less than $30,000; and there was a meal program in one of the schools to provide lunches for those children needing the service. There were high incidences of behavioral problems (over a thousand cases recorded annually) requiring school suspension or referrals to the principals for discipline.

Out of the total number of children in this study (121), the representation of children from non-English speaking homes was high; 71.1% of the children were from an ESL background whereas 28.9% were L1. Individually, the sample of grade 3 children from each of the two schools in this study had a higher percentage of ESL speaking children than L1 children: in the first school, 43.4% of the participating grade 3 children were L1 and 56.5% were ESL speaking; in the second school, 17% of the participating grade 3 children were L1 and 82.4% were ESL speaking. Most of the children from an ESL background spoke Punjabi as their first language. Five language groups were represented in the sample of children in this study and the percentages for the entire group (121) of children in the study are given in the brackets: English (28.9%), Punjabi (57.9%), Hindi (6.6%), Asian languages such as Vietnamese and Tagolog (3.3%), and Eastern European languages such as Russian and other Slavic languages (3.3%). A breakdown of the language groups represented in the two schools individually is as follows: in one school, 17.6% English, 70.6% Punjabi, 5.9% Hindi, 2.9% Asian, and 2.9% European; in another school, 43.4% English, 41.5% Punjabi, 7.5% Hindi, 3.8% Asian, and 3.8% European. Some of the language groups were so small in number that individual analysis of each language group was not possible; therefore, for the purpose of analysis in this study, the children were classified as either L1 (native speakers of English) or ESL (speakers of English as a second language).

Additional information on the two schools in this study is in Table 2.1. The support programs given to these schools are listed there and worthy of noting is that both schools were in the Inner City School funding category. Inner City Schools qualify for additional funding to provide for the educational needs of the children not covered in the regular school funding. In some cases, that funding may be used to provide extra one-to-one learning support. The individual principals are given the authority to use the funding with some flexibility in various situations unique to the inner city school setting.

In Table 2.1, the performance in the Foundation Skills Assessment (FAS) – an annual province-wide assessment of Grade 4 and 7 students in foundation skills such as reading comprehension, writing, and numeracy – from a previous year (as close to the date of the current research as possible) is also included to give a sense of the academic climate in these schools. The children are placed in three achievement categories based on their performance in the FAS. The categories are as follows: Not Yet within Expectation; Meets Expectation; and Exceeds Expectation. Students from both public and provincially funded independent schools take part in the FAS in the spring of each year. Also worth noting is that, according to Table 2.1, both of the schools in this study took part in the Kindergarten Phonemic Awareness Project where children were systematically taught phonics so that they have a better foundation for reading success.

The following steps were taken to recruit students for this study. Prior to the start of testing the children, the principals facilitated meetings that took place between the researcher and the grade three teachers. The teachers were given consent forms by the researcher and these forms were sent home to the parents with the children (see Appendix B for Consent form and Assent form). The children had one week to return the signed consent letters. The principals and teachers helped in identifying suitable participants for this study. Children were selected on the basis that they had no known sensory impairments, severe neurological disorders, or psychiatric disorders. Students new to Canada from a non-English speaking country were excluded from this study. According to the enrollment data provided by the principals, 70.2% of the total number of children in this study (121) were in the same school since kindergarten; 10.7% came to the school in grade one, 7.4% in grade two, and 11.6% in grade three. Individual breakdowns from the two schools are as follows: in one school, 66% enrolled in kindergarten, 15.1% in grade 1, 7.5% in grade 2, and 11.3% in grade 3; in another school, 73.5% enrolled in kindergarten, 7.4% in grade 1, another 7.4% in grade 2, and 11.8% in grade 3. Generally, inner city schools have a higher number of transient students; however, this did not appear to be a problem in the current sample of students.

The children's ages ranged from 8 years and 3 months to 9 years and 3 months. There were 63 (52.1%) boys and 58 (47.9%) girls in this study. The children were tested between April and May . The testing consisted of two parts, an individual test and a group tests. Quiet rooms were provided for the individual testing sessions and the group tests were administered in the children's classrooms.

2.2. Measures

2.2.1 Standardized measures

The standardized measures were selected based on the criteria discussed in Siegel (1999). Reading achievement was measured in terms of decoding ability (e.g., WJ-Word Attack), word recognition (e.g., WJ-Word Identification and WRAT-3 Reading Subtest), and reading comprehension (e.g., SDRT). Decoding ability reflects one of the most significant cognitive processes in the development of reading skills — that is, phonological processing (e.g., Siegel, 1993a & b). The ability to process phonological information effectively enables children to become proficient in acquiring a vocabulary for reading. Reading comprehension is a psychological process that requires making meaning out of words: without good word recognition skills which, to a large extent, are built upon the development of effective decoding or word attack skills, children's reading would in effect become slow and laborious, resulting in the lack of reading fluency. In fact, a phonological processing deficit may even compromise the workings of broader linguist processing such as verbal working memory (D"Angiulli, Siegel, & Maggi, 2004). It is difficult to construct tests of word recognition and reading comprehension that are free from biases: children being tested often bring with them vastly different personal histories which may or may not favor them when they have to identify words from certain word lists or understand reading passages based on certain topics. For that reason, the pseudoword reading (also referred to as word attack or nonword reading) which taps into decoding skills (e.g., phonological processing) is of paramount importance in any diagnostic reading assessment as it is free from the problems associated with typical vocabulary lists and comprehension passages in achievement tests (Siegel, 1999). The two standardized word recognition tests, the WRAT-3 Reading Subtest and the Woodcock Word Identification, were selected on the basis of available information on the validity of the tests; it was reported that these tests have a correlation of .88 ($p < .0001$) in a sample of 171 children ages 7 to 16 years (see Siegel, 1999, p. 310). The objective of having two word recognition tests in this study was to increase the chance of identifying children with reading problems; children not identified in one test may be identified in another.

The WRAT-3 Spelling test was intended to reflect children's ability to spell words that are appropriate for their age level. Again, spelling tests based on a vocabulary list have similar problems as the word recognition and reading comprehension tests discussed previously; it is hard to construct spelling tests that are totally free from the confounding of familiarity with other dimensions of a word. When a child spells a word correctly, it is possible that he/she is relying on visual memory (e.g., the word appears frequently in the child's environment) rather than an understanding of English orthography or phonology. Therefore, the GFW Nonword Spelling Test in this study served a very important purpose, that is, to help determine the spelling ability of the child being tested. Spelling may or may not be associated with reading difficulties; however, it is more reflective of a writing problem (Siegel, 1999) as poor spelling would necessarily affect the fluency of children's writing. As well, Siegel (1986) noted that spelling problems may or may not be associated with reading and/or arithmetic difficulties; however, it is rare to find a poor speller without problems in other areas of functioning.

Arithmetic ability was measured by the WRAT-3 Arithmetic Test which reflects working memory, retrieval of arithmetic facts, phonological rehearsing, and spatial-visual abilities. The working memory deficits known to be present in many children with arithmetic learning disabilities (e.g., Adams, 1998; Siegel & Feldman, 1983; Siegel & Linder, 1984) were identified by The Working Memory for Numbers test (Siegel & Ryan, 1989) in the nonstandardized measures. The format of this test was such that the children tested would not be able to rely on frequently encountered and previously learned arithmetic facts from long-term memory, for example, integer pairs and their sums, differences, products, or quotients.

These standardized achievement tests formed the basis of the achievement profiles to be analyzed in this study. Experimental measures tapping into various cognitive functions and language abilities were given to facilitate the assembling of the children's cognitive profiles for analyses. All the experimental tests are shown in Appendix C.

The following are the tests in this study arranged according to measurement categories; for example, tests that measure the same construct are placed together under the same heading. For each scale, the reliability coefficient (Cronbach's alpha) computed for the current research sample will be provided.

2.2.2 Reading subskills

Woodcock Johnson Reading Mastery Test-Revised (Form G); Word Attack (Woodcock, 1987). This subtest is a standardized measure and consists of pseudowords arranged in order of increasing difficulty. The objective was to decode as many pseudowords as possible from the list. Examples of tests items are as follows: tiff, nan, rox, zoop, lish, dright, jox, feap, gusp, snirk.

Woodcock Johnson Reading Mastery Test-Revised (Form G) Word Identification (Woodcock, 1987). This subtest has a list of words arranged in an ascending order of difficulty. The children were asked to read as many words as they can. The task was discontinued after an entire level of words was incorrectly read. Sample words from the list are: dog, must, because, island, process.

Wide Range Achievement Test-3: Reading Subtest (blue form): (Wilkinson, 1993). This is an individually administered test that has a capital letter naming component and a word-reading component. There are 42 unrelated words in the list, beginning with high frequency words and ending with relatively difficult and uncommon words. The easier words from the beginning of the list, for example, are: in, cat, book, tree, how, animal, even, spell. The word list ends with difficult items such as: omniscient, assuage, disingenuous, terpsichorean.

2.2.3 Reading fluency

One Minute Pseudoword Reading. These pseudowords were from the Word Attack List (Form H) (Woodcock, 1987). The word list was used in a timed test to assess reading fluency. The object was for each child to read as many words as possible within one minute. Standardized norms were not available because this list was presented as a timed task. This scale contained 45 items. When computing the reliability of the scale for the current research sample , the result is Cronbach's $\alpha = .95$ showing a very high reliability. See Appendix C for the entire word list.

One Minute Word Reading. This was an experimental timed reading test with real words of increasing difficulty. Each child was expected to read as many words as possible during the one minute time limit. Some sample words are as follows: see, red, milk, was, then, jar, letter. This scale contained 42 items and had high reliability (Cronbach's $\alpha = .88$). The entire list with instructions is in Appendix C.

2.2.4 Reading comprehension

Stanford Diagnostic Reading Test: Reading Comprehension (Karlsen & Gardner, 1994). This was a group test administered in the classroom. Each child worked from a booklet with short passages. This was a timed test in a multiple-choice format. The time allowed was 45 minutes.

2.2.5 Spelling

Wide Range Achievement Test-3: Spelling (blue form) (Wilkinson, 1993). Twenty words were orally presented to the children in a group test. Items were given in an ascending order of difficulty. Sample items are: and, in, him, make, cook, must, enter, light, reach, circle. A time limit of 15 seconds was allowed between words.

GFW Nonword Spelling: Spelling of Symbols Subtest of the GTW Sound-Symbols Test (Goldman, Fristoe, & Woodcock, 1974). This was an individually administered spelling test made up of 15 pseudowords. The words were orally presented to each child with 15 seconds allowed for each word. Sample words were: jesh, imbaf . It was expected that there would be different spellings for the same word in some cases (e.g., imbaf and imbaff were both considered acceptable). This spelling task was intended to measure phonological recoding. This scale had good reliability (Cronbach's $\alpha = .72$). The entire spelling list is in Appendix C.

2.2.6 Arithmetic

Wide Range Achievement Test-3: Arithmetic Subtest (blue form) (Wilkinson, 1993). This was a group test where the children were required to solve a variety of computational mathematic problems. Sample questions are as follows: 1 + 1; 8 – 4; 32 + 24 + 40; 3 x 4; 6 ÷ 2. The time allowed was 15 minutes.

2.2.7 Phonological processing

Rosner's Auditory Analysis Test (Rosner & Simon, 1971). This was a syllable and phoneme deletion task. The object was to test how well children can manipulate sounds in words. For example, a word was presented orally to a child and he/she was expected to say the word back to the examiner deleting the sound specified. Test items included deleting phonemes in initial, medial, and final position. Some examples were: "clip" without the sound /k/; "please" without the sound /s/; and "desk' without the /s/. There were 40 items arranged in ascending level of difficulty. The task was discontinued after 5 incorrect responses. The reliability was very high in this scale (Cronbach's $\alpha = .93$). The test with instructions included is in Appendix C.

2.2.8 Syntactic awareness

Oral Cloze (Siegel & Ryan, 1989; Willows & Ryan, 1986). The children were orally presented with 11 sentences and were asked to supply the missing word in each of the 11 sentences read to them. The children were expected to choose their answers from different grammatical categories from their own vocabulary (i.e., nouns, adjectives, adverbs, prepositions, and conjunctions). There was one missing word in each sentence. Test items and instructions are in Appendix C.

2.2.9 Working memory

Working Memory for Words (Siegel & Ryan, 1989). Sentences were arranged in sets of 2, 3, 4, and 5 designed to increase in level of difficulty for recall. The last word was missing in each of the cloze sentences and the child was expected to supply the missing work. After the child finished giving the oral responses for the set of sentences, he/she was required to recall the words in the sequence that the sentences were presented. The test was discontinued after a child failed all the sets in a given level.

Working Memory for Numbers (Siegel & Ryan, 1989). Each child was required to count yellow dots embedded in a background of blue dots of the same size on 5 x 8 inch index cards. The cards were arranged in sets of 2, 3, 4, and 5. There were 3 trials in each set. The object was to recall the number of yellow dots on each card in the order they were presented for each set. The sets were presented in an ascending order of difficulty, beginning with sets of 2 and continuing up to sets of 5. The task was discontinued when a child failed an entire set. See Appendix C for test instructions and format.

2.2.10 Lexical access

Rapid Automatized Naming Task (RAN). This was a timed test where a child was required to name individual numbers presented in random order in a 5 x 5 array. The performance of each child was timed in seconds. The RAN presumably assesses lexical access and has been conceptualized as an index of automaticity in lower level processes (Wolf, 1991), a fluency measure (Wolf, 1999), and a combination of skills necessary for the rapid retrieval of familiar graphological information. Test items and instructions are in Appendix C.

2.3 Design

The current study took a between-subjects approach in the form of a correlation design. Where possible, percentile scores were used in the analyses (Zimmerman & Zumbo, 2005). For research question (1), the standardized reading measures such as the Woodcock Johnson reading subtests and the WRAT-3 Word Identification were the dependent variable (DV) and, for research question (2), the WRAT-Arithmetic subtest was the dependent variable (DV). The independent variable for both research questions (1) and (2) in the correlation analyses were the measures tapping into the cognitive processes related reading and/or arithmetic. For research questions (3) and (4), the differences between groups were examined using parametric, and in some cases, non-parametric statistics.

2.4 Classification

2.4.1 Cutoff points for low achievement

In this study, the focus was on using a low achievement approach to identify reading disability and arithmetic disability. Therefore, it is essential that the standard of what constitutes low achievement be explained in detail. Generally, a score of ≤ 25th percentile as low is a criterion commonly adopted by those in the diagnostic profession; however, one standard deviation from the mean, which is approximately the 16th percentile, is also used widely. Reading, arithmetic, and other academic abilities necessarily exist on a continuum rather than as discrete entities (refer to discussion on cutoff points in Siegel, 1999); for example, in diagnostic situations, whether a child's reading is at the 25th or the 26th percentile in a standardized achievement test does not make a big difference in the final analysis because both of these are low scores reflecting inadequate grasp of reading. The borderline between disorder and normal functioning is arbitrary; however, the educational system has to have some sort of standard to determine who will receive special education service and these cutoffs serve as benchmarks for identifying children with learning problems. Therefore, for the sake of comparison and for the sake of satisfying scientific curiosity, in this study, three groups with different cutoff points for low and normal were used. These three groups were: the Stringent Group with a ≤ 17th percentile cutoff for low and a ≥ 35th percentile cutoff for normal; the Low Cutoffs Group with a ≤ 17th percentile cutoff for low and a ≥ 30th percentile cutoff for normal; and the High Cutoff Group with a ≤ 25th percentile cutoff for low and a ≥ 35th percentile cutoff for normal. The group of major interest in this study was the High Cutoff Group with the cutoffs designed to allow low achievers to be identified more readily and normally achieving children to be well above suspicion of being low achievers. A cutoff point for low at the 25th percentile has often been observed to correlate with teachers' and parents' observation in cases where there were significant learning problems in the children (Siegel, 1999; also see D"Anguilli & Siegel, 2003 for discussion of the validity of the use of the 25th percentile as a benchmark for identifying at-risk children in reading).

2.4.2 Types of low achievement in this study

There are three possible types of low achievement in this study: low reading, low arithmetic, and low in both reading and arithmetic. These low achievement types were compared to normally achieving children in the cognitive profile analyses in this study.

A criterion-based grouping was applied to the children in this study: tests scores expressed in percentiles in the standardized tests were used to create the groups. The Normally Achieving (NA) group and the low achievement groups described in table 2.2 in this study were comparable to similarly defined groups of grade three children across educational settings as these groups were created based on standardized achievement tests. The continuous variables, the standardized achievement tests, were collapsed into rank ordered categories: low = 1, marginal = 2, and normal = 3. To facilitate the achievement profile analyses in this study, a numeric code with six digits reflecting the performance profile of each child was created. The six standardized achievement tests used to form the numeric achievement codes were each assigned a particular digit. The standardized achievement tests with their assigned digits are as follows: 1st digit was for WJ-Word Attack; 2nd digit was for WJ-Word Identification; 3rd digit was for WRAT-3 Word Identification; 4th digit was for WRAT-3 Spelling; 5th digit was for the SDRT; and the 6th digit was for WRAT-3 Arithmetic. According to the phonological core deficit theory (e.g., Stanovich, 1998), a phonological processing deficit is at the heart of the reading problems in children, and the phonological component within the working memory model, if disrupted, may possibly also lead to problems in the arithmetic domain (e.g., Hitch & Baddeley, 1976; Shafrir & Siegel, 1994b; Stanovich, 2000a). Therefore, the WJ-Word Attack reading subtest representing phonological processing ability was intentionally placed in the first digit position. If the first digit had a low ranking, for example, the percentile score was ≤ 25 and the numeric code was 1, then, theoretically, the other areas of achievement such as word recognition, reading comprehension, spelling, and arithmetic had a higher chance of also being low. After the achievement codes were assembled for each of the children using the predetermined cutoff points, the entire group of 121 children was sorted in numerical order; for example, the first case would be 111111 and the last case would be 333333. The purpose was to detect the trend present in the group of children being studied and to identify the major low groups for analyses which would address reseasrch questions 1 and 2.

Table 2.2 shows the groups created by the current scheme that were selected for the cognitive profile analyses for research questions 3 and 4. Using the current achievement coding scheme described above, five groups emerged in this study for the cognitive profile analyses: the Normally Achieving (NA) with the numeric code 333333, the Reading Disabled (RD) with the numeric code 11111x, the Poor Comprehenders (PC) with the numeric code 33331x, the Arithmetic Disabled (AD) with the numeric code 333xx1, and the Reading and Arithmetic Disabled (RAD) with the numeric code 111xx1. Note that the "x" indicates that the achievement test represented by the particular digit was not considered in the formation of the achievement group in question. In forming the various achievement groups for analysis, sometimes the digits representing certain standardized tests were ignored to meet the group formation specifications. For example, to form the Reading Disabled (RD) group, the 6th digit in the numeric code which represents arithmetic achievement was omitted; the children's performance in arithmetic was not relevant to this particular group as the interest was focused on reading achievement only. Hence, the numeric code for the RD group would be 11111x where the "x" in the 6th digit represented the WRAT-3 Arithmetic that was omitted for consideration. Similarly, the Poor Comprehenders (PC) had a numeric code or achievement profile of 33331x where the 6th digit was also ignored because arithmetic was not the skill that was of interest in this group. As for the two arithmetic disabled groups in this study, there was one group with the achievement code of 333xx1 representing the Arithmetic Disabled (AD) proper and another group with the achievement code of 111xx1 representing the Reading and Arithmetic Disabled (RAD); both the 4th and 5th digits were ignored in these two achievement groups as the focus was on arithmetic disabled children with or without a phonological processing deficit. In the AD and RAD achievement groups, only the first three digits giving the most direct information about the children's phonological competence were important. The WRAT-Spelling represented by the 4th digit and the SDRT reading comprehension represented by the 5th digit were excluded for consideration because the information they provide did not contribute to what was being studied. Children with low arithmetic (e.g., the AD group) can be low or normally achieving in spelling and reading comprehension (e.g., SDRT represented by the 5th digit) was not the focus in this group. As for the RAD group, children with normal reading subskills such as word attack and word recognition can be low or normally achieving in reading comprehension, and hence the WRAT-Spelling and SDRT were excluded for consideration in forming this group for analysis.

To study the pattern of performance in the cognitive measures in relation to achievement in reading, arithmetic, and spelling, numeric rankings were also assigned to the scores in the cognitive measures. These rankings, however, unlike the rankings based on standardized tests, were sample specific; that is, the classification of low and normal was relative to the sample within the study. A score that was ≥ the average was considered normal and a score ≤ 1 standard deviation (SD) was considered low.

As noted previously, cutoffs are arbitrarily determined according to the conventions or the logic commonly accepted by professionals and researchers in the field of LD. For most part, the cutoff criteria were strictly adhered to in this study. Where there were exceptions, the deviation from the cutoffs were negligible; for example, the 18th percentile might be accepted as low in the Stringent Group and the Low Cutoff Group, or perhaps the 26th and 27th percentile might be accepted as low in the High Cutoff Group. Table 2.2 describes the details related to the groups where the cutoffs were not strictly used.

3 Results

3.1 Overall performance of children in this study

A summary of the children's overall performance in this study is shown in Table 3.1. Note the low reading comprehension where the mean was approximately at the 33rd percentile. The arithmetic performance, however, was at the 52nd percentile which was in the average range. Table 3.2 shows that, using the standards of the Stringent Group or the Low Cutoff Group, 30% of the children in the current study were low in reading comprehension and 8% were low in arithmetic. If the High Cutoff Group standards were used, the number would increase; 48% of the children in this study were low in reading comprehension and another 20% of these children were low in arithmetic.

After each of the children in this study was given numeric codes reflecting their achievement, they were sorted in ascending order. A pattern emerged showing a trend where, if phonological processing represented by the WJ-Word Attack was low (1), then it followed that the word recognition skills (e.g., the WJ-Word Identification and the WRAT-3 Word Identification), spelling skills (e.g., WRAT-3 Spelling), and reading comprehension (e.g., SDRT) would be also be either marginal (2) or low (1). The exception was arithmetic achievement where children low in the WJ-Word Attack can have a range of achievement rankings from normally achieving (3), marginal (2), to low (1).

As well, when the WJ-Word Attack was marginal (2), the word reading skills and spelling can range from marginal (2) to normal (3); however, the reading comprehension was practically always low (1). For example, eight children from a total of ten children in the High Cutoff Group with marginal word attack skills were low achieving in the SDRT; it was the same for the Low Cutoff Group, and for the stringent Group, thirteen children out of a total of fifteen children with marginal word attack skills were low achieving in the SDRT. Once the word attack skills were in the normally achieving range, then the word recognition skills and spelling tended to be normal (3); however, the SDRT reading comprehension was not necessarily in the normally achieving range. This suggests that additional reading related skills have to be present to facilitate the children's reading comprehension; word reading skills such as word attack and word recogntion are not adequate. In fact, in the High Cutoff Group, forty-one out of sixty (68.3%) of the children with normal word attack skills were normally achieving in reading comprehension; fifty-two out of ninety-six (54.2%) of the children with normal word attack skills were normally achieving in reading comprehension in the Low Cutoff Group; and forty-one out of ninety-three (44.1%) of the children with normal word attack skills were normally achieving in reading comprehension in the Stringent Group.

The pattern described is suggestive of a phenomenon where weaker cognitive functioning in some areas was being compensated by other more proficient cognitive functionings in the reading domain (e.g., Stanovich, 2000a). It appeared that when phonological processing was low (1), it was harder for other cognitive functions that were unimpaired to compensate for that particular weakness. For example, it was very difficult for a child who had marginal spelling skills (e.g., symptomatic of having poor orthographic and phonological processing skills), low reading subskill, low reading comprehension, and low arithmetic skills (e.g., an achievement profile of 111211) to compensate for the phonological processing spelling deficit to the level of being able to facilitate proficient word recognition and hence reading comprehension. Even when word recognition skills were relatively less impaired as in the case of a child with normal word reading in one of the two word recognition tests, marginal spelling, and marginal arithmetic (e.g., an achievement profile of 113212), the low phonological processing still prevented compensatory strategies from operating to produce a proficient reader.

3.2 Hypothesis: the phonological core deficit theory

The research hypothesis in this study was that the phonological core deficit theory (e.g., Stanovich, 1998) would provide a sufficient explanatory model of the data. A phonological deficit was expected to be a consistent defining feature in the low achieving groups with reading problems based on what is known about the importance role of phonological processing in vocabulary building (e.g., Gathercole et al., 1997) and in the working memory model (e.g., Adam & Hitch, 1998; Gathercole & Baddeley, 1990). It was also hypothesized that phonological processing may also have an important relationship with arithmetic (e.g., Hecht et al., 2001) because aspects of phonological processing such as phonological memory, rate of access, and phonological awareness have been implicated in the development of arithmetic skills.

3.3 The low achieving groups and their defining features

Table 2.2 shows the groups that were selected for the cognitive profile analyses for research questions 1 and 2. There were other types of low achieving children, but there were not enough cases in the current sample of children to create these groups for analysis. Using the current achievement coding scheme described previously, five groups emerged in this study for the cognitive profile analyses: the Normally Achieving (NA) representing children with normal achievement across all of the standardized achievement measures of reading, spelling, and arithmetic (e.g., 333333), the Reading Disabled (RD) with low achievement in all reading subskills, reading comprehension, and spelling (e.g., 11111x), the Poor Comprehenders (PC) who had low reading comprehension while having normal word attack, word recognition, and spelling at the same time (e.g., 33331x), the Arithmetic Disabled (AD) who had normal word reading subskills and low arithmetic (e.g., 333xx1), and the Reading and Arithmetic Disabled (RAD) who were low in word reading subskills and arithmetic (e.g., 111xx1). Note that the "x" indicates that the achievement test represented by the particular digit was not considered in the formation of the achievement group in question.

In forming the various achievement groups for analysis, sometimes the digits representing certain standardized tests were ignored to meet the group formation specifications. For example, to form the Reading Disabled (RD) group, the 6th digit in the numeric code which represents arithmetic achievement was omitted; the children's performance in arithmetic was not relevant to this particular group as the interest was focused on only reading achievement. Hence, the numeric code for the RD group would be 11111x where the "x" in the 6th digit represented the WRAT-3 Arithmetic that was omitted for consideration. Similarly, the Poor Comprehenders (PC) had a numeric code or achievement profile of 33331x where the 6th digit was also ignored because arithmetic was not the skill that was of interest in this group. As for the two arithmetic disabled groups in this study, there was one group with the achievement code of 333xx1 representing the Arithmetic Disabled (AD) and another group with the achievement code of 111xx1 representing the Reading and Arithmetic Disabled (RAD); both the 4th and 5th digits were ignored in these two achievement groups as the focus was on arithmetic disabled children with or without a phonological processing deficit – spelling skills and reading comprehension were not the variables of interest here. In the AD and RAD achievement groups, only the first three digits giving the most direct information about the children's phonological competence were important.

Note that ambiguities in a case were often resolved by examining the numeric codes created for the same case under other group criteria. For example, there was a case in this study where a child had low word attack and word identification skills, but somehow managed to have normal spelling, reading comprehension, and arithmeitc in the High Cufoff Group (e.g., an achievement profile of 111333). At first glance, this performance pattern seemed very unlikely, but examining this child under different cutoff standards revealed a slightly different picture: in the Stringent Group and the Low Cutoff Group, this child was actually low in word attack, and marginal in word recognition while being normally achieving in spelling, reading comprehension , and arithmetic (e.g., having an achievement profile of 122333). Therefore, a possible explanation for this child's normally achieving status in the reading comprehension (5th digit represents SDRT) may be that he was able to compensate for his poor word attack skills with somewhat functional word identification strategies and a fairly good sense of English orthography (4th digit represents spelling). As well, this child was probably very skilled in using contextual cues for reading comprehension.

In this study, the cutoff criteria were strictly adhered to most of the time. Where there were exceptions, the deviation from the cutoffs were negligible; for example, the 18th percentile might be accepted as low in the Stringent Group and the Low Cutoff Group, or perhaps the 26th and 27th percentile might be accepted as low in the High Cutoff Group. Table 2.2 describes the details related to the groups where the cutoffs were not strictly adhered to.

3.4 Were the low achieving children and normally achieving children differentiated by their cognitive profiles?

Analyses of the cognitive profiles of the low achieving groups identified in this study are presented here to address research questions 1 and 2. Where possible, that is, if there was a sufficient number of children that fit the criteria, an independent-sample *t*-test was conducted for each of the achievement groups with different cutoffs.

The hypothesis here was that the low and normally achieving children would be differentiated on variables associated with the core deficits referred to in the working theory of this study. Variables most directly related to phonological processing were expected to be implicated in the cognitive profile analyses.

3.4.1 The Reading Disabled (RD)

The Reading Disabled group (RD) was compared with the Normally Achieving (NA) children using three different cutoff criteria. Refer to Table 3.3 with stringent cutoffs (normal ≥ 35th percentile & low ≤ 17th percentile), Table 3.4 with low cutoffs, (normal ≥ 30th percentile & low ≤ 17th percentile), and Table 3.5 with high cutoffs, (normal ≥ 35th percentile & low ≤ 25th percentile).

Independent sample *t*-tests were conducted to evaluate the hypothesis that the low achieving children in this group and the normally achieving children were differentiated on the basis of their phonological processing, working memory, and syntactic awareness. Using Bonferroni technique, the *p* level was adjusted in the *t*-tests to 0.003 that corresponded to dividing the usual alpha = 0.05 by the number of tasks in the study (by 14). The results strongly supported the research hypothesis that the Reading Disabled (RD) group would be differentiated on measures of phonological processing, working memory, and syntactic awareness. Regardless of the cutoffs used (refer to Tables 3.3, 3.4, 3.5), the Normally Achieving (NA) children and the Reading Disabled (RD) children were differentiated on all of the measures. Note the substantial Cohen's *d* effect size in all the comparisons between the NA and RD groups; whether it was Table 3.3, 3.4, or 3.5, the effect size was large (e.g., with the Cohen's *d* above .9 in all of the cases).

From these *t*-test analyses of the RD groups with different cutoffs critera, it was apparent that this group of children were very seriously impaired in their cognitive functioning in the areas of phonological processing, working memory, and syntactic awareness. The deficits in these areas prevented these children from processing language information efficiently and hence, as seen in the timed measures of reading (e.g., Time Reading of Words and Timed Reading of Pseudowords), their performance was quite poor. When the word recognition process is slow and laboured, then reading comprehension is compromised. The RD children in this study were similar to the dyslexic children described in the reading disability literature (e.g., Siegel, 1993a); they all shared similar cognitive profiles: these RD children all had a severe phonological processing deficit.

3.4.2 Poor Comprehenders (PC)

Refer to Table 3.6 with stringent cutoffs (normal ≥ 35th percentile & low ≤ 17th percentile), Table 3.7 with low cutoffs, (normal ≥ 30th percentile & low ≤ 17th percentile), and Table 3.8 with high cutoffs, (normal ≥ 35th percentile & low ≤ 25th percentile). The Poor Comprehenders (PC) group was compared with the Normally Achieving (NA) children using three different cutoff criteria. Independent sample *t*-tests were conducted to evaluate the hypothesis that the Poor Comprehenders (PR) group and the Normally Achieving (NA) children were differentiated on the basis of their phonological processing, working memory, and syntactic awareness. Using Bonferroni technique, the *p* level was adjusted in the *t*-tests to 0.003 that corresponded to dividing the usual alpha = 0.05 by the number of tasks in the study (by 14).

The results showed that in Table 3.6, Table 3.7 and Table 3.8, if the Bonferroni-adjusted correction was used, the low achieving group and the normally achieving group would not be differentiated on any of the cognitive measures. However, if an alpha level of .05 was used, all three groups, regardless of cut-off criteria, would be most notably differentiated on the Oral Cloze tapping into syntactic awareness, Stringent Group, $t(36) = 2.35, p = 0.024$, effect size, $d = 0.79$, Low Cutoff Group, $t(50) = 2.27, p = 0.028$, effect size, $d = 0.69$, High Cutoff group, $t(36) = 2.35, p = 0.024$, effect size, $d = 0.79$, Also, using an alpha level of .05 may enable more detection of group differentiations in the High Cutoff Group, Working Memory for Numbers, $t(47) = 2.60, p = 0.012$, effect size, $d = 0.74$, Working Memory for Words, $t(47) = 2.06, p = 0.045$, effect size, $d = 0.58$, Timed Reading of Words, $t(47) = 2.33, p = 0.024$, effect size, $d = 0.66$, and Timed Reading of Pseudowords, $t(47) = 2.48, p = 0.017$, effect size, $d = 0.71$. Note that the effect size shown were all in the medium to large range (e.g., $d = .5$ as medium and $d = .8$ and above as large). It is unclear why the High Cutoff Group showed different results from the other cutoff groups. Possibly, the High Cutoff Group had more children in the PC group for comparison ($n = 24$) and hence had more statistical power. The Stringent Group had 13 children in the PC group and the Low Cutoff Group had14 children in the PC group.

The fact that the *t*-tests using an alpha level of .05 consistently suggested the possibility of the PC and NA groups being differentiated on the Oral Cloze indicates that the current findings using the Bonferroni-adjusted correction should be interpreted with caution. The Bonferroni-adjusted correction has been known to be very conservative and it may well have been responsible for not detecting differences where they actually existed.In comparison to the Reading Disabled (RD) group, the PC children appeared to be normally achieving in terms of their phonemic awareness (e.g., Rosner), spelling (e.g., both the WRAT-3 Spelling and the Nonword Spelling), and lexical access (e.g., RAN). However, the results reported in Table 3.8 where the working memory, both that of words and numbers, syntactic awareness, and speed of word recognition (e.g., the timed reading measures) of NA and PC children were different deserve further investigation with replications of this type of comparison. For sure, the children who were low in reading comprehension and yet had normal achievement in all reading subskills and spelling (e.g, an achievement profile of 33331x) were an interesting group; their word level subskills appeared to be intact, but they still had difficulties in reading comprehension. Worth noting is that in Table 3.8, children in the PC and NA groups were differentiated by the WJ-Word Attack which was a phonological processing measure. This may perhaps be explained by the bi-directional relationship between the development of reading and phonological sensitivity (e.g., Burgess & Lonigan, 1998); phonological sensitivity helps children develop a vocabulary for reading while at the same time, the reading experience facilitates further development of the children's phonological sensitivity.

3.4.3 The Arithmetic Disabled (AD)

An independent sample *t*-test was conducted to evaluate the hypothesis that the low achieving children in this group and the normally achieving children were differentiated on the basis of their phonological processing, working memory, and RAN. Using Bonferroni technique, the *p* level was adjusted in the *t*-tests to 0.003 that corresponded to dividing the usual alpha = 0.05 by the number of tasks in the study (by 14). The Arithmetic Disabled (AD) group was compared with the normally achieving children using the High Cutoff Group criteria only; there were insufficient cases for analyses using the other cutoff criteria. The results in Table 3.9 showed that the Arithmetic Disabled (AD) group and the Normally

Achieving (NA) group were differentiated on the basis of the Working Memory for Numbers, $t(36) = 3.93, p \leq 0.003$, effect size, $d = 1.30$, and the Timed Reading of Pseudowords, $t(36) = 3.67, p \leq 0.003$, effect size, $d = 1.31$. If an alpha level of .05 was used, more differentiations based on the cognitive measures would appear, Rosner Phoneme Deletion Test, $t(36) = 2.07, p = 0.045$, effect size, $d = 0.69$, Working Memory for Word, $t(36) = 2.07, p \leq 0.037$, effect size, $d = 0.78$, and the Timed Reading of Words, $t(36) = 2.30$, $p = 0.027$, effect size, $d = 0.77$. The cognitive profile that has emerged seemed to suggest that children with low arithmetic and normal reading subskills have deficits possibly in phonological rehearsal as implicated by the Rosner Phoneme Deletion which required children to hold a phonological representation in memory for manipulation. Another area of deficit was working memory, and on the basis of the analysis in Table 3.9, it would appear that both working memory for numbers and working memory for words were somehow implicated. The timed reading measures tapping into phonological retrieval also appeared to be important in differentiating the Arithmetic Disabled (AD) children who were low achieving in arithmetic and had normal word level reading subskills. These results appeared to support the hypothesis that children with difficulties in arithmetic would have problems in the phonological domain, and in particular, phonological rehearsal, phonological retrieval, and working memory would be implicated.

3.4.4 The Reading and Arithmetic Disabled (RAD)

An independent sample *t*-test was conducted to evaluate the hypothesis that the low achieving children in this group and the normally achieving children were differentiated on the basis of their phonological processing, working memory, and RAN. Using Bonferroni technique, the *p* level was adjusted in the *t*-tests to 0.003 that corresponded to dividing the usual alpha = 0.05 by the number of tasks in the study (by 14). The Reading and Arithmetic Disabled (RAD) group was compared with the Normally Achieving (NA) children using the High Cutoff Group criteria only; there were insufficient cases for analyses using the other cutoff criteria. The results in Table 3.10 showed that the low achieving and normally achieving groups were differentiated on the basis of the Rosner Phoneme Deletion Test, $t(30) = 5.39, p \leq 0.003$, effect size, $d = 1.82$, Working Memory for Numbers, $t(30) = 4.24, p \leq 0.003$, effect size, $d = 1.86$, Oral Cloze, $t(30) = 4.85, p \leq 0.003$, effect size, $d = 1.91$, RAN,

$t(30) = 3.50, p \leq 0.003$, effect size, $d = 1.30$, Timed Reading of Words, $t(30) = 6.71, p \leq 0.003$, effect size, $d = 2.68$, and Timed Reading of Pseudowords, $t(30) = 8.47, p \leq 0.003$, effect size, $d = 3.52$. Both the Working Memory for Words and the GFW Nonword Spelling were very close to being statistically significant, $t(30) = 3.04, p \leq 0.005$, effect size, $d = 1.33$, and $t(30) = 3.12, p \leq 0.004$, effect size, $d = 1.24$ respectively. The cognitive profile that has emerged seemed to suggest that the RAD children with low reading subskills and low arithmetic have a deficit pattern very similar to that of the RD children low in reading comprehension and reading subskills. It appears that low word attack skills as demonstrated in the WJ-Word Attack Reading Subtest are associated with a host of other cognitive deficits. The RAD children in this analysis appeared to have problems in the areas of phonological rehearsal (e.g., Rosner Phoneme Deletion Test), phonological retrieval (e.g., RAN, and the timed reading measures), and working memory. These results strongly support the hypothesis that children with difficulties in arithmetic and reading subskills would have problems in these cognitive processes.

3.4.5 Summary of Low Achievement Profiles

The Reading Disaled (RD)

The cognitive profile of the Reading Disabled (RD) group was that of dyslexics (e.g., Siegel, 1993 a). These children had deficits in phonological processing, working memory, and syntactic processing.

The Poor Comprehenders (PC)

The Poor Comprehenders (PC), strictly speaking, did not show a cognitive profile that was different from the Normally Achieving (NA) children. The two groups of children, NA and PC, were differentiated by the SDRT reading comprehension only.

Arithemetic Disabled (AD)

The Arithmetic Disabled (AD) children's cognitive profile showed more areas of deficit. In particular, phonological processing and working memory were implicated. The AD group were differentiated from the NA group on the basis of their performance in the WJ-Word Attack, the Timed Reading of Pseudowords, WRAT-Spelling, SDRT, and Working Memory for numbers.

Reading and Arithmetic Disabled (RAD)

The cognitive profile of the RAD group was very similar to the RD group. They were clearly differentiated from the Normally Achieving (NA) children on all the measures except for the Pseudoword Spelling and the Working Memory for words.

Table 3.12 provides a checklist of the areas of deficit for the low achievement types discussed above.

3.5 Were the L1 and ESL children differentiated by their cognitive profiles?

The hypothesis here is that children from an ESL home background would very likely be differentiated on language-related tasks but not on the arithmetic-specific tasks.

An independent sample *t*-test was conducted to evaluate the hypothesis that the L1 and ESL children were differentiated on the basis of their cognitive processes. Using Bonferroni technique, the *p* level was adjusted in the *t*-tests to 0.003 that corresponded to dividing the usual alpha = 0.05 by the number of tasks in the study (by 14). Table 3.11 showed that the L1 and ESL children were clearly differentiated on three cognitive measures, the Oral Cloze, $t(119) = 3.25, p \leq 0.002$, effect size, $d = 0.67$, the Timed Reading of Words, $t(119) = 3.73, p \leq 0.001$, effect size, $d = 0.71$, and the GFW Nonword Spelling, $t(119) = 3.26$, $p \leq 0.001$, effect size, $d = 0.63$. These results are not surprising as the ESL children's home language may have very different syntactic structure from English; as well, the lack of exposure to English compared to L1 children may put the ESL children in a disadvantageous position in terms of vocabulary acquisition. Note that in Table 3.11 that if an alpha level of .05 was used, the L1 and ESL groups were differentiated on both the WJ-Word Attack, $t(119) = 2.30, p \leq 0.05$, effect size, $d = 0.46$, and the Time Reading of Pseudowords, $t(119) = 2.29, p \leq 0.05$, effect size, $d = 0.47$.

An attempt was made to determine whether the Normally Achieving L1 and ESL children were differentiated on any of the measures used in this study. T-tests analyses were conducted for both of the Normally Achieving cutoffs (i.e., Normally Achieving = 30^{th} percentile, and Normally Achieving = 35^{th} percentile). No differences were detected between the Normally Achieving L1 and ESL children in these analyses.

3.6 Relationship between the achievement and cognitive variables

Pearson product-moment correlation coefficients were calculated to determine the strength of the relationship between the variables in this study and multiple regression analyses were conducted to further examine the nature of the relationship between the achievement variables (e.g., reading and arithmetic) and the cognitive variables of interest. In addition, Pearson's chi square analyses of contingency tables were calculated to provide information about the pattern of association between the variables in this study; percentile scores on the standardized measures and raw scores on the experimental measures were used to conduct these analyses. Low and normally achieving groups were created for chi square analyses according to the criteria described previously in the Method section.

The hypothesis here was that phonological processing would have a significant relationship with children's academic performance as measured in the standardized tests. It was anticipated that the pattern of relationship in studies of L1 children from middle-class backgrounds would also appear in this study, regardless of their SES status and home language background.

3.6.1 Unique feature of this study

The unique feature of this study was that, in addition to using a Pearson correlation coefficient, *r*, to describe the relationship between variables, a chi square design was also used to examine the nature of the relationship between the achievement variables and the cognitive variables; that is, whereas *r* provides information about the strength of the relationship between two variables, the contingency tables were able to offer information that was useful for individual diagnosis. It was possible to see the number of children distributed between the two levels (e.g., low or normal) of each of the variables being examined in the 2 x 2 contingency tables. From the 2 x 2 chi square tables, it was possible to obtain information about the likelihood of certain patterns of achievement, which, in clinical practice, would be tremendously helpful. For example, if the chi square table showed that children who were low in word attack skills were unlikely to be normal in word recognition, then, that means a child who has low word recognition skills in the classroom is likely to have a phonological deficit and that intervention addressing this area would be fruitful. Currently, to the author's knowledge, no other study has attempted to examine the relationship between the achievement variables and the cognitive variables in a comprehensive manner using a chi square design.

3.7 The achievement measures

The standardized achievement measures were all significantly correlated at the .001 level as shown in the correlation matrix in Table 3.12. The WJ-Word Attack which assessed sound-symbol correspondence related to word reading was strongly correlated with the word reading subtests, the WJ-Word Identification ($r = 0.784$) and the WRAT-3 Word Identification ($r = 0.787$); it also shared a high correlation with the WRAT-3 Spelling assessing English orthography as well as phonological processing ($r = 0.707$). The correlation of the WJ-Word Attack with the SDRT assessing reading comprehension was more moderate ($r = 0.506$), possibly because there were other psychological processes beyond the word reading level such as working memory and syntactic awareness also of importance to reading comprehension. The WJ-Word Attack was only moderately correlated with the WRAT-3 Arithmetic ($r = 0.374$) which suggests that work phonological processing, though important, is only one aspect in the totality of what makes up proficiency in arithmetic skills.

The two word reading measures tapping into the age appropriate word recognition skills of grade 3 children, the WJ-Word Identification and the WRAT-3 Word Identification, were also highly correlated ($r = 0.786$). The WJ-Word Identification was highly correlated with the WRAT-3 Spelling ($r = 0.717$) and the WRAT-3 Word Identification also shared a similar high correlation of ($r = 0.684$) with the WRAT-3 Spelling. The WJ-Word Identification correlated with the SDRT ($r = 0.516$) together with the WRAT-3 Word Identification ($r = 0.529$); both of these correlations were in the moderate range. Again, this suggests that word level proficiency is only a part of what constitutes the ability to read for comprehension.

The correlation between the word reading measures and the WRAT-3 Arithmetic was in the moderate range, the WJ-Word Identification ($r = 0.445$) and the WRAT-3 Word Identification ($r = 0.436$); possibly, certain aspects of phonological retrieval are common to word recognition and retrieval of arithmetic facts to perform calculations.

The WRAT-3 Spelling and the SDRT had a moderate correlation ($r = 0.399$), and the correlation with the WRAT-3 Arithmetic was also moderate ($r = 0.436$); while these were fairly low correlations, it is interesting to note that in this sample of children, spelling was more highly correlated to arithmetic than to a language-related ability such as reading comprehension. The SDRT and the WRAT-3 Arithmetic had a relatively low correlation of ($r = 0.253$) suggesting that these abilities share less in common in terms of the psychological processes at work.

Research questions 3 and 4 dealing with the relationship between the cognitive measures and the achievement measures are addressed in the following.

3.7.1 What was the relationship between reading achievement and the measures of phonological processing, working memory, and syntactic awareness?

Phonological processing

Table 3.13 is a correlation matrix showing the relationship between the variables in this study. The importance of phonological processing to word level reading skills was clear in this study. As noted previously, the WJ-Word Attack Reading Subtest, a test tapping directly into awareness of sound-symbol relationships in the English language, had strong correlations with the standardized measures of reading subskills; as well, it was also significantly correlated with the experimental measures of timed word reading, the Timed Reading of Words ($r = 0.792, p < .001$), and the Timed Reading of Pseudowords ($r = 0.904$, $p < .001$).

However, the WJ-Word Attack Reading Subtest was less strongly correlated with reading comprehension (SDRT) which required more than word level proficiency in reading. The 2 x 2 contingency tables (refer to Appendix D) revealed significant associations between the WJ- Word Attack Reading Subtest and all of the reading measures. It was extremely unlikely for children with low word attack skills to be normally achieving in word identification and reading comprehension across cutoff criteria; the overall likelihood was less than 5%. Children with normal word attack skills, however, did not necessarily do well in reading comprehension, and this was most evident in the High Cutoff Group, χ^2 (1, $N =$ 92) = 10.979, $p \leq .0001$) where 72% of the children with normal word attack skills were low achieving in reading comprehension. This strongly suggests that there were other factors at work that influenced the children's performance in reading comprehension.

The Rosner Phoneme Deletion Test, although thought of as a measure tapping into phonemic awareness, was essentially an auditory measure that did not demand an awareness of sound-symbol relationship; although it showed a high-moderate correlation with the standardized word level reading subskills, WJ-Word Attack Reading Subtest, ($r = 0.657$, $p < .001$), WJ-Word Identification ($r = 0.692, p < .001$), and WRAT-3 Word Identification, ($r = 0.663, p < .001$), these correlations were not as high as those related to the WJ-Word Attack, which was a more pure measure of sound-symbol relationship awareness. At the same time, the Rosner Phoneme Deletion Test was moderately correlated with the Timed Reading of Words, ($r = 0.629, p < .001$), and had a slightly higher correlation with the Timed Reading of Pseudowords with ($r = 0.705, p < .001$), a more pure phonological measure; its correlations with the GFW Nonword Spelling, which required phonological recoding, that is, converting sounds into symbols, was in the low-moderate range, ($r = 0.477, p < .001$). The Rosner Phoneme Deletion Test shared a low correlation with reading comprehension (SDRT), ($r = 0.451, p < .001$), corroborating previous observations regarding the role of word level reading subskills in reading comprehension. The 2 x 2 contingency table in Appendix E showed that children who were low in the Rosner Phoneme Deletion Test were extremely unlikely to be normally achieving in the reading subskills such as word attack and word identification across cutoff criteria. With reading comprehension, children low in the Rosner Phoneme Deletion Test were not necessarily low in reading comprehension, and this trend was most evident in the High Cutoff Group, χ^2 $(1, N = 78) = 5.966, p < .0001)$ where 66% of those with normal auditory analysis skills were low in reading comprehension.

The WRAT-3 Spelling measuring an aspect of phonological processing, that is, phonological recoding, as noted previously, also shared relatively high correlations with all of the standardized word level reading subskills; as well, it had strong correlations with the timed word reading measures tapping into reading fluency, the Timed Reading of Words, ($r = 0.739, p < .001$), and the Timed Reading of Pseudowords ($r = 0.788, p < .001$). Similar to other word level measures related to reading, the WRAT-3 Spelling Test only shared a low correlation with the SDRT, ($r = 0.399, p < .001$). The 2 x 2 contingency table in Appendix F showed that children with low spelling was highly unlikely to be normally achieving in the word reading subskills for all the cutoff criteria. Worth noting is that none of the children who were low in spelling were able to be normally achieving in reading comprehension (SDRT) across cutoff groups, but it was only in the High Cutoff group that this trend was more clear and certain with the two variables in question showing significant association with one another, χ^2 (1, N = 82) = 10.468, p = .001).

The GFW Nonword Spelling Test, in general, had low correlations with all aspects of reading, WJ-Word Attack, (r = 0.478, p < .001), WJ- Word Identification, (r = 0.466, p < .001), WRAT-3 Word Identification, (r = 0.427, p < .001), and in particular, reading comprehension, (r = 0.299, p < .001). As a phonological measure, one might expect that the Nonword Spelling Test would be as important as the WJ-Word Attack; however, according to the data, it appeared that the process of converting symbols into sound might be more important for reading (e.g., word attack) than the process of coding sounds into symbols (e.g., spelling). The 2 x 2 contingency table in Appendix G showed that children low in the GFW Nonword Spelling were very unlikely to be normally achieving in word attack. As for word identification, it appeared that it was quite unlikely for children with normal GFW Nonword Spelling skills to be low in the WJ Word Identification; and this was clearer in the High Cutoff Group where there was clearly a significant association between the two variables, χ^2 (1, N = 86) = 23.364, p < .0001). The same trend appeared in the WRAT-3 Word Identification across cutoff criteria, all the associations were significant at $p \leq 0.0001$. Worth noting was that, in both of the word identification measures, it was possible for children low in the GFW Nonword Spelling to be normally achieving. Theoretically, children with impaired phonological processing could still recognize high frequency words if they have good visual memory; that is, reading for these children would be more dependent on the visual route. As well, there was a pattern showing that children low in Nonword Spelling were less likely to be normally achieving in reading comprehension although the strength of the association was not as strong as in the other reading subskills. The chi square statistics computed for the Stringent Group, the Low Cutoff Group, and the High Cutoff group are as follows: χ^2 (1, N = 61) = 5.636, p = .018), χ^2 (1, N = 72) = 6.608, p = .010), and χ^2 (1, N = 77) = 3.766, p = .052).

Most interestingly, the RAN (Rapid Automatized Naming), which has been featured in the double deficit hypothesis for reading disability (e.g., Wolf, 1999), did not appear to be highly correlated with measures of reading in this study, WJ-Word Attack, (r = - 0.370, p < .001), WJ- Word Identification, (r = - 0.316, p < .001), WRAT-3 Word Identification, (r = - 0.284, p < .001), and in particular, there was no significant correlation with reading comprehension, (r = - 0.161, p > .05). The correlations were higher in the timed reading measures tapping into reading fluency, Timed Reading of Words, (r = 0.479, p < .001), and Timed Reading of Pseudowords, (r = 0.385, p < .001) which suggests that the RAN did tap into phonological retrieval at some level, though it may not be significant compared to other phonological measures. The 2 x 2 contingency tables in Appendix H did show significant associations between the RAN and the word level reading subskills; however, children low in the RAN were almost equally likely to be low or normal in the word reading subskills whereas children who were normally achieving in the RAN were less likely to be low in the word reading subskills. According to Appendix H, the RAN clearly did not have any significant association with SDRT, the measure for reading comprehension.

Working memory

There was no significant correlation between the Working Memory for Words and the WJ-Word Attack Reading Subtest (r = 0.168). To a large extent, the Working Memory for Words required children to have knowledge of semantics in order to retrieve appropriate words from their mental lexicon and hence this may explain why it had no significant correlation with the WJ-Word Attack, a task essentially for tapping into knowledge of sound-symbol relationships. The correlations between the Working Memory for Words the other word reading subtests and were low: the WJ-Word Identification (r = 0.273, p < .001), and the WRAT-3 Word Identification (r = 0.263, p < .001), and similarly, the correlation with SDRT, measure for reading comprehension, was also low, (r = 0.248, p < .001). As shown in Appendix I, there was clearly no significant association between the Working Memory for Words and the WJ-Word Attack Reading Subtest; however, the WJ-Word Identification did show an association with the Working Memory for Words, χ^2 (1, N = 82) = 3.844, p = .050). The pattern of association suggests that low working memory for words did not necessarily coexist with low word identification; in fact, in a puzzling sort of way, in this sample of children, those who were low in working memory for words were more likely to be normal in word identification. Again, this may be a sample specific phenomenon which may not replicate itself in future studies of a similar nature. There was a significant association between Working Memory for Words and SDRT at the ≤ 0.05 level across cutoff criteria, Stringent Group, χ^2 $(1, N = 58) = 6.169, p = .013)$, Low Cutoff Group, χ^2 $(1, N = 68) = 4.167, p = .041)$, and the High Cutoff Group, χ^2 $(1, N = 72) = 3.766, p = .023)$.

Syntactic awareness

In general, the Oral Cloze tapping into syntactic awareness had relatively low correlations with the standardized reading-related measures: the WJ-Word Attack ($r = 0.337, p < .001$), the WJ-Word Identification ($r = 0.378, p < .001$), the WRAT-3 Word Identification ($r = 0.426, p < .001$), and the SDRT reading comprehension ($r = 0.403, p < .001$). Additional chi square analyses in Appendix J revealed further insights into the pattern of relationship between syntactic awareness and phonological processing as measured by the WJ-Word Attack; there were significant associations across cutoff criteria, Stringent Group, χ^2 $(1, N = 88) = 12.253, p < .0001)$, Low Cutoff Group, χ^2 $(1, N = 91) = 11.738, p < .0001)$, and High Cutoff Group, χ^2 $(1, N = 93) = 15.631, p < .0001)$. Those who were normally achieving in the Oral Cloze were less likely to be low in word attack skills whereas those low in the Oral Cloze were almost equally likely to be low or normal in word attack skills. The Oral Cloze was significantly associated with the two standardized word identification tests; however, it is not clear how low achievement in the Oral Cloze is related to word identification as there appeared to be equal likelihood of being low or normal in these word identification tests. In reading comprehension, the pattern was clearer, the SDRT was significantly association with the Oral Cloze across cutoff criteria, and the trend was that those who were low in the Oral Cloze were highly unlikely to be normal in SDRT.

3.7.2 The role of phonological processing in reading

To assess the relative importance of the role of phonological processing in the reading model, a series of hierarchical regression analyses were conducted. The interrelationships among the phonological, syntactic, and working memory task are shown in Table 3.14. All possible forced hierarchical orderings of the predictor variables were examined for each of the four standardized reading measures in this study. The Rosner which was the phonological measure accounted for a large portion of the unique variance in three of the standardized word-level reading measures, regardless of the order it was entered into the equation. For example, phonological process (Rosner) remained to account for the most variance on the WJ- Word Attack, the WJ-Word Identification, and the WRAT-3 Word Identification in all three of the analyses with different predictor variable being entered first into the equation. It was only in the SDRT reading comprehension that phonological processing accounted for less of the variance (9.5%) than syntactic processing when it was entered last into the equation. However, in the analysis where phonological processing was entered first, it still accounted for most of the variance in the SDRT (20.4%).

The analyses appeared to support the view that phonological processing has a very important role to play in all aspects of reading, whether it is word attack, word reading, or reading comprehension. The phonological core deficit theory provided a convincing explanatory model for understanding reading in this study. Phonological processing was a robust predictor of reading achievement.

3.7.3 What was the relationship between arithmetic achievement and measures of phonological processing, working memory, and RAN?

As shown in Table 3.13, although the WRAT-3 Arithmetic was significantly correlated with practically all of the measures in this study except for the Oral Cloze, a measure for syntactic awareness, these correlations were in the moderate range, WJ-Word Attack, ($r = 0.374, p < .001$), WRAT-3 Spelling, ($r = 0.436, p < .001$), Rosner, ($r = 0.403, p < .001$), Working Memory for Number, ($r = 0.438, p < .001$), and RAN, ($r = -0.246, p < .001$). The contingency table in Appendix K showed that the WRAT-3 Arithmetic was not significantly associated with the WJ-Word Attack, and the WJ-Word Identification. In the High Cutoff Group, however, there was a significant association between the WRAT-3 Arithmetic and the WRAT-3 Word Identification, χ^2 $(1, N = 96) = 7.488, p < .006$). It is unclear whether this significant association was spurious or not; the size of the low groups in the Stringent Cutoff Group and the Low Cutoff Group may possibly be a factor. The WRAT-3 Arithmetic was significantly associated with WRAT-3 Spelling in all three cutoff groups, Stringent Group, χ^2 $(1, N = 77) = 9.887, p = .002$, Low Cutoff Group, χ^2 $(1, N = 92) = 4.034, p = .045$, and the High Cutoff Group, χ^2 $(1, N = 93) = 4.794, p < .029$. There was also a significant association between the WRAT-3 Arithmetic and the Rosner Phoneme Deletion Test in the Stringent Group and the Low Cutoff Group, χ^2 (1, N = 72) = 4.642, p = .031 and χ^2 (1, N = 79) = 4.275, p < .039 respectively; it is unclear why the High Cutoff Group did not show any significant association. The trend seemed to be that children who were normally achieving in arithmetic were less likely to be low in the Rosner Phoneme Deletion.

Contrary to what was expected, there was no association between the WRAT-3 Arithmetic and the RAN which to some extent reflects phonological retrieval of numbers.

3.7.4 The role of phonological processing in arithmetic

Table 3.15 shows the interrelationships among the predictor variables of interest pertaining to the research questions 3 and 4. Working memory for numbers accounted for 12.1% of the unique variance in WRAT-3 Arithmetic when entered first in the equation while phonological processing accounted for 9.2% of the unique variance when entered in second position. When phonological processing was entered first in the equation, it accounted for 16.2% of the unique variance in WRAT-3 Arithmetic while working memory accounting for only 5.1% of the unique variance in the model. Phonological processing appeared to have an important role to play in arithmetic, together with working memory for numbers. The RAN, however, did not appear to have a significant role in arithmetic in the current series of hierarchical regression analyses.

4 Discussion

This study originated with practical questions directed at addressing some of the issues faced by diagnostic professionals, school administrators, and teachers responsible for providing intervention to children with low academic achievement. First, the theoretical importance of this research will be discussed, and practical implications dealing with educational practice will follow.

The current research was guided by the phonological core deficit theory in reading research (e.g., Stanovich, 1998, 2000a) and some of the emerging theories in mathematics research (e.g., Assel et al., 2003; Baddeley & Hitch, 1974). The importance of the various aspects of phonological processing in academic achievement was shown in the correlations; word attack was basic to word level reading ability, and on the basis on the correlations between spelling and phonological processing, one may surmise that as children are required to meet more written work demands in later years, deficient phonological processing might be a serious impediment to academic success.

In this study, indications of a link between arithmetic and phonological processing also emerged. The correlations showed some moderate relationships between the WRAT-3 Arithmetic and word reading subskills associated with phonological processing (e.g., word attack and word recognition); the relatively higher correlations between arithmetic and the timed reading measures (e.g., Timed Reading of Words and Timed Reading of Pseudowords) suggest that phonological retrieval may be an important aspect in developing proficiency in arithmetic. As well, the Rosner Phoneme Deletion also showed a moderate correlation with the WRAT-3 Arithmetic; the Rosner requires children to hold phonological representations in memory to manipulate phonemes and as such involves phonological memory. Even more interestingly, whereas it was not as evident in the correlation matrix, in the 2 x 2 contingency tables, the children with normal arithmetic achievement clearly seemed less likely to be low in spelling than children with low arithmetic achievement. This perhaps should not be too surprising based the observed links between arithmetic and some of the phonological measures (e.g., Rosner) in this study. Children with low arithmetic achievement were differentiated from the normally achieving children on the basis of their performance in the Working Memory for Numbers and the Timed Reading of Pseudowords. The results suggest that phonological rehearsal (e.g., counting the yellow dots in the Working Memory for Numbers) and phonological retrieval (e.g., Timed Reading of Pseudowords) may be important in arithmetic. In addition to tapping into phonological processing, the Working Memory for Numbers also tapped into attention and visual-spatial abilities. That the children with differing abilities in arithmetic, low and normally achieving, that is, were differentiated on the basis of Working Memory for Numbers is significant because this finding shares the consensus that arithmetic disability is linked with visual-spatial deficits with researchers such as Hecht et al. (2001, 2003), Kulak (1993), Shafrir & Siegel (1994b), and Silver et al. (1999).

There was a concern whether previously identified patterns of relationship in studies of L1 children from middle class backgrounds (e.g., Gottardo et al., 1996) will emerge in the current study with children of low SES status who, in many cases, also spoke English as a second language. From the correlation patterns, the cognitive profile analyses of the various types of low achievers, and the hierarchical regression analyses examining the predictor variables for reading and arithmetic, there appears to be enough evidence to suggest that the phonological core deficit theory is universally applicable, even in this sample of children. L1 and ESL speaking children with reading disability are very similar (e.g., Lipka, Siegel, & Vukovic, 2005). Whenever low phonological processing is found in children, then it follows that there would be some problems in their academic performance; sometimes, these problems may be restricted to the area of reading and other times, arithmetic may be affected as well.

Because the theories of reading and arithmetic found support in the results of this study, and that children with low achievement were differentiated on key variables known to be related to reading and arithmetic disability, the low achievement approach to identifying children with learning disabilities appears to be a sound alternative to the IQ-discrepancy definition of learning disabilities. The credibility of the low achievement approach to identifying LD can only be supported if there is a critical mass of research showing that low achievers are similar to LD children, and in this study, the low achieving children in reading and arithmetic showed similar cognitive profiles as the LD children described in the research literature on learning disabilities. Furthermore, it is not necessary to wait until children are beyond grade three to diagnose their learning disability as it is often done within the school system. Since the cognitive processes associated with reading and arithmetic are known, children can be tested with standardized achievement tests as it was done in this study, and using the achievement profile, intervention can be planned meaningfully. For example, if there is a child with low achievement across all the standardized measures of reading, spelling, and arithmetic but has normal cognitive processing (i.e., normal performance as being above the mean performance), then there are good reasons to suspect that the low achievement may be caused by other non-cognitive factors such as the child's home circumstances. At the same time, there is always the possibility that the tests used had failed to identify some less commonly known aspect of cognitive functioning that is important for diagnosing this particular child. The cognitive processes related to reading and arithmetic identified thus far in research should not be regarded as an exhaustive list; more research may uncover new dimensions in the cognitive domain worthy of further investigation.

One of the most difficult challenges for diagnosticians is that sometimes it is hard to untangle whether the learning problems are related to home background variables or cognitive factors. From previous studies (e.g., Siegel & Himel, 1998), there is evidence that IQ-discrepancy based definitions of learning disabilities can fail to identify children from a low SES background, but using the low achievement approach, the problem can be avoided in most part.

The thorny problem of what constitutes an appropriate cutoff for low achievement is a question that this study attempted to address. As seen in this study where the children came from an inner city school district, the problem readers were at 48% and the low achievers in arithmetic were at 20% when a 25th percentile cutoff was used. The problem would appear less daunting if a 17th percentile cutoff was used, 30% problem readers and 8% low achievers in arithmetic; it would reduce the number of children requiring educational intervention. From this research, there was a clear indication that at the 25th percentile, children's academic difficulties are evident. For research purposes, however, most of the time, whether the cutoffs were at 17th percentile or the 25th percentile did not affect the findings.

An interesting observation was made from this study of children from a low SES background who were mostly ESL speakers. When the reading achievement of the children in this study was compared to the reading achievement of a group of grade 3 children who had participated in a study of early identification and intervention (see the Phonological Awareness Intervention Program in Lipka & Siegel, 2007), the differences were quite impressive. The children in the early identification and intervention study were screened in kindergarten and at-risk children were identified and given intervention individually and in small groups by classroom and resource teachers. All of the children received phonological awareness training in kindergarten, phonics training in grade 1, and reading comprehension training in grade 2 and 3. The comparison of the two groups of grade 3 children clearly showed a picture of disparity and it highlighted the importance of early identification and intervention for academic success.

Whereas the word reading performance means for Lipka and Siegel's group of L1 grade 3 children were in the mid-70th to 80th percentile range (e.g., WJ-Word Attack, M = 77.22, SD = 21.73; WJ-Word identification, M = 80.18, SD = 20.18; and WRAT-3 Word Identification M = 75.57, SD = 19.71), the L1 grade 3 children in this study had word reading performance means from the same measures at the high 50th to the low 70th percentile (refer to Table 3.11). Furthermore, the ESL speaking children in this study had word reading performance means in the low 40th to the high 50th percentile (refer to Table 3.11) while none of the ESL speaking groups (i.e., Chinese, Farsi, Slavic, Japanese, Romance, and Tagalog) in Lipka & Siegel's (2007) study had word reading performance means below the 70th percentile. What should be noted is that the current ESL groups in this study were predominantly Hindi speaking and that language group had no representation in Lipka and Siegel's study. However, what is apparent here is the disparity that exists between the word reading skills of children with and without the benefits of early identification and intervention; the ESL speaking children in the present study were clearly at a disadvantage in their reading development. Compared to the L1 children from the same inner city neighborhood (refer to Table 3.11), the ESL speaking children were already lower in their word reading skills, but when they were compared to the ESL speaking children in Lipka and Siegel's (2007) study on the same reading measures, the word reading achievement gap appeared even wider. Although low word reading scores in ESL speaking children may not necessarily be indicative of a reading disability (e.g., reading problems related to cognitive processing deficits) – the possible lack of exposure to English reading materials compared to

L1 children may account for the relatively poor vocabulary knowledge in some of the cases – it does make the task of reading for comprehension more difficult for these children as they have to devote more attentional resources to simply identifying individual words, and as such, their reading fluency will be compromised.

In the area of reading comprehension, the L1 children in this study had lower performance (e.g., SDRT, $M = 42.14$, $SD = 25.21$) whereas the L1 children in the Lipka and Siegel (2007) study had average performance (e.g., $M = 50.63$, $SD = 24.18$). For the ESL speaking children in this study, their reading comprehension performance was rather precarious (e.g., $M = 29.66$, $SD = 21.89$) and would be considered as marginal (e.g., $\leq 30^{th}$ percentile) according to the classification scheme used in this study. Worthy of noting is that in Lipka and Siegel study (2007), the Chinese language group and the Slavic language group actually had higher means in reading comprehension than the L1 children (e.g., SDRT, $M = 54.11$, $SD = 24.58$; and SDRT, $M = 57.07$, $SD = 26.28$ respectively). Although the ESL speaking children from the other language groups in Lipka and Siegel's study had lower SDRT performance means than the L1 children, none of them were as low as the ESL speaking children in this study; even the Farsi speaking children in the Lipka and Siegel study with the lowest performance mean (e.g., SDRT, $M = 34.82$, $SD = 20.32$) were not as low as the ESL speaking children in this study. The superior reading comprehension performance in the Lipka and Siegel group may be attributed to the Reading 44 program which was taught in the district; this program emphasized the teaching of reading strategies that good readers use (see Lipka & Siegel, 2007 for details).

The comparison between the children in the current study and the study of Lipka and Siegel (2007) suggests that differences do exist between ESL speaking children, not just by language groups, but by socioeconomic backgrounds as well. The children in Lipka and Siegel's study came from a range of socioeconomic backgrounds (Lipka & Siegel, 2007); however, the children in the current study were all from a low SES background. Interestingly, in the same group of children from North Vancouver, D'Angiulli, Siegel, and Maggi (2004) have found that early identification using systematic assessment and intervention using a literacy-intensive curriculum (e.g., explicit emphasis on sound-symbol relationship, reading in a variety of situations, and teaching effective reading strategies), the negative influence of SES on word reading may be reduced. As well, this type of literacy-intensive program appeared to be effective in improving the reading level of ESL speaking children so that their performance is comparable to L1 children (see results in D'Angiulli, Siegel, & Maggi, 2004). It is worth noting that while most of the children in the current study received phonemic awareness instruction in kindergarten – that is, those who were in the same school since kindergarten – a systematic early identification and intervention program such as the one in North Vancouver did not exist to support them from kindergarten to grade 3. The North Vancouver early identification and intervention program is a promising model for the children in this study who were mostly ESL speaking and came from a low SES background.

One of the significant findings in this study that had important implications for ESL speaking children was in the Oral Cloze. In the chi square analysis in Appendix J, it was found that children who were low in the Oral Cloze were highly unlikely to be normally achieving in reading comprehension. In the comparison of the cognitive profiles of L1 and ESL speaking children (refer to Table 3.11), the ESL children were lower in their syntactic processing skills according to their performance in the Oral Cloze. This difference between L1 and ESL speaking children in the current study should be of particular interest to teachers who work with children who are speakers of ESL from similar backgrounds. Because the ESL speaking children in this study had a less developed knowledge of English grammar, reading comprehension will likely be increasingly more challenging for them as they advance to higher grades, and in particular, when the grammatic structures in academic reading become more complex. The implication here is that the teaching of English grammatic structures to ESL speaking children is of paramount importance.In teaching English grammar to non-native speakers of English, one needs to be aware of the differences that exist between the ESL learners' native language and that of English. In the case of Punjabi and Hindi, which were the home languages of the majority of the children in this study, the grammatical structure of these two languages share enough commonalities between them that any first language interference observed in one language would also be found in the other (Shackle, 1987). Most notably, in Hindi, which can be said of Punjabi as well, masculine and feminine nouns exist whereas markers of the comparative and superlative forms of adjectives are lacking. Furthermore, there is no word class corresponding to the English articles (e.g., "the," "a," "an"), and the word order is very different from English as well. For example, the verb is often placed in the final position in a sentence. Hence, some of the "fill-in-the-blank" items in the Oral Cloze and Working Memory for Words in this study were expecially problematic for children from an ESL background with Indian languages as their native tongues. Recall questions in the Oral Cloze (see Appendix C, p. 112). Test Items 4 required a superlative for the answer and Test Item 5, 8, 10, and 11 required a verb in the middle of the sentence for the answer. Given what is known about the differences between the English language and Indian languages such as Punjabi and Hindi, some of the difficulties faced by these children who spoke Indian languages as their first language become more evident.

The Working Memory for Words test also posed some difficulties; many of the questions were structured in such a way that a missing noun at the end of the sentence had to be supplied by the children to fill in the blank. For children whose first language is Punjabi or Hindi, the Working Memory for Words posed a challenge on two fronts: that of lexicon and grammar. To fill in the blank, the children had to search for a suitable word – a task more difficult than assumed because the test item may require culture specific knowledge that is taken for granted by most native speakers of English. Take Question 4A.1 in the Working Memory for Words (p. 111) for example, "pepper" was one of the possible intended answer. For Canadian children, it is common practice to add salt and pepper to one's food at the table; however, having salt and pepper placed on the table is a culture specific practice of the Europeans. As for grammar, having to place a noun at the end of most of the sentences in the Working Memory for Words test may also have been difficult for the children. Familiar syntactic structures from Punjabi or Hindi may have been interfering with these childrens' attempt to search for words from the correct word class to fill in the blank: on one hand, a noun was required to fill in the blank at the end of the sentence, but on the other hand, the children were used to associating a verb to the final position of a sentence. Hence, the children from Indian language backgrounds faced multiple challenges when attempting the cloze items used in this study.

Another factor, which may interfere with the reading comprehension of the ESL speaking children in this study, was word reading fluency (e.g., Timed Reading of Words) which is mediated by reading experience. The ESL speaking children in this study were lower in their performance compared to the L1 children. When reading fluency is compromised, children have less attentional resources to devote to comprehension. The ESL children in this study and children in similar circumstances are more at-risk for reading comprehension failure and hence teachers need to direct more resources to ensure that these children have an adequate working vocabulary base for reading.

It is also important to stress that reading comprehension requires more than just having a good grasp of English grammar and an adequate vocabulary base. Studies have found that higher-level processing difficulties may result in poor reading comprehension in spite of adequate word reading skills (e.g., Cain & Oakhill, 1999; Cain, Oakhill, & Bryant, 2000). In fact, in this study, there was a low reading group with normal word reading skills and low reading comprehension (e.g., the Poor Comprehenders) which was different from the low reading group (RD) with word level reading deficits typical of dyslexics. For children who have adequate word reading skills and a specific deficit in reading comprehension, learning to make inferences may help improve their reading comprehension (e.g., Yuill & Oakhill, 1991). For the children in this study who were predominantly ESL speaking and came from a low SES background, it is imperative that explicit inference making skills be taught to them.

The children's knowledge about the subject matter in the reading assignment will affect their ability to draw inferences. Teachers need to be sensitive to the cultural and home background differences of the children they are teaching reading comprehension to. Certain experiences and knowledge may be beyond the reaches of these children; for example, children from Indian language backgrounds may not celebrate holidays such as Thanksgiving and Christmas. Reading passages dealing with these holidays may be difficult for these children to relate to. In the same way, children from a low SES background who are not necessarily ESL speakers may also find certain reading topics difficult to relate to, and hence their ability to make inferences may be compromised. For example, some of the children in this study may not have experienced Christmas in the way most Canadian children have, simply because their families do not have the financial means to provide them with such an experience. In short, teachers of children from diverse backgrounds need to make special efforts to understand the home situations of their students; this is the way to facilitate effective teaching.

In this study, there emerged two types of low reading achievement and arithmetic achievement. There were low reading achievement groups with and without word level reading deficits, for example, the RD and PC groups. Low achievement in reading associated with low word attack skills (e.g., WJ-Word Attack) and low arithmetic achievement associated with low word attack skills were the most problematic as these low achievement types showed more severe cognitive impairments. For the low reading RD group, if the word attack skills were low, the performance in other areas such as word reading, and often spelling, would also be low; as well, the likelihood was also higher for the arithmetic achievement to be low. There were a few exceptions, however, in this study where the children had dyslexic profiles (e.g., low word attack and low word reading skills) and relatively high arithmetic achievement. How these children circumvented their phonological processing deficits, which most likely would also implicate working memory functions, to achieve success in arithmetic should be an interesting topic for further research.

For intervention purposes, children with different cognitive profiles may require different approaches to treatment. The children with low reading comprehension and normally word level reading subskills are an interesting type and the question of whether these children were in fact a product of their social environment (i.e., home background lacking opportunities to learn) is worth exploring. To be certain, more information about this low reading group would be very helpful for practical intervention situations. Intervention based on explicit and intensive instruction similar to the one described in D'Angiulli, Siegel, and Maggi (2004) and training in higher level thinking such as learning effective strategies for making inferences in reading (e.g., Yuill & Oakhill 1991) may prove to be beneficial for the Poor Comprehenders.

In summary, at the micro level dealing with word reading, strengthening children's phonological processing through teaching phonemic awareness and word attack skills (e.g., Adams, 1990) will pave the way for vocabulary acquisiton. It is also the best strategy to prevent and ameliorate reading problems at the word level which is typical of many dyslexic children. Having a large vocabulary base to work from will enable children to read with a higher level of ease and confidence, and that will lead to further development in the language domain as well as growth in other cognitive areas. Exposing children to English morphology and learning Greek and Latin roots will also support vocabulary growth.

At the macro level, which is a broader level, teaching comprehension strategies and modelling effective inference making skills in the classrooms will help children struggling with comprehension to make sense of their reading tasks. It is through practicing wide and varied reading in a supportive environment that children can grow, not only in language skills, but in the acquisition of knowledge that will be useful for their academic development.

The acquisition of phonological processing skills may well cross over to the arithmetic domain: refining children's ability to process information via the phonological route may prove to be beneficial for performing arithmetic operations. Many of the tasks involved in arithmetic demand some sort of phonological processing. Counting, for example, relies on phonological memory to a large extent; children have to hold the phonological representations (e.g., the numbers) in memory. The accurate representation of these numbers as phonological representations will enable efficient processing in the various arithmetic operations.

Visual processing is also important to reading and arithmetic. Familiarity with the "target objects," whether they are words or combinations of numbers (e.g., sums and products) will translate into speed in processing. Frequent exposure to sight words will build up a lexicon for reading and familiarity with numbers and their patterns in different arithmetic operations (e.g., 2+2= 4 and 2x2=4) will build up automaticity in solving arithmetic problems. Intervention must necessarily involve frequent practice and the reinforcement of prevously acquired skills.

Children with reading and/or arithmetic disability are often affected by poor working memory. This has always been a serious challenge for many learning disabled children. Today, with the wide availability of recording devices, electronic calculators, and computers, what was previously regarded as giant obstacles to learning now can be overcome with relative ease. As well, commercial software programs with applications that are helpful for LD children have proliferated in recent years. For example, many reading disabled children a voice recognition program; the computer will type the words dictated and they can concentrate on the content of their composition and not be distracted by word level processing concerns such as spelling. The poor working memory in LD children can also be compensated by softwares programs that help them to organize their thoughts visually. Learning disabled children who prefer thinking visually can greatly benefit from such computer softwares as thinking tools.

Finally, LD children with impaired working memory functions or have fine motor difficulties which affect the speed and quality of their handwriting will require more time to be allotted to them for the completion of academic tasks (e.g., Siegel & Feldman, 1983). A combination of using modern computer technology and making allowances for more time for the completion of tasks is what LD children need to succeed in school. Teachers, parents, and school administrators have to be aware of this and be prepared to give these LD children the support they need to complete their academic work.

4.1 Conclusion

This study has demonstrated the efficacy of the low achievement approach in identifying learning problems. Using a cutoff point for low achievement at the 25th or the 17th percentile, it was possible to sort the low achievers into different achievement profile types for intervention purposes. The major achievement types identified in this study were the Reading Disabled (RD) who were dyslexics with a phonological deficit, the Poor Comprehenders (PC) who had a specific reading comprehension deficit, the Arithmetic Disabled (AD) who had a specific arithmetic disability, and the Reading and Arithmetic Disabled (RAD) who had a similar phonological deficit as the Reading Disabled (RD) group together with a deficit in the arithmetic domain. Each of these low achievement types had unique cognitive profiles which can be used to inform the design and delivery of intervention. A combination of standardized achievement tests to determine the type of the learning problem (e.g., reading disable or arithmetic disabled or both) and cognitive measures tapping into functionings related to different areas of academic achievement serves to identify most learning problems and to facilitate meaningful intervention.

The pattern of association between the standardized achievement measures and the cognitive measures that have emerged in this study have added much valuable information to support the low achievement approach to dianosing LD. It is now fairly certain that low phonological processing is always associated with poor reading comprehension; that points to the importance of word attack skills in facilitating vocabulary acquisition for reading. At the same time, low syntactic processing as measured by the Oral Cloze is also always associated with low reading comprehension. The abilility to use syntax is very much a higher level processing skill; it is an indication that a child can perceive order in language in meaningful ways. This knowledge helps to explain why some children with RD failed to improve even after intensive phonological awareness training. To comprehend what is being read requires lower level processing skills (e.g., phonological processing) working together with higher level processing skills (e.g., reasoning and perceiving order in language to create meaning as in syntactic processing).

From the pattern of association between low reading and the various cognitive measures, the fear of misdiagnosing Rd children from disadvantaged backgrounds can in part be alleviated. Phonological processing is an intrinsic cognitive function in an individual and has little to do with socioeconomic status; low phonological processing is the marker of a reading disability. Providing intervention for the phonological processing deficit is the first step in the treatment of reading disability. Some children may require further training in higher level reasoning for reading comprehension while other children with intact higher level thinking skills can do reading comprehension tasks without further training.

4.2 Limitations

This research was undertaken as a correlation study which involved using data collected at a single point in time. There were some achievement profile types such as the Reading and Arithmetic Disabled (RAD) group and the Reading Disabled (RD) group which would have benefited from more in-depth study; however, these types of low achievers were very rare and it may require testing many more children in order to accumulate enough cases for analysis.

In this study, the ESL speaking children from different language groups were studied as a single entity. As seen in Lipka's (2003) study, different language groups had very different performance in the achievement tests and it would be better to study ESL speaking children according to language groups. For this study, however, because the majority of the

ESL speaking children were Hindi speaking, the impact of the other language groups could not be assessed.

The methodological limitation of the present study is that a comparison group did not exist. Comparing two groups, one group with the benefit of early identification and intervention (e.g., D'Angiulli, Siegel, & Maggi, 2004), and another group not exposed to such a program, may yield very different results. It is possible that the group exposed to early identification and intervention may produce fewer low achievers. As well, the number of the children who are marginally at-risk in this group may be greatly reduced as a result of intervention leaving only those who are severely impaired in their cognitive functioning to appear as low achievers of different types (i.e., reading disabled and/or arithmetic disabled).

Additional measures for reading comprehension may have enriched this study further. Giving the children in this study cultural dependent and non-cultural dependent reading passages may provide insights into how L1 and ESL speaking children differ in their approach to reading comprehension. These insights will in turn help teachers to become more attuned to the knowledge gaps that children from another cultural context may have and to provide them with more background information during the pre-reading stage.

Expanding the number of measures for arithmetic and changing the way the tests are configured may also improve this study. These measures should reflect an awareness that children may have strengths and weaknesses in specific aspects of arithmetic (e.g., Dowker, 2005); for example, a child may be good at adding but have difficulties in multiplying. The heterogeneity of arithmetic difficulties must be taken into account. Currently, arithmetic achievement is represented by a composite score in this study. It would be better to separate arithmetic achievement measures according to type to reflect a child's areas of strength and weakness; for example, adding, subtracting, dividing, and multiplying are each treated as a subtest with a separate score. As well, from research on the development of arithmetic in children, both phonological processing and visual processing have been known to be important. Cognitive measures for arithmetic should be designed as such that they can identify more precisely what the deficit or deficits may be. For example, the Working Memory for Numbers task in this study tapped into both phonological processing and visual processing and it was a very effective tool for identifying children at-risk for arithmetic difficulties; however, it was not possible to determine from the composite score in this measure which one of the areas, whether it was phonological processing or visual processing, a child may be deficient in. Addition measures tapping into specific domains may provide valuable information for intervention design. For example, counting coloured dots can tap specifically into visual-spatial processing and repeating number strings can tap more directly into phonological processing. The way the Working Memory for Numbers task is configured currently does not enable precise identification of a child's area of weakness.

4.3 Future Directions

The low achievement approach to identifying learning problems has a promising start in this study. It is an effective way of sorting children into types for intervention purposes. Major achievement patterns or types have emerged in this study; however, these cognitive profiles need to be replicated in larger samples of children and in samples of children from other educational settings. The information obtained from these studies of the cognitive profiles of low achievers will be crucial for intervention purposes. As noted previously, some of the low achievers were using compensation strategies to circumvent their deficits related to phonological processing and working memory functions. Studying the adaptive strategies of these children (e.g., the dyslexics with good arithmetic skills) would be beneficial for those training children with cognitive deficits; some of the compensation strategies may be transferable to other children with similar challenges in learning.

It would also be helpful to study the cognitive profile of ESL speaking children according to language groups. In the context of a multi-cultural society, understanding the unique challenges faced by the ESL speaking children from various language groups is of great importance.

In conclusion, the current study has demonstrated the that the low achievement approach to identifying learning difficulties is robust even in a population of children known to carry confounding variables (e.g., ESL home background and low SES). A deficit in phonological processing appeared to be a consistent characteristic in those who were low achievers.

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Table 2.1 School profiles (2001-2002) based on Surrey School Board website

Enrolment Characteristics	School One	School Two
September 2001	639	588
ESL Enrolment (%)	54.3%	39.6%
District Programs		
Aboriginal Support	Yes	Yes
Band 7	Yes	
Challenge Program	Yes	
Child Care Worker	Yes	Yes
ESL Kindergarten	Yes	
Kindergarten Phonemic Awareness Project	Yes	Yes
Inner City School	Yes	Yes
Multicultural Worker		Yes
School Meal Program	Yes	
Soar to Success Pilot (ESL)	Yes	
Foundation Skills Assessment (May 2002)		
Grade 4		
Not Yet within Expectation		
Reading	20%	40%
Writing	2%	2%
Numeracy	22%	33%
Meets Expectation		
Reading	78%	60%
Writing	98%	98%
Numeracy	72%	67%
Exceeds Expectation		
Reading	2%	0%
Writing	0%	0%
Numeracy	6%	0%

Note: Aboriginal Support = Funding from the Ministry of Education given to the Aboriginal Education Department to deliver targeted academic and cultural support to Aboriginal students; Band 7 = A music program that teaches core music at the grade 7 level; Challenge Program = A pullout program to deliver enrichment to selected gifted students for a short period of time; Child Care Worker = A Child/Youth Care Worker participates in a collaborative model to assist students who have moderate to severe behaviour disorders which may be coupled with learning disabilities; ESL Kindergarten = A full day Kindergarten offered to ESL Kindergarten students as well as several other special categories of children to foster student success; Kindergarten Phonemic Awareness Project = This is a phonemic awareness program aiming to give children a better foundation for reading; Inner City School = This funding category is now called Community Link funding and it is given to selected schools with populations in need of extra funding that may be spent in a variety of ways, for example, additional child care worker time to support students with behavior or learning problems; Multicultural Worker = A liaison person providing a link between the school and parents from another culture who have language/cultural barriers; School Meal Program = Children who qualify are provided with a lunch daily; Soar to Success Pilot (ESL) = This is a small group reading intervention program for intermediate (grades 4 to 7) ESL learners to foster success in reading.

Table 2.2 Classification scheme: numerical code, group name, & description

Numeric Code	Group Name	Description
333333	Normally Achieving (NA)	Normally achieving in all of the standardized tests **Cutoff criteria were strictly adhered to in all three groups with different cutoffs.*
11111x[a]	Reading Disabled (RD)	Low reading comprehension and word level subskills **The Low Cutoff Group and the Stringent Group had one case out of a total of eleven cases that accepted the 18th percentile as low.*
33331x[a]	Poor Comprehenders (PC)	Low reading comprehension and normal word level subskills. **Cutoff criteria were strictly adhered to in all three groups with different cutoffs.*
333x[a]x[a]1	Arithmetic Disabled (AD)	Low arithmetic and normal reading subskills. **In one of the thirteen cases in the Stringent Group, the 30th percentile instead of the 35th percentile was accepted as being normal in the WRAT-Word Recognition. The decision was made on the basis of the WJ-Word Recognition achievement in this case which happened to be at the 44th percentile.*
111x[a]x[a]1	Reading & Arithmetic Disabled (RAD)	Low arithmetic and reading subskills **In the High Cutoff Group, out of the 8 cases in total, 3 cases did not adhere strictly to the cutoff criteria in the WJ-Word Attack. 1 case accepted the 27th percentile as low and 2 cases accepted the 26th percentile as low.*

Note: [a] The test represented by the digit was not considered for the formation of this group; 1st digit = Woodcock Johnson Word Attack; 2nd digit = Woodcock Johnson Word Identification; 3rd digit = Wide Range Achievement Test-3 Word Identification; 4th digit = Wide Range Achievement Test-3 Spelling; 5th digit = Stanford Diagnostic Reading Test; 6th digit = Wide Range Achievement Test-3 Arithmetic Test.

Table 3.1 Overall Performance of Children in this Study (Mean & Standard Deviation)

	Performance of Children in Study (N = 121)	
	M	*SD*
Reading Subskills		
1. WJ-Word Attack[a]	59.58	29.25
2. WJ-Word Identification[a]	61.44	28.24
3. WRAT-3 Word Identification[a]	46.75	21.80
Reading Fluency		
4. Timed Reading of words	14.79	3.76
5. Timed Reading Pseudowords	24.02	10.63
Reading Comprehension		
6. SDRT Reading Comprehension[a]	33.27	23.49
Spelling		
7. WRAT-3 Spelling[a]	53.54	23.37
8. Pseudoword Spelling	4.98	2.79
Arithmetic		
9. WRAT-3 Arithmetic[a]	51.60	23.89
Phonological Processing		
10. Rosner Phoneme Deletion	23.00	8.52
Working Memory		
11. Working Memory for Numbers	5.17	2.36
12. Working Memory for Words	2.52	1.31
Syntactic Awareness		
13. Oral Cloze	4.98	1.92
Lexical Access		
14. RAN[b]	11.29	2.56

Notes: [a]Percentile score; [b]Reverse scale operates here where less time in seconds denotes a better ability to name numbers quickly and vice versa.

Table 3.2 Number of Children with Low Achievement Status in this Study According to Different Cutoffs for Low (17^{th} & 25^{th} percentile)

Low Achievement Status N = 121	*Groups*			
Cutoff Points (%ile)	Stringent & Low Cutoff 17^{th}		High Cutoff 25^{th}	
	Number	*%*	*Number*	*%*
Standardized Achievement Test				
1. WJ-Word Attack	13	11%	18	15%
2. WJ-Word Identification	12	10%	20	17%
3. WRAT-3 Word Identification	12	10%	22	18%
4. WRAT-3 Spelling	6	5%	15	12%
5. SDRT	36	30%	58	48%
6. WRAT-3 Arithmetic	10	8%	24	20%

Table 3.3 Comparison of Normally Achieving (NA) & Reading Disabled (RD) Children using Stringent Cutoff

	Stringent Cutoffs					
	NA (N = 25)		RD (N = 11)			
Tasks	*M*	*SD*	*M*	*SD*	*t*-value	Cohen's *d*
Reading Subskills						
1. WJ-Word Attack[a]	83.65	17.38	8.47	5.70	13.92**	5.81
2. WJ-Word Identification[a]	82.00	14.89	17.00	7.75	17.18**	5.48
3. WRAT-3 Word Identification[a]	65.52	17.30	10.91	7.67	13.13**	4.08
Reading Fluency						
4. Timed Reading of Words	17.80	2.88	7.91	2.34	10.02**	3.77
5. Timed Reading Pseudowords	33.68	6.70	5.27	4.36	12.87**	5.03
Reading Comprehension						
6. SDRT Reading Comprehension[a]	64.24	16.67	8.27	5.5	15.03**	4.51
Spelling						
7. WRAT-3 Spelling[a]	72.88	15.03	20.18	9.28	10.71**	4.22
8. Pseudoword Spelling	6.16	2.41	2.45	1.75	4.58**	1.76
Arithmetic						
9. WRAT-3 Arithmetic[a]	70.88	17.03	38.73	22.11	4.76**	1.63
Phonological Processing						
10. Rosner Phoneme Deletion	29.16	4.92	9.45	5.56	10.64**	3.76
Working Memory						
11. Working Memory for Numbers	6.68	1.68	3.82	1.83	4.59**	1.63
12. Working Memory for Words	3.44	1.33	1.91	0.53	4.92**	1.51
Syntactic Awareness						
13. Oral Cloze	5.96	1.51	3.09	2.30	4.45**	1.48
Lexical Access						
14. RAN[b]	10.05	1.57	13.19	2.99	3.30**	1.31

Notes: [a]Percentile score; [b]Reverse scale operates here where less time in seconds denotes a better ability to name numbers quickly and vice versa;
** $p \leq .003$ based on a Bonferroni-adjusted significance level; NA = children with ≥ 35th percentile in all achievement measure; RD = children with ≤ 17th percentile in all reading achievement measures; Degrees of Freedom (*df*) = 34.

Table 3.4 Comparison of Normally Achieving (NA) & Reading Disabled (RD) Children using Low Cutoffs

	Low Cutoffs					
	NA (N = 38)		RD (N = 11)			
Tasks	*M*	*SD*	*M*	*SD*	*t*-value	Cohen's *d*
Reading Subskills						
1. WJ-Word Attack[a]	78.67	20.90	8.47	5.70	18.46**	4.58
2. WJ-Word Identification[a]	80.42	15.58	17.00	7.75	18.43**	5.16
3. WRAT-3 Word Identification[a]	62.08	17.19	10.91	7.66	13.40**	3.79
Reading Fluency						
4. Timed Reading of Words	17.05	2.84	7.91	2.34	9.75**	3.51
5. Timed Reading Pseudowords	31.05	7.78	5.27	4.36	14.15**	4.09
Reading Comprehension						
6. SDRT Reading Comprehension[a]	56.79	18.91	8.27	5.50	13.91**	3.48
Spelling						
7. WRAT-3 Spelling[a]	67.53	17.86	20.18	9.28	11.75**	3.33
8. Pseudoword Spelling	6.39	2.89	2.45	1.75	5.59**	1.66
Arithmetic						
9. WRAT-3 Arithmetic[a]	64.74	19.31	38.73	22.11	3.81**	1.25
Phonological Processing						
10. Rosner Phoneme Deletion	28.39	6.40	9.45	5.56	8.89**	3.16
Working Memory						
11. Working Memory for Numbers	6.21	1.83	3.82	1.83	3.82**	1.30
12. Working Memory for Words	3.03	1.33	1.91	0.54	4.15**	1.11
Syntactic Awareness						
13. Oral Cloze	5.79	1.47	3.09	2.30	4.68**	1.40
Lexical Access						
14. RAN[b]	10.75	2.13	13.19	3.00	3.04**	0.94

Notes: [a]Percentile score; [b]Reverse scale operates here where less time in seconds denotes a better ability to name numbers quickly and vice versa.

** $p \leq .003$ based on a Bonferroni-adjusted significance level; NA = children with ≥ 30th percentile in all achievement measure; RD = children with ≤ 17th percentile in all reading achievement measures; Degrees of freedom (*df*) = 47.

Table 3.5 Comparison of Normally Achieving (NA) & Reading Disabled (RD) Children using High Cutoffs

	High Cutoffs					
	NA (N=25)		RD (N=14)			
Tasks	*M*	*SD*	*M*	*SD*	*t*-value	Cohen's *d*
Reading Subskills						
1. WJ-Word Attack[a]	83.65	17.38	11.30	7.63	14.73**	5.39
2. WJ-Word Identification[a]	82.00	14.89	19.93	9.61	14.01**	4.95
3. WRAT-3 Word Identification[a]	65.52	17.30	15.14	11.34	9.76**	3.44
Reading Fluency						
4. Timed Reading of Words	17.80	2.88	8.50	2.41	10.25**	3.51
5. Timed Reading Pseudowords	33.68	6.70	7.00	5.20	12.87**	4.45
Reading Comprehension						
6. SDRT Reading Comprehension[a]	64.24	16.67	9.00	5.53	15.15**	4.45
Spelling						
7. WRAT-3 Spelling[a]	72.88	15.03	23.79	11.79	10.52**	3.63
8. Pseudoword Spelling	6.16	2.41	2.86	2.14	4.27**	1.15
Arithmetic						
9. WRAT-3 Arithmetic[a]	70.88	17.03	36.64	20.12	5.64**	1.84
Phonological Processing						
10. Rosner Phoneme Deletion	29.16	4.92	11.00	5.80	10.38**	3.38
Working Memory						
11. Working Memory for Numbers	6.68	1.68	3.86	1.80	4.92**	1.63
12. Working Memory for Words	3.44	1.33	1.64	0.84	4.57**	1.62
Syntactic Awareness						
13. Oral Cloze	5.96	1.51	2.86	2.10	5.33**	1.69
Lexical Access						
14. RAN[b]	10.05	1.57	12.71	2.82	3.26**	1.67

Notes: [a]Percentile score; [b]Reverse scale operates here where less time in seconds denotes a better ability to name numbers quickly and vice versa.
** $p \leq .003$ based on a Bonferroni-adjusted significance level; NA = children with ≥ 35th percentile in all achievement measure; RD = children with ≤ 25th percentile in all reading achievement measures; Degrees of freedom (*df*) = 37.

Table 3.6 Comparison of Normally Achieving (NA) Children & Poor Comprehenders (PC) using Stringent Cutoffs

	Stringent Cutoffs					
	NA (N = 25)		PR (N = 13)			
Tasks	*M*	*SD*	*M*	*SD*	*t*-value	Cohen's *d*
Reading Subskills						
1. WJ-Word Attack[a]	83.65	17.38	76.15	16.28	NS	
2. WJ-Word Identification[a]	82.00	14.89	78.98	14.41	NS	
3. WRAT-3 Word Identification[a]	65.52	17.30	57.08	15.16	NS	
Reading Fluency						
4. Timed Reading of Words	17.80	2.87	16.62	2.47	NS	
5. Timed Reading Pseudowords	33.68	6.70	28.62	7.53	2.12*	0.71
Reading Comprehension						
6. SDRT Reading Comprehension[a]	64.24	16.68	11.46	3.40	15.02**	4.35
Spelling						
7. WRAT-3 Spelling[a]	72.88	15.03	70.69	12.70	NS	
8. Pseudoword Spelling	6.16	2.41	5.62	2.43	NS	
Arithmetic						
9. WRAT-3 Arithmetic[a]	70.88	17.03	67.08	18.09	NS	
Phonological Processing						
10. Rosner Phoneme Deletion	29.16	4.9	27.00	6.04	NS	
Working Memory						
11. Working Memory for Numbers	6.68	1.67	5.46	2.15	NS	
12. Working Memory for Words	3.44	1.33	2.85	1.41	NS	
Syntactic Awareness						
13. Oral Cloze	5.96	1.51	4.69	1.70	2.35*	0.79
Lexical Access						
14. RAN[b]	10.05	1.57	9.82	1.80	NS	

Notes: [a]Percentile score; [b]Reverse scale operates here where less time in seconds denotes a better ability to name numbers quickly and vice versa.

** $p \leq .003$ based on a Bonferroni-adjusted significance level; * $p \leq .05$; NA = children with ≥ 35th percentile in all achievement measure; PR = children with ≤ 17th percentile in reading comprehension and normal reading sub-skills; Degrees of freedom (*df*) = 36.

Table 3.7 Comparison of Normally Achieving (NA) Children & Poor Comprehenders (PC) using Low Cutoffs

	Low Cutoffs					
	NA N = 38		PR N = 14			
Tasks	*M*	*SD*	*M*	*SD*	*t*-value	Cohen's *d*
Reading Subskills						
1. WJ-Word Attack[a]	78.66	20.90	73.50	18.53	NS	
2. WJ-Word Identification[a]	80.42	15.58	76.27	17.17	NS	
3. WRAT-3 Word Identification[a]	62.08	17.49	55.14	16.26	NS	
Reading Fluency						
4. Timed Reading of Words	17.05	2.84	16.57	2.38	NS	
5. Timed Reading Pseudowords	31.05	7.78	28.21	7.40	NS	
Reading Comprehension						
6. SDRT Reading Comprehension[a]	56.79	18.91	10.93	4.32	14.01**	3.34
Spelling						
7. WRAT-3 Spelling[a]	67.53	17.86	69.57	12.90	NS	
8. Pseudoword Spelling	6.39	2.87	5.50	2.38	NS	
Arithmetic						
9. WRAT-3 Arithmetic[a]	64.74	19.31	67.00	17.39	NS	
Phonological Processing						
10. Rosner Phoneme Deletion	28.39	6.40	26.43	6.19	NS	
Working Memory						
11. Working Memory for Numbers	6.21	1.83	5.29	2.16	NS	
12. Working Memory for Words	3.03	1.33	2.93	1.39	NS	
Syntactic Awareness						
13. Oral Cloze	5.79	1.47	4.71	1.64	2.27*	0.69
Lexical Access						
14. RAN[b]	10.75	2.13	9.93	1.78	NS	

Notes: [a]Percentile score; [b]Reverse scale operates here where less time in seconds denotes a better ability to name numbers quickly and vice versa.
** $p \leq .003$ based on a Bonferroni-adjusted significance level; * $p \leq .05$; NA = children with ≥ 30th percentile in all achievement measure; PR = children with ≤ 17th percentile in reading comprehension and normal reading sub-skills; Degrees of freedom (*df*) = 50.

Table 3.8 Comparison of Normally Achieving (NA) Children & Poor Comprehenders (PC) using High Cutoffs

	Low Cutoffs					
	NA N = 25		PR N = 24			
Tasks	*M*	*SD*	*M*	*SD*	*t*-value	Cohen's *d*
Reading Subskills						
1. WJ-Word Attack[a]	83.65	17.38	71.83	19.77	2.22*	0.63
2. WJ-Word Identification[a]	82.00	14.89	78.16	15.81	NS	
3. WRAT-3 Word Identification[a]	65.52	17.30	55.92	14.06	2.03*	0.61
Reading Fluency						
4. Timed Reading of Words	17.80	2.87	16.13	2.09	2.33*	0.66
5. Timed Reading Pseudowords	33.68	6.69	28.96	6.63	2.48*	0.71
Reading Comprehension						
6. SDRT Reading Comprehension[a]	64.24	16.68	15.29	6.41	13.70**	3.88
Spelling						
7. WRAT-3 Spelling[a]	72.88	15.03	69.33	13.85	NS	
8. Pseudoword Spelling	6.16	2.41	5.25	2.58	NS	
Arithmetic						
9. WRAT-3 Arithmetic[a]	70.88	17.03	68.83	15.07	NS	
Phonological Processing						
10. Rosner Phoneme Deletion	29.16	4.92	26.21	6.35	NS	
Working Memory						
11. Working Memory for Numbers	6.68	1.68	4.96	2.81	2.60*	0.74
12. Working Memory for Words	3.44	1.33	2.67	1.31	2.06*	0.58
Syntactic Awareness						
13. Oral Cloze	5.96	1.51	4.79	1.50	2.71*	0.78
Lexical Access						
14. RAN[b]	10.05	1.57	10.05	1.77	NS	

Notes: [a]Percentile score; [b]Reverse scale operates here where less time in seconds denotes a better ability to name numbers quickly and vice versa.
** $p \leq .003$ based on a Bonferroni-adjusted significance level; * $p \leq .05$; NA = children with ≥ 35[th] percentile in all achievement measure; PR = children with ≤ 25[th] percentile in reading comprehension and normal reading sub-skills; Degrees of freedom (*df*) = 47.

Table 3.9 Comparison of Normally Achieving (NA) Children & the Arithmetic Disabled (AD) using High Cutoffs

	High Cutoffs					
	Normal N = 25		AD N = 13			
Tasks	*M*	*SD*	*M*	*SD*	*t*-value	Cohen's *d*
Reading Subskills						
1. WJ-Word Attack[a]	83.65	17.38	62.46	18.00	3.52**	1.20
2. WJ-Word Identification[a]	82.00	14.89	63.54	20.76	2.85*	1.02
3. WRAT-3 Word Identification[a]	65.52	17.30	50.00	12.34	2.87*	1.03
Reading Fluency						
4. Timed Reading of Words	17.80	2.88	15.38	3.43	2.30*	0.77
5. Timed Reading Pseudowords	33.68	6.70	25.85	5.21	3.67**	1.31
Reading Comprehension						
6. SDRT Reading Comprehension[a]	64.24	16.68	38.85	24.17	3.81**	1.22
Spelling						
7. WRAT-3 Spelling[a]	72.88	15.03	46.08	19.43	4.72**	1.54
8. Pseudoword Spelling	6.16	2.41	4.69	1.93	NS	
Arithmetic						
9. WRAT-3 Arithmetic[a]	70.88	17.03	18.62	4.67	14.35**	4.19
Phonological Processing						
10. Rosner Phoneme Deletion	29.16	4.92	25.46	5.78	2.07*	0.69
Working Memory						
11. Working Memory for Numbers	6.68	1.68	4.23	2.09	3.93**	1.30
12. Working Memory for Words	3.44	1.33	2.54	0.97	2.07*	0.78
Syntactic Awareness						
13. Oral Cloze	5.96	1.51	6.00	1.29	NS	
Lexical Access						
14. RAN[b]	10.05	1.57	11.78	3.29	NS	

Notes: [a]Percentile score; [b]Reverse scale operates here where less time in seconds denotes a better ability to name numbers quickly and vice versa.
** $p \leq .003$ based on a Bonferroniadjusted significance level; * $p \leq .05$; NA = children with $\geq 35^{th}$ percentile in all achievement measure; AD = children with $\leq 25^{th}$ percentile in arithmetic achievement and Normal in reading subskills; Degrees of freedom (*df*) = 36.

Table 3.10 Comparison of Normally Achieving (NA) Children & the Reading and Arithmetic Disabled (RAD) using High Cutoffs

	High Cutoffs					
	NA N = 24		RAD N = 8			
Tasks	*M*	*SD*	*M*	*SD*	*t*-value	Cohen's *d*
Reading Subskills						
1. WJ-Word Attack[a]	83.26	17.64	16.63	10.18	10.07**	4.63
2. WJ-Word Identification[a]	81.50	14.99	32.50	16.55	7.81**	3.17
3. WRAT-3 Word Identification[a]	65.13	17.56	20.50	10.38	6.76**	3.10
Reading Fluency						
4. Timed Reading of Words	17.88	2.91	9.75	3.15	6.71**	2.68
5. Timed Reading Pseudowords	33.79	6.81	10.63	6.32	8.47**	3.52
Reading Comprehension						
6. SDRT Reading Comprehension[a]	64.71	16.86	11.03	7.92	8.61**	4.07
Spelling						
7. WRAT-3 Spelling[a]	72.29	15.06	29.38	12.60	7.24**	3.10
8. Pseudoword Spelling	6.21	2.45	3.00	2.73	3.12*	1.24
Arithmetic						
9. WRAT-3 Arithmetic[a]	70.38	17.20	19.38	5.66	12.62**	4.00
Phonological Processing						
10. Rosner Phoneme Deletion	29.08	5.01	14.88	9.80	5.39**	1.82
Working Memory						
11. Working Memory for Numbers	6.67	1.71	3.88	1.25	4.24**	1.86
12. Working Memory for Words	3.46	1.35	1.88	1.00	3.04*	1.33
Syntactic Awareness						
13. Oral Cloze	6.00	1.53	2.88	1.73	4.85**	1.91
Lexical Access						
14. RAN[b]	9.94	1.48	12.21	1.93	3.50**	1.30

Notes: [a]Percentile score; [b]Reverse scale operates here where less time in seconds denotes a better ability to name numbers quickly and vice versa.
** $p \leq .003$ based on a Bonferroni-adjusted significance level; * $p \leq .05$; NA = children with ≥ 35th percentile in all achievement measure; RAD = children with ≤ 25th percentile in all reading measures as well as in arithmetic; Degrees of freedom (*df*) = 30.

Table 3.11 Comparison of the Grade 3 L1 and ESL Children in this Study

N = 121	Language Group					
	L1 N=35		ESL N=86			
Tasks	*M*	*SD*	*M*	*SD*	*t*-value	Cohen's *d*
Reading Subskills						
1. WJ-Word Attack[a]	69.02	27.17	55.74	29.35	2.30*	0.46
2. WJ-Word Identification[a]	71.00	28.83	57.54	27.19	2.43*	0.48
3. WRAT-3 Word Identification[a]	57.20	20.33	42.50	21.04	3.52**	0.71
Reading Fluency						
4. Timed Reading of Words	16.69	4.00	14.01	3.40	3.73**	0.71
5. Timed Reading Pseudowords	27.43	9.52	22.64	10.80	2.29*	0.47
Reading Comprehension						
6. SDRT Reading Comprehension[a]	42.14	25.21	29.66	21.89	2.56*	0.53
Spelling						
7. WRAT-3 Spelling[a]	59.14	22.85	51.26	23.32	NS	
8. Pseudoword Spelling	6.23	2.92	4.48	2.58	3.26**	0.63
Arithmetic						
9. WRAT-3 Arithmetic[a]	53.06	24.05	51.42	23.96	NS	
Phonological Processing						
10. Rosner Phoneme Deletion	25.17	7.65	22.12	8.73	NS	
Working Memory						
11. Working Memory for Numbers	5.57	1.85	5.00	2.53	NS	
12. Working Memory for Words	2.80	1.32	2.41	1.30	NS	
Syntactic Awareness						
13. Oral Cloze	5.83	1.65	4.63	1.92	3.25**	0.67
Lexical Access						
14. RAN[b]	11.62	2.67	11.15	2.52	NS	

Notes: [a]Percentile score; [b]Reverse scale operates here where less time in seconds denotes a better ability to name numbers quickly and vice versa.

[1] Reversed scale applies where less time in seconds indicates more efficient naming; ** $p \leq .003$ based on a Bonferroni-adjusted significance level; * $p < .05$; Degree of freedom, $(df) = 119$.

Table 3.12 Low Achievement Profiles

	Low Achievement Types			
	RD	PC	AD	RAD
Reading Subskills				
1. WJ-Word Attack	√		√	√
2. WJ-Word Identification	√			√
3. WRAT-3 Word Identification	√			√
Reading Fluency				
4. Timed Reading of words	√			√
5. Timed Reading Pseudowords	√		√	√
Reading Comprehension				
6. SDRT Reading Comprehension[a]	√	√	√	√
Spelling				
7. WRAT-3 Spelling	√		√	√
8. Pseudoword Spelling	√			
Arithmetic				
9. WRAT-3 Arithmetic	√		√	√
Phonological Processing				
10. Rosner Phoneme Deletion	√			√
Working Memory				
11. Working Memory for Numbers	√		√	√
12. Working Memory for Words	√			
Syntactic Awareness				
13. Oral Cloze	√			√
Lexical Access				
14. RAN	√			√

Notes: RD = Reading Disabled; PC = Poor Comprehenders; AD = Arithmetic Disabled; RAD = Reading & Arithmetic Disabled.

Table 3.13 Correlation Matrix of Variables in the Study (N = 121)

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13
Reading Subskills													
1. WJ-Word Attack													
2. WJ-Word ID	.784**												
3. WRAT-3 Word ID	.787**	.786**											
Reading Fluency													
4. Timed Read-Words	.792**	.797**	.822**										
5. Timed Read-Pseudo	.904**	.826**	.796**	.803**									
Reading Comprehension													
6. SDRT	.506**	.516**	.529**	.539**	.539**								
Spelling													
7. WRAT-3 Spelling	.707**	.717**	.684**	.739**	.788**	.399**							
8. Nonword Spelling	.478**	.466**	.427**	.461**	.474**	.299**	.434**						
Arithmetic													
9. WRAT-3 Arithmetic	.374**	.379**	.445**	.436**	.457**	.253**	.436**	.287**					
Phonological Processing													
10. Rosner	.657**	.692**	.663**	.629**	.705**	.451**	.617**	.477**	.403**				
Working Memory													
11. WM-Words	.168	.273**	.263**	.269**	.259**	.248**	.222*	.224*	.336**	.309**			
12. WM-Numbers	.335**	.305**	.238**	.324**	.333**	.307**	.293**	.292**	.348**	.335**	.362**		
Syntactic Awareness													
13. Oral Cloze	.337**	.378**	.426**	.479**	.385**	.403**	.342**	.295**	.088	.390**	.403**	.165	
Lexical Access													
14. RAN[a]	-.370**	-.316**	-.284**	-.327**	-.401**	-.161	-.373**	-.006	-.246**	-.215*	-.100	-.198*	-.037

Note. * $p < .05$; ** $p < .001$; 1 = Woodcock Johnson Reading Mastery Test-Revised Word Attack subtest; 2 = Woodcock Johnson Reading Mastery Test-Revised Word Identification subtest; 3 = Wide Range Achievement Test-3 Word Identification subtest; 4 = Wide Range Achievement Test-3 Spelling Test; 5 = Stanford Diagnostic Reading Test: Reading Comprehension; 6 = Wide Range Achievement Test-3 Arithmetic subtest; 7 = Rosner Phoneme Deletion; 8 = Working Memory for Numbers; 9 = Working Memory for Words; 10 = Oral Cloze; 11 = Rapid Automatic Naming of numbers; 12 = Time Reading of Words; 13 = Timed Reading of Pseudowords; 14 = GFW Nonwords Spelling; [a] Reverse scale operates here where less time in seconds denotes a better ability to name numbers quickly and vice versa.

Table 3.14 Summaries of Hierarchical Regression Analyses R^2 Change for Reading Achievement

	Criterion variables			
Step variable entry order	1.	2.	3.	4.
1. Working memory for words	.028	.075*	.069*	.062*
2. Syntactic processing	.086*	.086*	.122**	.110**
3. Phonological processing	.329**	.333**	.281**	.095**
1. Working memory for words	.028	.075*	.069*	.062*
2. Phonological processing	.405**	.408**	.374**	.155**
3. Syntactic processing	.011	.011	.029*	.049*
1. Syntactic processing	.113**	.143**	.181**	.163**
2. Working memory for words	.001	.017	.010	.009
3. Phonological processing	.329**	.333**	.281**	.095**
1. Syntactic processing	.113**	.143**	.181**	.163**
2. Phonological processing	.326**	.350**	.291**	.102**
3. Working memory for words	.005	.001	.000	.001
1. Phonological processing	.431**	.479**	.439**	.204**
2. Working memory for words	.001	.004	.004	.013
3. Syntactic processing	.011	.011	.029*	.049*
1. Phonological processing	.431**	.479**	.439**	.204**
2. Syntactic processing	.008	.014	.033*	.061*
3. Working memory for words	.005	.001	.000	.001

Note. * $p < .05$; ** $p < .001$; Step variables: Phonological processing = Rosner Phoneme Deletion; Syntactic processing = Oral Cloze. Criterion variables 1 = Woodcock Johnson Word Attack; 2 = Woodcock Johnson Word Identification; 3 = Wide Range Achievement Test-3 Word Identification subtest; 4 = Stanford Diagnostic Reading Test.

Table 3.15 Summaries of Hierarchical Regression Analyses R^2 Change for Arithmetic Achievement

	Criterion variable
Step variable entry order	WRAT-3 Arithmetic
1. Working memory for numbers	.121**
2. RAN	.033*
3. Phonological processing	.078**
1. Working memory for numbers	.121**
2. Phonological processing	.092**
3. RAN	.018
1. RAN	.060*
2. Working memory for numbers	.093**
3. Phonological processing	.078**
1. RAN	.060*
2. Phonological processing	.128**
3. Working memory for numbers	.042*
1. Phonological processing	.162**
2. Working memory for numbers	.051*
3. RAN	.018
1. Phonological processing	.162**
2. RAN	.027
3. Working memory for numbers	.042*

Note. * $p < .05$; ** $p < .001$; Step variables: Phonological processing = Rosner; RAN = Rapid Automatic Naming.

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***Please detach this page and return to class teacher.

Parental Consent Form
For Doctoral Dissertation Research on
Cognitive Processes Related to Reading and Arithmetic

Your signature below indicates that you have received a copy of this consent form for your own records.

Please circle one choice:

I consent/ I do not consent to my child's participate in this study.

______________________ ______________
Parent/Guardian Signature Date

____
Please print the child's name here

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Assent Form
For Doctoral Dissertation Research on
Cognitive Processes Related to Reading and Arithmetic

Instruction: Read this orally to the child.

1. The purpose of this study is to find better ways to help children who are having difficulties in reading and arithmetic.

2. You will be doing some reading and arithmetic in this study so we can learn more about how children do their reading and arithmetic.

3. Only the researchers in this study will have access to your tests and scores for research purposes. We may let your teacher know about the learning problems we find in this study if we think it will help you. Everything is confidential otherwise.

4. Your parents have given permission for you to do this study. However, you do not have to do this study if you do not want to. You can go back to your class now if you do not want to do this test. Also, during the tests, you can choose to stop at anytime if you feel uncomfortable. If you do not participate in this study, it will not affect your grades in your class in any way.

Appendix C
Rosner Auditory Analysis Test

Instruction to the child:

Now we are going to play a game of removing sounds from words. I'm going to say a word and then tell you to take part of the sound off and then say what's left. Here is how it will work. First, say "**cowboy.**" (*wait for response*) Now say "**cowboy**" again, but without the "**boy**" sound. Now, say "**toothbrush**" (*wait for response*) Say "toothbrush" without the "**tooth**" sound. *If the child fails either of the two practice items, attempt to teach the task by giving the correct response, explaining why it is correct, and re-present the item(s). Then move on to the next practice item.* Say "**sat.**" Now say "**sat**" without the /**s**/ sound. *If the child fails to correctly respond to this practice test item, then discontinue testing and score the test zero. If the items are answered correctly, then proceed.* **Testing for all subjects ends after five consecutive errors.** *Present the remainder of the items in the same way. Check items answered correctly. Mark line under last item attempted.*

Sample Items:

1. Cow(boy)   2. Tooth(brush)   3. (S)at

1. birth(day)
2. (car)pet
3. m(en)
4. ro(de)
5. w(ill)
6. (l)end
7. (s)our
8. (g)ate
9. to(ne)
10. ti(me)
11. plea(se)
12. stea(k)
13. bel(t)
14. (sc)old
15. (c)lip
16. (s)mile
17. (p)lay
18. (b)lock
19. (b)reak
20. (s)mell
21. (t)rail
22. de(s)k
23. (sh)rug
24. cr(e)ate — remove [ee], answer [crate]
25. s(m)ack
26. re(pro)duce — remove [pra], answer [reduce]
27. s(k)in
28. s(w)ing
29. (st)ain
30. g(l)ow
31. st(r)eam
32. c(l)utter
33. off(er)ing — remove [er], answer [offing]
34. dy(na)mo — remove [nuh], answer [dimo]
35. auto(mo)bile — remove [muh], answer [autobeel]
36. car(pen)ter — remove [puhn], answer [carter]
37. Ger(ma)ny — remove [muh], answer [journey]
38. lo(ca)tion — remove [kaa], answer [lotion]
39. con(tin)ent — remove [tin], answer [conent]
40. phi(lo)sophy — remove [law], answer [fuhsophy]

Total ________/40

Working Memory for Numbers

Procedure: place card A in front of child. After the child finishes counting, immediately turn card over on a stack near yourself, not the child. Using card A, teach the child to count the yellow dots, ignoring the blue ones. Here is how you instruct the child.

- Count the yellow dots. Try not to pay attention to the blue dots. Just count the yellow dots. You should touch each dot with your finger while you count out loud. Now you can practice counting the yellow dots. (wait and let the child count)
- Tell me how many yellow dots there were. (record answer)

Proceed to card B and C.

- Now I want you to count the yellow dots on one card and then on another card Be sure to touch each yellow dot and to count out loud. Then I want you to tell me how many dots there were on the first card and then on the second card.
- Let's try it.
- Now we are going to count yellow dots on some more cards. You should start to count as soon as you see a new card. When you see a blank card, you should tell me how many yellow dots were on each card in that set. In the beginning, you will only count 1 card at a time, then 2 cards at a time, and then even more cards. Each time you see the blank card you should tell me the numbers for each card you counted. You should tell me the numbers in the order in which you saw the cards — that is, how many yellow dots on the first card, the second, and so on.

Discontinue when the child has failed an entire level (i.e. all three items — A, B, C, of a particular number).

Note: Announce each new level. Record numbers in the order the child has said them.

Practice:

1. Card A _____ 1b. Cards B & C ______ ______

Test Items:

2\. A. _____ ______
B. _____ ______
C. _____ ______

3\. A. _____ ______ _____
B. _____ ______ _____
C. _____ ______ _____

4\. A. _____ ______ _____ _____
B. _____ ______ _____ _____
C. _____ ______ _____ _____

5\. A. _____ ______ _____ _____
B. _____ ______ _____ _____
C. _____ ______ _____ _____

Total _______/12

Working Memory for Words

Instruction:
I am going to say some sentences and the last word in each sentence will be missing. I want you to tell me what you think the last word should be. Let's try one.

- *"For breakfast the little girl had orange _______."*

Now I am going to read two sentences. After each sentence, I want you to tell me the word that should go at the end of the sentence. When I finish the two sentences, I want you to tell me the two words that you said for the end of each sentences. Please tell me the words in the order that you said them. Let's try it.

- *"When we go swimming, we wear a bathing ______."*
- *"Cars have to stop at a red _________."*

Discontinue when the child has failed an entire level (i.e. all three items – A, B, C of a particular number).
Note: announce each new level. Record the words in the order the child has said them.

2A 1) In a baseball game, the pitcher throws the ______.
2) On my two hands, I have ten ______.
Child's response: ____________________ (ball, fingers)

2B 1) In the fall, we need to rake ________.
2) When we are sick, we often go to the _________.
Child's response: _______________________(leaves, doctor)

2C 1) An elephant is big, a mouse is _________.
2) A saw is used to cut ______.
Child's response: __________________(small, wood)

3A 1) Running is fast, walking is ______.
2) At the library people read ______ .
3) An apple is red, a banana is _______.
Child's response: _______________________(slow, books, yellow)

3B 1) The sun shines during the day, the moon at ______.
2) In the spring, the farmer plows the ______.
3) The young child had black hair and brown _____.
Child's response: ______________________(night, field, eyes)

3C 1) In the summer it is very ________.
2) People go to see monkeys in a _____.
3) With dinner, we sometimes drink ______.
Child's response: ______________________(hot, zoo, milk)

Working Memory for Words

4A 1) Please pass the salt and ______.
2) When our hands are cold we wear ______.
3) On the way to school I mailed a ______.
4) After swimming, I was soaking _____.
Child's response:__________________________(pepper, gloves, letter, wet)

4B 1) Snow is white, grass is ______.
2) After school, the children walked _______.
3) A bird flies, a fish _____.
4) In the barn, the farmer milked the _____.
Child's response:___________________________(green, home, swims, cow)

4C 1) In the autumn, the leaves fall off the ______.
2) We eat soup with a ________.
3) I go to the pool to _________.
4) We brush and comb our _______.
Child's response:__________________________(trees, spoon, swim, hair)

5A 1) For the party, the girls wore a pretty pink _______.
2) Cotton is soft, and rocks are ______.
3) Once a week, we wash the ______.
4) In the spring it is very _______.
5) I throw the ball up and then it comes ______.
Child's response:__________________________(dress, hard, car, rainy, down)

5B 1) The snail is slow, the rabbit is _____.
2) At a birthday party, we usually eat ice cream and ______.
3) Sandpaper is rough but glass is _______.
4) In a garden, we pick _______.
5) Over the field, the girl rode the galloping _________.
Child's response:______________________(fast, cake, smooth, flowers, horse)

5C 1) To cut meat we use a sharp ______.
2) In the daytime it is light, and at night it is ______.
3) Dogs have four _____.
4) At the grocery store, we buy _______.
5) A man is big, a baby is ______.
Child's response:__________________________(knife, dark, legs, food, small)

Oral Cloze Task – Grade 3

Instructions to the child:

- This time I will read something to you and there will be a word missing. Where the word is missing, I will say, "**beep**." For example, I might say, "The moon shines bright in the "**beep**." (pause and repeat) and I want you to say "sky." O.K.
- Let's try another. I'll say, "The children "**beep**" with the toys." (pause and repeat). What is the missing word?" (If the child fails to respond, say "How about "play?" Then it would be "The children play with the toys."
- Let's try another one. "The little puppy wags its "**beep**." (pause and repeat). Good!

Practice Items:
The moon shines bright in the _________.
The children ________ with the toys.
The little puppy wags its _______.

Test Items:

1. We have done the work already. We _______ityesterday.
2. John is a good player. Bill is a better player than John. But Tom is the _____ player of them all.
3. Jane _______her sister ran up the hill.
4. The brown dog is small; the gray dog is smaller; but the white one is the ________.
5. Betty _______a hole with her shovel.
6. Yesterday, Tina and Marie _______walking down the street.
7. The girl ______ is tall plays basketball well.
8. The hungry dogs have ________all the food
9. Jeffrey wanted to go ______the roller coaster.
10. Dad ______Bobby a letter several weeks ago.
11. Yesterday, Joe ______the ball.

RAN Task

(Speeded Number Naming)

Instruction:

When I turn over this piece of paper you are going to see some numbers. I want you to name them as quickly as you can. Start by going across the page and then do the next row. Keep going and don't stop.

(Use stopwatch to time and circle uncorrected errors)

4	1	3	2	5
9	4	2	7	5
3	6	1	9	3
6	8	9	4	8
3	1	5	2	6

Time (to the nearest second): ________

Number of uncorrected errors: ________

One Minute Word Reading

Instruction to the child:

- We want to know how quickly you can read.
- When I turn over this page you will see some words.
- I want you to read them out as quickly as you can starting with the first row and moving down the page.
- If you come across a word that you don't know, skip it and go on to the next word.
- When I say begin, start reading and don't stop until I tell you to do so.

1. see
2. red
3. milk
4. was
5. then
6. jar
7. letter
8. city
9. between
10. cliff
11. stalk
12. grunt
13. huge
14. plot
15. sour
16. humidity
17. clarify
18. residence
19. urge
20. rancid
21. conspiracy
22. deny
23. quarantine
24. deteriorate
25. rudimentary
26. mosaic
27. rescinded
28. audacious
29. mitosis
30. protuberance
31. longevity
32. predilection
33. regime
34. beatify
35. internecine
36. regicidal
37. puerile
38. factitious
39. lucubration
40. epithalamion
41. inefficacious
42. synecdoche

Total ________/42

One Minute Pseudoword Reading

Instruction:

- I want to know how quickly you can sound out words that are not real words.
- When I turn over this page you will see some words that are called pseudowords.
- I want you to sound them out as quickly as you can starting with the first row and moving down the page.
- If you come across a pseudoword that you cannot sound out, skip it and go on to the next word.
- When I say begin, start reading and don't stop until I tell you to do so.

(1 point each)

1. ____ree .....r-ē
2. ____ip ....i-p
3. ____din ......d-i-n
4. ____ig ....i-g
5. ____dat ......d-a-t
6. ____tay ......t-ā
7. ____yee .....y-ē
8. ____rayed ....r-ā-d
9. ____mem ....m-e-m
10. ____olt ......o-lt
11. ____glack ....gl-a-k
12. ____hend ....h-e-nd
13. ____shum ....sh-u-m
14. ____eb ......e-b
15. ____dreek ...dr-ē-k
16. ____weaf ....w-ē-f
17. ____knap ....n-a-p
18. ____ful's .....f-u-lz
19. ____sess ....s-e-s
20. ____chur .....ch-ar
21. ____zoath ....z-ō-th
22. ____rejune ...rə/joon
23. ____depine ...də/pīn
24. ____viv ......v-i-v

Total ____________

25. ____yox .....y-o-ks ______ 24-31-23
26. ____rhunk ...r-u-ŋk ______ 16-32-26
27. ____throbe ...thr-ō-b ______ 27-36-1
28. ____sloy .....sl-oi ______ 26-38
29. ____sprawn't ....spr-aw-nt ____________ 27-37-26
30. ____quox ....kw-o-ks______ 10-31-23
31. ____phet .....f-e-t ______ 4-29-19
32. ____brecked ..br-e-kt ______ 26-29-26
33. ____wrault ...r-aw-lt ______ 16-37-26
34. ____darlanker ....dar/laŋ/kar ____________ 72/73/74
35. ____whumb ..hw-u-m ______ 7-32-12
36. ____mieb ....m-ī-b ______ 12-35-1
37. ____squow ...skw-ou ______ 27-40
38. ____pelnidlun ....pel/nid/lun ____________ 75/76/77
39. ____hopdalhup ......hop/dal/hup ____________ 78/79/80
40. ____untroikest ....un/troik/est ____________ 81/82/83
41. ____lunap ....loo/nap ______ 84/85
42. ____cedge ...s-e-j ______ 17-29-8
43. ____pnir .....n-ar ______ 13-41
44. ____ceisminadolt .... sēz/min/ə/dolt; sīz/min/a/dolt ______ 86/87/88/89
45. ____byrcal ...bar/kal ______ 90/91

GFW Nonword Spelling
Grade 3

1. nad	
2. gog	
3. lev	
4. besh	
5. poe, po	
6. yoy, yoi	
7. jesh	
8. abfim	other acceptable spelling: abphim, abphym
9. imbaf	other acceptable spelling: imbaf
10. quibbest	other acceptable spelling: quibest
11. wush	other acceptable spelling: whush
12. ull	
13. shenning	
14. bofmib	other acceptable spelling: boffmib
15. etbom	other acceptable spelling: etbomb

Appendix D
Woodcock Johnson Word Attack Reading Test (2 x 2 Contingency Tables)

Percentile	*Woodcock Johnson Word Attack* Stringent 17th Low	Stringent 35th Normal	Low Cut-Offs 17th Low	Low Cut-Offs 30th Normal	High Cut-Offs 25th Low	High Cut-Offs 35th Normal
Reading Subskills						
WJ-Word ID						
Low	9	2	9	2	14	3
Normal	0	87	1	91	1	87
	$\chi^2 = 78.380, p \le .0001$****		$\chi^2 = 73.050, p \le .0001$****		$\chi^2 = 76.750, p \le .0001$****	
WRAT-Word ID						
Low	9	2	9	2	14	5
Normal	0	83	0	88	1	83
	$\chi^2 = 75.099, p \le .0001$****		$\chi^2 = 79.200, p \le .0001$****		$\chi^2 = 65.448, p \le .0001$****	
Reading Fluency						
Timed Read_Word[a]						
Low	12	3	12	4	15	3
Normal	0	72	0	72	1	72
	$\chi^2 = 66.816, p \le .0001$****		$\chi^2 = 62.526, p \le .0001$****		$\chi^2 = 66.942, p \le .0001$****	
Timed Read_Psd[a]						
Low	12	0	12	1	15	0
Normal	0	65	1	65	0	65
	$\chi^2 = 77.000, p \le .0001$****		$\chi^2 = 70.909, p \le .0001$****		$\chi^2 = 80.000, p \le .0001$****	
Reading Comprehension						
SDRT						
Low	10	18	10	19	14	36
Normal	1	41	2	52	1	41
	$\chi^2 = 14.093, p \le .0001$****		$\chi^2 = 14.452, p \le .0001$****		$\chi^2 = 10.979, p \le .001$***	
Spelling						
WRAT-Spell						
Low	3	2	3	2	9	4
Normal	1	79	3	90	2	79
	$\chi^2 = 36.220, p \le .0001$****		$\chi^2 = 26.610, p \le .0001$****		$\chi^2 = 48.321, p \le .0001$****	
Pseudoword Spelling[A]						
Low	7	10	7	12	10	10
Normal	3	59	3	60	4	59
	$\chi^2 = 15.934, p \le .0001$****		$\chi^2 = 14.030, p \le .0001$****		$\chi^2 = 20.628, p \le .0001$****	
Arithmetic						
WRAT-Arithmetic						
Low	2	6	2	7	5	15
Normal	7	72	9	80	8	72
	$\chi^2 = 2.040, p = .153$		$\chi^2 = 1.203, p = .273$		$\chi^2 = 3.183, p = .074$	
Phonological Processing						
Rosner[a]						
Low	9	5	9	6	10	5
Normal	0	67	0	68	0	67
	$\chi^2 = 48.455, p \le .0001$****		$\chi^2 = 45.762, p \le .0001$****		$\chi^2 = 50.870, p \le .0001$****	
Working Memory						
WM-Number[a]						
Low	3	13	3	14	5	13
Normal	5	65	5	66	6	65
	$\chi^2 = 2.080, p = .149$		$\chi^2 = 1.866, p = .172$		$\chi^2 = 4.952, p = .026$*	
WM-Word[a]						
Low	2	17	2	18	4	17
Normal	3	54	3	56	5	54
	$\chi^2 = 0.642, p = .423$		$\chi^2 = 0.609, p = .435$		$\chi^2 = 1.734, p = .188$	
Syntactic Awareness						
Cloze[a]						
Low	7	11	7	12	10	11
Normal	5	65	5	67	7	65
	$\chi^2 = 12.253, p \le .0001$****		$\chi^2 = 11.738, p \le .001$***		$\chi^2 = 15.631, p \le .0001$****	
Lexical Access						
RAN[a]						
Low	7	8	7	9	7	8
Normal	3	63	3	62	6	63
	$\chi^2 = 20.038, p \le .0001$****		$\chi^2 = 18.171, p \le .0001$****		$\chi^2 = 13.581, p \le .0001$****	

Note. [a] Experimental test with the same cutoff points: low = ≥ 1 *SD* below the *M*; normal = ≥ the *M*.
*$p \le .05$. **$p \le .01$. ***$p \le .001$. ****$p \le .0001$.

Appendix E
Rosner Phoneme Deletion Test (2 x 2 Contingency Tables)

	Rosner Phoneme Deletion Test					
	Stringent		Low Cut-Offs		High Cut-Offs	
Percentile	17th Low	35th Normal	17th Low	30th Normal	25th Low	35th Normal
Reading Subskills						
WJ-Word Attack						
Low	9	0	9	0	10	0
Normal	5	67	6	68	5	67
	χ^2=48.455, $p \leq$ .0001****		χ^2=45.762, $p \leq$ .0001****		χ^2=50.870, $p \leq$ .0001****	
WJ-Word ID						
Low	5	1	5	1	10	2
Normal	4	68	8	68	4	68
	χ^2=32.824, $p \leq$ .0001****		χ^2=22.097, $p \leq$ .0001****		χ^2=44.800, $p \leq$ .0001****	
WRAT-Word ID						
Low	7	0	7	0	10	3
Normal	5	65	7	66	5	65
	χ^2=41.708, $p \leq$ .0001****		χ^2=36.164, $p \leq$ .0001****		χ^2=36.057, $p \leq$ .0001****	
Reading Fluency						
Timed Read_Word[a]						
Low	12	1				
Normal	0	59				
	χ^2=65.354, $p \leq$ .0001****					
Timed Read_Psd[a]						
Low	11	1				
Normal	0	53				
	χ^2=58.480, $p \leq$ .0001****					
Reading Comprehension						
SDRT						
Low	11	15	11	15	14	27
Normal	4	33	4	40	4	33
	χ^2=8.351, p=.004**		χ^2=10.710, $p \leq$ .001***		χ^2=5.966, p=.015*	
Spelling						
WRAT-Spell						
Low	3	1	3	1	6	2
Normal	5	64	9	68	5	64
	χ^2=17.787, $p \leq$ .0001****		χ^2=12.077, $p \leq$ .0001****		χ^2=26.876, $p \leq$ .0001****	
Pseudoword Spelling[a]						
Low	10	5				
Normal	3	48				
	χ^2=27.075, $p \leq$ .0001****					
Arithmetic						
WRAT-Arithmetic						
Low	4	4	4	4	5	12
Normal	11	53	13	58	11	53
	χ^2=4.642, p=.031*		χ^2=4.275, p=.039*		χ^2=1.266, p=.260n.s.	
Working Memory						
WM-Number[a]						
Low	6	7				
Normal	8	49				
	χ^2=6.825, p=.009**					
WM-Word[a]						
Low	5	9				
Normal	6	44				
	χ^2=4.321, p=.038*					
Syntactic Awareness						
Cloze[a]						
Low	8	8				
Normal	9	49				
	χ^2=8.427, p=.004**					
Lexical Access						
RAN[a]						
Low	6	7				
Normal	8	47				
	χ^2=6.425, p=.011*					

Note. [a]Experimental test with the same cutoff points: low = ≥ 1 *SD* below the *M*, normal = ≥ the *M*.
*$p \leq$ .05. **$p \leq$ .01. ***$p \leq$ .001. ****$p \leq$ .0001.

Appendix F
Wide Range Achievement Test-3 Spelling (2 x 2 Contingency Tables)

	WRAT-3 Spelling Test					
	Stringent		Low Cut-Offs		High Cut-Offs	
Percentile	17^{th} Low	35^{th} Normal	17^{th} Low	30^{th} Normal	25^{th} Low	35^{th} Normal
Reading Subskills						
WJ-Word Attack						
Low	3	1	3	3	9	2
Normal	2	79	2	90	4	79
	χ^2=36.220, p<.001***		χ^2=26.610, p<.001***		χ^2=48.321, p<.001***	
WJ-Word ID						
Low	4	1	4	3	8	3
Normal	1	79	2	88	5	79
	χ^2=52.713, p<.001***		χ^2=33.759, p<.001***		χ^2=36.717, p<.001***	
WRAT-Word ID						
Low	4	1	4	3	9	5
Normal	1	73	2	86	3	73
	χ^2=48.866, p<.001***		χ^2=32.994, p<.001***		χ^2=37.247, p<.001***	
Reading Fluency						
Timed Read_Word[a]						
Low	5	1	5	6	11	1
Normal	0	66	0	71	2	66
	χ^2=59.104, p<.001***		χ^2=34.368, p<.001***		χ^2=59.001, p<.001***	
Timed Read_Psd[a]						
Low	4	2	4	7	9	2
Normal	1	60	1	62	2	60
	χ^2=33.449, p<.001***		χ^2=17.977, p<.001***		χ^2=45.090, p<.001***	
Reading Comprehension						
SDRT						
Low	4	19	4	23	12	35
Normal	0	35	0	52	0	35
	χ^2=6.538, p=.011*		χ^2=8.115, p=.004**		χ^2=10.468, p=.001**	
Spelling						
Pseudoword Spelling[a]						
Low	10	5				
Normal	3	48				
	χ^2=27.075, $p \le .0001$****					
Arithmetic						
WRAT-Arithmetic						
Low	2	3	2	7	5	11
Normal	3	69	4	79	8	69
	χ^2=9.887, p=.002**		χ^2=4.034, p=.045*		χ^2=4.764, p=.029*	
Phonological Processing						
Rosner[a]						
Low	3	5	3	9	6	5
Normal	1	64	1	68	2	64
	χ^2=17.787, p<.001***		χ^2=12.077, p=.001**		χ^2=26.876, p<.001***	
Working Memory						
WM-Number[a]						
Low	1	11	1	15	2	11
Normal	5	60	5	65	8	60
	χ^2=0.006, p=.939n.s.		χ^2=0.16, p=.899n.s.		χ^2=0.132, p=.716n.s.	
WM-Word[a]						
Low	0	14	0	18	3	14
Normal	3	50	3	57	6	50
	χ^2=0.830, p=.362n.s.		χ^2=0.936, p=.333n.s		χ^2=0.580, p=.446n.s.	
Syntactic Awareness						
Cloze[a]						
Low	4	10	4	14	6	10
Normal	1	60	1	69	5	60
	χ^2=13.274, p<.001***		χ^2=11.552, p=.001**		χ^2=9.720, p=.002**	
Lexical Access						
RAN[a]						
Low	1	7	1	11	5	7
Normal	3	58	3	61	7	58
	χ^2=0.744, p=.388n.s.		χ^2=0.269, p=.604n.s.		χ^2=7.351, p=.007**	

Note. [a]Experimental test with the same cutoff points: low = ≥ 1 *SD* below the *M*; normal = ≥ the *M*.
*$p \le .05$. **$p \le .01$. ***$p \le .001$. ****$p \le .0001$.

Appendix G
Pseudoword Spelling Test (2 x 2 Contingency Tables)

	Pseudoword Spelling Test					
	Stringent		Low Cut-Offs		High Cut-Offs	
Percentile	17th Low	35th Normal	17th Low	30th Normal	25th Low	35th Normal
Reading Subskills						
WJ-Word Attack						
Low	7	3	7	3	10	4
Normal	10	59	12	60	10	59
	χ^2=15.934, $p \leq .0001$****		χ^2=14.030, $p \leq .0001$****		χ^2=20.628, $p \leq .0001$****	
WJ-Word ID						
Low	5	4	5	4	12	4
Normal	11	59	12	61	11	59
	χ^2=7.837, p=.005**		χ^2=7.460, p=.006**		χ^2=23.364, $p \leq .0001$****	
WRAT-Word ID						
Low	7	2	7	2	11	8
Normal	7	56	11	57	7	56
	χ^2=22.345, $p \leq .0001$****		χ^2=16.838, $p \leq .0001$****		χ^2=18.648, $p \leq .0001$****	
Reading Fluency						
Timed Read_Word[a]						
Low	12	5				
Normal	6	49				
	χ^2=24.667, $p \leq .0001$****					
Timed Read_Psd[a]						
Low	14	3				
Normal	3	49				
	χ^2=40.469, $p \leq .0001$****					
Reading Comprehension						
SDRT						
Low	13	15	13	15	17	27
Normal	6	27	8	36	6	27
	χ^2=5.636, p=.018*		χ^2=6.608, p=.010**		χ^2=3.766, p=.052	
Spelling						
WRAT-Spell						
Low	3	1	3	1	7	6
Normal	9	55	15	59	9	55
	χ^2=9.619, p=.002**		χ^2=6.403, p=.011*		χ^2=10.389, $p \leq .001$***	
Arithmetic						
WRAT-Arithmetic						
Low	3	4	3	4	7	11
Normal	15	50	18	55	15	50
	χ^2=1.319, p=.251		χ^2=1.093, p=.296		χ^2=1.089, p=.179	
Phonological Processing						
Rosner[a]						
Low	10	3				
Normal	5	48				
	χ^2=27.075, $p \leq .0001$****					
Working Memory						
WM-Number[a]						
Low	6	6				
Normal	14	46				
	χ^2=3.545, p=.060					
WM-Word[a]						
Low	8	11				
Normal	11	38				
	χ^2=2.627, p=.105					
Syntactic Awareness						
Cloze[a]						
Low	11	8				
Normal	11	45				
	χ^2=10.014, p=.002**					
Lexical Access						
RAN[a]						
Low	6	10				
Normal	12	40				
	χ^2=1.308, p=.253					

Note. [a]Experimental test with the same cutoff points: low = ≥ 1 *SD* below the *M*; normal = ≥ the *M*.
*$p \leq .05$. **$p \leq .01$. ***$p \leq .001$. ****$p \leq .0001$.

Appendix H
Rapid Automatized Naming Task (2 x 2 Contingency Tables)

	Rapid Automatized Naming Task (RAN)					
	Stringent		Low Cut-Offs		High Cut-Offs	
Percentile	17^{th} Low	35^{th} Normal	17^{th} Low	30^{th} Normal	25^{th} Low	35^{th} Normal
Reading Subskills						
WJ-Word Attack						
Low	7	3	7	3	7	6
Normal	8	63	9	62	8	63
	χ^2=20.038, $p \le .0001$****		χ^2=18.171, $p \le .0001$****		χ^2=22.247, $p \le .0001$****	
WJ-Word ID						
Low	5	3	5	3	9	6
Normal	7	62	8	64	6	58
	χ^2=14.937, $p \le .0001$****		χ^2=13.971, $p \le .0001$****		χ^2=19.331, $p \le .0001$****	
WRAT-Word ID						
Low	5	4	5	4	9	6
Normal	6	58	6	62	6	57
	χ^2=13.149, $p \le .0001$****		χ^2=14.175, $p \le .0001$****		χ^2=19.873, $p \le .0001$****	
Reading Fluency						
Timed Read_Word[a]						
Low	9	7				
Normal	4	50				
	χ^2=19.471, $p \le .0001$****					
Timed Read_Psd[a]						
Low	8	4				
Normal	3	46				
	χ^2=23.905, $p \le .0001$****					
Reading Comprehension						
SDRT						
Low	6	17	6	17	9	32
Normal	6	30	9	33	6	30
	χ^2=0.769, p=.381		χ^2=0.182, p=.670		χ^2=0.341, p=.559	
Spelling						
WRAT-Spell						
Low	1	3	1	3	5	7
Normal	7	58	11	61	7	58
	χ^2=0.744, p=.388		χ^2=0.269, p=.604		χ^2=7.351, p=.007**	
Pseudoword Spell[a]						
Low	6	12				
Normal	10	40				
	χ^2=1.308, p=.253					
Arithmetic						
WRAT-Arithmetic						
Low	2	4	2	4	5	10
Normal	11	55	13	59	11	55
	χ^2=1.033, p=.310		χ^2=0.832, p=.362		χ^2=2.142, p=.143	
Phonological Processing						
Rosner[a]						
Low	6	8				
Normal	7	46				
	χ^2=6.425, p=.013*					
Working Memory						
WM-Number[a]						
Low	2	10				
Normal	8	49				
	χ^2=0.055, p=.814					
WM-Word[a]						
Low	2	14				
Normal	7	38				
	χ^2=0.088, p=.767					
Syntactic Awareness						
Cloze[a]						
Low	4	12				
Normal	12	44				
	χ^2=0.092, p=.762					

Note. [a]Experimental test with the same cutoff points: low = ≥ 1 *SD* below the *M*, normal = ≥ the *M*.
*$p \le .05$. **$p \le .01$. ***$p \le .001$. ****$p \le .0001$.

Appendix I
Working Memory for Words Test (2 x 2 Contingency Tables)

	Working Memory for Words Test					
	Stringent		Low Cut-Offs		High Cut-Offs	
Percentile	17th Low	35th Normal	17th Low	30th Normal	25th Low	35th Normal
Reading Subskills						
WJ-Word Attack						
Low	2	3	2	3	4	5
Normal	17	54	18	56	17	54
	χ^2=0.642, p=.423		χ^2=0.609, p=.435		χ^2=1.734, p=.188	
WJ-Word ID						
Low	2	4	2	4	6	6
Normal	16	54	17	56	16	54
	χ^2=0.336, p=.562		χ^2=0.306, p=.580		χ^2=3.844, p=.050*	
WRAT-Word ID						
Low	2	2	2	2	6	7
Normal	15	51	15	55	15	51
	χ^2=1.526, p=.217		χ^2=1.746, p=.186		χ^2=3.054, p=.081	
Reading Fluency						
Timed Read_Word[a]						
Low	5	6				
Normal	12	46				
	χ^2=3.054, p=.081					
Timed Read_Psd[a]						
Low	5	6				
Normal	9	39				
	χ^2=3.526, p=.060					
Reading Comprehension						
SDRT						
Low	10	13	10	13	14	23
Normal	5	30	9	36	5	30
	χ^2=6.169, p=.013*		χ^2=4.167, p=.041*		χ^2=5.136, p=.023*	
Spelling						
WRAT-Spell						
Low	0	3	0	3	3	6
Normal	14	50	18	57	14	50
	χ^2=0.830, p=.362		χ^2=0.936, p=.333		χ^2=0.580, p=.446	
Pseudoword Spell[a]						
Low	8	11				
Normal	11	38				
	χ^2=2.627, p=.105					
Arithmetic						
WRAT-Arithmetic						
Low	3	4	3	4	5	12
Normal	16	47	19	51	16	47
	χ^2=0.971, p=..324		χ^2=0.770, p=.380		χ^2=0.111, p=.738	
Phonological Processing						
Rosner[a]						
Low	5	6				
Normal	9	44				
	χ^2=4.321, p=.038*					
Working Memory						
WM-Number[a]						
Low	5	7				
Normal	11	44				
	χ^2=2.544, p=.111					
Syntactic Awareness						
Cloze[a]						
Low	12	4				
Normal	7	48				
	χ^2=24.253, $p \leq .0001$****					
Lexical Access						
RAN[a]						
Low	2	7				
Normal	14	38				
	χ^2=0.088, p=.767					

Note. [a]Experimental tests test with the same cutoff points: low = ≥ 1 *SD* below the *M*, normal = ≥ the *M*.
*$p \leq .05$. **$p \leq .01$. ***$p \leq .001$. ****$p \leq .0001$.

Appendix J
Oral Cloze Test (2 x 2 Contingency Tables)

	Oral Cloze Test					
	Stringent		Low Cut-Offs		High Cut-Offs	
Percentile	17th Low	35th Normal	17th Low	30th Normal	25th Low	35th Normal
Reading Subskills						
WJ-Word Attack						
Low		5	7	5	10	7
Normal	11	65	12	67	11	65
	χ^2=12.253, $p \le .0001$****		χ^2=11.738, $p \le .001$***		χ^2=15.631, $p \le .0001$****	
WJ-Word ID						
Low	5	5	5	5	10	8
Normal	12	62	13	66	12	62
	χ^2=6.229, p=.013*		χ^2=6.190, p=.013*		χ^2=12.315, $p \le .0001$****	
WRAT-Word ID						
Low	8	2	8	2	11	7
Normal	10	61	11	66	10	61
	χ^2=22.035, $p \le .0001$****		χ^2=22.391, $p \le .0001$****		χ^2=17.615, $p \le .0001$****	
Reading Fluency						
Timed Read_Word[a]						
Low	12	8				
Normal	7	54				
	χ^2=19.753, $p \le .0001$****					
Timed Read_Psd[a]						
Low	11	8				
Normal	6	47				
	χ^2=16.820, $p \le .0001$****					
Reading Comprehension						
SDRT						
Low	18	13	18	13	21	27
Normal	1	37	2	44	1	37
	χ^2=26.291, $p \le .0001$****		χ^2=27.792, $p \le .0001$****		χ^2=18.836, $p \le .0001$****	
Spelling						
WRAT-Spell						
Low	4	1	4	1	6	5
Normal	10	60	14	69	10	60
	χ^2=13.274, $p \le .0001$****		χ^2=11.552, $p \le .001$***		χ^2=9.720, p=.002**	
Pseudoword Spell[a]						
Low	11	11				
Normal	8	45				
	χ^2=10.014, p=.002**					
Arithmetic						
WRAT-Arithmetic						
Low	4	6	4	6	7	15
Normal	11	56	16	62	11	56
	χ^2=3.085, p=.079		χ^2=1.917, p=.166		χ^2=2.435, p=.119	
Phonological Processing						
Rosner[a]						
Low	8	9				
Normal	8	49				
	χ^2=8.427, p=.004**					
Working Memory						
WM-Number[a]						
Low	5	11				
Normal	13	50				
	χ^2=0.817, p=.336					
WM-Word[a]						
Low	12	7				
Normal	4	48				
	χ^2=24.253, $p \le .0001$****					
Lexical Access						
RAN[a]						
Low	4	12				
Normal	12	44				
	χ^2=0.092, p=.762					

Note. [a]Experimental test with the same cutoff points: low = ≥ 1 *SD* below the *M*; normal = ≥ the *M*.
*$p \le .05$. **$p \le .01$. ***$p \le .001$. ****$p \le .0001$.

Appendix K
Wide Range Achievement Test-3 Arithmetic Test (2 x 2 Contingency Tables)

	WRAT-3 Arithmetic Test					
	Stringent		Low Cut-Offs		High Cut-Offs	
Percentile	17th Low	35th Normal	17th Low	30th Normal	25th Low	35th Normal
Reading Subskills						
WJ-Word Attack						
Low	2	7	2	9	5	8
Normal	6	72	7	80	15	72
	χ^2=2.040, p=.153		χ^2=1.203, p=.273		χ^2=3.183, p=.074	
WJ-Word ID						
Low	1	9	1	10	4	12
Normal	5	67	7	77	18	67
	χ^2=0.121, p=.728		χ^2=0.007, p=.932		χ^2=0.116, p=.734	
WRAT-Word ID	1	7	1	9	8	10
Low	4	66	5	78	12	66
Normal	0	81	1	90	4	81
	χ^2=0.551, p=.458		χ^2=0.234, p=.629		χ^2=7.488, p=.006**	
Reading Fluency						
Timed Read_Word[a]						
Low	4	10	4	13	8	10
Normal	5	57	5	62	12	57
	χ^2=4.601, p=.032*		χ^2=3.659, p=.056		χ^2=5.902, p=.015*	
Timed Read_Psd[a]						
Low	3	11	3	14	5	11
Normal	4	50	4	55	10	50
	χ^2=2.367, p=.124		χ^2=1.864, p=.172		χ^2=1.696, p=.193	
Reading Comprehension						
SDRT						
Low	3	23	3	27	13	37
Normal	2	33	5	46	7	33
	χ^2=0.672, p=.412		χ^2=0.001, p=.977		χ^2=0.929, p=.335	
Spelling						
WRAT-Spell						
Low	2	3	2	4	5	8
Normal	3	69	7	79	11	69
	χ^2=9.887, p=.002**		χ^2=4.034, p=.045*		χ^2=4.794, p=.029*	
Pseudoword Spell[a]						
Low	3	15	3	18	7	15
Normal	4	50	4	55	11	50
	χ^2=1.319, p=.251		χ^2=1.093, p=.296		χ^2=1.809, p=.179	
Phonological Processing						
Rosner[a]						
Low	4	11	4	13	5	11
Normal	4	53	4	58	12	53
	χ^2=4.642, p=.031*		χ^2=4.275, p=.039*		χ^2=1.266, p=.260	
Working Memory						
WM-Number[a]						
Low	3	12	3	13	6	12
Normal	4	60	4	66	10	60
	χ^2=2.845, p=.092		χ^2=2.960, p=.085		χ^2=3.492, p=.062	
WM-Word[a]						
Low	3	16	3	19	5	16
Normal	4	47	4	51	12	47
	χ^2=0.971, p=.324		χ^2=0.770, p=.324		χ^2=0.111, p=.738	
Syntactic Awareness						
Cloze[a]						
Low	4	11	4	16	7	11
Normal	6	56	6	62	15	56
	χ^2=3.085, p=.079		χ^2=1.917, p=.166		χ^2=2.4535, p=.119	
Lexical Access						
RAN[a]						
Low	2	11	2	13	5	11
Normal	4	55	4	59	10	55
	χ^2=1.033, p=.310		χ^2=0.832, p=.362		χ^2=2.142, p=.143	

Note. [a]Experimental test with the same cutoff points: low = ≥ 1 *SD* below the *M*; normal = ≥ the *M*.
**p* ≤ .05. ***p* ≤ .01. ****p* ≤ .001. *****p* ≤ .0001.