THE INTERRELATIONSHIPS BETWEEN BEHAVIOURAL INATTENTION, WORKING MEMORY AND ACADEMIC OUTCOME IN A COMMUNITY SAMPLE OF ELEMENTARY SCHOOL-AGED CHILDREN

by

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Abstract

A body of empirical studies has found that inattentive behaviour in the classroom is linked to low academic functioning. The literature suggests that poor working memory (WM), as well as behavioural inattention and academic underachievement, comprise a developmental risk triad. The nature of this relationship triad is not yet understood. There were two overall objectives of this dissertation research: one was to examine the strength of the evidence for a relationship between behavioural inattention and academic underachievement. The second was to investigate the role WM plays in relation to inattention and academic outcomes.

Firstly, a systematic review was conducted to evaluate the evidence and strength of association of the relationship between inattention and lower standardized test scores and classroom performance. Large heterogeneity in the results of individual studies pointed to differences based on covariates, outcome measures and ages of participants. Overall, there was a consistent evidence-based link between inattention and lower academic achievement. The heterogeneity in results raised questions about other factors that play a role in the relationship between inattention and academic achievement.

The second objective was addressed through two sets of analyses using contemporaneous and longitudinal data from a community sample of school children. Mediation analysis was used to assess whether WM is a mediator of the relationship between inattention and poor achievement. The first
analysis demonstrated that the contemporaneous nature of the connections among inattention, WM and academic outcomes was such that inattention had both a direct relationship and an indirect relationship to math and reading fluency through auditory-verbal WM.

The second set of analyses examined this same relationship across time. Results indicated that across time, auditory-verbal WM continues to be important for reading fluency, but visual-spatial WM becomes more important when predicting math outcomes for boys. This pattern was the same when classroom performance was used as an outcome measure.

Results provide insight into the nature of the relationship between inattention, WM and poor achievement in the general elementary classroom population.
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CHAPTER 1

Rationale and Overview of Dissertation Research
1.1 Introduction

This thesis examines the relationship between everyday behaviours that represent difficulty with attention in a classroom setting, working memory, and academic outcomes. Forgetting instructions, losing pencils, looking out the window instead of at the teacher, and getting distracted are all examples of overt observable inattention (American Psychiatric Association, 2013). Inattentive behaviour in the classroom is considered a risk factor for both current low academic functioning and poor long-term academic outcomes (Giannopulu, Escolano, Cusin, Citeau, & Dellatolas, 2008; Pingault et al., 2011; Polderman, Boomsma, Bartels, Verhulst, & Huizink, 2010; Rogers, Hwang, Toplak, Weiss, & Tannock, 2011). This risk factor remains significant when controlling for IQ, social-economic status (SES) and co-occurring disorders (Polderman et al., 2010).

Barkley and Peters (2012) argue that the earliest description of inattentive behaviour and its functional significance was written by Dr. Melchior Weikard, in a chapter of a German medical textbook from 1775 (Barkley & Peters, 2012). Alexander Crichton wrote a more detailed and broader description of inattentive behaviour and its impact on academics in 1798. Crichton astutely described the children he observed as having ‘the incapacity of attending with a necessary degree of constancy to any one object’ (Crichton, 1798). Far ahead of his time, he suggested a different instruction and educational format for these children to ensure academic success.

More recently, the literature has turned to examining inattention as a dimension, across the normal spectrum of development (Salum et al., 2014). Inattentive behaviours are often studied together with hyperactive and impulsive behaviours. When severe, these symptoms can form part of the diagnosis of Attention Deficit Hyperactivity Disorder (ADHD). However, it is the dimension of inattention, not hyperactive/impulsive symptoms that are predictive of poor academic achievement (Pingault et al., 2011).
There is a growing group of studies that suggest a relationship between inattention and poor academic outcomes (Frazier, Youngstrom, Glutting, & Watkins, 2007; Polderman et al., 2010). One issue with this body of literature is that many of these studies (including a systematic review) do not separate inattention from hyperactivity and impulsivity. A comprehensive systematic review of the evidence of the relationship between inattention and academic achievement is needed to contribute to this literature base; taking into account the quantity and quality of studies, the outcome variables used, age of participants and range of results. Therefore, conducting such a systematic review is the first main objective of this thesis.

Within the literature that suggests a link between behavioural inattention and poor academic outcomes, inattention is placed as the posited ‘causal’ factor influencing academic achievement. When teachers or parents rate inattentive behaviour, however, there are a number of factors that could be assessed along with actual observed behaviours. We do not yet know which underlying variables are playing a role in the link between inattention, as measured through rating scales, and poor academic achievement.

The literature suggests that the function of working memory (WM) is a potential variable to investigate as a factor in the relationship between inattention and academic outcomes. Working memory has been found to be related to both behavioural inattention and academic outcomes (Alloway & Alloway, 2010; Alloway, Elliott, & Place, 2010), and appears to form an integral part of day to day academic functioning (Alloway, Gathercole, Kirkwood, & Elliott, 2009). Taken together, this literature indicates a triad of impairment that encompasses inattention, low WM functioning and poor academic outcomes.

Therefore, the second main goal of this thesis is to examine whether the posited effect of inattention on academic outcomes may be mediated by a process variable, working memory. Mediation
analysis can provide support for a presumed model, and support for direction of influence, although it cannot provide definitive answers to causal questions. Support for models that look at how inattention is related to poor academic outcomes can help to develop theories about whether the actual behaviours are an appropriate target for intervention, or if teachers are observing behaviours that reflect underlying cognitive differences, such as WM differences. If there are underlying cognitive differences, one would predict that cognitive differences would mediate the effect of inattention on academic outcome.

One theoretical account posits that there are two pathways through which inattention (in their model, clinically diagnosed ADHD) impacts academic outcomes. The first of the two pathways is a behavioural-based pathway through which behavioural inattention directly impacts academic achievement. The second is a cognitive-based pathway from behavioural inattention, through underlying poor cognitive functioning (in their model, short-term memory) to poor academic outcomes (Rapport, Scanlan, & Denney, 1999).

Based on the dual pathway model, this thesis seeks to examine the pathways to poor academic outcome through studying both behavioural and cognitive (specifically WM) difficulties with attention and their relationship to achievement across time, and whether there are differences that vary across gender. The Rapport model focused on clinically diagnosed ADHD. However this dissertation is focused on inattention across the normal spectrum of development.

Furthering our theoretical knowledge of what accounts for childhood underachievement across a wide spectrum of normal development will allow for clinical and educational suggestions related to Crichton’s original recommendation for appropriate differentiation of instruction and classroom format for children experiencing difficulties with attention.
1.2 Organization of Thesis

This doctoral thesis is presented in portfolio format in six chapters, which includes a general introduction, the three manuscripts, a supplementary analysis, and a general discussion section that integrates and interprets the findings from the three manuscripts. Therefore, there is some unavoidable overlap and repetition throughout the thesis.

The first chapter summarizes and provides relevant detail about the three main constructs of focus in this thesis: behavioural inattention, working memory, and academic achievement. I discuss the differences between cognitive and behavioural attention and the spectrum of difficulty with attention. This is followed by a discussion of two different measures of academic achievement: classroom performance and standardized achievement, both of which are used as outcome measures in this thesis.

The introductory section also reviews theories of how attention is related to WM, and presents Baddeley’s (2003, 2010) theoretical framework for WM that is employed in the study design and interpretation. Finally, I discuss an earlier theoretical model (proposed by Rapport and colleagues in 1999) that outlines potential pathways of influence between ADHD behaviours and academic underachievement, a portion of which is tested in the current thesis.

The end of the introductory section provides an overall summary of the research objectives for the thesis, as well as general hypotheses and the analysis approach.

The second chapter reports the first manuscript titled Systematic Review: The relationship between Inattention and Academic Achievement. This systematic review identified and appraised the body of literature that links teacher and parent-rated inattention with underachievement in reading, writing and math throughout development. The review identified all articles within the study parameters, selected articles based on a relevance rating and then assessed the articles’ risk of bias. Data synthesis revealed several studies with a low risk of bias that, overall, provide strong evidence
that inattention predicts lower academic outcomes across the elementary school grades. However, the evidence was not strong enough to conclusively support this relationship in all age groups. Variance across the studies in terms of the strength of association (correlations ranged from 0.10 to 0.64) suggests that other unexamined factors may be contributing to this relationship.

The third chapter comprises a second manuscript, focused on exploring working memory as a factor that may share variance in the established relationship between inattention and underachievement. This manuscript, titled *The Inter-Relationships between Behavioural Inattention, Working Memory and Academic Fluency in a Canadian Community Sample of School Children* found evidence for a risk triad within a sample of typically developing children. Specifically, teacher-rated inattention and WM were important predictors of math and reading fluency. The cross-sectional nature of this study led to the following third manuscript that examined relationships among study variables across two school years.

Chapter four, a manuscript entitled *Longitudinal Relations among Inattention, Working Memory, and Academic Achievement: Testing Mediation and the Moderating Role of Gender* examined visual-spatial and auditory-verbal WM as mediators of the relationship between teacher-rated inattention and important academic skills across two school years. Inattention and WM were found to be longitudinal predictors of reading and math outcomes. Skills assessed included word reading, reading fluency, addition and subtraction fluency and math calculation. Visual-spatial WM was found to be a mediator of the relationship between inattention and math outcomes for boys and not girls.

A supplementary analysis using a teacher-rated measure of academic performance is presented in the fifth chapter, as it was outside the scope of the main manuscripts, however, relevant to research objectives and findings from the systematic review.
The sixth and concluding chapter is a general discussion that links the findings of all three manuscripts and additional analyses. In this chapter, I discuss clinical and theoretical implications of the thesis work, along with strengths and limitations. Conclusions based on the overall findings are discussed.

1.3 Attention

In this section I will discuss the construct of attention and its overt (behavioural) and covert (cognitive) forms. Attention, in the form of overt behaviour, is the main predictor in both mediation models examined in this thesis, and is the focus of the systematic review.

Attention is a complex phenomenon that can be conceptualized using theories that integrate genetic, neural, cognitive and social/cultural influences (Posner & Rothbart, 2007). Posner and Rothbart propose an integrative theory in which the development of neural attentional control networks is specified by genetics, and influenced by social and cultural experiences to produce individual differences in attention (Posner & Rothbart, 2007). They propose that the cognitive basis of attention refers to a complex system of processes that operate through neural networks. These networks encompass self-regulation of sensory input, motor output and emotional control (Posner & Raichle, 1998; Posner & Rothbart, 2007). According to an updated theory of how these attention networks function, the three major networks originally proposed: alerting, orienting and executive control, can be differentiated based on neurochemical and neuroanatomical differences (Petersen & Posner, 2012).

There is evidence to support the overlap of functions within the executive control network and the central executive (CE) component of WM (for example, D’Esposito, Postle, Ballard, & Lease, 1999). Working memory is defined as “the mental workspace where important information is kept in a highly active state, available for a variety of other cognitive processes” (Fougnie, 2008 p.3). The relationship between cognitive attention and WM is complex and not well understood. The overall
evidence suggests that certain components of cognitive attention are differentially related to or overlap with specific components of WM (see Fougnie, 2008 for a review). For this thesis, I have conceptualized WM as a marker of cognitive attention, while recognizing that these are distinct systems (Posner & Peterson, 1990). This is based on many theories that emphasize the overlapping functions and close relationship between these two constructs (Cowan, 1995; Rensink, 2000).

Attention refers to overt observable behaviour as well as the covert cognitive processes embedded in the major neural networks outlined above. The construct of overt behavioural inattention is comprised of descriptions of behaviour that include forgetfulness, disorganization, distractibility and poor concentration (American Psychiatric Association, 2013). Behavioural inattention refers in part to overt, off-task behaviour that includes difficulty with visual fixation on an appropriate stimulus, person or event (for example, a workbook, the teacher or the trajectory of a ball), as well as difficulty with following directions and with organization and time management. The concept of disorganization is also encompassed by behavioural inattention, and includes difficulty keeping track of materials and locating items. This thesis focuses on these observable behavioural symptoms of inattention.

The cognitive functions and behavioural descriptions of attention are not easy to map onto each other (for a review, see Tannock 2003). A group of studies demonstrate that ratings of overt behavioural inattention are related to lower functioning on tasks that that index the executive control network. Specifically, tasks that index WM with the executive control network (Lui & Tannock, 2007; Martinussen & Tannock, 2006). One study found that elementary school-aged boys rated as inattentive by their teachers performed poorly, compared to good attenders, on cognitive tasks that tap into the alerting and orienting networks (Cornish, Wilding, & Hollis, 2008). Providing support for a consistent association between errors on attentional control tasks and overall poor attention, a more recent study found this similar pattern (Rezazadeh, Wilding, & Cornish, 2011). Another study with a similar-aged
sample of boys found that behaviourally, the only difference between the poor and good attenders was a measure of executive control (conflict network). However, the boys who had severe difficulties with inattention used different brain regions than their typically developing peers for processing tasks that tap into all three networks (Konrad, Neufang, Hanisch, Fink, & Herpertz-Dahlmann, 2006). It is important to note that these studies do not provide support for causality between overt and covert attention. Moreover, although some of the results are consistent, the magnitude of the relationship was small to medium in two studies with reported effect sizes (eta squared was 0.08, correlation was 0.39 respectively; Cornish et al., 2008; Rezazadeh et al., 2011).

**1.3.1 Behavioural inattention.** Much of the research looking at cognitive differences in poor versus strong attenders is carried out with clinical samples of children diagnosed with attention-deficit/hyperactivity disorder (ADHD). The current thesis reports on a community sample of children and is focused on inattention as a dimension, not as a categorical disorder. The current literature emphasizes that behavioural inattention is a dimensional or continuous trait in the general population. That is, inattentive behaviours are normally distributed throughout the population, such that there are people who score on the low, middle, and high ends of questionnaires that measure behavioural inattention (Greven, Asherson, Rijsdijk, & Plomin, 2011; Groen-Blokhuys et al., 2014; Marcus & Barry, 2011). This research has emphasized the importance of the spectrum of inattention, whether or not an individual is diagnosed with a clinical disorder of attention. Those who fall into the high end of difficulty with inattention may be diagnosed with ADHD. In order to fall within this clinical category, using the 5th edition of *The Diagnostic and Statistical Manual of Mental Disorders* (DSM 5), children, adolescents or adults have to experience difficulties with inattention and/or with hyperactive/impulsive behaviours (six symptoms from either or both groups of symptoms, or five if over 17 years of age). Among other criteria, these symptoms must functionally impair their social, school or work functioning
Children and adolescents who fall into this category of clinically severe symptoms consistently have lower school grades and perform poorly on standardized achievement tests as compared to their typically developing peers (Frazier et al., 2007; Molina et al., 2009; Polderman et al., 2010; Spira & Fischel, 2005). They also have higher levels of school dropout and grade repetition, and more need for special education services (Frazier et al., 2007). The academic difficulties that university students with ADHD experience, however, take the form of lower GPA scores and functional struggles with performing in the post-secondary environment, rather than difficulties with standardized tests, on which they perform in the average range (Gray, Fettes, Woltering, Mawjee, & Tannock, 2015).

1.4 Relationship between Inattention and Academic Outcomes

The association between ADHD status and poor achievement is accounted for primarily by the dimension of inattention, rather than the dimension of hyperactivity/impulsivity (Garner et al., 2014; Pingault et al., 2014; Rabiner & Coie, 2000). In light of these findings, the studies in this thesis measure inattention only and do not further test the relationship between other ADHD symptom domains and academic achievement. The consistent relationship between behavioural inattention and academic achievement is addressed using a systematic review reported in Chapter 2.

1.4.1 Measurement of academic achievement. This section will briefly outline the importance of academic achievement in the elementary school years and the age group of the sample in this thesis, and discuss categories of achievement relevant to outcomes of interest in the thesis objectives.

Academic achievement in the elementary school years is an important predictor of outcomes across the lifespan. Chronic underachievement, such as seen in those with ADHD, can result in far-reaching negative implications for financial and occupational success and stability (Barkley, Murphy, & Fischer, 2010; Biederman et al., 2006). Research has found that both standardized achievement and
school performance (prior grades) are strong predictors of high school grades (Casillas et al., 2012) and high school grades are predictors of entry into college or university and success in these institutions (Geiser & Santelices, 2007).

Academic achievement is a broad term that captures both performance in a classroom and performance on standardized academic tests. Both domains are important to consider when examining academic outcomes, as they encompass different factors that account for performance, and are predicted by different measures (Langberg et al., 2011; Loe & Feldman, 2007). Standardized achievement is measured through testing children on a specific battery that has been normed from an appropriate comparative sample. Standardized academic test batteries are separated into different academic domains in an attempt to specifically test a child’s competency in, for example, math fluency, math problem solving, word reading or reading comprehension. The environment in which standardized achievement is typically assessed is very different from that in which classroom performance is measured. Standardized testing usually takes place in a small group or one to one setting (although often in a full classroom for benchmark testing), with concrete time restrictions and an element of performance or test stress. These tasks are completed under optimal conditions: a controlled organized testing environment with trained testers who may offer structure and breaks, and sometimes praise and encouragement. Classroom performance on the other hand can be measured through grades, GPA, graduation/failure to graduate or pass a class, or teacher ratings of the child’s academic ability. Teacher ratings of the child’s academic ability involve a longer time period of assessment, as compared to standardized tests that look at performance at one specific point in time. Individual cognitive and other factors, such as engagement and motivation, share a significant amount of variance in predicting indicators of academic test performance (Plamondon & Martinussen, 2015). However, classroom performance measures may encompass a wider array of cognitive, as well as
behavioural, motivational and social-emotional factors that impact grades and teacher perceptions of academic performance (Farrington et al., 2012). One study found that homework materials management and parent education best predicted classroom performance, while IQ, inattention, receipt of special education services and family income predicted standardized achievement. Teacher-rated classroom performance predicted both (Langberg et al., 2011).

Teacher ratings of academic performance correlate at a high level \( r = .70 \) with elementary school students’ standardized test performance (Demaray & Elliot, 1998). This same study found that teachers’ ratings were slightly more accurate, or congruent with standardized test performance, for students who were high achieving. Another study looking at kindergarten children found that teachers could predict with a high level of sensitivity, specificity, and accuracy standardized math and reading scores in Grade 1. In contrast to the study with elementary age children, teachers more accurately predicted poor achievement over strong achievement (Teisl, Mazzocco, & Myers, 2001). Given the differences between the discussed domains of achievement, this thesis will test whether WM mediates the relationship between inattention and standardized achievement, as well as classroom performance as measured by teacher ratings of achievement.

1.5 Working Memory

A third construct that is central to this dissertation is working memory. This section will discuss theories of working memory and its relationship to inattention and to academic functioning in the classroom setting.

Working memory is a multi-component function that holds and manipulates information that is held ‘online’ in the mind temporarily in the face of distraction, and produces an output based on these representations of information (Baddeley & Hitch, 1974; Miyake & Shah, 1999). This memory function is essential for numerous every day functions, from grocery shopping to re-arranging furniture
to reading an article (Miyake & Shah, 1999). For children, WM is essential for functioning in the school setting that comprises most of their day. Following teacher’s directions, carrying out a multistep task, reading and doing math problems all require that bits of information are held in mind while connecting them with each step of the task, and producing a relevant output. A classroom has multiple opportunities that require children to process visual, spatial and verbal information in the face of distraction.

From their early conceptions of WM, Baddeley & Hitch (1974) proposed and found support for two functionally separate domains of WM. The domain that stores and manipulates visual or spatially based information is called the visual-spatial sketchpad. The phonological loop is the domain that is responsible for processing of verbal or auditory-based information. Both domains are involved in short-term storage, rehearsal and manipulation processes pertaining to these different types of stimuli. An overarching function called the central executive is positioned as a coordinator, that monitors all components of WM and controls processes of attention (Baddeley, 1986). Included in an update to Baddeley’s proposed model is the limited-capacity episodic buffer. This buffer combines pieces of information from the phonological loop and visual-spatial sketchpad and allows for interaction with the central executive and long-term memory (Baddeley, 2000, 2003).

Throughout the current dissertation, visual-spatial and auditory-verbal memory are conceptualized according to Baddeley’s model of WM (Baddeley, 2003, 2010). Therefore, both short-term storage and short-term manipulation of information are conceptualized as an integrated system under the umbrella term of working memory. Instead of naming the simple visual-spatial task described in both manuscripts as short-term memory (STM), it was decided that retaining STM within the construct of working memory, therefore naming it as such, was more theoretically consistent with Baddeley’s model. Baddeley’s work maintains STM within the integrated construct of WM. There is
some discrepancy in the literature, however, as to whether STM and WM are separate constructs. While early research (Miller, Galanter, & Pribram, 1960) did not distinguish between short-term and WM, and Engle (Engle, 2002) uses the term WM for only the aspects of short-term memory that are related to attention, Cowan (2008) conceptualized short-term storage as different than the processing and attention components of WM. Research has shown that there are differences in storage-only tasks and tasks that require processing, in that tasks that require processing are more strongly related to cognitive aptitudes (for a summary see Cowan, 2008).

1.5.1 Working memory and inattention. Despite the different models that separate or link STM and WM, much of the literature stemming from Baddeley’s model is in agreement that it is the concept of the central executive that links WM to control of cognitive attention (Awh, Vogel, & Oh, 2006). WM is essential for filtering irrelevant from relevant information; it is important for tasks that tap into selective attention (Conway, Cowan, & Bunting, 2001; Kane & Engle, 2003). This supervisory attention system (CE) can over-ride the automatic system of selective attention, in which the most demanding source wins the attention, by taking into account one’s previous knowledge, preferences, or the teacher’s instructions for example (Norman & Shallice, 1986). Therefore if working memory is impaired, it will impact an individual’s ability to control attention. However, the relationship is not necessarily uni-directional; for example some researchers theorize that one’s capability for controlled attention drives individual differences in WM (Engle, Kane, & Tuholski, 1999). This is supported by a study that found poor attenders did worse on tasks that required central executive processing. When IQ differences were not accounted for, poor attenders not only had lower scores on central executive tasks but also on phonological loop and visual-spatial sketchpad results (Cornish, Wilding, & Grant, 2006). The overlap in functions between attention and WM indicate that neurocognitive problems with
cognitive attention and WM would both impact one’s ability to perform in the classroom setting, although the direction of causation remains unclear (Dehn, 2008).

The connection between inattention and WM so far in this chapter has been discussed in the cognitive context, that is, that the central executive is hypothesized to be necessary for selective attention on a cognitive level. This relationship is also significant when looking at behavioural inattention, measured through rating scales. With children and adults who are rated as severely inattentive, falling into the clinical range of ADHD, two studies confirm that this group has large deficits in WM compared to their typically developing peers (Kasper, Alderson, & Hudec, 2012; Martinussen & Tannock, 2006). This relationship is also found in community samples of children; poorer performance on WM tasks is related to ratings of overt behavioral inattention (Lui & Tannock, 2007).

1.5.2 Working memory and academic outcomes. Of specific relevance to the current project are the findings that WM is related to academic outcomes across the lifespan (Alloway & Alloway, 2010). In the Alloway and Alloway (2010) study, correlations between verbal WM and literacy and numeracy are in the medium effect range (Cohen, 1992); they range from 0.35 to 0.45. Working memory accounted for 16% and 21% of the variance in literacy and numeracy outcomes respectively, in a model that included IQ, phonological awareness, and phonological and visuospatial short-term memory. Working memory is strongly correlated ($r = 0.59, 0.56$ which corresponds to a large effect within Cohen’s guidelines) with performance in reading and mathematics (Gathercole, Alloway, Willis, & Adams, 2006). There are some domain-specific findings for this relationship: visual-spatial span (short-term storage) ability at age three predicts math ability four years later (Bull, Espy, & Wiebe, 2008). Similarly, gains in visual-spatial WM across first to fifth grade have been shown to be important for achievement in mathematics (Li & Geary, 2013). One study found that visual-spatial WM was
important for English, math and science achievement with children ages 11-12, while verbal WM was associated with achievement in English only (St. Clair-Thompson & Gathercole, 2006). A study with younger children found that strong auditory-verbal WM at age three gave children an advantage in both reading and math, and these benefits were maintained over three years (Bull et al., 2008). Bull and colleagues (2008) found that overall executive function skills predicted general achievement, rather than domain-specific achievement at each point in time, as was the case with WM.

When interpreting studies of WM and academic outcome, it is important to note which proximal variables are also measured, as this will have an impact on the strength and significance of association between WM and reading and math outcomes (Raghubar, Barnes, & Hecht, 2010; Savage, Lavers, & Pillay, 2007). Processing speed is another cognitive function that is tightly related to WM in childhood and is important for academic achievement, particularly in tasks with a speed component (Chhabildas, Pennington, & Willcutt, 2001; Rucklidge & Tannock, 2002). These two cognitive factors are separable, however, and as children move from pre-school age to senior kindergarten and first grade, executive functions independently predict math achievement, controlling for processing speed (Clark et al., 2014).

1.6 Theoretical Model

The different lines of research outlined in this introduction identify three factors that comprise a risk triad: inattention, poor WM and academic underachievement. A theoretical model of how inattention influences academic achievement is presented below. Although the literature has expanded significantly since the introduction of the model, it provides a testable model of how the variables of interest in this thesis, described above, may be related.

A theoretical model proposing possible explanations as to why achievement is lower in those with ADHD was developed by Rapport and colleagues (Rapport et al., 1999). Rapport and colleagues hypothesized that behavioural and cognitive pathways would work in parallel to account for the
relationship between ADHD and poor achievement. They also hypothesized that classroom performance would mediate this relationship for the behavioural pathway, and that vigilance and short-term memory would mediate this relationship in the cognitive pathway (Rapport et al., 1999)

This model was tested in a study of males and females between the ages of 7 and 16, who were given tests of IQ, vigilance (using a continuous performance task), and a learning task (paired associate learning task). Teachers rated students’ academic performance and classroom behaviour and also filled out questionnaires on symptoms of ADHD and conduct disorder. Three to four years later, the same students completed SAT achievement tests, producing standardized achievement scores for overall reading, math and language. Results were consistent with hypotheses: ADHD symptoms affected both behavioural and cognitive mediating variables that, in turn, accounted for the association between features of ADHD and academic achievement. Interestingly, the direct effect of IQ on academic achievement was weak, after accounting for the mediating effects of behavioural and cognitive variables (Rapport et al., 1999).

The current thesis addresses remaining questions that further test and specify components of Rapport’s model. Specifically, it is unknown how the two different domains of WM, using simple, short-term and WM tasks (visual-spatial, auditory-verbal) relate to childhood achievement and for which domains of achievement they are most important (fluency, calculation, word reading, etc.). The current research also addresses whether the dual pathway model holds true for symptoms of inattention only, through a dimensional approach, in elementary school-aged children, as well as whether the pathways are different for boys and girls. Of importance, the longitudinal design of this thesis work helps to address the nature of the link, and direction of influence among teacher ratings of inattention, WM and academic outcomes across the elementary school years.
1.7 Overview of Research Objectives and Hypotheses

This section will provide a broad overview of the thesis research objectives and will outline specific hypotheses to be tested by the different sets of analyses. Methodology, including participants, procedures, measures (descriptions and psychometric properties) and analytical approach are described in detail in each manuscript. Therefore to reduce repetition, a brief overview of the statistical approach is presented in this section. Details about database preparation that were not included in the manuscripts are included in Appendix A.

The overall objective of this research was to further understand and delineate the nature of the inter-relationships among behavioural inattention, WM and academic outcomes for boys and girls of elementary school age. Much of the previous research has investigated just two of these variables at a time, most frequently, inattention and academic achievement. This literature provides evidence that inattention, WM and academic outcomes are related, including information about variance accounted for by inattention and WM when predicting academic outcomes. However, answers to two main questions of interest have not yet been confirmed. First, what is the strength and consistency of the overall body of research linking inattention to poor academic outcomes? Second, what is the role that WM plays in the relationship between inattention and academic outcomes? To my knowledge, only one previous study (with adolescents) used a mediation design to examine the nature of the relationship between these three factors (Rogers et al., 2011). Through the use of a systematic literature review, and mediation analyses with cross-sectional and longitudinal data, as well as controlling for important covariates in the model, this thesis research can address some of the gaps in the current literature.

Research objective 1: The first objective of this thesis is to conduct a systematic review to ascertain the strength and consistency of the relationship between behavioural inattention and academic outcomes across different ages and outcome measures.
Research objective 2: The second objective of this thesis is to further delineate the nature of the relationship between classroom inattention, WM domains and academic achievement through using both cross-sectional data and a longitudinal mediation design. Specifically, the objective is to determine whether WM is a mediator of the relationship between inattention and academic outcomes in a community sample of elementary school children, and to determine whether gender moderated the associations among the measures. Included in this objective is to examine teacher ratings of academic performance as the outcome to assess generalizability to other indicators of achievement.

Hypotheses for research objective 2: Firstly, it was hypothesized that teacher-rated inattention at year 1 would directly influence standardized reading and math outcomes during the same school year and one year later, controlling for initial levels of achievement. A second main hypothesis is that there would be an indirect relationship between classroom inattention and subsequent math outcomes through auditory-verbal and visual-spatial WM. In addition, it was hypothesized that inattention would indirectly influence reading outcomes through auditory-verbal WM. A third hypothesis is that the same patterns will be found when using a teacher-rated academic achievement measure, but with the model accounting for a larger amount of variance using these teacher ratings as the outcome one year later, as compared to using standardized achievement as the outcome measure.

1.8 Main Analysis Approach

The main statistical approach in this thesis includes mediation analysis and moderated mediation analysis. The same sample and a similar but not identical statistical approach are used for the cross-sectional and longitudinal analyses. As described by Field (2013), “mediation refers to a situation when the relationship between a predictor variable and an outcome variable can be explained by their relationship to a third variable (the mediator)” (Field, 2013, p. 408). Mediation analysis attempts to disentangle the direct effects from the indirect effects between two variables. The direct effect is the
part of the relationship between two variables that is not mediated by a given mediator variable. The indirect effect is the mediated effect; the part of the relationship that is mediated by a given mediator (Hayes, 2013). Moderated mediation is when the mediation effect is stronger for one group. That is, the effect of the predictor variable on the mediator or outcome variable differs based on the moderator variable (Hayes, 2013).

The SPSS Macro, PROCESS, was used as the computational tool to complete the mediation analyses in chapters 3 and 4. The PROCESS macro is a user-friendly program that operates within the SPSS platform. This tool computes indirect and direct effects, using bootstrapping to test hypotheses about indirect effects (Preacher & Hayes, 2008). This is a method that has been developing over recent years, and is preferred over the Sobel test (Sobel, 1982) because it is more powerful and produces more realistic assumptions about the shape of the sampling distribution for indirect effects (Hayes, 2013). All variables in this thesis were observed, no mediators were dichotomous, and the model tested was not a moderated serial mediation analysis. Therefore, it was not necessary to use a structural equation modeling program such as Mplus.
CHAPTER 2

Systematic Review: The Relationship between Inattention and Academic Achievement
2.1 Abstract

A body of literature has emerged that links inattentive symptoms of ADHD to poor academic achievement. The aim of this review is to provide a qualitative synthesis of these studies that 1) use community samples and 2) examine inattention as a separate dimension from hyperactivity/impulsivity. A systematic search was carried out using two databases. Out of 1748 citations found, 27 articles met the specific inclusion criteria. The QUIPS tool was used to rate the quality of studies, followed by a best evidence synthesis to summarize these results. Results point to a strong effect according to the best evidence synthesis: 7 studies that have low risk of bias found that teacher-rated inattention is significantly predictive of poor academic achievement in community samples of children. The relationship between inattentional traits and academic outcomes is robust in elementary school children, in terms of both classroom performance and standardized achievement. The average relationship was stronger when classroom performance was measured, as compared to standardized achievement. However, the quantitative strength of relationship has not been confirmed with a meta-analysis. Variance across the studies in terms of the strength of association suggests that other unexamined factors (e.g., cognitive function, motivation) may be contributing to this relationship. Implications for educators and clinicians who work within the school setting are discussed.
2.2 Rationale

Behavioural inattention is defined by observable behaviours that signal distractibility, difficulty with organization, forgetfulness, and difficulty with following directions and attending to a relevant stimulus (American Psychiatric Association, 2013). Symptoms of inattention are dimensional, in that they represent a spectrum that follows a normal population curve and are present in the general population to varying degrees (Groen-Blokhuis et al., 2014; Marcus & Barry, 2011). When symptoms are severe, impinging, and persistent, they form part of the diagnostic criteria for Attention Deficit Hyperactivity Disorder (ADHD). The diagnosis of ADHD includes behavioural descriptors of inattention, hyperactivity and impulsivity (American Psychiatric Association, 2013). These behavioural descriptors can be observed and quantified via the use of rating scales completed by teachers, parents, clinicians, as well as self-report (by children and youth).

Over the past several years, the literature has shifted toward examining symptoms of all mental health diagnoses along dimensions, instead of categorically (for a summary see Adam, 2013; Krueger & Bezdjian, 2009). In both community-based and clinical studies it is the dimension of inattention that predicts poor academic achievement: hyperactivity does not contribute additively or interactively to this prediction (Breslau et al., 2009; Currie & Stabile, 2006; Fergusson, Lyskey, & Horwood, 1997; Massetti et al., 2008; Pingault et al., 2011). Due to the lack of evidence of a relationship between hyperactivity and poor academic outcomes, this review focuses on inattention.

Several studies have concluded that inattention is a risk factor for poor academic outcomes (Dobbs, Doctoroff, Fisher, & Arnold, 2006; Fuchs et al., 2005; Giannopulu et al., 2008; Rabiner & Coie, 2000). For example, Warner-Rogers, Taylor, Taylor, & Sandberg (2000) state: “the presence of even a few inattentive behaviours in early childhood should be viewed as a developmental risk factor” (Warner-Rogers et al., 2000 p.15). However, there is major variation across studies that render
conclusions about this relationship complex. Different academic outcome measures, separation/joining of inattention and hyperactivity/impulsivity dimensions, variation in control factors, different age groups and co-morbidities are important factors to consider within a comprehensive synthesis of this link. Moreover, measures of behavioural inattention and academic achievement are simple measures that attempt to summarize complex phenomena. The relationship between these two factors may not be direct.

2.2.1 Measures of academic achievement. A salient issue with the interpretation of this literature is the variation in measurement of academic outcome. Academic outcome can be measured using standardized achievement tests or measures of classroom performance.

Standardized achievement. Standardized achievement measures include normed tests, which focus on a particular academic skill, and are generally administered in a quiet one-to-one setting. One strength of using standardized achievement as an outcome measure in educational studies is that it compares outcomes to the norms of the general population. Standardized tests are more objective measures of pure academic skill as compared to teacher ratings of academic skill or grades. This strength can also be a disadvantage; standardized achievement is more limited in terms of ecological validity and may not reflect actual outcome in school (Loe & Feldman, 2007). For example, a child could receive A’s in school and yet be scoring in the mid-range percentile rank on standardized achievement tests.

Classroom performance. Classroom performance includes functional indices such as grades, GPA, and school dropout, as well as teacher ratings of academic performance in the classroom setting. Classroom performance may be a useful measure of academic outcome, in that it has stronger ecological validity as compared to standardized achievement (Langberg et al., 2011). Classroom performance measures, however, are prone to teacher bias. This bias comes into play when behaviour is
conflated with academic performance, as is the case when the same teacher rates the student’s inattentive behavior and grades or classroom performance.

**Achievement measures and inattention.** Scores on standardized academic tests have been found to be related to inattention as rated by teachers (Becker & Langberg, 2012). However to our knowledge, there is no conclusive evidence that inattention is more strongly associated with academic achievement than with classroom performance measures (for example, see Langberg et al., 2011 vs Frazier et al., 2007). One study found that grades are more predictive of first year university/college performance than are standardized testing scores (Geiser & Santelices, 2007), although it is unknown how consistent this finding is at different levels of schooling. Therefore, these two indices should not be used interchangeably (Loe & Feldman, 2007).

2.2.2 Previous reviews. The relationship between ADHD symptoms and academic outcomes has been examined in three reviews. One strength of a quantitative meta-analysis including 72 studies (Frazier et al., 2007) was that it compared the strength of relationship based on specific academic area and measurement of academic outcome (standardized tests and classroom performance). This meta-analytic study concluded that there was a stronger relationship between ADHD symptoms and standardized achievement as compared to classroom performance. Similarly, a recent review including 176 studies found a negative impact of ADHD on both types of academic outcome, with more impairment on standardized achievement (Arnold, Hodgkins, Kahle, Madhoo, & Kewley, 2015). A major limitation of both the Frazier et al. (2007) meta-analysis and the review by Arnold et al. (2015) was that neither study separated the two dimensions of ADHD, thereby precluding conclusions about a possible differential impact of inattention and hyperactivity symptoms on academic outcome.

A systematic review by Polderman and colleagues (2010) included 16 studies and stressed the importance of looking at the two dimensions of attention and hyperactivity separately when predicting
academic outcome (Polderman et al., 2010). They found strong evidence of a relationship between inattention and poor academic outcome based on prospective studies, which did not hold for symptoms of hyperactivity. A major limitation of this study was the small number of studies included, which precluded robust conclusions based on differences between outcome measures, or age groups. Neither review examined the link between inattention and high school dropout, a major factor that is linked with poor social-economic, occupational and health outcomes (Freudenberg & Ruglis, 2007), and is examined in the current review.

2.3 Objectives

This comprehensive systematic review sought to 1) answer the question of whether the relationship documented between inattention and academic outcomes in ADHD also holds for the dimensional trait of inattention as manifest in non-clinical community samples of children and adolescents, 2) assess the level of evidence for this relationship using a best evidence synthesis based on a quality review of each study, 3) qualitatively assess the strength of relationship based on outcome measure and age group. This provided a base from which to move forward in theoretical testing for different mediators and moderators underlying this relationship, which has implications for educators. Before educational interventions can be put in place, we need to understand the factors that contribute to this relationship.

Prior to investigating factors that might mediate the relationship between inattention and academic outcomes, we sought to establish more specifically the range of variance in the relationship across studies, to evaluate the overall quality of this body of literature, and identify gaps or weaknesses in study design and identify areas for future research.

There was very little overlap in article inclusion between this review and the three previous reviews. The Merrell & Tymms (2001) article was included in all reviews with the exception of the
Arnold et al. review. The article by Molina, Smith, & Pelham (2001) was included in this review and the Frazier et al. review, and one study (Massetti et al., 2008) in this review overlapped with the Polderman et al. review. Most articles from the Frazier et al. study were not included in this review because dates of inclusion were different; our review focused on studies from 2000 onward, whereas the most recent article in the Frazier et al. paper was 2004. Articles included in the Polderman et al. review spanned from 1985 to 2009, still leaving six years of literature covered by the present review. Overlap with the most recent review (Arnold et al., 2015) included Rogers et al., 2011, Pingault et al., 2011, Diamantopoulou, Rydell, Thorell, & Bohlin, 2011, and Massetti et al., 2008. In addition to date differences, this review did not overlap much with other reviews because it did not include studies that focused on clinical populations, co-occurring disorders, studies that only examined hyperactivity, or those that did not separate measures/analyses between inattention and hyperactivity/impulsivity.

2.4 Methods

2.4.1 Protocol. A protocol for conducting systematic reviews, developed by the Cochrane Review group, was used as a guide for the methods in this review (Hayden, Cote, & Bombardier, 2013). Methods were also based on an exemplar article from another field, produced from the Cochrane Back Review Group (Hayden, Tougas, Riley, Iles, & Pincus, 2014). We used the QUIPS tools (see Table 1) developed by the Cochrane group to rate the quality of included studies and reported the review according to PRISMA guidelines (see Figure 1).
2.4.2 Eligibility criteria. The inclusion criteria were sufficiently broad to include all possible forms of academic outcome variables, dimensions of inattention symptoms and age. Inclusion criteria were as follows: (1) English language studies assessing the relationship between teacher or parent-rated inattention and academic outcome (standardized achievement scores, school grades, GPA, grade retention/dropout, or teacher rated classroom performance), (2) peer-reviewed articles (3) studies with valid measures of teacher- or parent-rated attention as predictor variables.

The exclusion criteria for this study were as follows: (1) studies that did not separate the dimensions of inattention and hyperactivity/impulsivity for analysis, (2) studies that examined clinical populations with ADHD only (3) studies with a medical or intervention-based manipulation, (4) studies with a specific focus on comorbid disorders, (5) case studies or those with very small samples (n < 10).

2.4.3 Information sources. Searches were performed using PsychInfo and PubMed databases. References found in identified articles were searched for additional relevant studies.

2.4.4 Search. The search was conducted using the following search strategy, modified as per key words appropriate to each database, with dates restricted to between January 1, 2000 and February 22, 2015 (in order to include only those diagnosed using DSM-IV criteria): "Attention Deficit Disorder with Hyperactivity"[Mesh] OR "Attention"[Majr] OR ("Attention Deficit Disorder with Hyperactivity"[Mesh] OR "Attention"[Majr] OR "Behaviour"[Mesh:noexp] OR Inattenti* OR "Distractibility") AND ("Achievement"[Mesh] OR "Underachievement"[Majr] OR Schola* OR School* OR Academic OR classroom performance OR "Educational Status"[Mesh] OR "Mathematics"[Mesh:noexp] OR "Reading"[Mesh] OR "Writing"[Mesh:noexp]) AND Teacher*

2.4.5 Study selection. See Figure 1 for details about the study selection process. Abstracts were reviewed and accepted or rejected according to the inclusion/exclusion criteria. Full text was accessed for the remaining studies, and evaluated in more detail against the inclusion/exclusion criteria.
2.4.6 Assessment of study bias. Study bias was assessed through examining the specific areas of quality detailed in Table 1. Major areas assessed included study participation, study attrition, prognostic factor measurement, outcome measurement, study confounding and statistical analyses and reporting. Use of this detailed QUIPS quality-rating tool allowed us to determine patterns of strengths and weakness in study design and reporting for this body of literature (Hayden et al., 2013).

2.4.7 Best evidence synthesis. Following the assessment of study bias, we used the best evidence synthesis described by Sackett, Straus, Richardson, Rosenberg, and Haynes (2000). In this synthesis a strong level of evidence is defined as consistent findings in at least two high quality studies (Sackett et al., 2000). ‘Consistent’ is defined as at least 75% of the studies agreeing on the existence and direction of the relationship between inattention and academic outcomes. A moderate level of evidence refers to consistent findings in one high quality study and at minimum one study that is of lower quality. The level of evidence is considered weak if there are no consistent findings in high quality studies but there are consistent findings in at least three lower quality studies. Evidence was deemed inconclusive if the direction of relationship was inconsistent (with no dependence on study quality) or if there were fewer than three lower quality studies available (Sackett et al., 2000).

2.5 Results

2.5.1 Study characteristics. Through the search terms, 1748 articles were retrieved (after eliminating duplicates). Out of 58 articles selected after abstract review, 27 were retained for inclusion in the review (see Figure 1 for details of study selection).

Reasons for excluding the 31 studies included lack of separation of inattention and hyperactivity constructs (or they had separate composites, but only used the combined one in the analyses), use of a clinical ADHD sample only, a focus on co-occurring learning disabilities, and
measures of achievement that didn’t fit into our criteria, for example, placement in a special education classroom as an indicator of achievement.

Overall, there were 13 cross-sectional and 10 longitudinal studies, as well as 4 studies that included analyses based on both cross-sectional and longitudinal data. In terms of participant ages, 4 focused on pre-school/kindergarten children, 1 focused on adolescents, while the majority (11) studied elementary school-aged participants. The remaining studies examined outcomes across age groups, with 6 studies using longitudinal data from pre-school/kindergarten to elementary school, 3 from elementary to high school, and 2 spanned from pre-school/kindergarten to high school. Although no studies were included that only used participants diagnosed with ADHD, 3 studies used a sample with participants who had ADHD symptoms that didn’t meet clinical criteria for a diagnosis.

Only about 1/3 of the studies included used both parent and teacher ratings; most (about 2/3) relied on teacher data only, and just one study included students’ self-ratings, in addition to parent and teacher ratings. The results to follow focus only on teacher ratings, as all studies gathered teacher ratings and they are of particular relevance when examining classroom outcomes.

Outcome measures included measures of math, reading, writing and general composites of achievement, such as GPA, teacher ratings of achievement, and overall school grades. Fifteen studies used standardized achievement measures, 9 used measures of classroom performance and 3 included both of these types of measurement.

2.5.2 Risk of bias within studies. Overall, the body of literature included in this review was rated at low to moderate risk of bias. Table 1.2 presents the details of the quality assessment for each study. Results indicated that the domains of study participation and study confounding were at higher risk of bias, while outcome measurement and statistical analyses were at lower risk of bias for the group of studies as a whole.
Including, describing, and measuring important confounders is an area that received many partial or unknown ratings in the studies included in this review. Very few studies included all confounding factors that are important to consider when studying inattention and academic outcomes, such as age, social economic status (SES), diagnosis and comorbidity status (if applicable to the sample), and initial achievement scores in a longitudinal design. Through examining covariates used in each study, we found that many studies controlled for IQ but with little to no discussion as to why IQ was entered as a covariate. This habitual practice of entering IQ as a covariate is problematic, given the arguments put forth by Dennis and colleagues (2009). Using IQ as a covariate in studies of neurodevelopmental disorders can skew results when a factor of interest (for example, memory) is highly correlated with IQ (Dennis et al., 2009). In a similar fashion, sex was very often entered as a covariate in these studies, without discussion of why the authors want to partial out the effects of sex and the impact this would have on the results. Studies that did not include initial achievement scores, when conducting longitudinal analyses with achievement as the outcome variable, often did not discuss the limitations of not being able to partial out the effect of initial achievement on later achievement. See Table 1.2 for a summary of these discussed strengths and weakness in chart form.
2.5.3 Best evidence synthesis results. Overall, results from the systematic review including the quality analysis point to a very consistent pattern of relationship between inattention and academic achievement. All 27 studies, cross-sectional and longitudinal designs, found that teacher-rated inattention is significantly predictive of poor academic achievement. Out of these, five studies had a low risk of bias in all but one of the six categories, meaning these studies had a very strong design and reporting of study details, thus were categorized as ‘high quality’ studies. See Table 1.3 for a summary of bias risk for each domain.

**Strength of overall relationship.** Using a best evidence synthesis described in the methods section, the five high quality studies indicate a strong level of evidence that there is a negative relationship between attention difficulties and academic outcomes. When teachers report high levels of inattentive behaviour, these students have lower academic achievement scores and results. However, it is important to note that the actual size of this relationship varies widely. Variance accounted for by inattention in predicting academic outcomes ranged from 5% – 16% (cross-sectional) and 2.4% to 15% (longitudinal). For studies that included correlations, Pearson’s r (absolute values, all in the expected direction) ranged from 0.15 to 0.64 (cross-sectional) and 0.10 to 0.48 (longitudinal), which corresponds to negligible to strong correlations. When designs included groups with different levels of attention, Cohen’s D ranged from small to large: 0.26 to 0.79. Very few studies used odds ratios to estimate the odds of poor academic outcomes, but in those that did, odds ratios ranged from 1.5 to 12.5 for cross-sectional studies and from 3.87 to 7.66 for longitudinal ones.

**Inattention and standardized achievement.** Out of the 15 studies that examined only standardized achievement, 80% were considered at low risk of bias (see Table 1.3). All of the 12 studies that were of high quality found inattention to be significantly linked with lower scores on
standardized academic achievement. This corresponds to a strong level of evidence that higher levels of teacher rated inattention correspond to lower scores on standardized achievement tests.

**Inattention and classroom performance.** Out of the nine studies that examined classroom performance only as an outcome measure, three (33%) were found to be of high quality with low risk of bias. All three showed a negative relationship between inattention and the classroom performance outcome measures. One study that included measures of both standardized achievement and classroom performance was identified as a high quality study and results were consistent with the other high quality papers. Therefore, using a best evidence synthesis, there is also strong evidence that higher levels of inattention predict lower scores on classroom performance measures. Teacher-rated inattention consistently predicts lower school grades, lower teacher ratings of academic competence, and a reduced likelihood to graduate from high school. The most commonly used outcome measure for the studies focusing on classroom performance was teacher or parent ratings of academic performance. Other classroom performance measures used in the reviewed studies was high school graduation or failure, overall GPA and school placement.

**Comparison of standardized achievement and classroom performance.** It is clear that there is a larger body of high quality evidence when standardized achievement is the outcome measure (n = 12 studies) compared to those measuring performance (n = 4), therefore caution should be used when comparing the results the two groups of studies. However, when analysis is restricted to high quality studies only, it appears that there is a stronger correlation between inattention and classroom performance than between inattention and standardized achievement scores. The median and mean of correlations between inattention and classroom performance measures are .60 and .56 respectively, while the median and mean for standardized achievement outcomes are .32 and .35 respectively. Only
1 study reported variance accounted for with respect to classroom performance, therefore reported variances are not compared between the two groups of studies.

**Age-related changes in the relationship between inattention and academic outcomes.** There is strong evidence of a relationship between inattention and academic outcomes in elementary school children, as confirmed by three consistent high quality studies. There was moderate evidence of a relationship between inattention and academic outcome in pre-school aged children, based on one high quality study and three of lower quality. The evidence was inconclusive for the high school age group, as there was only one study, and this study did not reach the highest quality rating. Two high quality studies, however, confirmed that there is a strong level of evidence that inattention in elementary school continued to predict poor academic outcomes in high school. Notably, none of the six studies that followed children from pre-school to elementary school was at the highest quality level, which corresponds to a weak level of evidence. Neither of the two studies that followed children longitudinally from pre-school to high school were rated at the highest level of quality, therefore the evidence was inconclusive for longer-term relationships (Pingault et al., 2011 had high risk of bias in the area of study attrition, and Massetti et al., 2008 had moderate risk in two areas, see Table 1.3).

These results suggest that teacher-rated attention is predictive of low academic achievement early on, and continues to be predictive in elementary school, and from elementary school into high school. However, more high quality studies that follow children from pre-school to high school and studies focused on the high school age group are needed to provide conclusive evidence of the stability of this relationship across age groups.

### 2.6 Discussion

A main goal of this review was to systematically assess the quality and strength of the large body of literature that connects inattentive behaviour with lower academic outcomes in a typically
developing population and draw conclusions based on this assessment. Results presented above show strong evidence that higher levels of inattentive behaviour as rated by teachers are associated with lower levels of both standardized test scores and classroom performance outcomes. Although we did take into account some quantification of the strength of relationship, the large range of study designs, outcome measures and covariates in the analyses precluded an analysis of overall effect sizes, as in statistical meta-analysis.

Through the best evidence synthesis we can be confident of strong support for the consistency and direction of this relationship. However the actual strength varies when examining only high quality studies; an average of a moderate negative relationship was found when standardized tests were used as outcome measures, whereas the average negative correlation was strong when using classroom performance variables to measure outcome. These findings provide confidence that using a more ecologically valid measure of classroom performance is a promising method of studying the relationship between inattention and future academic outcomes. However, consideration should be given to the possibility that the stronger relationship between inattention and classroom performance measures are due to the bias introduced by teachers rating both inattention and academic performance, and teachers determining grades and class failure. It is difficult to confirm this bias in the high quality studies looking at classroom performance measures in this review, as one study aggregated teacher and parent ratings, one found that teachers and parents were just as good at predicting school performance (in terms of acceptance into certain programs) in Grade 4 but teachers were better at predicting this in Grade 1, and the last study only included teacher ratings.

The relationship between inattention and academic outcomes was consistently shown to be in the expected direction within elementary age groups, and moderate evidence supported findings in the pre-school age group. However there were not enough high quality studies to provide solid evidence of
differences in the relationship between inattention and achievement longitudinally from pre-school to high school and within the high school age group. Two studies that investigated this relationship longitudinally from pre- to high school did have a number of strengths that provide insight into the long term stability of the relationship between inattention and academic outcomes (Massetti et al., 2008; Pingault et al., 2011). Pingault et al. (2011) found that participants in their stable high inattention group were least likely to have a high school diploma, while those in the stable low inattention group were more likely to have graduated from high school. This study indicates that all trajectories with the exception of ‘stable low’ increased the risk of not graduating from high school, showing that inattention at age 6 or 7, no matter what the following trajectory, is highly predictive of high school dropout (Pingault et al., 2011). However, more high quality studies that use this longitudinal design are needed before the strength of the relationship across all developmental stages can be assessed and confirmed.

The results from the quality rating system employed in this review provide recommendations and implications for researchers who focus on inattention and academic outcomes. Future studies should include a description of the time period of recruitment, provide inclusion criteria as well as exclusion criteria, and report characteristics of participants lost to follow up and reasons for loss to follow up. Researchers should also consider the use of a scale that captures variance on both the positive and negative ends of the dimension of behavioural inattention/attention. Most studies in this review used typical 4-point rating scales, which don’t approximate the normal distribution of either attentive or inattentive behaviours in a population (Swanson et al., 2001). Meta-analyses in this domain of research should separate inattention from other ADHD symptoms, and account for gender imbalance in samples, age of participants, and type of academic outcome measure and covariates employed in each study.
A major factor in the large variance in results across studies was discrepancy in the use of confounders. For example, authors should always control for initial level of achievement when studying achievement outcomes across time, and should carefully consider the appropriateness of using IQ and sex as covariates, as well as consider other important covariates such as social-economic status (SES) and age. Although it is recognized that practical limitations can render it difficult to control for most important variables, one critique of this body of literature is the paucity of discussion and acknowledgement about missing or added covariates and the impact this has on conclusions.

2.6.1 Clinical and educational implications. The finding about inattention and classroom performance measures versus standardized assessment has implications for clinicians who are providing assessment and intervention for students who struggle with attention difficulties. The strong level of evidence for a relationship between inattention and scores on standardized achievement tests extends to measures of classroom performance, which are extremely important for future academic success. Moreover, although there are no causal conclusions from this review, inattention appears to have a stronger relationship with overall grades, school dropout and teacher ratings of academic performance than with standardized achievement tests. It is important that clinicians gather classroom performance data and put weight not only on the typically used standardized tests results, but also on performance measures when assessing the impact of attention problems on academic performance (for example, see the Academic Performance Rating Scale; DuPaul, Rapport, & Perriello, 1991). Currently, lower than expected scores on standardized achievement tests are often required for formal accommodations to be implemented. The results from this review indicate that classroom performance outcomes should also be given consideration when providing accommodations and supports for children who struggle with attention difficulties.
This paper aimed to review the relationship between inattention and academic outcomes for children and adolescents who do not have clinically significant levels of inattention or hyperactivity. The fact that this relationship holds for those who do not have a diagnosis of ADHD is salient for educators who work in a school setting. Right from preschool and kindergarten age, it is important that teachers are aware of how to identify inattention, for children who may or may not be showing hyperactive, impulsive or acting out behaviour. This more disruptive behaviour often commands more intervention/support efforts as compared to inattentive behaviour in children who do not have a formal diagnosis. In terms of intervention, the results of this review show large variation in strength of the relationship between inattention and academic outcomes. Intervention targeting either academic skill or inattentive behaviour might not have direct effects on the other variable, because the relationship may be indirect.

2.6.2 Limitations. As with all systematic reviews or meta-analyses, it is important to note that the evidence of a relationship between inattention and academic outcomes may be overestimated, due to the effect of unpublished studies, which were not included in this review. All attempts were made to perform quality assessment ratings according to guidelines that minimize spurious results, however it is acknowledged that all such rating systems, even with two independent raters, are at risk for some subjectivity. Only studies written in English were included, which may have introduced a systematic bias.
2.6.3 Conclusions. This review provides systemic evidence that there is a consistent, negative relationship between inattention and both standardized academic test achievement and classroom performance outcomes for children in pre-school (moderate evidence), elementary school, and longitudinally from elementary to high school. More research, incorporating recommendations that resulted from this review, is needed to confirm this relationship longitudinally and in high school and college/university students.

When examining outcomes across all studies, and even within age groups and categories of outcome measurement, there was a very wide range of results (variance accounted for ranging from 2.4% – 15%). The best evidence synthesis suggests strong evidence for this relationship; however, the variation in outcomes indicates that there are a number of other factors within the child, classroom and larger environment that could be accounting for or moderating the relationship between inattention and academic achievement. These outcomes open up questions about what other factors are being measured when teachers rate symptoms of inattention, which factors share variance in this relationship, and what are the causal pathways within the relationship between inattention and lower academic outcomes. Future research should move toward investigating variables that account for or mediate or moderate the relationship between inattention and poor academic outcomes for children and adolescents, taking into account the important variables of social-economic status, sex and initial levels of academic achievement.
Figure 1. PRISMA Flow Diagram
Table 1
Criteria List for the Quality Assessment of Studies on Inattention and Academic Achievement

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Study Participation</td>
<td>(A) The source population or population of interest is adequately described for key characteristics.</td>
</tr>
<tr>
<td></td>
<td>(B) The sampling frame and recruitment are adequately described, including methods to identify the sample sufficient to limit potential bias.</td>
</tr>
<tr>
<td></td>
<td>(C) Period of recruitment is adequately described.</td>
</tr>
<tr>
<td></td>
<td>(D) Place of recruitment (setting and geographic location) is adequately described.</td>
</tr>
<tr>
<td></td>
<td>(E) Inclusion and exclusion criteria are adequately described.</td>
</tr>
<tr>
<td></td>
<td>(F) There is adequate participation in the study by eligible individuals.</td>
</tr>
<tr>
<td></td>
<td>(G) The baseline study sample (i.e., individuals entering the study) is adequately described for key characteristics.</td>
</tr>
<tr>
<td>2. Study Attrition</td>
<td>(A) Response rate is adequate.</td>
</tr>
<tr>
<td></td>
<td>(B) Attempts to collect information on participants who dropped out of the study are described.</td>
</tr>
<tr>
<td></td>
<td>(C) Reasons for loss to follow-up are provided.</td>
</tr>
<tr>
<td></td>
<td>(D) Participants lost to follow-up are adequately described for key characteristics.</td>
</tr>
<tr>
<td></td>
<td>(E) There are no important differences between key characteristics and outcomes in participants who completed the study and those who did not.</td>
</tr>
<tr>
<td>3. Prognostic Factor (PF) Measurement</td>
<td>(A) A clear definition or description of PF is provided and method of PF measurement is adequately valid.</td>
</tr>
<tr>
<td></td>
<td>(B) Method of PF measurement is adequately valid and reliable to limit misclassification bias.</td>
</tr>
<tr>
<td></td>
<td>(C) Continuous variables are reported or appropriate cut-points are used.</td>
</tr>
<tr>
<td></td>
<td>(D) The method and setting of measurement of PF is the same for all study participants.</td>
</tr>
<tr>
<td></td>
<td>(E) Adequate proportion of the study sample has complete data for PF variable.</td>
</tr>
<tr>
<td></td>
<td>(F) Appropriate methods are used if imputation is used for missing PF data.</td>
</tr>
<tr>
<td>4. Outcome Measurement</td>
<td>(A) A clear definition of outcome is provided.</td>
</tr>
<tr>
<td></td>
<td>(B) The method of outcome measurement used is adequately valid and reliable to limit misclassification bias.</td>
</tr>
<tr>
<td></td>
<td>(C) The method and setting of outcome measurement is the same for all study participants.</td>
</tr>
<tr>
<td>5. Study Confounding</td>
<td>(A) All important confounders are measured.</td>
</tr>
<tr>
<td></td>
<td>(B) Clear definitions of the important confounders measured are provided.</td>
</tr>
<tr>
<td></td>
<td>(C) Measurement of all important confounders is adequately valid and reliable.</td>
</tr>
<tr>
<td></td>
<td>(D) The method and setting of confounding measurement are the same for all study participants.</td>
</tr>
<tr>
<td></td>
<td>(E) Appropriate methods are used if imputation is used for missing confounder data.</td>
</tr>
<tr>
<td></td>
<td>(F) Important potential confounders are accounted for in the study design.</td>
</tr>
<tr>
<td></td>
<td>(G) Important potential confounders are accounted for in the analysis.</td>
</tr>
<tr>
<td>6. Statistical Analysis and Reporting</td>
<td>(A) There is sufficient presentation of data to assess the adequacy of the analysis.</td>
</tr>
<tr>
<td></td>
<td>(B) The strategy for model building is appropriate and is based on a conceptual framework or model.</td>
</tr>
<tr>
<td></td>
<td>(C) The selected statistical model is adequate for the design of the study.</td>
</tr>
<tr>
<td></td>
<td>(D) There is no selective reporting of results.</td>
</tr>
</tbody>
</table>
Table 1.2
Results of Quality Assessment of Studies on Inattention and Academic Achievement

<table>
<thead>
<tr>
<th>Domain</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Criterion</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>E</td>
<td>F</td>
</tr>
<tr>
<td>4.</td>
<td>Rogers et al. (2011)</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>P</td>
</tr>
<tr>
<td>5.</td>
<td>Pingault et al. (2011)</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>7.</td>
<td>Swanson et al. (2011)</td>
<td>P</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>P</td>
</tr>
<tr>
<td>9.</td>
<td>Bernad et al. (2014)</td>
<td>P</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>10.</td>
<td>Cain &amp; Bignell (2014)</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>P</td>
</tr>
<tr>
<td>11.</td>
<td>Câmara Costa et al. (2013)</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>14.</td>
<td>Holmberg &amp; Bölte (2014)</td>
<td>P</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>P</td>
</tr>
<tr>
<td>15.</td>
<td>Plourde et al. (2015)</td>
<td>P</td>
<td>P</td>
<td>N</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>17.</td>
<td>Sassier et al. (2014)</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>P</td>
<td>N</td>
</tr>
<tr>
<td>18.</td>
<td>Sims &amp; Longan (2013)</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>19.</td>
<td>Fuchs et al. (2005)</td>
<td>Y</td>
<td>Y</td>
<td>P</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>20.</td>
<td>Trentcosta &amp; Izard (2007)</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>P</td>
<td>N</td>
</tr>
<tr>
<td>24.</td>
<td>Fuchs et al. (2006)</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>P</td>
<td>Y</td>
</tr>
<tr>
<td>26.</td>
<td>Molina et al. (2001)</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>P</td>
</tr>
<tr>
<td>27.</td>
<td>Warner-Rogers et al. (2000)</td>
<td>P</td>
<td>P</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
</tr>
</tbody>
</table>

**Note:** Domain 1, study participation; 2, study attrition; 3, prognostic factor measurement; 4, outcome measurement; 5, study confounding; 6, statistical analysis and reporting (see Table 1); ‘Y’, study was rated positive on criterion; ‘N’, study was rated negative on criterion; ‘P’, study was rated partial on criterion; ‘U’, study rating for criterion was unable to be determined or not reported; ‘-’, criterion not applicable for study.
Table 1.3

Results Showing Levels of Risk for Bias in Each Domain of the Quality Assessment for Studies on Inattention and Academic Achievement

<table>
<thead>
<tr>
<th>Domain</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.</td>
<td>Giannopulu et al. (2008)</td>
<td>Moderate</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td>3.</td>
<td>Rodriguez et al. (2007)</td>
<td>Low</td>
<td>High</td>
<td>Moderate</td>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td>4.</td>
<td>Rogers et al. (2011)</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>5.</td>
<td>Pingault et al. (2011)</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>Moderate</td>
<td>Low</td>
</tr>
<tr>
<td>6.</td>
<td>Massetti et al. (2008)</td>
<td>Low</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>7.</td>
<td>Swanson (2011)</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Low</td>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td>8.</td>
<td>Grimm et al. (2010)</td>
<td>Low</td>
<td>High</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Low</td>
</tr>
<tr>
<td>9.</td>
<td>Bernad et al. (2014)</td>
<td>Moderate</td>
<td>High</td>
<td>Moderate</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>11.</td>
<td>Camara Costa et al. (2013)</td>
<td>Moderate</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td>12.</td>
<td>Garner et al. (2014)</td>
<td>Moderate</td>
<td>Low</td>
<td>Low</td>
<td>Moderate</td>
<td>Low</td>
</tr>
<tr>
<td>15.</td>
<td>Plourde et al. (2015)</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>17.</td>
<td>Sasser et al. (2014)</td>
<td>Moderate</td>
<td>High</td>
<td>Moderate</td>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td>19.</td>
<td>Fuchs et al. (2005)</td>
<td>Moderate</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>21.</td>
<td>Wolraich et al. (2003)</td>
<td>Moderate</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>22.</td>
<td>Pierrehumbert et al. (2006)</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Low</td>
<td>Moderate</td>
<td>Low</td>
</tr>
<tr>
<td>23.</td>
<td>Diamantopoulou et al. (2007)</td>
<td>Moderate</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td>24.</td>
<td>Fuchs et al. (2006)</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>26.</td>
<td>Molina et al. (2001)</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Moderate</td>
<td>Low</td>
</tr>
<tr>
<td>27.</td>
<td>Warner-Rogers et al. (2000)</td>
<td>Moderate</td>
<td>Low</td>
<td>Moderate</td>
<td>Low</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

Note. Bias is rated as either High, Moderate, or Low and is based on consideration of the ratings of individual criteria in each domain. Domain 1, study participation; 2, study attrition; 3, prognostic factor measurement; 4, outcome measurement; 5, study confounding; 6, statistical analysis and reporting.
CHAPTER 3

Cross-sectional Relations Among Behavioural Inattention, Working Memory and Academic Achievement in a Canadian Community Sample of School Children
3.1 Abstract

Objective: To test the hypothesis that working memory (WM) mediates the association between children’s inattention and academic fluency. Methods: A sample of 204 students, grades 1-4 (49.5% female), were recruited from Canadian elementary schools. Teachers completed the SWAN scale and children underwent assessment of academic fluency and WM. Mediation analysis was used to determine whether the path from behavioural inattention to poor academic fluency was mediated by WM. Results: Auditory-verbal WM mediated the effect of inattention on math fluency and reading fluency, but visual-spatial WM only mediated the association between inattention and math fluency. Conclusion: WM is a key variable that shares a significant amount of variance in the relationship between teacher-rated inattention and academic fluency. Longitudinal models are needed to establish causal pathways. Findings highlight the importance of attention and WM in relation to academic fluency in elementary-aged children.
3.2 Introduction

Inattentive behaviour in the classroom has been linked to low academic functioning and identifies children at risk for poor academic outcomes (Pingault et al., 2011; Polderman, Boomsma, Bartels, Verhulst, & Huizink, 2010; Smallwood, Fishman, & Schooler, 2007; Spira & Fischel, 2005). Behavioural inattention, not hyperactivity, is seen as a developmental risk factor for school failure and low academic achievement across the lifespan (Garner et al., 2014; Rabiner & Coie, 2000). A growing body of literature confirms that symptoms of Attention Deficit Hyperactivity Disorder (ADHD) are continuously distributed in the population (for example, Groen-Blokhus et al., 2014). Therefore, it follows that this relationship between inattention and low achievement is found in community and subclinical groups as well as clinical groups whose symptoms reach criteria for ADHD (Breslau et al., 2009; Currie & Stabile, 2006; Fletcher & Wolfe, 2008; Pingault et al., 2011). Related to the differing demands of the classroom versus home setting, when attention is rated by teachers instead of parents, the relationship to achievement is stronger (Garner et al., 2014). A recent study found that children who have a stable trajectory of teacher-rated inattention across elementary and high school years are at risk for school failure, and those with a rising trajectory are at an even higher risk (Pingault et al., 2014).

The link between inattention and achievement has been found for key skills in both reading and math achievement. For example, inattentive behaviour in kindergarten and grade 1 was found to predict lower reading achievement one to five years later (Giannopulu et al., 2008; Rabiner & Coie, 2000). Inattention is related to lower scores on reading comprehension (Cain & Bignell, 2014), word reading (Camara Costa et al., 2013) and reading fluency (Grills-Taquechel, Fletcher, Vaughn, Denton, & Taylor, 2013; Jacobson et al., 2011). Similarly, inattention predicts difficulties in math problem solving performance across the elementary school years (Swanson, 2011) as well as arithmetic (Gold et al., 2013; Raghubar et al., 2009), math fact fluency (Fuchs et al., 2006; Lewandowski, Lovett, Parolin,
Gordon, & Coddin, 2007) and overall math achievement (Fitzpatrick & Pagani, 2013). Furthermore, inattentive behaviours have been found to predict poor response to reading intervention (Dion et al., 2011; Rabiner & Malone, 2004) and math tutoring intervention (Fuchs et al., 2005). Many, although not all of these studies also took into account variables related to reading and math outcomes, such as processing speed, phonological coding, and phonological processing.

Recent studies, however, have found differential predictive effects of inattention on intervention success, based on skills targeted and intensity and length of intervention (Miller et al., 2014; Roberts et al., 2014). Roberts and colleagues found that when reading intervention intensity was increased over three years (for those who were not showing response initially), results showed improvements in both reading and attention. The reading intervention took the form of multiple phases, encompassing decoding (word study), vocabulary, sentence and paragraph understanding, reading fluency and comprehension, as well as comprehension applied to science and social studies texts. The authors suggest that their reading intervention may have targeted executive skills as well as direct reading instruction, thus shared cognitive factors underlying reading and attention may have mediated the success of this intervention (Roberts et al., 2014). It also appears that inattention has different effects on the success of reading intervention based on the developmental sequence of reading skill. Miller et al. (2014) found that following a year-long reading intervention, the relationship between inattention in grade 1 and reading comprehension in grade 3, was mediated by development in word reading.

Fluency has been found to be distinct from other components of reading and math, and is an important factor in the development of higher-order skills, as well as a predictor of academic achievement (Fuchs, Fuchs, Hosp, & Jenkins, 2001; Russell, 2000). Samuels (2012) defines reading fluency as the ability to decode and understand the text at the same time, through obtaining a level of automaticity in which “the text can be decoded with ease, speed, and accuracy” (Samuels, 2012 p.5).
Reading words fluently can free up cognitive space to focus on gaining meaning from text. Reading fluency is predictive of concurrent and later reading comprehension (Roehrig, Petscher, Nettles, Hudson, & Torgesen, 2008). Oral reading fluency (ORF) is related to reading comprehension over and above contributions of word reading and listening comprehension, and has unique contributions to reading comprehension as children move into Grade 2 (Kim, Wagner, & Lopez, 2012). One study found that ORF in grade 1 is the strongest predictor (when compared with vocabulary, letter-naming, phonemic segmentation, and nonsense word fluency) of reading comprehension in grades 1, 2 and 3 (Pearce & Gayle, 2009). Highlighting the importance of reading fluency in academic achievement, several studies across ethnic and socio-economic groups have found that ORF in grades 1-3 is strongly associated with high-stakes testing in both elementary and middle school (Baker et al., 2015; Baker et al., 2007; Pearce & Gayle, 2008; Pearce & Gayle, 2009). Moreover, the slope of ORF added more accuracy in predicting criterion measures of reading on these high-stakes tests (Baker et al., 2007).

Reading fluency continues to be an important predictor of reading comprehension into adulthood (Tighe & Schatschneider, 2014). Math fluency is another academic domain of fluency that is distinct from other dimensions of math, but is an important predictor of overall math achievement (Fuchs et al., 2008; Hart, Petrill, & Thompson, 2010). One study has found that math fluency may be more challenging to ameliorate with intervention, as compared to math computation and application (Fuchs et al., 2005). Math fact fluency, the ability to quickly and automatically solve basic arithmetic problems, is predictive of overall math ability, and is genetically distinct from untimed math (Petrill, Logan, & Hart, 2012). This dimension of fluency is the only component of math that has these unique genetic influences (Hart, Petrill, Thompson, & Plomin, 2009). It is important to note that although it is distinct, math fluency is more closely related to other math domains than to measures of timed reading (Hart et al., 2010). Therefore,
math and reading fluency are etiologically distinct, while sharing some genetic covariance related to
timed measures. Following from this finding, the current study places math and reading fluency as
distinct outcomes, while examining whether a potential cognitive factor of importance, working
memory, has similar influences on the two achievement domains.

One cognitive function that is important in reading and math fluency is working memory (WM)
(Fuchs et al., 2008). Working memory is a cognitive system that allows us to maintain information
‘online’ in the mind for a few seconds and manipulate the information to produce an output (Baddeley,
2010; Miyake & Shah, 1999). Baddeley’s model posits that visual-spatial (VS) and auditory-verbal
(AV) working memory plays a role in storage, rehearsal and manipulation (Baddeley, 2010). An
example of a task that taps into the auditory-verbal (AV) WM domain is the commonly used digit
repetition task, in which a participant is asked to repeat a series of numbers immediately after the
examiner reads the sequence, this is done forwards and then backwards. The visual-spatial domain is
often tested by tasks that require a participant to immediately copy visual sequences forwards and
backwards.

Lack of fluency in academic tasks increases demand on WM, which is already impaired for
many children who have difficulties with attention (Martinussen & Tannock, 2006). Similarly,
processing speed also has an impact on fluency and is often found to be impaired in those who have
disorders of attention (Chhabildas et al., 2001; Rucklidge & Tannock, 2002). Recent findings suggest
that WM and processing speed are highly intertwined when children are in the early stages of
development (approximately age 3), however, both cognitive constructs emerge as unique predictors of
reading and math fluency as children move into the elementary school age (Clark et al., 2014; Jacobson
et al., 2011). Working memory is found to be an important mechanism for students with ADHD
(Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005) and is related to attention across the population
spectrum (for example, Gathercole & Pickering, 2000). Children with low WM perform poorly on tasks of math and reading, even when IQ is taken into account, and teachers rate these children as having high levels of inattention (Alloway, Gathercole, Kirkwood, & Elliott, 2009). In a cross-sectional study with children aged 8-12, Kibby and colleagues found that both verbal WM and attention control were significant predictors of reading fluency (Kibby, Lee, & Dyer, 2014). Thus, current theoretical and empirical work suggests a possible triad of impairment that encompasses inattentive behaviour, impaired WM, and poor academic functioning.

Understanding how these three components are interrelated is necessary in order to develop effective intervention techniques that target the relevant cognitive factors underlying behaviours that disrupt learning in a classroom setting. A previous study seeking to delineate these relationships found that WM was a mediator of the relationship between inattention and reading and math composite scores in adolescents with ADHD (Rogers, Hwang, Toplak, Weiss, & Tannock, 2011). Another study with kindergarten children found that overall executive functioning was a mediator between inattention and pre-academic skills, however a composite was used that grouped both WM domains and response inhibition (Thorell, 2007). To our knowledge, there are no studies that test these relationships, with a focus on fluency, using a mediation model in a community sample of school-aged children. Other studies have combined the WM domains and created a composite of achievement, whereas in the current study, we examine auditory-verbal and visual-spatial WM as mediators with different pathways, and reading and math fluency as separate outcome variables. We also focus specifically on academic fluency in order to parse out influences that are directly related to this important aspect of academic achievement.

The current study draws from a community sample of elementary school boys and girls. One objective is to assess the inter-relationships amongst the triad of impairments along the continuum of
behaviour. Mediation analysis allows for delineating more precisely the nature of these relationships. That is, if a mediation effect is present, the underlying construct of WM may prove to be an important function that accounts for a significant amount of variance in the relationship between, and may be one aspect of a bridge or pathway from, inattention to impairment in academic fluency.

Our main objective is to test visual-spatial and auditory-verbal WM as mediators of the relationship between teacher-rated inattention and reading and math fluency. Our main hypothesis is that both auditory-verbal and visual-spatial WM will be mediators of the relationship between inattention and academic fluency. A secondary hypothesis is that visual-spatial WM will be a weaker mediator for the relationship between inattention and reading fluency.

3.3 Materials and Methods

3.3.1 Participants. Participants were 204 children (49.5% female) in grades 1-4 with a mean age of 7.67 years (range 5.96 - 9.83 years). Data were drawn from a larger prospective sample of 524 students. This subgroup was selected by rank ordering teacher SWAN scores, and then selecting 2-3 students from the highest, middle and lowest ranking bracket in each class, with stratification for sex. The purpose of this selection procedure was to create a sample that was representative of the continuum of classroom attention amongst elementary school-aged children, as only this subgroup received second individualized assessments of WM and academic measures. Parents gave consent for 2 testing sessions across the year, and understood that their child may not participate in the second testing session. Children and their teachers and parents were recruited from 7 elementary schools in Southern Ontario, Canada. These schools, which constituted 20% of 33 schools in a large rural and suburban school district, were stratified across different socioeconomic groups. Participants were primarily Caucasian, with English as their first language, and 29% were in French immersion (see Table 2 for demographic data). There were no significant demographic differences between males and females (see Table 2),
with one exception: females were more likely to have a parent (informant, most frequently mother) with less than high school education. Although students were in mainstream classrooms, 11.8% had an Individual Education Plan (IEP), as reported by teachers. Out of the 52 teachers who participated, 95% were Caucasian and 95% were female, and 38% had additional qualifications in special education. Teachers had an average of 14.8 (SD = 7.9) years of experience, ranging from 1 – 33 years.

Inclusion criteria for children in the larger-scale study who gave verbal assent and had written informed consent from their parents and teacher included 1) placement in mainstream English or French classrooms and 2) no major physical or sensory impairment that would prohibit the child from hearing instructions or completing the tasks. In addition to these criteria, inclusion in the current study was determined by the selection procedures described above. All 204 students from this representative sample were included in the current study.

3.3.2. Procedures. Institutional Review Board (IRB) approval was obtained from the hospital institution involved and participating school boards. Principals of potential participant schools were presented with information about the study at an initial meeting. Those who chose to participate then contacted the research team. Information sessions for teachers from grades 1-4 were held in the various schools: consenting teachers and parents then received a package of questionnaires. Teachers completed the questionnaires in November of the school year, to allow time for them to get to know their students. All consenting students completed the tests of oral reading fluency and math fluency in November. Subsequently, teacher’s scores on the SWAN behaviour rating scales were ranked separately for each class to select a representative sample from SWAN scores in the top, middle, and bottom tertiles of each class. These tertiles were created through random sampling, stratified by sex. We were permitted to work with students for a maximum of 30 minutes, and dates were specified by the school to avoid pre-scheduled conflicting events and special dates during the school year. Therefore,
WM measures were administered individually, for those selected in the process described above, during the second assessment session, April of the same school year.

3.3.3. Measures. Data for this study were derived from the following set of cognitive, academic and symptom rating scale measures. Data was collected as part of a larger 2 year prospective study which included further measures of behaviour, neuropsychological and academic functioning.

Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behaviour Scale (SWAN). This scale is designed to measure differences in attention in a normal population-based sample, and provides a more precise measure of attention across 7 rating points (Swanson et al., 2001; Young, Levy, Martin, & Hay, 2009). This scale is coded such that 3 = Far below average, 2 = Below average, 1 = Slightly below average, 0 = Average, -1 = Slightly above average, -2 = Above average, -3 = Far above average. Therefore positive scores indicate higher levels of inattentive behaviour and negative scores indicate lower levels of inattentive behaviour, that is, stronger attention. Attention has been shown to be on a continuum (Levy, Hay, McStephen, Wood, & Waldman, 1997; Normand, Flora, Toplak, & Tannock, 2012), therefore this sensitive and positively-worded scale avoids the psychometric flaws that arise with skewed distributions found in the typical negatively-worded four-point rating scales used to measure attention.

Wechsler Intelligence Scale for Children (WISC-IV), Digit Span Subtests (DS). To extend previous findings about the relationship between WM and attention in a clinical sample of adolescents (Rogers et al., 2011) to this non-clinical population of school-aged children, we used the WISC-IV digit span composite score, which includes forward and backward subtests. This test is a highly reliable and well-validated measure of auditory-verbal short term memory and WM, with an internal consistency of .87 and test-re test stability of .82 (Wechsler, 2003). Age-adjusted scaled scores were used in the analyses.
**Woodcock Johnson – Third Edition (WCJ-III), Math Fluency subtest.** This standardized battery measures math fluency across the academic trajectory. It is widely used and has strong psychometric properties (Woodcock, McGrew, & Mather, 2001). Participants are asked to complete as many problems as possible on a page of basic arithmetic problems, progressing through addition, subtraction, multiplication and division, with a time limit of 3 minutes.

**Wide Range Assessment of Memory and Learning (WRAML-2), Finger Windows Forward Subtest (FWF).** For this task, the examiner follows a sequence of movements on an 8x11 plastic card with asymmetrically located holes or ‘windows,’ which becomes more challenging as the task progresses. The participant who is seated across from the examiner is asked to replicate the sequences with their finger at a rate of one ‘window’ per second. This psychometrically strong task taps into the visual-spatial storage element of WM (Sheslow & Adams, 2003). The raw score is made up of the total number of correct sequences, and these scores were converted into age-adjusted standard scores for the analyses.

**Dynamic Indicators of Basic Early Literacy Skills (DIBELS, 5th ed), Oral Reading Fluency Subtest.** This curriculum based reading measure has moderate to good concurrent and predictive validity and alternate form reliability is .94 (Good, Kaminski, Smith, Laimon, & Dill, 2001). The task is administered individually; participants are asked to read a grade level appropriate passage out loud as accurately as possible in 1 minute. Any words that were incorrectly pronounced, omitted, substituted were counted as incorrect, as were hesitations for over 3 seconds. The oral reading fluency score was the median number of correct words.

**3.3.4 Analytic approach.** Investigation of the amount of missing data for individual variables and scales showed that the scale variable (SWAN) had less than 5% of missing data and individual variables (DIBELS, WJC-III, WISC-IV, WRAML-2) had less than 10% of missing data. When the
amount of missing data does not exceed 10-15%, an imputation strategy is suggested (McKnight, McKnight, Sidani, & Figueredo, 2007). The imputation was performed using the regression model when the imputed values are predicted based on all the information available from the dataset. The imputation was performed 5 times and the results were averaged across the five imputations to produce a complete dataset that was used for analyses.

Complete parent demographic data was available for 182 students and 204 complete sets of study questionnaire and measure data were available. IBM SPSS version 21 was used to perform the statistical tests.

**Associations between study variables.** Pearson correlations were performed to examine the linear relationships between study variables and potential covariates. Multiple linear regressions were carried out to test whether behavioural inattention, as measured by the SWAN scale, predicted level of academic fluency. Prediction of mediator variables and relationship of mediator variables to academic fluency were also tested in this manner. Influences of age, sex and parent education on each model were also investigated.

**Mediators of the hypothesized associations between behavioural inattention and academic fluency.** Multiple mediation analysis, using bias-corrected 95% confidence intervals for the indirect effect was carried out using the PROCESS macro for SPSS (Hayes, 2013). Two variables were tested in parallel as possible mediators of the relationship between behavioural inattention and academic fluency: visual-spatial WM and auditory-verbal WM (see Figure 2 for conceptual diagram).

### 3.4 Results

**3.4.1 Preliminary analyses.** Table 2.1 presents partial correlations that were conducted to explore the interrelationships between study variables and children’s sex and parent education level while controlling for age. The two mediator variables, visual-spatial WM and auditory-verbal WM
were not significantly correlated. This is consistent with literature that supports, through both factor analytic (Alloway & Alloway, 2013; Alloway, Gathercole, & Pickering, 2006) and neuroimaging (Fassbender & Schweitzer, 2006) methods, a domain-distinct model of WM. However, other studies have found these variables to be correlated (for example, Rogers et al., 2011) and the two domains are hypothesized to share some overlap (Alloway & Alloway, 2013). As expected, all predictor and outcome variables were correlated with each other and with mediator variables in the expected direction, at the .01 level (see Table 2.1). Age was included as a control variable, and as a covariate in further analyses as it was correlated with reading and math fluency at the .01 level as well as with visual-spatial WM at the .05 level. Sex was weakly correlated with one outcome measure, reading fluency, and one mediator variable, visual-spatial WM, as well as moderately correlated with inattention, thus sex was also included as a covariate in further analyses. A body of literature has established a relationship between family socio-economic status (SES), of which parental education is a proxy, and reading and math achievement (for a review see Sirin, 2005). Our findings are consistent with this literature, and extend to a significant correlation with fluency in particular. Parental education was not correlated with visual-spatial WM, however it was significantly related to auditory-verbal WM at the .05 level.

3.4.2. Regression analyses.

**Behavioural inattention as a predictor of academic fluency.** To test our hypothesis of a relationship between teacher-rated behavioural inattention and academic fluency, we conducted a hierarchical regression analysis. At step 1, age, sex and parental education were entered. Teacher-rated SWAN scores, entered at step-2, were found to positively predict both reading and math fluency, accounting for a significant increase in variance from step 1, 18.3%, to step 2, 38.6% (reading fluency: change\(F_{1,177} = 59.625, p < .001\); math fluency: change\(F_{1,177} = 41.281, p < .001\). The standardized and
unstandardized regression coefficients, standard error and $R^2_{\text{adjusted}}$ for each step of the model are presented in Table 2.3.

**Behavioural inattention as a predictor of potential mediators.** Mackinnon, Lockwood, Hoffman, West, & Sheets (2002), suggest that before mediation analysis is conducted, a relationship between the predictor and mediator, and mediator and outcome variable should be established. Indeed, we found that behavioural inattention significantly predicted both visual-spatial ($R^2_{\text{adjusted}} = .126$, $F(4) = 7.517, p < .001$, $\beta = -.256, p = .001$) and auditory-verbal WM ($R^2_{\text{adjusted}} = .065$, $F(4) = 4.146, p < .01$, $\beta = -.536, p < .001$). Age also significantly predicted visual-spatial WM ($\beta = -.160, p < .05$).

**Potential mediators as predictors of academic fluency.** Visual-spatial WM was found to positively predict both reading and math fluency, accounting for a significant increase in variance after sex, age, and parental education were entered (reading fluency: $R^2_{\text{adjusted}} = .224$, change$F_{1,177} = 10.305$, $p < .01$; math fluency: $R^2_{\text{adjusted}} = .130$, change$F_{1,177} = 15.423$, $p < .001$). Other significant predictors of fluency in this model were parental education (math: $\beta = .188, p < .01$; reading: $\beta = .217, p < .01$) and age (math: $\beta = -.128, p < .001$; reading: $\beta = .423, p < .001$).

The model with covariates (step 1) and auditory-verbal WM (step 2) as predictors of academic fluency was significant (reading fluency: $R^2_{\text{adjusted}} = .237$, change$F_{1,177} = 13.533$, $p < .001$; math fluency: $R^2_{\text{adjusted}} = .206$, change$F_{1,177} = 33.796$, $p < .001$). Along with Auditory-verbal WM for academic fluency, parental education significantly predicted math fluency outcomes ($\beta = .148, p < .05$) and age ($\beta = -.153, p < .05$). Predictors of reading fluency included sex ($\beta = .143, p < .05$), parental education ($\beta = .155, p < .05$), age ($\beta = .401, p < .001$). The model fit for visual-spatial WM or auditory-verbal WM as predictors of reading fluency was similar, accounting for 22.4% and 23.7% of the variance, respectively. However, the domains differed as predictors of math fluency; with visual-spatial WM and covariates accounting for 13% of the variance, and auditory-verbal WM and covariates
accounting for 20.6%. This suggests that auditory-verbal WM plays a stronger role in both reading and math fluency in this age group.

3.4.3. Mediation analyses. A second hypothesis predicted an indirect, or mediated, effect of the relationship between teacher-rated behavioural inattention and academic fluency reported above, through visual-spatial and auditory-verbal WM. The direct and indirect effects, as well as the significance of inferential tests are examined when interpreting results. Age, sex and parent education were included as covariates in both models. Consequently, analyses were based on a sample size of 182, the number of parent-demographic questionnaires that were available. It should be noted that significance remains unchanged when parent education is omitted and the models are run with the full sample of 204.

Figures 2.1 and 2.2 illustrate the results of the mediation models tested. As can be seen in Figure 2.1, the significant direct effect is negative ($c' = -0.272, p < .01$), therefore higher levels of inattention estimate lower math fluency scores when working memory scores are equal. A bias-corrected bootstrap confidence interval for the total indirect effect ($ab = -0.099$) based on 1000 bootstrap samples did not include zero (-0.167 to -0.051). Results indicate a significant indirect effect for both mediators (auditory verbal WM: $ab = -0.062$, visual-spatial WM $ab = -0.037$). Therefore, these results indicate that auditory-verbal and visual-spatial WM are mediators of the relationship between teacher-rated inattention and math fluency in this sample. That is, with each increase in behavioural inattention, through its effect both directly and through WM, there is a decrease in math fluency scores.

When reading fluency is the outcome variable, the direct path from behavioural inattention to reading fluency is significant and negative (-1.497, $p < .01$), indicating that when behavioural inattention is higher, reading fluency scores are estimated to be lower (Figure 2.2). A bias-corrected bootstrap confidence interval for the indirect effect through auditory-verbal WM ($ab = -0.121$) based
on 1000 bootstrap samples did not include zero (-0.289 to -0.015). The confidence interval for the indirect effect through visual-spatial WM did include zero (-0.248 to 0.027). Thus, visual-spatial WM was not a significant mediator of the relationship between behavioural inattention and reading fluency, but auditory-verbal WM was.

Recent research has proposed that ‘age for grade’ is an important variable to consider when conducting analysis of attention within the school setting (Morrow et al., 2012). We carried out a moderated mediation analysis that tested the variable ‘young for grade’ as a moderator. The results indicated that this variable was not a significant moderator.

3.5 Discussion

Our major objective of this study was to examine cognitive mediators of the relationship between inattentive behaviour and reading and math fluency in a community sample of school aged children. Using the approach to mediation described by Hayes (2013), we tested the hypothesis that visual-spatial and auditory-verbal WM mediates the relationship between teacher-rated children’s inattention and the youngsters’ reading and math fluency. Secondary aims were to examine the relationships within the proposed triad of impairment; behavioural inattention, WM and academic underachievement, as well as covariates, using correlation and regression analyses.

Consistent with our hypothesis, we found that WM was a significant mediator of the relationship between behavioural inattention and academic fluency. Specifically, visual-spatial and auditory-verbal WM were significant mediators of the relationship between teacher-rated inattention and math fluency. We found that for reading fluency as the outcome of interest, only auditory-verbal WM was a significant mediator. These findings contribute unique data to support the hypothesis that WM plays a critical role in the well-documented relationship between behavioural inattention and academic under-achievement, for school-aged children across the normal spectrum of development. To
our knowledge, reading and math fluency have never been specifically examined using this mediation model. Therefore, our findings extend the literature to include WM as a key factor accounting for a significant portion of variance in the link between inattention and poor reading and math fluency.

We found that visual-spatial WM was not significantly predictive of reading fluency. This is consistent with the study by Rogers et al. (2011), who found the same result in a sample of adolescents referred for ADHD. This provides evidence for the developmental model that places auditory-verbal WM as a function with consistent importance across the elementary school years. Children at the age of 8, close to the mean age of this sample, start to encode visual-spatial information into phonologically represented information (Pickering, 2001). Moreover, our findings indicate that auditory-verbal WM is important specifically for academic fluency. A longitudinal design is needed to establish whether these patterns are consistent across development. In our sample, we found that although there was a significant mediation effect of WM, there was also a significant direct relationship between inattention and reading and math fluency outside the effect of WM. Other important variables, outside the scope of this paper, need be considered as other contributors to this link. For example, classroom and teacher factors, such as the match between material and students’ level or teachers instructional supports and activities and the students’ ability to engage in these tasks could be considered in future models, as well as student factors such a mind wandering or other cognitive variables not measured in this study.

The strong body of literature presenting correlational relationships between inattention and academic outcome, presented in the systematic review in chapter 2, provides a base from which to compare these results. The outcomes of our correlation analyses are as expected, the majority of study variables were significantly correlated in the expected direction. The one exception was the finding that visual-spatial WM was not correlated with auditory-verbal WM. Other studies have found that the two domains of WM are ‘moderately’ related, but dissociable constructs (Alloway & Alloway, 2013). It is
possible that the lack of correlation in our study is due to our measure of visual-spatial WM, which taps into the storage domain of WM, but did not include a manipulation component (Baddeley, 2010).

Results indicate a strong relationship between teacher-rated inattention and reading and math fluency. The direction of the relationship is negative, which demonstrates that when a student presents with higher levels of inattention, fluency scores are lower. A weak and moderate correlation between auditory-verbal WM and reading and math fluency, respectively, demonstrate the importance of auditory-verbal WM to math fluency in this age group. Regression analyses also provided evidence that auditory-verbal WM is more influential than visual-spatial WM when predicting both reading and math fluency. We found that behavioural inattention and control variables (sex, age, parent education) accounted for more variance in reading fluency outcomes (38.6%) as compared to math fluency outcomes (23.3%). This is consistent with another study with first grade children, that found attention to be a significant predictor of math fact fluency (Fuchs et al., 2005). One factor to consider, brought up by Fuchs and colleagues (2005), is that teacher ratings of behaviour may be biased, and influenced by students’ academic performance, thus conflating the two measures. Although this is a salient factor to consider in our data, it is of course more problematic when teachers are also rating academic performance, which is not the case in the current study.

There are some limitations within this study to consider in the application of results and in future research. Our main cognitive variable of interest, WM, is closely related to other cognitive constructs not measured in this study, such as processing speed. Rapid digit naming, as well as verbal skills (for example word reading and comprehension) are not measured in this study and are also related to speed and accuracy in fluency outcomes. Future research may investigate a combination of distal and proximal (for example processing speed) cognitive mediators of the inattention and academic fluency relationship. Another factor to consider is that our measure of auditory-verbal WM uses
numbers, therefore number processing could also be a predictive element in this model. A limiting factor in this study is that we used data that was collected within only one academic school year, thus precluding any causal interpretations. As Hayes (2013) argued, there is value in using mediation to examine a set of relationships that are not designed longitudinally, when conclusions contain appropriate cautions and are based on solid theory built from the literature. Further research is needed to examine the differences between this data collected over one year, and the relationships modeled across elementary school years, as well as to establish causal pathways that can reveal more about the developmental relationships within the triad of impairment.

3.5.1. Conclusions. Working memory accounts for a significant portion of the shared variance between teacher-rated inattention and reading and math fluency in school aged children. Consistent with findings in the adolescent literature, auditory-verbal WM is a predictor of math and reading ability, while visual-spatial WM is more clearly related to math. In this study, these relationships are found with fluency specifically, and findings are extended to a community sample of elementary school children. Findings emphasize the strong relationships between teacher-rated inattention math and reading fluency, with WM as a key variable accounting for part of this relationship. However, longitudinal analysis is needed to establish the direction of causation.

3.5.2. Clinical and educational implications. Results highlight that inattention, poor WM and poor academic fluency comprise a risk triad in non-clinical samples of school-aged children, with auditory-verbal WM as a key domain of importance in relation to academic fluency. Further longitudinal research will help to address a key remaining question around which area of impairment is the optimal target for intervention. Current programs designed to improve WM capacity have shown limited generalization to academic improvement (Dunning, Holmes, & Gathercole, 2013; Gray et al., 2012), and behavioural interventions to improve attention or remediate academics also show limited
effectiveness with inattentive children (Fuchs et al., 2005; Rabiner & Malone, 2004). There is little evidence of clinically meaningful academic change after treatment with stimulant medication (Langberg & Becker, 2012). Preventative efforts may be placed on teaching strategies that reduce WM load in the classroom, as WM is an important function that students rely on for academic success.
Table 2

Demographic Data for Male and Female Participants

<table>
<thead>
<tr>
<th></th>
<th>Total N = 204</th>
<th>Males (n = 103)</th>
<th>Females (n = 101)</th>
<th>F or χ² (1,202)*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Children</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>7.67 (0.91)</td>
<td>7.75 (0.90)</td>
<td>7.58 (0.92)</td>
<td>1.67</td>
</tr>
<tr>
<td>Grade</td>
<td>2.22 (0.89)</td>
<td>2.26 (0.85)</td>
<td>2.18 (0.92)</td>
<td>0.46</td>
</tr>
<tr>
<td>Primary language (% English)</td>
<td>83.3</td>
<td>82.5</td>
<td>84.2</td>
<td>7.50</td>
</tr>
<tr>
<td>Ethnicity (% Caucasian)</td>
<td>80.6</td>
<td>81.8</td>
<td>79.3</td>
<td>11.1</td>
</tr>
<tr>
<td><strong>Teacher reported exceptionality</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADHD (%)</td>
<td>5.5</td>
<td>7.7</td>
<td>3.3</td>
<td>1.74</td>
</tr>
<tr>
<td>Learning disability (%)</td>
<td>3.8</td>
<td>4.4</td>
<td>3.3</td>
<td>0.16</td>
</tr>
<tr>
<td>Language impairment (%)</td>
<td>4.9</td>
<td>6.6</td>
<td>3.3</td>
<td>1.09</td>
</tr>
<tr>
<td>Behaviour difficulty (%)</td>
<td>1.6</td>
<td>1.1</td>
<td>2.2</td>
<td>0.33</td>
</tr>
<tr>
<td>Developmental disability (%)</td>
<td>0.5</td>
<td>1.1</td>
<td>0</td>
<td>1.02</td>
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<tr>
<td><strong>Parents (informant)</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relationship to child (% mothers)</td>
<td>92.3</td>
<td>92.3</td>
<td>92.4</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>Education level</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; High school (%)</td>
<td>2.7</td>
<td>0</td>
<td>5.4</td>
<td>5.03*</td>
</tr>
<tr>
<td>High school/GED (%)</td>
<td>5.5</td>
<td>7.8</td>
<td>3.3</td>
<td>1.79</td>
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<tr>
<td>College/University graduate (%)</td>
<td>57.7</td>
<td>58.9</td>
<td>56.6</td>
<td>1.98/1.10</td>
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<tr>
<td>Post-graduate degree (%)</td>
<td>11.0</td>
<td>7.8</td>
<td>14.1</td>
<td>1.88</td>
</tr>
</tbody>
</table>

*Note:* *p* < .05.

*aOne-way ANOVA for continuous variables, Pearson chi-square statistic for categorical variables.
<table>
<thead>
<tr>
<th>Variables</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Teacher-rated Inattention</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Reading Fluency</td>
<td>-.538**</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Math Fluency</td>
<td>-.414**</td>
<td>.583**</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Auditory-Verbal WM</td>
<td>-.229**</td>
<td>.282**</td>
<td>.422**</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Visual-Spatial WM</td>
<td>-.341**</td>
<td>.265**</td>
<td>.284**</td>
<td>.135</td>
<td>–</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Sex</td>
<td>-.366**</td>
<td>.147*</td>
<td>-.044</td>
<td>-.046</td>
<td>.156*</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>7. Parent education level¹</td>
<td>-.224**</td>
<td>.215**</td>
<td>.214**</td>
<td>.163*</td>
<td>.096</td>
<td>.034</td>
<td>–</td>
</tr>
</tbody>
</table>

*Note: Significant correlation: * $p < .05$. ** $p < .01$.  

Teacher-rated Inattention: total raw score, positive scores indicate higher inattention levels. 

Reading and Math Fluency, WM variables: Standard Scores. 

¹ Based on sample size of $n = 182$
Table 2.3

Hierarchical Regression: Teacher-rated Inattention Predicting Reading and Math Fluency

<table>
<thead>
<tr>
<th>Regression Step</th>
<th>$R^2_{\text{adjusted}}$</th>
<th>$b$</th>
<th>SE $b$</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reading Fluency</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 1</td>
<td>.183**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sex</td>
<td>12.370</td>
<td>6.409</td>
<td>.130</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>20.772</td>
<td>3.616</td>
<td>.388</td>
<td></td>
</tr>
<tr>
<td>Parental education</td>
<td>6.012</td>
<td>2.073</td>
<td>.195</td>
<td></td>
</tr>
<tr>
<td>Step 2</td>
<td>.386**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sex</td>
<td>-4.637</td>
<td>5.979</td>
<td>-.049</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>20.890</td>
<td>3.136</td>
<td>.390</td>
<td></td>
</tr>
<tr>
<td>Parental education</td>
<td>2.775</td>
<td>1.846</td>
<td>.090</td>
<td></td>
</tr>
<tr>
<td>Teacher-rated Inattention</td>
<td>-1.703</td>
<td>.221</td>
<td>-.497</td>
<td></td>
</tr>
<tr>
<td><strong>Math Fluency</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 1</td>
<td>.060*</td>
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Note: * $p < .01$, ** $p < .001$
**Figure 2.** Conceptual model for mediators of the relationship between behavioural inattention and academic fluency. *Note: outcome variables are separated in analyses.*

**Figure 2.1** Mediation effect of working memory on the relationship between behavioural inattention and math fluency. Unstandardized regression coefficients are presented.

* $p < .05$, ** $p < .01$
Figure 2.2 Mediation effect of working memory on the relationship between behavioural inattention and reading fluency. Unstandardized regression coefficients are presented.

* $p < .05$, ** $p < .01$
CHAPTER 4

Longitudinal Relations among Inattention, Working Memory, and Academic Achievement:
Testing Mediation and the Moderating Role of Gender.

*Note:* This manuscript has been published as Gray, S.A., Rogers, M., Martinussen, R., & Tannock, R. (2015). Longitudinal relations among inattention, working memory, and academic achievement: testing mediation and the moderating role of gender. *PeerJ*, 3, e939. doi:10.7717/peerj.939

Some minor wording changes have been made in order to be consistent with the rest of the dissertation.
4.1 Abstract

Behavioral inattention, working memory (WM), and academic achievement share significant variance, but the direction of relationships across development is unknown. The aim of the present study was to determine whether WM mediates the pathway between inattentive behaviour and subsequent academic outcomes. **Methods.** 204 students from grades 1-5 (49.5% female) were recruited from elementary schools. Participants received assessments of WM and achievement at baseline and one year later. WM measures included a visual-spatial storage task and auditory-verbal storage and manipulation tasks. Teachers completed the SWAN behaviour rating scale both years. Mediation analysis with PROCESS (Hayes, 2013) was used to determine mediation pathways. **Results.** Teacher-rated inattention indirectly influenced math addition fluency, subtraction fluency and calculation scores through its effect on visual-spatial WM, only for boys. There was a direct relationship between inattention and math outcomes one year later for girls and boys. Children who displayed better attention had higher WM scores, and children with higher WM scores had stronger scores on math outcomes. Bias-corrected bootstrap confidence intervals for the indirect effects were entirely below zero for boys, for the three math outcomes. WM did not mediate the direct relationship between inattention and reading scores. **Discussion.** Findings identify inattention and WM as longitudinal predictors for math addition and subtraction fluency and math calculation outcomes one year later, with visual-spatial WM as a significant mediator for boys. Results highlight the close relationship between inattention and WM and their importance in the development of math skills.
4.2 Introduction

A strong body of literature has provided evidence of a link between inattentive behaviour in the classroom and academic underachievement (see Chapter 2; Systematic Review: The Relationship between Inattention and Academic Achievement). As a behavioural descriptor, attention refers to overt on-task behaviours (for example, visual fixation on a relevant stimulus such as a teacher) as well as organization (for example, keeping track of materials) and is measured using behavioural rating scales (for example, the SWAN rating scale, Conners-3) filled out by a parent or teacher who regularly observes a child’s behaviour. Inattention refers to off-task behaviour, and includes the concept of disorganization. It is the dimension of inattention that has consistently been found to be a risk factor for poor academic achievement across development (Garner et al., 2014; Pingault et al., 2011). Teacher-ratings of behavioural inattention are more strongly linked to academic outcomes than are parent-ratings, and are more sensitive to the demands of the classroom environment (Garner et al., 2014).

4.2.1 Inattention and math achievement. Teacher-rated inattention is an independent predictor of performance in multiple achievement domains that are important throughout the elementary school years, including arithmetic fluency (Fuchs et al., 2006; Lewandowski, Lovett, Parolin, Gordon, & Codding, 2007), arithmetic word problems (Fuchs et al., 2006; Swanson, 2011) and algorithmic computation (Fuchs et al., 2006; Li & Geary, 2013; Raghubar et al., 2009), as well as for composites of arithmetic fluency and algorithmic computation (Fitzpatrick & Pagani, 2013; Gold et al., 2013). These three domains of math are distinguishable (Fuchs et al., 2006). Arithmetic fluency is defined as solving simple math facts, with a timing component, where students are expected to quickly and accurately solve math fact problems. As children become efficient counters, associations between pairs of numbers become consolidated in long-term memory, therefore relying more on retrieval memory and putting less burden on working memory (WM) for answering math fact questions fluently.
(Geary, Brown, & Samaranayake, 1991). Petrill and colleagues (2012) found that arithmetic fluency is genetically distinct from other non-timed measures of math calculation, problem solving and number concepts (Petrill, Logan, Hart, Vincent et al., 2012). Arithmetic fluency plays a role in the development of algorithmic computation, which is defined by Fuchs et al. (2006, p.30) as “adding, subtracting, multiplying or dividing whole numbers, decimals or fractions using algorithms and arithmetic.” This type of math is differentiated from arithmetic fluency as it includes carrying and borrowing; moving outside of simple arithmetic to include the use of algorithm, and necessitating the ability to follow procedural steps as well as reliance on math fact retrieval.

4.2.2 Inattention and reading achievement. Reading fluency is another important domain of achievement during the elementary school years, as it is a consistent predictor of later reading comprehension skills (Pearce & Gayle, 2009; Roehrig et al., 2008). The ability to read fluently in the early grades is also predictive of high-stakes achievement test scores in elementary and middle school, and continues to predict reading comprehension scores into adulthood (Baker et al., 2015; Tighe & Schatschneider, 2014). There is some evidence that reading fluency is linked to attention, in that inattentive behaviour is a predictor of poor reading fluency outcomes in typical developing school children (Pham, 2013). A study using a community sample of elementary school children found that mid-term teacher-rated inattention predicted word reading fluency at the end of the same year, although it did not predict basic reading (word reading without timed component and decoding ability; Grills-Taquechel, Fletcher, Vaughn, Denton, & Taylor, 2013). Studies with clinical groups have also found that children with Attention-Deficit/Hyperactivity Disorder (ADHD) have lower reading fluency outcomes than their peers (Jacobson et al., 2011; Willcutt, Pennington, Olson, & DeFries, 2007).

The mechanisms of association between inattention and math and reading outcomes are
not yet delineated. Although it is teacher-rated inattention that is strongly linked with poor academic achievement, attention encompasses both behavioural and cognitive components, and these two aspects of attention do not readily map onto each other (for a review, see Tannock, 2003). As a cognitive descriptor, attention refers to a complex set of processes that operate through a series of neural networks. Three specific networks have been delineated; alerting, orienting and executive control (Posner & Rothbart, 2007). It is not known whether cognitive aspects of attention mediate the relationship between behavioural inattention and poor academic achievement. Within the cognitive network of executive control, the functional domain of working memory (WM) has been implicated in math and reading achievement and is strongly related to inattention, and thus presents as a possible mediating variable within this relationship (Fuchs et al., 2005; Martinussen & Tannock, 2006; Swanson & Beebe-Frankenberger, 2004).

A number of educational studies draw upon Baddeley’s multicomponent model of WM in which WM is viewed as a limited-capacity system that temporarily holds and manipulates information. This model includes separate storage modules for auditory-verbal (phonological loop) and visual-spatial information (visual-spatial sketchpad), and a central executive component that interfaces with other systems such as long term memory and perceptual systems (Baddeley, 2003, 2012). Within this model, both short-term storage modules and modules that process or manipulate information are considered to be part of WM. Following from this model, as well as research that provides evidence that these domains overlap significantly and may not tap into separate constructs, both storage and manipulation components will be conceptualized under the domain of WM within the current study (Colom, Shih, Flores-Mendoza, & Quiroga, 2006; Engle, Tuholski, Laughlin, & Conway, 1999; Akira Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001). Differences have been found, however, between
tasks that require short-term storage or manipulation, with the latter showing relationships to fluid intelligence and cognitive aptitudes (Cowan, 2008; Engle, Tuholski, et al., 1999).

Children with poor WM ability demonstrate impaired academic performance, including impaired performance on tests of overall reading and math, and reading fluency (Alloway, Gathercole, Kirkwood, & Elliott, 2009; Bental & Tirosh, 2007; Gathercole & Pickering, 2000; Jacobson et al., 2011). These same children are rated by teachers as having more problems with inattention and distractibility (Alloway et al., 2009). Similarly, a study with a sample of children representing the normal range of WM ability found that WM is long-term predictor of literacy and numeracy outcomes (Alloway, Elliott, & Place, 2010). A recent study found that WM (a composite of both auditory-verbal and visual-spatial WM), was an important predictor of math achievement for students with high levels of ADHD symptoms (Rennie, Beebe-Frankenberger, & Swanson, 2014). Visual-spatial storage, when measured in pre-school children, was also found to predict first grade math outcomes (Bull et al., 2008).

Working memory deficits often co-occur with attention difficulties, both in those individuals with disorders of attention and across the spectrum of typical behaviour (Gathercole & Pickering, 2000; Martinussen & Tannock, 2006; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). Moreover, when examined across one school year, inattention, WM and academic fluency were found to share a significant amount of variance in a community sample of elementary school children (Gray, Rogers, Martinussen, & Tannock, 2015), supporting the hypothesis that these three factors comprise a triad of impairment during the elementary years and into high-school (Rogers, Hwang, Toplak, Weiss, & Tannock, 2011).

Currently there is no robust evidence regarding the direction of the relationships within this triad of impairment, and causal pathways are unknown. One study found that trajectories of ADHD behaviour could be established based on cognitive features at 15 and 24 months, and that those with
more severe ADHD symptoms in grade 3 did show some behavioural differences prior to starting school (Arnett, Macdonald, & Pennington, 2013). The researchers found that early signs of both behavioural and cognitive difficulties were associated with a stable trajectory of poor academic achievement into grade 3 (Arnett et al., 2013). Although this study provides evidence as to the early emergence of both behavioural and cognitive difficulties, and their association with low academic achievement, a grouping of cognitive features based on general intelligence and grouping inattention with an ‘externalizing behaviour’ composite does not allow for looking at domains of specific relevance to academic achievement, such as WM and the spectrum of inattention. Another study, examining a sample of term and pre-term children, found that a measure of executive function (EF) (including visual-spatial WM) did not contribute unique variance to teacher-rated inattention scores in preschool, but visual-spatial span did contribute unique variance to these scores in primary school (Aarnoudse-Moens, Weisglas-Kuperus, Duivenvoorden, van Goudoever, & Oosterlaan, 2013). These studies indicate changes in the relationship between teacher-rated inattention and WM throughout early development.

Other studies have investigated possible mediators that provide some account of the consistent relationship between inattention and academic achievement. In a sample of high school students presenting with clinical and sub-clinical levels of ADHD symptoms, WM was found to be a mediator of the relationship between inattention and reading and math composite scores (Rogers et al., 2011). Thorell (2007) examined WM in a mediating role within an EF composite score. They found that this EF score mediated the relationship between inattention and pre-academic skills in kindergarten-aged children (Thorell, 2007).

The current study sought to extend these studies to a community sample of elementary school children and to further delineate the nature of the relationship between classroom inattention, WM
domains and academic achievement through using a longitudinal mediation design. Differential influences of visual-spatial and auditory-verbal WM are of interest, given previous research that implicates visual-spatial WM as an important factor in math achievement in elementary and high school, and previous findings of differential relationships between WM domain and achievement domain (Li & Geary, 2013; Rogers et al., 2011). As sex differences are often evident in overall levels of inattentive behaviour (Gershon, 2002), sex was investigated in the current study. Moreover, given recent, although limited evidence that sex differences in attention disorders may be due to underlying genetic and cognitive differences between the sexes (Arnett, Pennington, Willcutt, DeFries, & Olson, 2014), we included sex as a moderator of the direct and indirect effects. Based on the previous studies described, as well as on examination of this sample within a one year time frame (Gray, Rogers, Martinussen, & Tannock, 2015), it is hypothesized that there will be a direct relationship between classroom inattention at one point in time and both math and reading outcomes one year later. Additional hypotheses posit that inattention will indirectly influence math outcomes through visual-spatial and auditory-verbal WM, and indirectly influence reading outcomes through auditory-verbal WM.

4.3 Materials and Methods

4.3.1 Participants. Participants were 204 elementary school-aged children (49.5% female) in grades 1-4 (ages 5-9, M = 7.67, SD = 0.91), who were drawn from a larger sample of 524 students, as described below. Students and their teachers and parents were recruited from a large suburban and rural school district in Southern Ontario, Canada. The 7 participating schools (20% of the 33 schools in the district) were stratified across socio-economic groups. Stratifying for sex, this subsample of 204 was created by randomly selecting 2-3 students in each class from the highest, middle and lowest ranking
levels of attention, based on teacher ratings of inattentive behaviour in the classroom, which were rank ordered. This smaller sample, representative of the continuum of attention across students, was then given more in-depth academic and cognitive assessments in the second half of each study year.

The majority of participants were Caucasian (80.6%) with English as their primary language (83.3%). All students that were in mainstream English or French classrooms (29% in French Immersion) were eligible for the study, providing that they did not have major sensory or motor impairment that would preclude the ability to complete the tasks or hear instructions. Teacher reports indicated that 11.8% of the sample had an Individual Education Plan (IEP) with 5.5% identified with ADHD, 3.8% a learning disability, 4.9% a language impairment, 1.6% a behaviour difficulty, 0.5% a developmental disability. In terms of parent education level, 2.7% of participating parents had less than high school education, 5.5% had graduated from high school or an equivalent, 57.7% had graduated from college or university, and 11% had a post graduate degree. No sex differences were found on any demographic variables, with one exception: females were more likely to have a parent (92.3% of parents who filled out questionnaires were mothers, and 7.7% were fathers) with less than high school education.

4.3.2 Procedures. In accordance with procedures approved by the hospital and school board Institutional Review Boards (REB approval number 1000013136), study information was presented in an initial meeting with principals of potential participant schools. Interested principals then contacted the research team, after which an information session for teachers was held at each participating school.

In the Canadian school system, the school year starts in September and ends in June. Thus, November is in term one (term A) and April is in term two (term B) of the school year. In the current study, there were four waves of data collection across two years. The first wave took place in
November of study Year 1, and will be referred to as Year 1 term A (Year 1A). The second wave took place in April of Year 1 and will be referred to as Year 1 term B (Year 1B). Similarly, in the second year of the study, data was collected in November (Year 2A) and in April (Year 2B).

Teachers and parents who gave written informed consent to participate in the current study completed questionnaire packages in November of Years 1 and 2 of the study (Year 1A, Year 2A). This gave the teachers two months to get to know their students (September and October) before completing the questionnaires. At the time of consent, parents were aware that their children might participate in either two or four testing sessions across the two years. Children who had written informed consent from parents and gave verbal assent, participated in academic testing sessions in November of Years 1 and 2 of the study (Year 1A, Year 2A). All assessments were conducted in English, and all materials were English. As described above, after the teacher-rated inattentive behaviour questionnaires were completed, a subset of students from each class, from the lowest, middle and highest bracket of the continuum of attention were randomly selected to participate in further tests of cognitive (including working memory) and academic functioning. These further tests were administered to the same subset of 204 students in April of study Years 1 and 2 (Year 1B, Year 2B).

4.3.3 Measures. The following measures, including a behaviour questionnaire, and standardized tests of academic achievement and WM were selected from a larger study that included a range of behavioural, cognitive and academic measures.

Assessment of classroom attention. Classroom attention was measured using the *Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behaviour Scale* (SWAN; http://www.adhd.net/SWANSCALE.pdf), completed by teachers in November of Year 1 and Year 2 (Year 1A, Year 2A) of the study. This scale assesses behaviour using a sensitive 7-point scale (3 = Far below average, 2 = Below average, 1 = Slightly below average, 0 = Average, -1 = Slightly above...
average, -2 = Above average, -3 = Far above average). This allows for measuring the full range of 
behavioural attention in a population-based sample, using positively worded probes. This design avoids 
psychometric flaws such as negative or positive skewedness that can arise with 4 point-scales, in which 
scores for the majority of children cluster around zero. The SWAN scale provides a range of scores for 
children who have average attention as well as good or poor attention at either end of the spectrum 
(Arnett et al., 2011). The scale is divided into ‘inattention’ and ‘hyperactivity’ subscales. The 
inattention subscale only was employed in this study, considering the large body of evidence that links 
inattention with academic achievement, and does not provide evidence of such a link between 
hyperactivity and academic outcomes (Garner et al., 2014; Rabiner & Coie, 2000). This inattention 
subscale consists of 9 items. Internal consistency of this scale is acceptable and consistent with other 
often used behaviour rating scales (full scale, \( \alpha = .88 \); inattention subscale, \( \alpha = .94 \). Test-retest 
reliability estimates for the full scale range from .72 - .90 (Arnett et al., 2011; Swanson et al., 2001; 
Young, Levy, Martin, & Hay, 2009). In the current sample, a correlation of .74 was found for the 
inattention subscale at Year 1A and Year 2A. Scores are distributed and coded based on a 7-point scale: 
Negative scores indicate stronger attention; lower levels of inattentive behaviour, while positive scores 
indicate weak attention; higher levels of inattentive behaviour.

**Measures of math achievement.** To assess students’ math abilities across the two years, 
subtests from two commonly used batteries were administered at each wave of data collection. The 
addition and subtraction probes from *AIMSweb® M-CBM, Mathematics Curriculum-Based 
Measurement* were used to test grade-level fluency in addition and subtraction, therefore was used as a 
measure of arithmetic fluency. This reliable and valid curriculum-based measure (CBM) assesses math 
fluency; probes are taken from the school curriculum and standardized. Test-retest reliability is high 
(.87), as is inter-rater reliability (.83), and alternate form reliability is moderate (.66) (Thurber, Shinn,
& Smolkowski, 2002). Forms for grades 1-3 included 60 math fact problems (basic subtraction and addition), and forms for grade 4 students included 84 math fact problems. Math problems did not require borrowing or carrying, and contained digits 0-12, thus some computations were either single (1 + 8) multi-digit (11 - 8). The content was the same for both forms, with the only difference being the number of available questions. The scoring is unique in that credit is given to each individual correct digit that appears in the solution. This allows for a more precise analysis of a child’s math skills, as it captures emerging and partial skills as well as fully mastered skills, thus providing a sensitive measure of math fluency. The test is administered in a group format, and students are given 2 minutes to complete as many problems as they can. This task is sensitive to both short-term and long-term improvement in student achievement, thus is appropriate for a longitudinal study design (Thurber et al., 2002).

The Math Calculation subtest from the Woodcock-Johnson - III Tests of Achievement (WJ-IIIACH) was administered to assess a second component of math achievement, within the area of algorithmic computation. The WJ-IIIACH is a highly reliable standardized battery that can be used throughout the academic trajectory. Internal consistency reliability is .86 for Math Calculation (Woodcock, McGrew, & Mather, 2001). The problems in this task do start out with simple arithmetic (i.e. 2 + 3), similar to the CBM addition and subtraction fluency tasks, however problems quickly move into borrowing and carrying (i.e. 16 + 6) and to multiplication and division. The difficulty of the questions increases as the student progresses. The test is timed, however time is not emphasized in the instructions and a full seven minutes is given for the participants to complete as many questions as they can. Partial points are not given as in the CBM tasks, the questions in this task are either given one point or zero points.
Throughout this paper, the WJ-IIIACH Math Calculation task that taps into components of algorithmic computation will be referred to as ‘math calculation.’ The CBM math addition and subtraction fluency tasks described above will be referred to as ‘addition fluency’ and ‘subtraction fluency.’

Previous research has found that addition and subtraction fluency (short time limit for simple arithmetic problems) and math calculation (algorithmic computation, longer time limit), cluster together under the narrow math ability factor, and both are related to perceptual speed. However, these domains of math are separable factors, and only math fluency is related to the broad ability of processing speed (Woodcock et al., 2001).

**Measures of reading achievement.** Reading fluency was assessed using the *Dynamic Indicators of Basic Early Literacy Skills (DIBELS, 5th ed)*, Oral Reading Fluency Subtest. This test is an individually administered curriculum-based measure (CBM) of oral reading fluency, with good predictive validity, and strong concurrent validity (.91 - .96), and alternate-form reliability (.89 - .96) (Good, Kaminski, Smith, Laimon, & Dill, 2001). Students are given 3 grade level passages to read out loud, and are instructed to read as accurately as possible, and to read as many words as they can within one minute. Points are deducted for omissions, substitutions, inaccurate pronunciation and hesitations over 3 seconds. The median number of errors across the three passages is scored, as is the median number of correct words; this latter score was used as the oral reading fluency measure in the current study. One subtest from the *Woodcock-Johnson - III Tests of Achievement (WJ-IIIACH)*, Letter-Word Identification, was used from the “Reading ability” cluster of this battery in order to test fluent single word reading ability. This subtest presents single words listed on a page and words increase in difficulty as the student progresses. Credit is given if the word is said out loud smoothly and accurately.
Throughout this paper, the CBM Oral Reading Fluency subtest will be referred to as ‘Reading Fluency’ and the WJ-ACHIII Letter-Word-Identification test will be referred to as ‘Word Reading.’

Assessment of working memory. To assess WM, the following two tests were chosen for their strong psychometric properties and in order to extend previous findings from studies using these measures. The *Wechsler Intelligence Scale for Children (WISC-IV), Digit Span Subtests (DS)* is a widely-used test of auditory-verbal WM, with an internal consistency of .87 and test-retest reliability of .82 (Wechsler, 2003). The test requires participants to listen to and recall a series of digits. In the Digit Span Forward task, participants are asked to recall the digits exactly as heard, while in the Digit Span Backward task, participants are asked to reproduce the digits heard in backward sequence. The standardized composite score of these two tasks was used in the current study. The *Wide Range Assessment of Memory and Learning (WRAML-2), Finger Windows Forward Subtest (FWF)* was administered in order to assess visual-spatial WM. This test has high internal consistency (.99) and taps into the visual-spatial storage component of WM (Sheslow & Adams, 2003). This battery does not contain a visual-spatial WM task that requires manipulation in addition to short-term storage. Participants are presented with an 8x11 plastic grid with ‘windows’ distributed throughout the grid. Participants, who are seated directly across from the examiner, are asked to replicate the examiner’s visual sequence, created with a pencil tapping different sequences of ‘windows.’ The sequence becomes longer as participants progress. A standardized score is calculated from the total number of correct sequences that the participant is able to replicate.
4.3.4 Statistical approach. Missing data was imputed according to the methods suggested by McKnight, McKnight, Sidani, & Figueredo (2007), when not more than 10-15% of data is missing. It should be noted that for analyses in which parental education is a covariate, only 182 records were complete with this information, thus analyses are based on this reduced sample size. No significant outliers were detected. Assumptions of normality and homoscedasticity were satisfied, with the exception of the Year 2B Math Addition variable, where the Levene’s test was significant for the male sample (however, the test was not significant for the full sample). As a precaution, the HC3 test in the SPSS macro PROCESS (Preacher & Hayes, 2008) was used to produce heteroscedasticity-consistent standard error estimates for this variable.

Relationships between study variables. Partial correlations were calculated to examine the relationship between all study variables. Age was placed as a control variable, as it is an important factor in CBMs across grades and initial analysis indicated that age was differentially related to WM variables. A one-way ANOVA was used to examine sex differences between study variables.

Mediation analyses. All mediation models were designed with visual-spatial WM and auditory-verbal WM at Year 1B as parallel mediators between teacher-rated inattention at Year 1A and academic outcomes at Year 2B, with sex as a moderator. Moderated mediation analyses were carried out using the PROCESS macro for SPSS, developed and described by Hayes (2013) and Preacher & Hayes (2008). Their suggested procedures allow for detecting the difference between the direct effect of a predictor on an outcome variable, and the indirect effect after accounting for the mediator. Using this macro also allows for testing the relative strength of auditory-verbal WM and visual-spatial WM as mediators within each analysis (Hayes, 2013; Preacher & Hayes, 2008). Year 1A academic scores were added in each analysis as a covariate, along with parent education and age. This model allows for partialing out the influence of baseline academic scores collected at Year 1A and examining influences
of each variable across time. Outcome variables were examined in separate models instead of in one simultaneous model in order to elucidate the role of inattention and WM in the development of specific skills within math and reading at the elementary school level. All analyses were carried out with IBM SPSS version 21.

4.4 Results

4.4.1 Correlations between study variables. Partial correlations between all study variables, controlling for age, are presented in Table 3. Teacher-rated inattention, measured at Year 1A, was significantly correlated in the expected direction with WM measures at Year 1B and all academic outcome variables at Year 2B. All main study variables were significantly correlated in the expected direction at the .01 level, with the exception of visual-spatial and auditory-verbal WM which were not significantly correlated. This finding is somewhat unexpected as a previous study using an adolescent sample found that both domains of WM were moderately correlated (Rogers et al., 2011). This finding is discussed further below.

A very strong positive relationship was found between reading fluency and word reading, and between the math addition and subtraction fluency tests, as would be expected given previous research looking at the overlap and differences within these domains of reading achievement (Woodcock et al., 2001), and because the math CBM subtests are both measures of math fact fluency within the same test format. The correlation between math calculation and fluency of math addition and subtraction was lower by comparison, but still strong. This is also expected, as these domains clearly require a similar skill base, however, math fluency is uniquely related to processing speed, while the calculation subtest is related to perceptual speed, and requires higher level procedural skill (Woodcock et al., 2001). Parent education was weakly to moderately correlated with all variables, with the exception of visual-spatial
WM, which appears to be related to sex but not to parental education in this sample. Conversely, auditory-verbal WM was not related to sex, but was weakly correlated with parental education. Sex was significantly correlated with inattention at the .01 level, and with reading fluency, math subtraction and visual-spatial WM at the .05 level. No significant differences on any study variables were found between students in French Immersion or English classrooms ($ps > .05$). For all models, parent education and age were entered into the model as covariates along with Y1A academic scores.

To further examine sex differences in this sample, means and standard deviations for study variables, for boys and girls are presented in Table 3.1. Significant sex differences were found for teacher-rated inattention (boys are rated as more inattentive than girls), reading fluency (girls have higher scores than boys), and math subtraction (boys have higher scores than girls). However, when applying a Bonferroni family-wise correction for each of the comparisons, with the threshold for significance at an alpha level of .0063, the only remaining sex difference was between teacher-rated inattention. The eta-squared for this significant difference is 0.13, therefore 13% of the variance in teacher-rated inattention is accounted for by sex. To assess sex differences in the hypothesized model, sex was entered as a moderator of the mediation analyses.

4.4.2 Mediation analyses

*Math outcomes.* Moderated mediation analyses with two parallel mediators, and sex as a moderator, conducted using ordinary least squares (OLS) path analysis, revealed that teacher-rated inattention indirectly influenced math addition and subtraction fluency outcomes through its effect on visual-spatial WM (see Figures 3 and 3.1), but for boys only. Unstandardized regression coefficients are reported below and in the figures, in accordance with the recommendation of Hayes (2013). Standardized regression coefficients are not produced by PROCESS, and the absolute size of the direct
and indirect effect does not indicate whether effects are small or large, as they are tied to our measures that differ across questionnaire/test. A discussion of effect size follows the presentation of results.

Figure 3 presents results of the analysis with addition fluency as the outcome measure. Children who displayed lower levels of teacher-rated inattention at Year 1A (negative scores correspond to better attention) had higher visual-spatial WM scores ($a = -0.16, p < .01$) at Year 1B, and children with higher visual-spatial WM scores had stronger scores on addition fluency outcomes at Year 2B (visual-spatial WM: $b = 0.59, p < .05$). A bias-corrected bootstrap confidence interval (BCa CI) for the conditional indirect effect for boys ($ab = -0.06$) based on 10,000 bootstrap samples was entirely below zero (-0.13, -0.01), therefore is significant. There was also evidence that teacher-rated inattention influenced addition fluency scores the following year independently of its effect on WM (addition $c' = -0.28, p < .001$). The overall model accounts for 59% of the variance for math addition scores at Year 2 ($R^2 = 0.59, p < .001$). For boys, WM and teacher-rated inattention account for an additional 4.5% of the variance in Year 2B addition scores significantly over and above Year 1A addition scores, parent education and age.

Results were similar for subtraction fluency outcomes (see Figure 3.1). The only difference was that children with higher visual-spatial and auditory-verbal scores had stronger math subtraction outcomes at the end of Year 2B (visual-spatial WM: $b = 0.52, p < .05$, auditory-verbal WM: $b = 0.59, p < .05$). The overall model accounts 55% of the variance for math subtraction scores at Year 2 ($R^2 = 0.55, p < .001$). For boys’ subtraction scores, 11.4% of the variance is accounted for by WM and teacher-rated inattention, which is substantially larger than variance accounted for when looking at addition fluency outcomes.

The proposed model was also significant for boys’ math calculation outcomes at Year 2B. The conditional indirect effect was significant, $b = -0.03$, BCa CI [-0.07 -0.00], as was the direct effect, $b =$
-0.14, BCa CI [-0.22, -0.06], see Figure 3.2. Overall, this model accounted for 53% of the variance for Year 2B math calculation scores \( (R^2 = 0.53, p < .001) \), with teacher-rated inattention and WM accounting for an extra 10.5% of the variance over and above Year 1A calculation scores, parent education and age.

The BCa CIs for all three models passed through zero for girls, thus the mediation through WM was not significant for girls’ addition fluency outcomes (visual-spatial WM: [-0.07, 0.01]; auditory-verbal WM: [-0.05, 0.02]), subtraction fluency outcomes (visual-spatial WM: [-0.06, 0.01]; auditory-verbal WM: [-0.07, 0.00]) or math calculation outcomes (visual-spatial WM: [-0.04, 0.01]; auditory-verbal WM: [-0.04, 0.00]).

A study with a comparable design found that with an adolescent sample, the full model accounted for 40% of the variance in math outcomes (Rogers et al., 2011), which is somewhat less but still comparable to the variance accounted for in our elementary school-aged sample (59%, 55% and 53% for math addition, subtraction and calculation, respectively). Thus far in mediation research, options for calculating overall effect size are limited to simple mediation models without covariates (Preacher & Kelley, 2011). Preacher and Kelley outline the difficulty with classic effect size measures, as they do not fit with indirect effects; the product of two regression coefficients. The most robust effect size measure for indirect effects to date is Preacher & Kelley’s Kappa-squared \( (K^2; Hayes, 2013; Preacher & Kelley, 2011) \). Therefore, recognizing that this is of limited applicability to our full model that includes covariates, we calculated the \( K^2 \) for each significant model, that is, for boys, using visual-spatial WM at Year 1B as a mediator, teacher-rated inattention at Year 1A as the predictor, and math scores at Year 2B as outcome variables. Results indicate that for math addition, \( K^2 = .06, BCa CI [0.01, 0.14] \), for math subtraction \( K^2 = .04, BCa CI [0.00, 0.13] \), and for math calculation \( K^2 = .13, BCa CI [0.06, 0.21] \). This can be interpreted as the indirect effect being about 13% of the maximum value that
it could have been for calculation outcomes, which is between a medium and large effect (Field, 2013; Preacher & Kelley, 2011). According to Field (2013), this is a ‘reasonable’ size for psychological science. The effect sizes for the models with math addition and subtraction fluency as outcome variables are between small and medium effects, with the indirect effects being 4% and 6% of the maximum value that could have been accounted for in the model.

**Reading outcomes.** When predicting reading outcomes, although approaching significance, there was no significant direct relationship between teacher-rated inattention and reading fluency \((b = -0.27, p = .055)\) or word reading \((b = -0.02, p = .54)\) scores one year later (see Supplemental Figures A and B). There were also no significant mediation effects for reading fluency (visual-spatial WM BCa CI \([-0.13, 0.06]\), auditory-verbal WM BCa CI \([-0.16, 0.04]\)) or word reading (visual-spatial WM BCa CI \([-0.02, 0.04]\), auditory-verbal WM BCa CI \([-0.00, 0.02]\)). Significant predictors of reading fluency at Year 2B were auditory-verbal WM at Year 1B \((b = 1.63, p < .05)\), parental education \((b = 3.10, p < .01)\), and Year 1A reading fluency scores \((b = 0.76, p < .001)\). The only significant predictors of word reading were Year 1A word reading scores and age \((b = 0.78, p < .001, b = 1.88, p < .001)\).

To investigate this same model using WM scores at Year 2B, which allows us to control for previous levels of WM at Year 1B (which we cannot do when using Year 1B scores as the mediating variable), we modeled teacher-rated inattention at Year 1A as the independent variable, academic outcomes at Year 2B as outcome variables with WM at Year 2B as a potential mediator. Results replicate the first model in that visual-spatial WM was a significant mediator of the relationship between teacher-rated inattention and math calculation, the confidence interval for the indirect effect for boys was entirely below zero (BCa CI \([-0.10, -0.01]\)). However WM was not a significant mediator for math CBM addition (BCa CI \([-0.10, 0.03]\)) and subtraction (BCa CI \([-0.09, 0.01]\)), reading fluency (BCa CI \([-0.10, 0.12]\)) or word reading (BCa CI \([-0.03, 0.03]\)). Results from this model need be
interpreted with caution, as WM at Year 2B was collected at the same time point as the outcome
variables, thus this model is subject to issues with reverse causation.

A reverse model was conducted in order to confirm directionality of the predictor and mediating
variables. No mediation models were significant when reversing the role of mediator and independent
variable, with Year 1B WM modeled as the independent variable, Year 2A teacher-rated attention as
the mediating variable, Year 2B academic variables as outcomes, sex as a moderator and age, parental
education, Year 1A academic scores, and Year 1A attention scores as covariates.

4.5 Discussion

The present study contributes to our understanding of the longitudinal relationships between
classroom inattention, WM, and math and reading outcomes in a community sample of elementary
school children. We hypothesized that inattention would directly and indirectly influence math
outcomes through auditory-verbal and visual-spatial WM, and influence reading outcomes through
auditory-verbal WM. Using OLS regression based mediation analyses, we found support for a model in
which children’s classroom inattention, as rated by teachers at the beginning of the school year, was
indirectly associated with math outcomes one year later through visual-spatial WM, but only for boys.
There was also a significant direct association between teacher rated inattention and all measured math
outcomes the following year. These findings were consistent with our first hypothesis; the proposed
model held for math CBM addition and subtraction fluency scores as well as math calculation
outcomes.

Our second hypothesis, that auditory-verbal WM would play a role in math outcomes, was not
confirmed in the current study. Explanations for this finding based on the literature are discussed below.
These new findings raise interesting questions about sex differences in the role of visual-spatial WM on different aspects of math skill development, and about the role of auditory-verbal WM across academic outcomes.

One interesting result that came out of initial analyses is that there was no significant correlation between auditory-verbal and visual-spatial WM measures in this sample. Factor-analytic and neuroimaging studies suggest that the two aspects of WM are distinct domains that overlap, thus proposing a domain-distinct model of WM (Alloway & Alloway, 2013; Alloway, Gathercole, & Pickering, 2006; Fassbender & Schweitzer, 2006). One explanation for the lack of correlation could be that our visual-spatial measure taps into storage, while our auditory-verbal measure taps into both storage and processing components of WM; again, related but separable components (Alloway et al., 2006). However, this is unlikely to be the explanation in our sample, because there is also no significant correlation between the two measures of storage only (visual-spatial storage and auditory-verbal storage, \( r = .12, p = .09 \)). Furthermore, a lifespan study provided support that working memory skills are not driven by differences in function (storage versus manipulation) but by domain differences (Alloway & Alloway, 2013). This finding is further supported by the current study that suggests domain differences in a sample of children, representative of the full range of inattentive behaviours in a classroom setting.

The main finding that visual-spatial WM, measuring storage only, was a significant mediator of the relationship between teacher-rated inattention and both math fluency and math calculation outcomes is consistent with expectations based on current literature. The visual-spatial domain of WM is consistently linked to math outcomes, both when the measure includes manipulation demands and short-term storage only (Alloway & Passolunghi, 2011; Bull, Espy, & Wiebe, 2008; Li & Geary, 2013; Rogers et al., 2011). However, there were differences in the effect size between the two math domains;
with successively larger effect sizes for addition fluency, subtraction fluency and calculation, with the calculation effect size reaching a medium to large effect ($K^2 = .13$). The addition and subtraction fluency tests and the WJ-IIIACH math calculation test all require basic math fact skill, and the calculation subtest builds from these basic skills to include procedural knowledge and higher processing demands (Fuchs et al., 2006). There are clear differences between these two measures that may account for the differential influence of WM in terms of effect size and variance accounted for by inattention and WM. Taken together, the robust effect size for calculation scores, and the fact that this model remained significant when controlling for earlier WM (Year 1B) scores, but did not remain significant for fluency scores, indicates that across time, WM appears to play a more significant role as a mediator between inattention and higher-level math calculation skills than for math fluency skills. As elementary school children move from using counting based methods for solving math facts, to fluent memory-based retrieval, there is a parallel shift from activation in the fronto-parietal WM systems, to increased hippocampal activation (Qin et al., 2014). Therefore, it appears that demands on WM for solving math facts are lessened across the early school years, whereas for math calculation tasks that require online processing it is hypothesized that WM load remains high (Geary, 1994). It follows to reason that the influences of inattention on higher-level math outcomes, which require more attention to algorithm and less reliance on fluent retrieval, are partially accounted for by visual-spatial WM. Furthermore, our results that differentiate math fluency from higher-level calculation, with similar effects of visual-spatial WM but different magnitude, can be considered in the context of genetic studies which provide evidence that math fluency is a distinct construct from other domains of math (Petrill, Logan, Hart, et al., 2012).

Another unexpected finding was related to sex differences; in that visual-spatial WM was a significant mediator for boys but not for girls. This was not specifically addressed in an initial
hypothesis, but rather came out of analyses that demonstrated sex differences, therefore leading to the examination of sex as a moderator. To our knowledge, this is the first study to examine sex differences on the role of WM in the relationship between teacher-rated inattention and academic outcomes in the form of standardized achievement. Two studies that looked at variance accounted for by inattention and WM in predicting academic outcomes did not report an assessment of sex differences, outside of the equal distribution of males/females between ADHD and non ADHD groups (Rennie et al., 2014; Rogers et al., 2011). The current results suggest that although sex differences were not found on visual-spatial WM, this construct plays an important role as a mediator between classroom inattention and math outcomes for boys. One possible explanation is through a line of research with adults, which suggests that spatial numerical associations may be represented differently between males and females (Bull, Cleland, & Mitchell, 2012). Bull and colleagues hypothesize that men may rely more on spatial representations of number, thus providing a theory of why visual-spatial WM played a mediating role in boys’ math outcomes. The study was not replicated with children, however, a study with 8th grade students found that boys’ scores on mental rotation predicted math achievement, but this was not found for girls (Ganley & Vasilyeva, 2011). This may suggest that in this higher level of 8th grade math, girls rely less on spatial reasoning for math problem solving than do boys. Future research might examine math anxiety as an additional mediator in this model. Studies have found that math anxiety of female-teachers relates to their female students’ math performance via endorsement of sex stereotypes of who is good at math (Beilock, Gunderson, Ramirez, & Levine, 2010). Therefore it could be that for girls, math anxiety may play a role such that lower performance is not due to visual-spatial WM difficulties, as it is for boys.

Another finding related to sex differences is differential scores for boys and girls on our measure of teacher-rated inattention. In our mediation model, the direct relationship between
inattention and math outcomes was significant for both boys and girls. However, our results show higher levels of inattention for boys, which is consistent with existing research. It has been widely reported that boys have higher levels of inattention as rated by teachers and parents, at least for those who fit diagnostic criteria for ADHD (for a review see Gershon, 2002). However conclusions regarding gender differences in symptoms of inattention are somewhat equivocal, depending on the sample (Biederman et al., 2005). Of particular relevance to the current study, Ramtekkar and colleagues found a similar pattern to our results, using the SWAN scale in a community sample of children aged 7-12, with girls showing stronger levels of attention than boys (Ramtekkar, Reiersen, Todorov, & Todd, 2010).

In terms of sex differences on WM tasks, the current results are in line with findings in clinical ADHD populations (for example, Castellanos et al., 2000; Rucklidge & Tannock, 2002). However, the evidence for sex differences in the general population, on visual-spatial WM is mixed. A body of literature provides consistent findings that males outperform females in visual-spatial rotation tasks, which involve short-term storage as well as transformation (Masters & Sanders, 1993). A study with children found that males outperformed females on an abstract visual-memory task and a memory for location task, while females outperformed males on two verbal tasks (Modesto-Lowe, Yelunina, & Hanjan, 2011). However, similar to our results, there were no sex differences on the visual-sequential memory task (most similar to the WRAML finger windows task in the current study) or the digit span tasks (Modesto-Lowe et al., 2011). Similarly, a study with high-school students found no sex differences on a visual-spatial storage task, but did find that males performed better than females on visual-spatial WM tasks that required processing (Kaufman, 2007). Therefore, the current study provides evidence that boys and girls perform equally on the WM tasks included in this study, when examining a community sample of elementary-school aged children.
The finding that auditory-verbal WM did not significantly mediate the relationship between teacher-rated inattention and academic outcomes makes sense given the mean age of our participants and the nature of the math outcome measures. Conflicting results in the role of auditory-verbal WM in math outcomes may be due to the use of a math composite score in previous studies, that included higher-level math and problem-solving skills that are more strongly associated with verbal WM and executive skills (Passolunghi & Siegel, 2004; Rogers et al., 2011; Swanson, 2011). In addition, although our sample size did not allow for separate mediation analyses within each grade, differences in relative contribution of auditory-verbal WM to math fluency skills between grades were found in the cited studies. Therefore, another possibility is that the children in our sample are young (mean age is 7.67) and may rely mostly on visual-spatial WM to process information at this stage, not having gone through the developmental shift toward relying more on auditory-verbal WM for information processing (Fastenau, Conant, & Lauer, 1998; Raghubar, Barnes, & Hecht, 2010). Another consideration is the presentation format of math problems. It is possible the presentation of problems in a vertical format influenced our results (although 5/45 questions in the math calculation task were horizontal), in that this presentation format recruits more visual-spatial WM resources than math problems that are presented in horizontal format (Trbovich & LeFevre, 2003).

A second main hypothesis in the current study was that inattention would indirectly influence word reading and oral reading fluency outcomes, through auditory-verbal WM. We did not find such an indirect effect, and interestingly, the direct effect of teacher-rated inattention at Year 1A on Year 2B reading fluency and word reading scores was also not significant, while controlling for Year 1A reading fluency scores. In the context of other studies in which inattention is a predictor of reading fluency (for example, Pham, 2013), it is important to note that in the current study, inattention and WM were modeled along with covariates, including parental education, age and Year 1A reading fluency.
scores, which all significantly predicted reading fluency scores at Year 2B. Examination of this sample within a one year time frame indicated a significant relationship between inattention at Year 1A and reading fluency at Year 1A (Gray et al., 2015). However, contrary to these findings, inattention does not appear to play a significant role in predicting reading scores one year later independent of its association with reading fluency at Year 1A. This highlights the strong stability of reading fluency across the elementary school grades. However, auditory-verbal WM was a significant predictor for reading fluency. Thus, although not found to play the hypothesized mediating role, auditory-verbal WM is positioned as an important factor in the development of reading fluency across the elementary school years. These results are consistent with the findings of Li and Geary (2013), who also found that visual-spatial WM was not a predictor of reading outcomes, but that gains in visual-spatial WM were associated with stronger math scores at the end of elementary school.

Although outside the scope of this paper, future studies could seek to account for other mediators within the relationship between inattention and academic outcomes, in addition to the aforementioned construct of math anxiety. The current study focused on WM, however other cognitive functions, such as processing speed and naming speed are important to consider in relation to academic fluency (Fuchs et al., 2008; Jacobson et al., 2011; Martinussen, Grimbos, & Ferrari, 2014). WM and processing speed are highly related in the early years of development. However, recent findings suggest that these two constructs independently predict academic fluency as children move into the elementary-school aged years (Clark et al., 2014; Jacobson et al., 2011). Therefore, future studies might examine the role of processing speed as well as WM in the relationship between classroom inattention and academic fluency, while also controlling for more proximal indicators such as phonemic awareness. Other more distal mediators, such as teacher instructional supports, and parent factors such as support
with homework, may be important to consider as mediating variables in community samples (Daley & Birchwood, 2010; Langberg et al., 2011).

Strengths of this study include the large sample size, as well as the longitudinal design, in which the predictor is collected before the mediating variables, and the outcome variables are collected one year later. Separation of WM domains and academic skill outcome variables allowed for a more specific understanding of these relationships across two school years.

There are some limitations to consider in the design and interpretation of this study. One limitation includes our narrow measures for WM, as we did not have a visual-spatial WM measure that required processing or manipulation, the WRAML measure only taps into short-term storage. Although measures used in the current study are highly reliable, future studies might employ a variety of WM measures for each domain, providing the ability to create a comprehensive composite for each domain. A previous study found that visual-spatial storage was a strong predictor of math achievement early in the first grade, but by age 8, a visual-spatial measure that required manipulation also predicted math outcomes (Bull et al., 2008). It could be that the importance of visual-spatial WM was underestimated by not including a measure that would include all components of visual-spatial WM. Indeed, one study found that the manipulation component of visual-spatial WM did contribute additional variance to math outcomes above the contributions of visual-spatial short-term storage (Geary, Hoard, & Nugent, 2012).

Another limitation in our study design is that practical considerations limited data collection time points, such that our mediating variable was collected at 2 time points across two years, whereas the outcome variables were collected at 4 time points. It would have been ideal to have baseline WM measures, however, time allotted by the school for each testing session as well as date restrictions did not permit for collecting cognitive measures for the full sample of 524.
Strengthening the confidence in outcomes is the fact that when reverse modeling WM and inattention, where WM is placed at the predictor, and inattention as the mediator, WM measures at Year 1 do not predict levels of inattention in Year 2. Our outcomes regarding visual-spatial WM are afforded more confidence, as we were able to run the analysis with WM at Year 2 as the mediating variable, thus accounting for the influence of prior WM scores (at Year 1). This model continued to reach significance for calculation outcomes, however this model is interpreted with caution, as WM measures at Year 2 were collected at the same time point as the academic outcome measures. Therefore, although further evidence is needed to substantiate the developmental directionality between inattention and WM, these findings add to our knowledge about longitudinal predictors of academic outcomes in elementary school children and further specify the nature of the relationship between inattention, WM and academic outcomes across elementary school, for typically developing children.

4.5.1 Conclusions. Findings extend previous research and confirm and replicate the body of literature that positions behavioural inattention as a robust predictor of later math achievement, further specifying that this relationship is robust for arithmetic fluency and algorithmic computation, in typically developing elementary school children. Further, findings add new information about the role WM plays for boys and girls in the relationship between inattention and math and reading outcomes across two school years. Contrary to results from cross-sectional studies, our findings provide evidence that after controlling for initial reading fluency scores, auditory-verbal WM is a more robust predictor of reading fluency across two school years, as compared to teacher-rated inattention, which did not predict growth in reading fluency beyond the contribution of Year 1A inattention.

Although math fluency shares significant variance with inattention and both domains of WM (Gray, Rogers, Martinussen, & Tannock, 2015), the current study provides evidence that boys’ classroom inattention (as rated by teachers) directly influences their math fact fluency and math
calculation scores across time, controlling for age, parental education and math scores at Year 1. Main findings emphasize that for boys, inattention has a direct effect as well as an indirect influence on math fluency and calculation skills through visual-spatial WM in the elementary school grades.
Table 3
Partial Correlations, Controlling for Age, Between Study Variables for Full Sample (N = 204)

<table>
<thead>
<tr>
<th>Variables</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Teacher-rated Inattention</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Word Reading</td>
<td>-.49**</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Reading Fluency</td>
<td>-.54**</td>
<td>.81**</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Math Calculation</td>
<td>-.48**</td>
<td>.49**</td>
<td>.51**</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Addition Fluency</td>
<td>-.48**</td>
<td>.42**</td>
<td>.52**</td>
<td>.59**</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Subtraction Fluency</td>
<td>-.40**</td>
<td>.44**</td>
<td>.47**</td>
<td>.58**</td>
<td>.82**</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Auditory-Verbal WM</td>
<td>-.23**</td>
<td>.31**</td>
<td>.35**</td>
<td>.33**</td>
<td>.30**</td>
<td>.34**</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Visual-Spatial WM</td>
<td>-.34**</td>
<td>.24**</td>
<td>.24**</td>
<td>.33**</td>
<td>.33**</td>
<td>.32**</td>
<td>.14</td>
<td>–</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Sex</td>
<td>-.37**</td>
<td>.08</td>
<td>.16*</td>
<td>.08</td>
<td>.00</td>
<td>-.15**</td>
<td>-.05</td>
<td>.16*</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>10. Parent education level</td>
<td>-.22**</td>
<td>.23**</td>
<td>.31**</td>
<td>.22**</td>
<td>.20**</td>
<td>.24**</td>
<td>.16*</td>
<td>.10</td>
<td>.03</td>
<td>–</td>
</tr>
</tbody>
</table>

Note: Significant correlation: * p < .05. ** p < .01.
Measured at Year 1 Time A: Teacher-rated Inattention, Age, Sex, Parent education level.
Measured at Year 1 Time B: All working memory measures.
Measured at Year 2 Time B: All academic measures.
Table 3.1

Means and Standard Deviations for Study Variables, for Girls and Boys  \( (N = 204) \)

<table>
<thead>
<tr>
<th></th>
<th>Total ( M (SD) )</th>
<th>Males ( M (SD) )</th>
<th>Females ( M (SD) )</th>
<th>( F^a )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teacher-rated Inattention</td>
<td>-1.58 (13.92)</td>
<td>3.43 (13.07)</td>
<td>-6.69 (12.91)</td>
<td>30.95**</td>
</tr>
<tr>
<td>Word Reading</td>
<td>102.0 (11.79)</td>
<td>100.53 (12.52)</td>
<td>103.56 (10.84)</td>
<td>3.41</td>
</tr>
<tr>
<td>Reading Fluency</td>
<td>102.2 (44.26)</td>
<td>95.95 (44.83)</td>
<td>108.47 (42.98)</td>
<td>4.14*</td>
</tr>
<tr>
<td>Math Calculation</td>
<td>95.00 (9.61)</td>
<td>94.15 (9.35)</td>
<td>95.87 (9.83)</td>
<td>1.65</td>
</tr>
<tr>
<td>Addition Fluency</td>
<td>41.67 (18.14)</td>
<td>42.37 (19.51)</td>
<td>40.96 (16.70)</td>
<td>0.31</td>
</tr>
<tr>
<td>Subtraction Fluency</td>
<td>29.82 (13.90)</td>
<td>32.23 (14.88)</td>
<td>27.36 (12.43)</td>
<td>6.44*</td>
</tr>
<tr>
<td>Auditory-Verbal WM</td>
<td>8.77 (2.45)</td>
<td>8.78 (2.33)</td>
<td>8.76 (2.58)</td>
<td>0.002</td>
</tr>
<tr>
<td>Visual-Spatial WM</td>
<td>8.12 (3.25)</td>
<td>7.73 (3.31)</td>
<td>8.51 (3.16)</td>
<td>3.01</td>
</tr>
</tbody>
</table>

Note: \( *p > .05 \), \( **p > .001 \)

\( ^aF \) statistic for one-way ANOVA

Measured at Year 1 Time A: Teacher-rated Inattention, Age, Sex, Parent education level.
Measured at Year 1 Time B: All working memory measures.
Measured at Year 2 Time B: All academic measures.
Figure 3. Significant moderated mediation: Visual-spatial WM as a mediator of the relationship between teacher-rated inattention and boys’ math addition scores one year later.
Figure 3.1. Significant moderated mediation: Visual-spatial WM as a mediator of the relationship between teacher-rated inattention and boys’ math subtraction scores one year later.
Figure 3.2. Significant moderated mediation: Visual-spatial WM as a mediator of the relationship between teacher-rated inattention and boys’ math calculation scores one year later.
CHAPTER FIVE

Supplementary Analyses
5.1 Purpose of Supplemental Analyses

The purpose of this set of analyses is to assess the same mediation model described in chapter 5, using classroom performance outcome measures instead of standardized achievement scores that were used in studies described in chapters 4 and 5. These analyses were not included in the manuscript (chapter 5) in order to keep the paper objectives and outcomes parsimonious. The methods in this supplemental analysis are exactly the same those described in chapter 5, and are not repeated here. The only differences are the outcome measures.

5.2 Measures

5.2.1 Academic functioning questionnaire. This academic functioning questionnaire is a simple measure developed specifically for this study. The participants’ teachers filled out this short questionnaire at the same time as all of the other questionnaires about demographics and behaviour in years 1 and 2 of the study. The academic functioning questionnaires that were filled out in Year 2 of the study were used in this analysis, in order to assess classroom performance outcomes across two school years. Teachers answered the following questions on paper, using a 1-5 scale (1 = well below, 2 = below, 3 = average, 4 = above 5 well above): 1) How does this student perform in reading fluency relative to other students at this grade level? 2) How does this student perform in math computation fluency relative to other students at this grade level? 3) How does this student perform in mathematical reasoning relative to other students at this grade level?

5.3 Results

5.3.1 Correlations. See Supplemental Table A for partial correlations between all variables. When comparing these correlations to the correlations tables with standardized achievement scores (Table 3), they are similar in that they are all strong negative correlations, with the values being higher for the classroom performance values. This higher correlation would be expected as it was teachers that
were rating both inattention and classroom performance. To ensure that multicollinearity was not a problem for the analyses, the variance inflation factor (VIF) was calculated. The results (tolerance: 1.0000, VIF 1.000) indicate that multicollinearity is not a problem for the following analyses.

5.3.2 Mediation analyses. The following analyses were conducted using ordinary least squares path analysis, with multiple mediators (visual-spatial WM and auditory-verbal WM). Teacher-rated inattention directly, and indirectly influenced teacher-rated math fluency through visual-spatial WM. Participants with higher ratings of attention had stronger visual-spatial WM scores ($a = -0.144$). Although in the expected direction but not reaching the .05 level of significance, participants who had stronger visual-spatial WM scores were rated by teachers as having better math fluency skills as compared to peers ($b = 0.033$). A bias-corrected bootstrap confidence interval for the indirect effect ($ab = -0.003$) was significant; based on 5000 bootstrap samples it was entirely above zero (-0.008, -0.000).

There was also evidence that teacher-rated inattention directly influenced teacher-rated math fluency scores 1 year later, independent of its effect on WM ($c' = -0.015$, $p > .01$). This mediation effect was significantly moderated by sex (index = 0.002, 0.000 – 0.007), therefore this model is only significant for males. The mediation effect does not hold for female participants.

The moderated mediation model was also significant when using teacher-rated math reasoning in Year 2 as the outcome variable. Participants with higher ratings of attention had stronger visual-spatial WM scores ($a = -0.157$). Participants who had stronger visual-spatial WM scores had better math reasoning skills as compared to peers, according to teacher ratings ($b = 0.038$). A bias-corrected bootstrap confidence interval for the indirect effect ($ab = -0.003$) was significant; based on 5000 bootstrap samples it was entirely above zero (-0.008, -0.001). Teacher-rated inattention also directly influenced teacher-rated math reasoning scores 1 year later, independent of its effect on WM ($c' = -$
0.013, p > .05). This mediation effect was also significantly moderated by sex (index = 0.003, 0.000 – 0.007).

Although results indicated that there is a direct effect of inattention on teacher-rated reading fluency (c’ = -0.012, p > .05, p = .04), there is no evidence of mediation through either auditory-verbal or visual-spatial WM.

These results have a very similar pattern to the results presented in the main analyses (chapter 5). Visual-spatial WM was a significant mediator in the relationship between teacher-rated inattention and classroom performance outcomes, but only for boys. There was a direct relationship between teacher-rated inattention and teacher-rated reading fluency, however no mediation effect was found, through either WM domain.

The Kappa squared (K^2) values were calculated to evaluate effect size for these mediation models. As described in chapter 5, the K^2 value can only be calculated for a model with one mediator and no covariates. Therefore, the same caution need be applied here, as these effect sizes are not representative of this model with important covariates included. However, keeping this caveat in mind, the K^2 values were as follows: Teacher-rated math fluency = 0.10 and teacher-rated math reasoning = 0.10. The effect size of .10 is in between a medium and large effect (Field, 2013). The effect size for the mediation model with teacher-rated math fluency is quite a bit larger than the small to medium effect sizes found when standardized math addition and subtraction fluency scores were used (.04, .06). It is not possible to direct compare the standardized score for math calculation and the teacher-ratings of math reasoning, given the differences in the type of math these two measures are assessing. However, it should be noted that the effect size for the mediation models are similar between these two variables (0.10 for teacher-rated math reasoning and 0.13 for standardized math calculation outcomes).
**Partial Correlations, Controlling for Age, Between Supplemental Variables for Full Sample (N = 204)**

<table>
<thead>
<tr>
<th>Variables</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Teacher-rated Inattention</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. TR Reading Fluency</td>
<td>-0.62**</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. TR Math Fluency</td>
<td>-0.60**</td>
<td>0.74**</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. TR Math Reasoning</td>
<td>-0.57**</td>
<td>0.74**</td>
<td>0.94**</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Auditory-Verbal WM</td>
<td>-0.23**</td>
<td>0.32**</td>
<td>0.29**</td>
<td>0.25**</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Visual-Spatial WM</td>
<td>-0.34**</td>
<td>0.27**</td>
<td>0.33**</td>
<td>0.33**</td>
<td>0.14</td>
<td>–</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Sex</td>
<td>-0.37**</td>
<td>0.16*</td>
<td>0.08</td>
<td>0.08</td>
<td>-0.05</td>
<td>0.16*</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>8. Parent education level</td>
<td>-0.22**</td>
<td>0.21**</td>
<td>0.25**</td>
<td>0.24**</td>
<td>0.16*</td>
<td>0.10</td>
<td>0.03</td>
<td>–</td>
</tr>
</tbody>
</table>

*Note: Significant correlation: *p < .05. **p < .01.*

Measured at Year 1 Time A: Teacher-rated Inattention, Age, Sex, Parent education level.

Measured at Year 1 Time B: All working memory measures.

Measured at Year 2 Time B: All measures of teacher rated performance.
CHAPTER SIX

Discussion and Implications
6.1 Summary of Key Findings

The objectives of this dissertation work were to 1) assess the level of evidence and strength of the relationship between inattentive behaviours and academic underachievement, 2) explore the role WM and other covariates play in the contemporaneous relationship between inattention and math and reading fluency and 3) to follow up from the cross-sectional analysis to assess the nature of these relationships across time and with both standardized achievement and classroom performance measures.

A systematic literature review was warranted in order to thoroughly review the evidence for a relationship between inattention, measured dimensionally, and academic achievement in a typically developing population. A quality analysis revealed that overall, this literature base was at a low to moderate risk of bias. Strengths and weaknesses in the quality of studies were highlighted and may be useful for future research in this area. Using a best evidence synthesis, the evidence was strong for a relationship in which higher levels of inattention were consistently linked to lower scores on both standardized achievement measures and on classroom performance measures. Although this has not been confirmed through a meta-analysis, contrary to expectations the average correlations were higher when the outcome was a classroom performance measure. A comparison of the correlations from the second set of analyses in this thesis provides more support for this finding (see Table 3 and Supplemental Table A). Both sets of correlations between inattention and standardized test and classroom performance outcomes were in the strong range. However, correlations between inattention and classroom performance were slightly stronger. It follows that if teachers are rating both inattention and math performance, the correlations would be somewhat higher. However, this finding is useful to note in terms of measurement and moderators of the effect magnitude in future studies.

The evidence was strong when synthesizing results across the elementary school age, moderate for the pre-school age and inconclusive during the high school years. The overall magnitude of
correlations and variance accounted for by inattention were modest and highly variable. This suggests that the association between inattention and academic underachievement is not direct. These results point toward the need to investigate other factors that may play a mediating role in the relationship between inattention and academic outcomes. Therefore, I investigated WM, a relevant cognitive construct to both inattention and academic achievement, as a mediator.

To test auditory-verbal and visual-spatial WM as possible mediators of the relationship between inattention and academic outcomes, I analyzed two waves of data for this dissertation. My analysis of the first wave of data provided insight into the shared variance between inattention and academic fluency (measured at the same time point) and WM, while controlling for age, parental education and sex. The results of these analyses indicate that auditory-verbal WM plays a stronger role in both reading and math fluency as compared to visual-spatial WM. Another finding was that sex, age and parental education account for more variance in reading fluency than math fluency. These results provide evidence that WM is a key factor that accounts for a significant amount of variance in the link between inattention and poor academic fluency. The findings also provide confidence that WM is a viable mediator to examine further in longitudinal models.

The second wave of data analysis constituted the main manuscript in this dissertation, and included a range of outcome measures collected across two school years. The main study provided new findings about sex differences in the role that visual-spatial WM plays in the relationship between inattention and math achievement. These findings showed that visual-spatial WM is a significant mediator of the relationship between inattention and math outcomes for boys but not for girls. These sex differences were found when examining both standardized test scores and classroom performance measures. One line of research to consider in understanding these sex differences is the idea that spatial numerical associations may be represented differently by males and females (Bull, Cleland, & Mitchell,
Another line of research to consider could be that for girls, math anxiety may be more salient than for boys (Beilock, Gunderson, Ramirez, & Levine, 2010). Therefore, it could be that lower performance in girls is more closely related to math anxiety, and may not be due to visual-spatial difficulties as it is for boys.

The findings also indicated a differential magnitude of importance for WM in different standardized math outcomes. The indirect effect of inattention on math calculation skills through visual-spatial WM was larger than for math fluency outcomes, only for standardized test outcomes. The magnitude of the effect (in between medium and large) was not different when comparing teacher ratings of math fluency and math reasoning. It is possible that teachers were not differentiating specifically between math fluency and math reasoning. Teacher judgment accuracy could have been improved if teachers were informed about the standard of comparison for their rating (Südkamp, Kaiser, & Möller, 2012). After controlling for parental education, age and fluency scores in the first year of the study, I found that auditory-verbal WM was not a significant mediator between inattention and math outcomes. This contrasts with the results from the first study in which both auditory-verbal WM and visual-spatial WM were mediators with math fluency as the outcome. Across time, it appears that auditory-verbal WM was a more robust predictor of reading fluency than was inattention, and did not fit into the role of a mediator.

Taken together, these results do support the dual pathway to poor academic achievement model (Rapport et al., 1999), with differences based on outcome measure and examination of variables across time. When looking at math outcomes, behavioural inattention both directly and indirectly, through visual-spatial WM, influenced math achievement for boys. This supports Rapport’s hypothesis that both behavioural and cognitive variables would account for the relationship between ADHD and lower academic outcomes, although the current study extends this to inattention measured dimensionally,
without hyperactivity. Moreover, these results are consistent not only with standardized achievement tests, but also with classroom performance outcomes (when teachers rate math performance). When examining reading fluency outcomes, it appears that the dual pathway (cognitive and behavioural influences on academic achievement) only holds for the contemporaneous results. In the first study, inattention had a direct influence on reading fluency, and an indirect influence through both domains of WM. Over the longer term, auditory-verbal WM played a stronger role in reading fluency outcomes, and inattention did not play a role independent of its association with reading fluency in the first year of the study. The longitudinal study design provided some evidence that both inattention in the classroom (behavioural factor), and WM (cognitive factor) are pathways of influence for academic outcomes. It appears that these two pathways, specifically visual-spatial WM for the cognitive pathway, continue to be important for boys’ math outcomes across the elementary school years. For both sexes, the fact that inattention did not influence reading fluency above and beyond its contribution at year 1 highlights the stability of reading fluency and the importance of auditory-verbal WM in this academic skill. This finding also may relate to skills that rely on the development of auditory-verbal WM, such as language, which in turn is important for reading fluency and reading comprehension (Riedel, 2007).

6.2 Clinical and Educational Implications

The results of all three studies taken together confirm that inattention, poor WM and poor academic achievement comprise a risk triad in non-clinical samples of school-aged children, with visual-spatial WM as a key domain of importance for boys in relation to math calculation outcomes. A model in which to consider the results from a clinical or educational perspective is the framework of multiple risk factors (social or child factors) that impact long-term school outcomes (Gutman, Sameroff, & Cole, 2003). Gutman and colleagues examined multiple social risk factors and the child factors of IQ and mental health that comprised high- and low-risk groups. Taking into account this dissertation
research, it is possible that children in the high-risk group also had cognitive risk factors, such as visual-spatial WM difficulties. It may be that visual-spatial WM difficulties constitute an additional risk factor that puts inattentive boys at risk for poor math achievement.

The results of this dissertation research suggest that WM may be an important target for clinical or educational intervention when attempting to ameliorate academic outcomes for students who are inattentive. The results lead to the hypothesis that intervention programs targeting WM, in terms of capacity or efficiency enhancement, would have positive benefits for academic achievement. However, programs designed to improve WM capacity have shown limited cognitive benefits and no robust transfer to academic improvement (Gray et al., 2012; Melby-Lervåg & Hulme, 2013). Alternative methods for targeting WM include modifying the classroom context and altering instructional language and supports to provide a learning environment that is less taxing for children who have attention and WM difficulties (Gathercole & Alloway, 2004; Tannock & Martinussen, 2007). Perhaps the most promising avenue of intervention is through early childhood intervention/prevention. Intervention as early as age 4, through social emotional as well as physical development programming, is both practically and theoretically promising for prevention of the academic achievement gaps between students with high and low attention and WM capacities (Diamond & Lee, 2011).

It is important to note that these thesis analyses did not include other variables related to WM and academic achievement that may be salient factors in the relationship between inattention and academic outcomes. For example, processing speed, naming speed, phonemic awareness, or more distal factors such as student engagement and motivation are factors to consider along with WM in future models examining academic outcomes.
6.3 Conclusions

From the systematic review, we can conclude that the literature supports a consistent relationship in which high levels of classroom inattention predict lower academic achievement across a range of outcome measures. However, the variability in results leads to the question of which other variables are at play when teachers rate inattention. This dissertation research found evidence that inattention both directly (for both sexes) and indirectly, through visual-spatial WM, influenced boys’ math outcomes. Poor visual-spatial WM may be an additional risk factor for low achievement, and can be added into risk models that assess multiple risk domains. The variance accounted for by inattention and WM is a significant magnitude considering the complex classroom environment. The results leave much room, however, for investigating other cognitive, social-emotional, and classroom factors that play different roles in the relationship between inattention and academic achievement.
References


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doi:10.1016/j.jecp.2005.08.003


doi:10.1016/j.jecp.2012.03.003


Appendix A

Data Preparation Procedures

The following details regarding data cleaning and data checks were carried out prior to the main analyses that are described in Chapters 3 and 4.

A number of steps were taken to ensure that data used in this study are accurate and to ensure its appropriate structure and integrity. Manual checks were completed prior to analyses to confirm accurate data entry and the absence of mistyped data. Next, two separate databases were created: the first was comprised of all variables that were collected for the full sample (years 1 and 2, time A), the second was comprised of cases that were selected for phase 2 participation, that is, cases with both time A and time B data for years 1 and 2. Separate databases for the full sample and the subsample allowed for missing data exploration and imputation. The presence and patterns of missing data were explored using SPSS software (version 22). The full sample size before removing subjects was $N = 524$. About three quarters of the sample ($n = 371$) had full data at Year 1 and Year 2, and 122 cases had partial data (23% of the full sample). Only 3 participants had entire records missing at year 1, and 28 more had missing records at year 2. Thus, these 31 participants (5.9% of the original sample) were excluded from all analyses. The sample size for time A data was $N = 493$, after excluding these subjects. Sample size for phase two subjects used in the thesis analyses was $n = 204$. Demographic data was collected from 182 parents; therefore any analyses that included parent education as a variable were based on 182 cases.

Investigation of the amount of missing data for individual variables and scales showed that the rating scale variables (SWAN, WMRS, SDQ) had less than 5% of missing data and individual variables (teacher-rated reading and math fluency, CMB ORF, WJ math fluency) had less than 10% of missing data. These amounts of missing data support the imputation strategy, which is recommended
when the amount of ‘missingness’ does not exceed 10-15% (McKnight, McKnight, Sidani, & Figueredo, 2007). The imputation was performed using the regression model when the imputed values were predicted based on all the information available from the dataset. The imputation was performed 5 times and the results were averaged across the five imputations to produce a complete dataset that was used for further analyses.

After missing data were imputed, the distributional properties of each variable were examined to investigate the presence of outliers and to check whether the normality assumption held for continuous variables. No significant outliers were detected in either year 1 or year 2 data, and assumptions of normality and homoscedasticity were satisfied. One exception was the Year 2B Math Addition variable, where the Levene’s test for equality of variances was significant for the male sample, but not the full sample. Heteroscedasticity-consistent standard error estimates were produced for this variable using the HC3 test in PROCESS (Preacher & Hayes, 2008).
Appendix B

Supplementary Figures

Supplemental Figure A. WM is not a significant mediator of the relationship between teacher-rated inattention and word reading scores one year later.
Supplemental Figure B. WM is not a significant mediator of the relationship between teacher-rated inattention and reading fluency scores one year later.