

**WORKING MEMORY AND INHIBITORY CONTROL  
AS PREDICTORS OF EMERGENT HANDWRITING**

by

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Bachelor of Arts, University of Calgary, 2002

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## ABSTRACT

This study sought to determine whether working memory played a role in explaining young children's emergent handwriting abilities and whether inhibitory control mediated any found relationship between the two variables. Fifty-nine children (29 boys and 30 girls) participated in this study. Participants were assessed using various handwriting and cognitive measures, including an adapted day-night Stroop task which assessed inhibitory control. Analysis using correlational design indicated an association between tasks assessing sentence writing ability and working memory differed in magnitude but was statistically significant. Children with larger verbal/visual working memory capacities performed better on various handwriting tasks. Results of hierarchical regression techniques found that inhibitory control did not mediate the relationship between handwriting and working memory. This study is useful in providing teachers with information and ideas on how to reduce the cognitive load experienced by young children who are learning how to handwrite.

## DEDICATION

I would like to dedicate this work to my loving grandmothers; Gertrude, for teaching me to never settle for anything that is even moderately unsatisfactory and to live with a sense of fun and adventure, and Kay for teaching me the value of family and sacrifice. You have both been a source of inspiration and strength to me and I have valued your life lessons and teachings.

I would like to thank my father, Bruce, for instilling in me a work ethic that has driven me to achieve my goals, my mother, Linda, for being a friend and a driving force behind me, and my sister, Kathleen, for being a brave soul who is always willing to lend a hand to anyone who needs it.

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## CHAPTER ONE: INTRODUCTION

For young children, handwriting is a complicated process involving a multitude of cognitive, language and kinaesthetic systems. Handwriting refers here to printing the orthography of an alphabetic script to represent known words and/or ideas. To do this activity, children must learn to visually recognize letters of an alphabet, they must master fine motor control in order to handwrite in certain defined spaces, and they must learn to concentrate and sustain attention for extended lengths of time to copy and practice a single letter. When children learn to reproduce the alphabet, all 26 unique symbols, they must further deal with the surprise that each letter has a capitalized form that they must master as well, and use only in certain circumstances. Learning to handwrite to produce legible text that allows for effective communication with others is indeed a complicated process. Researchers have identified six prerequisite skills that children must acquire before handwriting instruction can begin: (1) small muscle development, (2) eye-hand coordination, (3) the ability to hold utensils or writing tools, (4) the ability to form basic strokes smoothly, such as circles and lines, (5) letter perception; including the ability to recognize forms, notice likenesses and differences, infer the movements necessary for the production of the form, and give accurate verbal descriptions of what was seen, and (6) orientation to printed language, which involves the visual analysis of letters and words along with right-left discrimination (Donoghue, 1975; Lamme, 1979). Learning to handwrite clearly requires a lot of skill for young emergent writers but surprisingly they seem ready for learning just such a task.

The emergence of children's knowledge about print occurs long before formal instruction begins. From birth onward, young children soon learn to recognize the function of environmental print found on food labels, billboards, books, flyers and toys. Children also engage in literacy practices that involve print through interactions with others at the library, in childcare programmes, and at the supermarket. Through exposure to these culturally defined literacy practices, children begin to make connections between letters and the acts of reading and handwriting before they are explicitly taught to do so. By age 3 years, most children recognize the form of certain words in familiar contexts. Since incidental learning precedes formal instruction of handwriting, it is important to study the capabilities of young children prior to school entry, including children's comprehension and production of letters and symbols (Gombert & Fayol, 1992). In preschool environments, children become familiar with words and letters, learning letter features, naming letters, discriminating between letters, words and sounds, and reading a small number words when they are presented in a familiar context (Lomax & McGee, 1987). However, it is not until they enter Kindergarten and reach the age of 5 or 6 years that children fully understand directionality, book handling, and the differentiation between print and pictures (Gombert & Fayol, 1992, Lomax & McGee, 1987).

Developmental patterns observed in young children's written output indicate that before children can produce recognizable symbols, they approximate handwriting practices (i.e., holding a pencil and writing on paper), however, their written products can range from scribbling, wavy lines, drawings, circles, pseudo-letters, letters mostly from their first name, other letters and at times, they may refuse to produce a script (Gombert & Fayol, 1992). Even though children may have produced written output in previous

sessions, a refusal to write may be thought of as a more advanced response than handwriting pseudo-letters because it is here that children are beginning to recognize that their written output does not always approximate the writing of adult models (Gombert & Fayol, 1992). Collectively these findings suggest that learning to handwrite and/or compose a written text is a complicated task for young children involving significant cognitive processes and effort.

Much of the research on the cognitive system that underlies the writing process has traditionally focussed on the writing of mature adult writers or of older children with writing disabilities. These studies show that composing written text involves a functional cognitive system that draws upon multiple component processes (Berninger, Vaughan, Abbott, Rogan, Brooks, Reed, & Graham, 1997). These cognitive processes can be divided into two categories: low level, which involve creating a letter memory, retrieving the letters quickly and effortlessly from long-term memory, motor planning, and motor production (i.e., handwriting), and high level, which involve strategies for planning, generating language at the sentence and text levels, and reviewing and revising written text (i.e., composing) (Berninger et al., 1997). However, learning to handwrite is influenced by both external environmental factors and by internal cognitive processes. External factors refer to instructional procedures and materials used during writing. Internal processes include abilities such as visuomotor skills, visual perception, motor planning, in-hand manipulation, and kinaesthetic awareness (Marr, Windsor, & Cermak, 2001). Marr and his colleagues (2001) hypothesize that cognitive readiness affects children's handwriting performance and before handwriting performance can become optimal, a certain level of cognitive/language ability needs to exist (Marr et al., 2001).

The authors also propose that the nature of internal factors, and their relationship to handwriting have not been studied extensively and it is necessary to do so in the future (Marr et al., 2001).

One line of research that has potential to inform the study of handwriting performance among young children concerns the development of executive function. Executive function refers to the cognitive processes that result in goal-directed behaviour (e.g. inhibition of prepotent responses, working memory, planning, and mental flexibility) and are typically associated with the functions of the prefrontal cortex (Hughes, 1998). Researchers have found that executive functions and their relevance to academics can be measured as early as preschool and additionally, rapid change related to executive functions occurs over the preschool year (Sonuga-Barke, Dalen, Daley, & Remington, 2002). Generating a piece of text is viewed as a complex process involving many simultaneous subgoals and interacting processes which may be sensitive to executive operations, specifically, limited working memory capacity (Swanson & Berninger, 1996).

Working memory is a processing resource of limited capacity, holding information in the mind and manipulating this information while other cognitive tasks are simultaneously occurring (Swanson, 1992). According to this view, handwriting is an interactive process, and the overall quality is limited by the writer's working memory resources as the writer must use memory-consuming cognitive executive routines to manage the handwriting enterprise (Swanson & Berninger, 1996). Working memory plays a role in coordinating all of the processes that interact with each other during text generation (Berninger, 1999). As handwriting requires the juggling of multiple goals

such as selecting words to be written, producing text, and monitoring what has been written, working memory may seem more critical to advanced writers partaking in lengthy script exercises but for young, emergent writers the working memory system may be taxed on activities such as letter copying and production tasks. One aim of the current study is to investigate the role of working memory on handwriting performance of young, school-aged children.

Another aim of the study is to investigate whether working memory operates in conjunction with, or independent of, an executive system related to inhibitory control. Inhibitory mechanisms serve to restrict access to information that is relevant, delete information that is no longer relevant, and restrain the production of incorrect retrieval of information from working memory (Hasher & Zacks, 1988). Research is available that suggests declines in working memory capacity among the elderly occur partially as a result of increasingly ineffective inhibitory mechanisms. A study performed by Andrés, Van der Linden, and Parmentier (2004) examined age differences in working memory and inhibition among young ( $n = 72$ ) and elderly ( $n = 72$ ) adults. Trigrams (three letters) were created that did not resemble acronyms and these were presented to the participants under three conditions. In the *single-trigram* condition, one trigram was presented for retention. Participants were asked to complete an interpolated activity which involved reading a string of numbers aloud for ten seconds and then participants were asked to recall the trigram. In the *interference* condition a second trigram was presented immediately following the presentation of the first trigram and the participant had to recall each trigram after completion of the interpolated activity. In the *directed-forgetting* condition, two trigrams were presented consecutively as in the interference

condition; however, after the presentation of the second trigram, a card was held up immediately for 500 ms that read “to be forgotten”, prompting participants to forget this second trigram as they would not be required to recall it after the completion of the interpolated activity. Results indicated that the presentation of a second trigram to be remembered in the *interference condition* decreased recall performance in both groups compared to the *single-trigram* or the *directed-forgetting* condition; however, the effect was more dramatic for elderly participants than was found among the younger participants. Taken together, the results show that elderly participants are more sensitive to interference on memory tasks than are their younger counterparts and elderly participants are less efficient in inhibiting no-longer relevant information.

Whether the relations between inhibitory control and working memory declines also explain working memory capacity development of young children is not well understood. Wolfe and Bell (2004) examined relations between cognitive inhibition and working memory capacity among 4 1/2 year old children using a day-night Stroop-like task and a yes-no task. The day-night Stroop-like task was administered by instructing the child to say “day” when shown a black card with a picture of a yellow moon and to say “night” when shown a white card with a picture of a yellow sun. The yes-no task is conceptually similar to the day-night task as the child is instructed to say “yes” when the experimenter shakes her head no and to say “no” when the experimenter nods her head yes. Physiological recordings of brain activation during these tasks were collected by placing an electroencephalogram (EEG) cap upon the child’s head and placing electrodes around the scalp. Heart period (HP) was recorded by placing electrodes on the left collarbone and lower right rib cage. Readings from the medial frontal electrodes



indicated significant increases between baseline and working memory/inhibitory control task performance was evident for all children. Additionally, a decrease in HP (corresponding to an increase in heart rate) was noted from baseline to task, although this variation in task performance was consistent across all children and individual variability was non-significant. These results indicate that tasks that involve cognitive inhibition and working memory are cognitive stressors for young children and that effortful, volitional abilities appear to mature during early childhood. However, whether inhibitory mechanisms mediate working memory capacity among young children is not clearly understood. Relatedly, little is known about relations between working memory, inhibitory control and children's performance on handwriting tasks.

To conclude, cognitive and executive memory processes likely contribute to the learning of handwriting and to handwriting production among young children. The goal of this study is to determine the role of working memory on these emerging handwriting abilities and to determine if inhibitory control mediates the effect of working memory on handwriting.

Specifically, the current study poses two questions:

1. Does working memory play a role in explaining young children's emergent handwriting abilities?
2. Does inhibitory control mediate the relationship between working memory and handwriting for young children?

Two main hypotheses guide the study.

The first hypothesis states that variation in working memory capacity is a reliable predictor of normal variation in children's handwriting performance. This hypothesis

originates from studies of children's handwriting that show that skill development in early handwriting ability is an effortful task for young children. Whether or not the working memory system that underlies early handwriting performance reflects a domain general system (i.e., related to both visual and verbal domains) or whether this system is limited to a specific domain is not clear; however, results from this study may inform this issue. That is, if correlations between handwriting ability and visual working memory tasks and between handwriting ability and verbal working memory are both significant, evidence for a domain general working memory system is found. On the other hand, if correlations between handwriting and visual/verbal working memory tasks are significantly different, evidence for a domain-specific working memory system is found.

A second hypothesis predicts that the relationship between working memory and children's performance on handwriting tasks is mediated by their inability to cognitively inhibit information that is irrelevant to the task at hand. Cognitive inhibition requires that children withhold responding, delay responding, engage in the cessation of ongoing responses, and resist distraction or disruption by competing events (Barkley, 1997). In this view, inhibitory mechanisms are designed to serve the information processing system by preventing irrelevant information from entering a child's working memory, deactivating irrelevant information and preventing irrelevant information from re-entering the mind once it has been suppressed (Lahar, Issak, & McArthur, 2001). Evidence in support of this hypothesis is found if correlations between working memory and handwriting performance become non-significant, once the variance in handwriting ability that is attributable to cognitive inhibitory control is partialled from the association.

## **CHAPTER TWO: LITERATURE REVIEW**

The study of emergent handwriting among young children is generally an understudied field of research. Generating text for emergent writers is a process that involves a multitude of cognitive and kinaesthetic functions including: focusing capabilities, behavioural dispositions, gross and fine motor control, and memory. However, the research literature to date has generally emphasized the development of handwriting ability with little attention paid to the cognitive components that underlie this process. This literature review therefore is divided into two parts. Part A will explore research on emergent handwriting skills of children and the development and usefulness of measures that provide a window to observe typical and problematic forms of handwriting. Part B will examine theories of working memory and inhibitory control and the relationship of these constructs to current models of handwriting development.

### **Part A: Handwriting**

Handwriting research increased during the 1980's. However, interest in the issues surrounding handwriting development waned by the late 1990's (Graham & Weintraub, 1996). During the early 1980's, researchers from all backgrounds, including education, experimental and clinical psychology, linguistics, neurology, and bio-engineering, and from many countries such as Australia, Canada, France, Hong Kong, the Netherlands, Norway, the United Kingdom, and the United States investigated all aspects of the handwriting process (Graham & Weintraub, 1996). Five factors accounted for this initial

influx of interest. First, in regards to issues in motor control and motor behaviour, handwriting was often used as the protocol with which researchers gathered their data. Second, recording and scoring handwriting samples and precisely monitoring specific movements through technologically advanced means such as digitized tablets made handwriting more attractive to many researchers. Third, multiple theoretical models regarding handwriting have been proposed which prompted further development, testing, and scrutiny by other researchers. Fourth, the population of children with handwriting difficulties and learning disabilities sizably increased resulting in much effort put forth to study these difficulties. Fifth, a forum of handwriting researchers was formed, the International Graphonomics Society (IGS), where researchers from around the world were able to share their work and findings with other interested colleagues. For these five reasons handwriting research gained popularity and the field was significantly advanced. Surprisingly, by the 1990's research on handwriting had ebbed, despite a lack of studies concerned with the interrelationships among script characteristics (Blöte & Hamstra-Bletz, 1991) and the lack of comprehensive and critical review of the research previously composed (Graham & Weintraub, 1996).

Much of the research in the past has focused on emergent handwriting and investigated developmental trends in written output across diverse groups of school-aged children. However, before written output can be examined, it is useful to acknowledge that young children's print-related knowledge and conceptions about print emerge long *before* they are immersed in a school environment and before children are taught specific letter and symbol associations (Weiss & Hagen, 1988). Reviews of the literature provide converging evidence to suggest that children in a literate society begin to read and write

early in life, reading and handwriting abilities reinforce each other, developing in a concurrent and interrelated manner rather than sequentially. Moreover, handwriting abilities develop out of real-life necessity as children learn to write purposefully as they engage in literacy activities with their parents or caregivers. Learning to handwrite involves developmental processes that children pass through in a variety of ways and at different ages (Weiss & Hagen, 1988).

Many authors recognize the variation in children's literacy development; however, two contrasting views that explain the emergence of early print-related knowledge are found in the literature. First, some researchers suggest that children's print awareness is a body of knowledge that young children acquire through experiences in their environment and the extent of this knowledge can be evaluated by measures of children's conventional reading readiness skills including letter name knowledge, visual discrimination, and auditory discrimination (Hiebert, 1981). Other researchers emphasize children's understanding of the literacy practice known as "reading" as the major component of print knowledge, including: elemental understanding of print and the awareness of one's own ability to participate in print-related literacy practices, and children's understanding of the various meaningful uses of print within a social context (Hiebert, 1981). Hiebert (1981) studied print knowledge among 60 three, four and five year old children attending daycares and preschools from a predominantly middle-class background using both reading readiness measures and concept of print measures. Results suggest that most three year olds have some proficiency in letter naming, visual discrimination, auditory discrimination, and some understanding of the purposes of using print (Hiebert, 1981). Print knowledge among the subjects increased significantly from

the beginning to the end of the preschool period with five-year olds outperforming three-year olds on measures of print knowledge. The magnitude of performance differences between three- and four-year olds were statistically significant and greater than performance differences found between four- and five-year olds (Hiebert, 1981). Findings such as these indicate that the acquisition of print-related knowledge is particularly salient during the early part of the preschool period (Hiebert, 1981).

Diversity in children's background knowledge may explain variance in children's development of print-related knowledge. Longitudinal studies that chart the emergent literacy of children from different generations suggest that most children are provided with opportunities to learn about print through cultural activities such as exposure to television shows such as "Sesame Street" and access to books (Hiebert, 1981). Huba and Kontos (1985) developed a 15-item test to assess prereaders' understanding of the function of print in diverse social and cultural environments. The authors felt that children's knowledge of the function of printed symbols was likely learned in settings before formal instruction occurred and included such notions as (a) language has a written symbol, (b) people write down their language for efficient communication, (c) reading is a process by which one deciphers written language to obtain meaning, and (d) written language can represent, in one-to-one correspondence, the words uttered by a speaker (Huba & Kontos, 1985).

Although children may have had numerous experiences with print activities prior to school entry, handwriting activities in kindergarten and grade one are no longer given as much priority as they had in past (Berninger, Vaughan, Abbot, Abbot, Rogan, Brooks, Reed, & Graham, 1997). However, research findings suggest that early detection of

children's handwriting difficulties is critical to allow for the provision of remedial teaching practices that result in positive outcomes for children (Hamstra-Bletz & Blöte, 1993). Other researchers suggest that handwriting instruction should continue throughout grades one to six with emphasis being placed on maintaining proper form characteristics while increasing speed, rather than having children sacrifice legibility for speed (Hamstra-Bletz & Blöte, 1993).

Children's ability to quickly and effortlessly reproduce letters accurately may be related to their processing speed and ability to quickly retrieve letter forms from long-term memory. Rapid automatic naming of letters has long been associated with fluent word recognition among typically developing readers. Moreover, naming speed deficits have been consistently found among samples of children and adults with reading disabilities (Wolf et al., 2000). Performance on serial naming speed tasks is thought to provide an early, simple approximation of the reading process as it is similar to the combination of reading rapidly, serial processing and integration of attentional, perceptual, conceptual, and motoric subprocesses (Wolf et al., 2000). Whether the rapid processing of an alphabetic orthography is also related to handwriting development is not clear. Certainly, a trade-off between speed and legibility of handwriting exists; however, what needs further clarification is whether speed of serial processing mediates legibility of handwriting output.

In the long-run, sacrificing legibility for speed may have negative effects on academic achievement. Teacher evaluations of handwriting samples of lower legibility but equal content are often graded lower than papers where the quality of legibility is much higher (Graham & Weintraub, 1996). Academic grades may therefore suffer and

this problem could exist throughout a child's academic career. A study performed by Blöte and Hamstra-Bletz (1991) evaluated the scripts of 63 elementary school children over the course of five years using the *Concise Evaluation Scale for Children's Handwriting, Dutch Translation* (BHK). They found that performance on handwriting measures was stable across elementary school grades and that latent variables (fine motor ability, structural performance, and stylistic preference) were also valid for all grades. The authors conclude that grade-related changes in handwriting are predominantly quantitative, not qualitative in nature (Blöte & Hamstra-Bletz, 1991). Together these findings imply that poor legibility early on in childhood may persist throughout elementary school and likely beyond these years and across the lifespan.

For many children, their style of handwriting deviates from the form that they were initially taught (Graham, Weintraub, & Berninger, 1998) and some researchers feel that these deviations are due to less time being spent on handwriting instruction (Berninger et al., 1997), and to the finding that the instruction provided is inadequate (Graham & Weintraub, 1996). In a review of the literature, Graham and Weintraub (1996) found that time spent teaching handwriting, ranged from 20 to 60 minutes per week among elementary school teachers. Children who experience problems related to handwriting and text generation early on in life run the risk of going undetected and may "fall through the cracks" when such a short time is allocated for handwriting instruction (Sandler, Watson, Footo, Levine, Coleman, & Hooper, 1992). Children with handwriting difficulties are often described as simply being lazy, noncompliant, or lacking motivation and these difficulties are often not awarded the same legitimacy as other disabilities in areas such as reading and mathematics (Sandler et al., 1992).



It is important for teachers to be aware of potential problems that children may have during handwriting activities. A study performed by Marr, Windsor, and Cermak (2001) examined the relationship between the cognitive understanding of spatial and temporal locatives and graphomotor production among 138 kindergarten children over two points during the year. In using the *Developmental Test of Visual-Motor Integration* (VMI) and the *Scale of Children's Readiness In PrinTing* (SCRIPT) the authors found a moderate positive relationship between visuomotor skills and handwriting (Marr et al., 2001).

Researchers have studied teaching methods that reportedly facilitate handwriting development and the subsequent acquisition of handwriting skills among young children and have noted consistencies in regards to which methods are effective and which methods are not. Researchers recognize that learning to compose text requires both low level (e.g. creating letter representations in memory, accessing and retrieving these representations in memory, motor planning, and motor production) and high level (e.g. strategies for planning, generating language at the sentence and text levels, and reviewing and revising written text) processes and it is necessary to aim and integrate instruction towards both of these processes (Berninger et al., 1997). By developing a strong foundation in these processes, especially low level processes, functions become automatic and motor and cognitive efforts are freed up allowing higher processes to work more fluently (Berninger et al., 1997). In order to achieve this aim quickly and successfully it is imperative to examine instructional techniques which allow children to master the basics swiftly and effectively. Berninger et al. (1997) examined five instructional approaches of letter formation: *motoric imitation* where the teacher

modelled the motoric acts the child was to imitate; *visual cues* where children were provided with numbered arrows as cues to the nature and order of each of the component strokes necessary in the letter production; *memory retrieval* which required children to cover their letters and write them from memory; *visual cues plus memory* which combined both numbered arrows and then letter covering and memory retrieval, and finally a *copying approach* where children examined a model letter and then reproduced what they saw without any cuing from the instructor. An initial screening of 700 first grade children led to the resultant participatory population of 144 children identified as at-risk for handwriting problems. These children were randomly assigned to six conditions, one being a control and the other five reflecting the outlined instructional approaches. Upon completion of all 24 lessons, results consistently indicated that the instructional method which combined the visual cues of numbered arrows and memory retrieval was the most effective method for facilitating automaticity of the handwriting process (Berninger et al., 1997). Employing this instructional technique for typical and atypical developing children may be useful in curbing further difficulties. Some children who have difficulty mastering handwriting skills early on avoid handwriting and adopt a mind-set that they cannot write; this can lead to delayed or arrested handwriting development (Graham, Harris, & Fink, 2000).

In the past, handwriting instruction involved simple repetitive copying drills and today, even with the enhancement of computer technology, handwriting using pencils and paper seems to be the most effective means of learning to scribe letters and words. Studies across diverse cultural contexts have shown that visual and verbal modelling is superior to no modelling at all (Hayes, 1982). The language of Japanese is logographic

and quite challenging; it is often taught through the repeated practice of handwriting the symbols (Naka, 1998). Naka (1998) sought to determine if this method was indeed effective for first, third, and fifth grade students. Results from four different studies indicated that recall of letters and characters was far superior when children practiced handwriting letters and received feedback from instructors as opposed to no feedback or only looking (Naka, 1998). Other researchers have examined the influence of the motoric process on the learning of spelling words and have found that children are able to recall spelling words more often and are more likely to spell words correctly if they have learned and practiced these words by handwriting them out as opposed to practicing them on a computer or using letter tiles to spell out the words (Cunningham & Stanovich, 1990). Taken together, these studies indicate that explicit instruction of handwriting together with repeated practice facilitates children's learning how to accurately and efficiently form letters and words.

Certain factors play a role in successful handwriting development such as small muscle development, eye-hand coordination, the ability to hold utensils or writing tools. Also important is the ability to form basic strokes smoothly, letter perception, including the ability to recognize forms, notice likenesses and differences, infer the movements necessary for the production of the form and give accurate verbal descriptions of what was seen, and orientation to printed language (Donoghue, 1975; Lamme, 1979). Weil and Amundson (1994) examined the relationship between children's performance on the VMI and their ability to copy letters legibly and found a significant relationship between the two factors (Weil & Amundson, 1994). Further, the authors found that handwriting

performance could be accurately predicted by children's scores on the VMI (Weil & Amundson, 1994).

Lomax and McGee (1987) describe a five component model of children's print-related knowledge: concepts about print, graphic awareness, phonemic awareness, grapheme-phoneme correspondence knowledge, and word reading. These processes are sequentially related and children move through these phases in a manner beginning with concepts about print and finishing with word reading (Lomax & McGee, 1987). Before children can move to a subsequent phase, they must have the fundamentals of the previous developmental component in place. For example, 91% of the variance in children's ability to visually discriminate letters and words was found by the authors to depend upon the development of concepts about print (Lomax & McGee, 1987).

Levin and Landsmann (1989) suggest that children's first written output consists of arbitrary marks on the page. This phase is followed by a referential period during which children attribute word length to physical features of the referent (e.g. children select or write the word "snake" with more signs than the word "butterfly" because a snake is longer in size). Landsmann and Levin (1987) studied the handwriting (in Hebrew) of 120 boys and girls from nursery school, kindergarten, and grade one in Israel. The subjects in this study had not been exposed to conventional teaching methods and none of them could produce written words or sentences. The authors found that even among older children, handwriting samples were produced that reflected referential characteristics and more objects or larger objects were written with more characters than a single object or a smaller object.

Pontecorvo and Zucchermaglio (1988) interviewed seventeen Italian children

seven times over the course of three years and also found support for the idea that a referential period exists in young children's handwriting development. Specifically, the authors investigated the adequacy of the minimum quantity principle (MQP), first described by Ferreiro and Teberosky (1979). According to the MQP, children believe that anything can be communicated using a minimum number of letters. However, results of Pontecorvo and Zuccheromaglio's study showed that children referentially assigned more letters to larger objects and fewer to smaller ones.

Gombert and Fayol (1992) describe a three phase model of handwriting development. In the first phase, children approximately three years of age are able to produce non-figural graphics that imitate the elemental flow of an alphabetic script. By age 3 to 4 years, children produce handwriting samples composed of discrete units consisting of strings of circles or pseudo-letters. Nearer to the age of 4 years, children produce handwriting samples that consist of letters that are known to the children and are often part of their first name. More specifically, across the ages of 3 to 7 years, children usually progress in a manner beginning with scribbles, followed by the production of wavy lines, drawings, pseudo-letters, letters mostly from the child's first name, other letters and a refusal to write (Gombert & Fayol, 1992). The final stage, refusal, is actually a more advanced stage than even pseudo-letters because this indicates that children recognize what handwriting is, what it requires, and their realization that they cannot achieve this request to write because they do not know how to carry out the task.

Prior to the introduction of formal schooling, the developmental sequence that underlies the handwriting process appears to parallel the development of knowledge about handwriting. When 45 three, four and five year old children are shown pictorial

images and artificial letters, figures, or scribbles, they are able to distinguish pictures from print stimuli using three criteria: linearity, multiplicity, and variety (Lavine, 1977). Even before children are formally taught the basics about what to look for to distinguish handwriting from other forms of visual stimuli, children have preconceived notions about what characteristics make the sample an authentic piece of writing in their native language.

Stennett, Smythe, Hardy, and Wilson (1972) investigated the developmental trends of children's letter-printing skills during the primary grades and noted four general findings. In their examination of children's ability to copy upper- and lower-case letters the authors discovered that children of all ages found lower-case letters somewhat more difficult to copy than upper case letters and that kindergarten children varied in their ability to produce lower-case letters. On average, children in the sample tended to have less difficulty copying relatively simple lower-case letters requiring only one stroke (o, c, l, s) and they had more difficulty with letters requiring delicate and concentrated vasomotor control and more than one stroke (r, u, h, t). Finally, most children found the upper-case letters of O, E, H, and I the easiest to copy and the letters D, Z, G, N the most difficult to copy.

Graham, Weintraub, and Berninger (2001) examined handwriting samples of 200 primary-grade children according to legibility, the frequency of breaks, additions, rotations and correct proportion and form. Results were similar to other studies in that a small number of letters contributed to the majority of all legibility issues for all children. Four to eight letters at each grade level were identified as difficult for children to form

and q, z, and u were difficult for all children across three grade levels. The letters s, e, and c were the most accurately formed letters found in the writing samples.

Studies of handwriting output utilize scoring protocols that range in specificity from assessing general letter and word formation to evaluating specific stroke order and detecting common errors. Graham (1986) sought to determine the reliability, validity, and utility of three measures of letter-formation quality: (a) a holistic rating system where accuracy of letter formation is assessed on a five-point Likert-type scale, (b) a holistic rating system with model letters used by raters as exemplars to score the letters and (c) a correct/incorrect procedure where transparent overlays were placed on the writing sample in order to accurately score the letters. Results indicated that the holistic scoring measures were valid but their reliability was minimal and was not improved by the provision of model letters to guide scoring (Graham, 1986). The use of transparent overlays was the most valid and reliable measure of handwriting development. These findings lead to the development of the *Scale of Children's Readiness In PrinTing (SCRIPT)* in 1994 which includes specific criteria for raters to follow when scoring children's handwriting samples (Weil & Amundson, 1994). SCRIPT is a reliable measure that many researchers and teachers can use to determine the developmental progression of children's writing, noting any variations which may indicate the presence of a learning disability (Marr, Windsor, & Cermak, 2001).

## **Part B: Working Memory and Inhibitory Control**

Whereas the study of handwriting development has received a lot of attention in the literature, the influence of cognitive factors such as working memory, inhibitory control, attention, and short term memory on handwriting performance have received far

less consideration from researchers (Brown & Donnenwirth, 1990). Rather, relations between children's working memory and inhibitory control has been almost exclusively examined through research on attention deficit hyperactivity disorder (ADHD). Thus, the following begins with a discussion of theories of working memory and inhibitory control and then reviews the relevant research on ADHD in children that is applicable to the aims of the current study.

### **Working Memory**

Working memory refers to a processing resource of limited capacity and tasks which measure individuals' capability to use this process require a person to hold a small amount of material in their mind for a short time while they simultaneously carry out further operations (Swanson, 1992). Baddeley's (1986) multi-component model of working memory is foundational to most studies of working memory-achievement relations. In this model, working memory is composed of three components including the central executive, which is the control system that selects and operates various processes, the articulatory loop, which specializes in verbal storage, and the visuo-spatial 'scratch-pad' which specializes in imagery and spatial storage (Baddeley, 1986). The storage demands are usually met by the peripheral systems of the articulatory loop and the visuo-spatial scratch pad allowing the executive system to attend to processing activities such as information organization and long-term memory retrieval but when storage demands exceed the peripheral systems' capacity some central executive capacity can be devoted to storage (Swanson, Cochran, & Ewers, 1990). These overtaxing storage demands will result in fewer resources being available for processing activities resulting in decreased overall working memory capabilities (Swanson et al., 1990). Since



Baddeley's multi-component model of working memory was first introduced, alternative models have since been proposed to further refine the description of the working memory system, including theories regarding capacity, the strategic allocation of resources, processing efficiency, and inhibitory control.

A *capacity* theory of working memory adopts the basic premise that thinking is resource limited and the storage and processing functions of working memory compete for limited resources in a capacity-restricted system (Just & Carpenter, 1992). In terms of Baddeley's representational constructs of working memory, capacity theory is unidirectional assuming that processing and storage components of the visuo-spatial scratch pad and the articulatory loop are determined by the total amount of activation occurring in the central executive (Just & Carpenter, 1992). Cognitive processes are then limited to the capacity in which working memory can handle incoming information. This limitation affects certain other processes such as writing since writing involves the processes of transcription and translation and working memory plays a role in the coordination of these processes that interact recursively during text generation (Berninger, 1999). Transcription processes require access to briefly stored information whereas text generation requires multiple stores and multiple processes to be coordinated in working memory; both of these processes compete for the limited resources available in working memory which is why handwriting and spelling should be taught to the point that these skills are displayed automatically by children, thus freeing up the limited working memory capacity for higher-order processes (Berninger, 1999).

Brain-imaging studies provide limited evidence to a capacity theory of working memory. Using fMRI imaging technology, Just, Carpenter, & Keller (1996) found

significant activation in both Wernicke's and Brocca's areas during sentence processing; however, increases in task demands paralleled increases in activation in the Wernicke's area. The authors compared their results to those of studies using Positron Emission Tomography (PET) that show PET activation during the "rest" phase describes the size of the patients' potential resource supply and therefore places a limit on the amount of information that could be comprehended (Karbe, Herholz, Szelies, Pawlik, Wienhard, & Heiss, 1989; Metter, Hanson, Jackson, Kempler, Van Lancker, Mazziotta & Phelps, 1990). Together these studies support the capacity theory and additionally illustrate the potential for solving issues about the nature of the working memory system through future brain-imaging studies (Just et al., 1996).

The idea of freeing up processing resources gives way to another theory of working memory based on the *allocation of resources*. When attempting to learn something new or work out a problem an individual has to devote a certain amount of their cognitive resources to the task at hand. Researchers have looked at this allocation separation in various cognitive tasks such as reading comprehension, educational television show watching, and handwriting. Researchers have examined the differences that exist between younger and older adults during reading tasks in terms of their resource allocation when they are processing text and have found that both younger and older adults do similar things when they read but recall scores are higher for younger adults because of their increased allocation of time used at encoding (Stine-Morrow, Loveless, & Soederberg, 1996). In this view, limits on processing capacity could be lessened if new patterns of resource allocation were developed for older adults (Stine-Morrow et al., 1996).

An alternative position states that performance on working memory tasks is a function of *processing efficiency*. This theory postulates that the constructs of Baddeley's model, the articulatory loop and the visuo-spatial scratch pad, have a bidirectional influence on each other. Indeed, a meta-analysis of data from 77 studies showed that in terms of language comprehension, tasks that measured both processing and storage capacity were better predictors of comprehension than just storage capacity alone (Daneman & Merikle, 1996). Additionally, other researchers have shown that processing efficiency is increased when the speed of perceptual and cognitive task completion is enhanced (Salthouse, 1991). One study which examined the processing speed of adults found that age-related variance in terms of working memory is reduced by at least 70% or more after controlling for perceptual speed and speed at which relevant information can be processed; rate of information decay or displacement is not responsible for the relations among age, speed, and working memory (Salthouse, 1991).

The *inhibitory control* model of working memory finds support from Hasher, Zacks, and May (1999) as they explain three ways in which the flow of information from thought and perception is regulated by inhibitory attentional processes. Accordingly these three processes limit access to consciousness of goal relevant information, extract and remove no longer relevant information from consciousness, and restrain strong responses for evaluation before expression (Hasher et al., 1999). The deletion function is especially important in regards to proactive interference as it suppresses the consideration of no longer relevant information and this is typically more efficient for younger rather than older adults (Hasher, Chung, May, & Foong, 2002). Inefficient inhibitory control over deletion has been found in older adults as displayed in their poorer abilities to

correctly recall words on a memory task and for both younger and older adults, those with decreased inhibitory control appeared to have more items cluttering their working memory (Hasher et al., 1999).

### **Inhibitory Control**

Studies of inhibitory control have traditionally focused on populations of older adults and children with ADHD. Studies have shown that older adults are less able to ignore irrelevant information in assessments of working memory, deletion functions, attentional blink, and reading abilities, as compared to younger adults (Andres, Van der Linden, & Parmentier, 2004; Charlot & Feyereisen, 2004; Lahar, Issak, & McArthur, 2001; Newsome & Glucksberg, 2002). Hasher and Zacks (1988) first proposed that older adults were less able to inhibit irrelevant information and developed the inhibitory deficit hypothesis to explain why this happens. The inhibitory deficit hypothesis proposes that inhibitory mechanisms serve the information processing system by preventing irrelevant information from entering the working memory, deactivating irrelevant information within working memory and preventing attention from returning to irrelevant information once it has been suppressed (Hasher & Zacks, 1988). Inhibitory control is part of the executive system which refers to higher-order self-regulatory cognitive processes, including the control of attention and motor responses, resistance to interference, and delay of gratification (Carlson, Mandell, & Williams, 2004). This executive system undergoes rapid development during the toddler and preschool years and continues to develop well into the second decade of life (Rothbart, Ahadi, Hershey, & Fisher, 2001). Evidence indicates that inhibitory control develops after early infancy and for these

reasons temperament characteristics are also seen in early childhood as individuals begin to develop their own levels of inhibition and inhibitory control (Rothbart et al., 2001).

The Stroop Interference Test was originally developed in 1935 to measure selective attention and cognitive flexibility including cognitive inhibition (Homack & Riccio, 2004; Stroop, 1935). The Stroop task requires that individuals (a) remember two specifically defined rules in their mind and (b) inhibit the response that they are most inclined to make. The ability for children to inhibit prepotent responses improves between the ages of 3 to 6 years and for this reason tasks have been developed that utilize the same theoretical base as the Stroop task but are more age appropriate (Diamond & Taylor, 1996). The day-night Stroop task is one in which children are shown either a card with a sun on it and asked to say “night” or a card with a moon and stars on it and asked to say “day” (Gerstadt, Hong, Diamond, 1994). This adapted version is more age-appropriate for younger children who are not yet able to read at a proficient level to enable them to complete the regular Stroop task. One hundred and sixty children aged 3½ to 7 were administered the day-night Stroop task and eighty children were administered a control task. Results on the day-night Stroop task indicate that the younger children in the sample had more difficulty with these tasks and the percentage of correct responses increased continuously over the age range (Gerstadt et al., 1994). Findings such as these indicate that there is marked developmental improvement in young children and their ability to display inhibitory control.

Children’s ability to display inhibitory control can be described both cognitively and behaviorally. Young children’s inability to perform well on Stroop or Stroop-like tasks is considered by some researchers to be not a result of cognitive inadequacies but

rather because children are struggling to gain control over their own behaviour in proceeding from cognition to action (Gerstadt et al., 1994). From a behavioural perspective, children who are more inhibited are unlikely to approach unfamiliar adults, are sometimes viewed as anxious or fearful by parents and peers, and show little spontaneous positive social initiation (Fox, Henderson, Rubin, Calkins, & Schmidt, 2001). Some researchers liken inhibitory control and temperament as related constructs that cannot be teased apart (Scarpa, Raine, Venables, & Mednick, 1995). Indeed, when administering temperament questionnaires such the *Children's Behavior Questionnaire* (CBQ), assessments on 15 different temperamental characteristics are included with inhibitory control being one of them (Rothbart et al., 2001).

### **Inhibitory Control, Working Memory, and ADHD**

Research has shown that linking ADHD with executive deficits in response inhibition, working memory, planning, and attentional flexibility is consistent across numerous studies although the profile of the association between these deficits is fairly uneven (Karatekin, 2004, Kerns, McInerney, Wilde, 2001; Reader, Harris, Schuerholz, & Denckla, 2004; Sonuga-Barke et al., 2002).

One theory of ADHD posits that children's inhibitory control impacts their general achievement capabilities in that inhibition is responsible for suppressing irrelevant or marginally relevant information that is no longer needed in working memory (May, Zacks, Hasher, & Multhaup, 1999) and without this mechanism in place working memory becomes cluttered and performance on various tasks is significantly decreased (Hasher et al., 1999). Lack of behavioural inhibition can also lead to lesser academic achievement as lack of knowledge to appropriate behaviour or social norms can result in

peer rejection (Walker et al., 2001). Besides peer rejection, children with ADHD may experience learning difficulties. Motor difficulties, especially in fine motor control, make handwriting a common deficit noted in this population (Piek et al., 1999). Assessment of motor performance among children with ADHD is a matter of routine in clinical practice (Piek et al., 1999) and although poor handwriting does not prompt medical intervention, it may provide a large window into challenges that children with ADHD may be experiencing.

Mariani and Barkley (1997) found deficits in working memory were common among preschool children with ADHD. However, these results have not always been corroborated in the research. For instance, Sonuga-Barke et al. (2002) studied working memory and attentional abilities of 160 children between the ages of 3 and 5½ years both with and without ADHD. Results indicated that large discrepancies existed among the children as a result of age differences; some children had clearly well-developed planning, working memory, and inhibitory control skills whereas others were lacking (Sonuga-Barke et al., 2002). Kerns, McInerney, & Wilde (2001) studied 21 children aged 6-13 with ADHD and their matched controls. They also found that the groups did not differ significantly on their assessments of working memory but the ADHD group did perform significantly below the control group on measures of inhibition and attention (Kerns et al., 2001). Karatekin (2004) compared the performance of 25 children with ADHD and 27 children without ADHD on measures of verbal and spatial working memory and concluded that children with ADHD may have an impairment in their central executive component of working memory, which is part of the brain that controls

an individuals' ability to divide attention between visual and verbal working memory tasks (Karatekin, 2004).

Some authors have suggested that poor behavioural inhibition in children with ADHD will likely lead to secondary deficits in working memory and its subfunctions (Barkley, 1997). These deficits would include such things as information recalled from memory (retrospective function) should be temporally disorganized, significant deficiencies should exist in the performance of social skills, and performance under cross-temporal (if-then) contingencies due to lack of inhibitory control will be noted, among other things.

Inhibitory control and motor control are two interrelated constructs and although many studies have been performed that investigate inhibitory control and ADHD, very few have explored the relationship between inhibitory control and motor skills (Tseng, Henderson, Chow, & Yao, 2004). In order for any motor response to be made a stimulus-response reaction is exhibited beginning with a "response decision processing stage" which links perception and action and is based on decision rules and reasoning (Van der Meere, Vreeling, & Sergeant, 1992). This is followed by a "motor programming processing stage", which details of the response are specified such as speed, direction, and force, then a "program loading stage" translates information into a muscular language, and finally a "motor adjustment processing stage" is engaged before the execution of the response occurs (Van der Meere et al., 1992). This final stage is associated with motor presetting, which is something that many children with ADHD appear to have difficulty with (Van der Meere et al., 1992). When 12 children, 9 with ADHD, were examined for their motor presetting abilities using computer programs that



recorded their responses to visual stimulus, all of the children traded accuracy for speed but those with ADHD did so to a greater extent (Van der Meere et al., 1992).

The relationship between impulse control and motor skills in children with ADHD is an understudied issue (Tseng et al., 2004). Tseng et al. (2004) studied the performance of 42 children with ADHD and 42 matched controls without ADHD on measures of motor performance, activity levels, attention, and impulse control. Results indicated that significant performance differences existed across measures between those with and without ADHD (Tseng et al., 2004). Specifically, children's gross motor control was reliably predicted by attention, impulse control and activity levels. Children's fine motor control was found to be related to attention and impulse control. (Tseng et al., 2004). These findings suggest that lack of, or impaired, inhibitory control may have detrimental effects on children's motor skills and additionally, the influence that inhibitory control has on fine motor skills for children with ADHD may explain why so many children have difficulty with handwriting and graphomotor output (Tseng et al., 2004).

Handwriting difficulty is not typically a basis for medical referral, nor is it a clinical indication for treatment, but poor handwriting is often an indication of underlying disabilities affecting a child (Gadow, 1983). ADHD is usually evident in early childhood but is often not diagnosed until the child attends school and both their behavioural and academic output brings attention to their situation (Peeples, Searles, & Wellingham-Jones, 1995). Poor handwriting often leads to academic failure and so many parents turn to medication to ease their child's symptoms and academic challenges. The use of

methylphenidate (Ritalin) has been attributed to aiding ADHD children with their handwriting output (Lerer, Artner, & Lerer, 1979).

In summary, the body of literature reviewed here provides empirical support for the idea that children's knowledge about print and their handwriting skills emerge prior to school entry and evolves over time. However, there is little understanding of the cognitive factors that mediate this process. To address this issue, the goal of the current study is to examine the role of working memory and inhibitory control on handwriting development among young kindergarten aged children.

## CHAPTER THREE: METHODS

### Research Design

The study employed a correlational research design. This design was chosen to examine associations among measures of handwriting, working memory, and inhibitory control for a sample of children of Kindergarten age. Correlations among the variables were examined using the Statistical Analysis System (SAS) to determine if, where, and to what degree, relationships among the variables existed.

### Participants

Fifty-nine children (29 boys and 30 girls) aged 60 to 81 months participated in this study. These children were selected from a larger longitudinal data set and all had been recruited one year earlier. Initially letters were mailed out to all preschools and licensed daycares listed in the local phonebooks of the Lower Mainland of British Columbia, outlining the purpose of the study. An approximate response rate of 60% was received from this initial mail-out with the majority of interest stemming from preschools rather than daycares. All preschools and daycares were located in urban areas encompassing regions of low, middle, and high socioeconomic status (SES). Children in the current study were tested at their schools during their kindergarten year. All of the children were Canadian born and had no known developmental or physical disabilities.

## **Materials**

All administered tasks were done so in a one-to-one manner between the experimenter and the participant in a quiet room. All of the data was collected using paper and pencil tasks for the children or response-recording by the experimenter. For all applicable tasks participants used only a primary pencil and were not provided with an eraser so as to examine all written output. For certain tasks extra materials were utilized and provided by the experimenter.

For Story Recall a plush giraffe hand puppet was utilized to tell the short story and engage the children's attention. The Visual Matrix task required various grids printed on paper and coloured poker chips to place on the grids, and the participant tapped the sequences on the chips using a primary pencil. For the Spatial Organization task a paper with large circles was provided and small toys including a car, a deflated balloon, a plastic cat, a hair barrette, a ring, a rubber stamp, and a birthday candle were used as items placed on various circles on the page. The day-night Stroop task utilized specially made cards. The "night" cards were black with a yellow moon and stars on the front and the "day" card was white with a yellow sun on the front.

## **Measures**

### **Verbal Ability**

Verbal ability was assessed with the Vocabulary subtest of the *Stanford-Binet Intelligence Scale –Fourth Edition (SB:FE)*. On the first part of this subtest, children are required to name or label the most important detail of a picture. On the second part of the subtest, children are requested to provide definitions for words orally presented.

According to the technical manual of the SB:FE, the internal consistency (KR20) of this subtest is .82 and test-retest reliability coefficient for children five years of age is .75.

### **Working Memory**

Four tasks in this study developed by Hoskyn (2004) were utilized to examine children's verbal and visual working memory. Previous research (Hoskyn, 200f) reports that internal consistency estimates using Cronbach's alpha range for all working memory measures range from .79 to .83. A brief description of each task follows.

### **Story Retelling**

The purpose of the Story Retelling task is to assess the child's verbal auditory processing and their ability to remember a series of episodes presented in a paragraph. The experimenter explains the task to the child by introducing the child to a plush giraffe puppet named Spotty. The experimenter explains that they are going to tell a story using the puppet, Spotty, and after the story they, the child, can have Spotty and tell the story back. The experimenter then reads the story to the child using Spotty as animation, then asks a process question, and then gives the child Spotty and asks them to say exactly the same story that they just heard.

The story read to the participant included salutations and consists of seven sentences ranging from four to twelve words. The paragraph explains that it is Spotty's birthday, he's going to have a party, he's turning a certain age (the same age as the child) and there will be various associated birthday items at this party. The dependent measure in this task is the number of sentences remembered correctly in order (range = 0 to 12).

For a sentence to be considered correct it must include the main idea and be in the correct sequence.

### **Visual Matrix**

The purpose of this task is to assess the child's visual working memory as they remember visual sequences within a matrix. Initially the child is presented with a grid containing four squares and the experimenter places poker chips on the squares on the paper. The experimenter then explains that first they, the experimenter, will tap the chips on the paper in a certain order, then they will ask the child a question, and finally the child will tap the chips in the same order they just saw. As the task progresses the grids get increasingly larger, up to ten squares, as the child continues to tap the correct sequence. If the child fails the process question, the task is stopped. If the child taps the sequence incorrectly the experimenter will provide a probe by tapping the correct sequence for the child again. The experimenter can provide two probes and if the child fails again the task is stopped. The dependent measure was the number of tapping sequences the child was able to correctly complete (range = 0 to 20).

### **Rhyming Words**

The purpose of the Rhyming Words task was to assess children's verbal working memory and their ability to differentiate between similar sounding words and phonemes. The experimenter explains to the child that they, the experimenter, will say some rhyming words, then the child will be asked a related question. The child will then be asked to tell the experimenter the rhyming words they heard initially. The task continues unless the process question is failed for both items in the set. The experimenter may also

provide up the two probes to assist the child in their recall before the task is stopped at the participant's highest level of completion.

There are three sets of words in total, each containing two groups of words. The sets contain 2 to 4 monosyllabic rhyming words. The dependent measure in this task was the correct recall of the said rhyming words (range = 0 to 18).

### **Spatial Organization**

The purpose of the Spatial Organization task was to assess children's visual working memory while they studied the spatial arrangement of certain objects on a page. The experimenter begins by taking a number of small toys out of a bag and places them just out of reach of the child and places a sheet of paper with large circles arranged separately around the page in front of the child. The experimenter explains that they are going to play a game where certain toys will be placed on special circles on the paper and the child needs to remember where everything was placed. The child is then told to look away while the experimenter arranges the toys. The child is then called back to study the objects once they have been placed on the page. The child has ten seconds to look at the toys before the experimenter scoops them up. The child is then asked a process question and upon answering correctly they are offered more toys than were used in the arrangement and asked to place the toys where they were on the page and to give back any toys that were not used.

If the child fails the process question the task is stopped. If the child makes errors in their placements they are given up to two prompts before the task is finished with their highest level of achievement. The dependent measure in this task was the correct recall of the spatial organization of certain objects (range = 0 to 20).

### **Processing Speed**

Children's ability to quickly and effortlessly recognize letters of the alphabet was estimated using the *Rapid Letter Naming* subtest of the *Comprehensive Test of Phonological Processing (CTOPP)*. This task utilized 26 small flashcards, each with one lower case letter of the alphabet printed in the centre. The experimenter begins the task by explaining to the child that they are going to quickly flash the cards one at a time to the child and the child is to name each letter out loud as soon as they see it. The cards are presented in a consistently randomized order across all participants. Each of the participant's answers are recorded as either correct or incorrect, noting the answer the participant offered when they did not name the correct letter. The reliability estimate for individual subtests ranged from .70 to .97 and for composite scores ranged from .78 to .95.

### **Orthographic Awareness**

The purpose of the orthographic awareness task was to assess the children's ability to recognize letters within words. Initially the child was shown a word for one second and then it was covered up and they were shown a letter that may or may not have been present in the word. The child was asked if the letter they were now looking at was in the word they had just seen and the response was scored. Then the experimenter proceeded to the open condition where both the word and letter were exposed together and the child was told to take as much time as they wanted looking at both to determine if their first response was correct. The participants' response to this question was scored. In this task probes were not administered and all words were completed. The dependent



measure in this task was the ability to correctly identify the presence of a letter in a word (range = 6 to 16).

## **Handwriting**

### **Letter Copying Accuracy**

The purpose of this task was to assess how accurately the participants could copy a letter when a model for the letter formation was present. The children were given a primary pencil to write with and were given sheets of paper with various letters on them. The children were asked to copy the letter they saw on the sheet below them. The letters were never named and some of the letter combinations were timed beginning from the time the child put the pencil on the paper to the moment when the pencil was lifted from the sheet. The dependent measure on this task was letter copying accuracy (range = 12 to 30).

### **Letters from Memory**

The purpose of this task was to assess children's visual working memory in their ability to accurately write down letters they had just seen on a flash card. Initially the child was presented with a primary pencil and a sheet of blank paper. The experimenter explained that they were going to flash a card for the child to see, which had letters on it, for five seconds and then they would put the card away. Once the card was away the child was instructed to write down the letter, or letters, they had seen on the card. The child was given a practice trial and then subsequent trials were completed and timed from the point of contact between the pencil and the paper and finished when the pencil was

lifted from the paper. The dependent measure on this task was the child's ability to accurately write down letter sequences from memory (range = 0 to 12).

### **The "Quick Brown Fox" Sentence**

The purpose of this task was to assess children's ability to copy a sentence which utilized every letter in the alphabet except for 's', accurately. The children were supplied with a primary pencil and a sheet of paper with "The quick brown fox jumped over the lazy dog." printed on the top. Below the sentence on the same sheet of paper were a series of lines. The experimenter instructed the child to copy all of the letters in the space and on the lines below and ensured that the letters were never named. Prompts were not administered for this task and the task was finished when the child expressed that they were done even if all of the letters had not been completed.

This task had a series of dependent measures. First, each letter was scored on its legibility (range = 0 to 36). Second, the words were rated for legibility (range = 0 to 4). Third, the entire sentence was rated for the ease at which it could be deciphered (range = 0 to 5). Fourth, punctuation was assessed by its inclusion or omission (range = 0 to 2) and fifth, word boundaries were assessed by their existence (range = 0 to 3).

### **Short Term Auditory Memory**

The Memory for Sentences subtest from the *Stanford-Binet Intelligence Scale – Fourth Edition (SB:FE)* was administered to assess children's short term memory and recall of orally presented sentences. The task was explained to the child by stating that the experimenter would say a sentence aloud and the child would then repeat the sentence back. The sentences were grouped into sets of two and became increasingly longer as the

task went on. The task was finished when the child failed to accurately repeat both sentences in a set. The dependent measure in this task was the child's ability to accurately repeat previously heard sentences (range = 12 to 29). According to the technical manual of the SB:FE, the test-retest reliability coefficient for children five years of age is .89.

### **Day-Night Stroop Task**

The purpose of this task was to assess children's ability to exhibit inhibitory control when providing their answers. The day-night Stroop task was constructed specifically for this study based on its previous success found by other researchers. In a similar manner to that of Gerstad, Hong, and Diamond (1994), sixteen trials were administered to each child in which eight "day" cards and eight "night" cards were presented in a predetermined order. For all children the cards were presented in the same order: night (n), day (d), d, n, d, n, n, d, d, n, d, n, n, d, n, d. The experimenter began this task by showing the subject the black card with the yellow moon and stars on and gave the child the instructions, "When you see this card, I want you to say 'day'". The experimenter then showed the subject the white card with the yellow sun on it and gave the child the instructions, "When you see this card, I want you to say 'night'". The experimenter, while still showing the cards, then asked, "What is it that I would like you to say?"

The experimenter then proceeded to the practice trial, and without offering instruction, held up a white sun card. If the subject hesitated the experimenter offered a prompt by saying, "What do you say for this one?" During the entire testing session, the experimenter never used the word "day" or "night" as a prompt. If the subject responded

correctly the experimenter moved on to the “night” practice trial, and without instruction held up the black card with the moon and stars on it. If the subject responded correctly the experimenter offered praise and counted the practice sessions as trials 1 and 2. If the child offered an incorrect response or no response at all, these practice trials were not counted and the experimenter immediately reminded the child of the rules beginning with the card the child responded to incorrectly. The experimenter then began the practice session again from the beginning. Each subject was required to respond to both practice trial cards correctly before they could be counted as useable. This was necessary in order for the subjects to demonstrate their understanding of the task before the session could count. The practice trials were counted because participants who caught on quickly displayed boredom if continued practice was used. The dependent measure for this task was the children’s ability to inhibit their expected response to the card presented and reply with the opposite, yet correct, word (range = 6 to 16).

### **Data Collection**

This study is part of a larger longitudinal research project which began in 2003 when the children were in daycare or preschool. All of the participants had been tested one year prior on various measures. Data was collected for this portion of the study during the children’s kindergarten year between September, 2004 and June, 2005. All of the data was collected by trained graduate student research assistants who, upon approved arrangements, met with each participant individually at their school. To control for distractions, children completed all of the tasks in a quiet room or space where they could concentrate fully.

## **Procedures**

All experimenters were trained prior to their assistance on this project by the project co-ordinator of this study. Training consisted of explanation and thorough demonstration of each task, allowable prompts, and correct scoring procedures. Experimenters were provided with the equipment to carry out these tasks and once experimenters were reliable in their administration, they were assigned to specific students at various schools throughout the Lower Mainland area of British Columbia, Canada.

Experimenters contacted the schools in which their participants were enrolled and explained the nature of the study and the child's previous involvement with the study. Times were arranged through the principal and kindergarten teacher to determine the best times to go to the school. Parents were then contacted to explain that testing would be taking place again and to confirm that on previously discussed dates the child would be in attendance at school.

On the day of testing the experimenter arrived at the participant's school, checked-in at the main office, then met with the kindergarten teacher. A quiet space was negotiated where the testing could take place. The participant was then introduced to the experimenter by the teacher and both the participant and experimenter went to the designated testing area. After some introductions and 'small talk' to put the participant at ease, testing began. Upon completion of the tasks children were rewarded with small tokens of appreciation such as stickers or toys.

## **Scoring of Handwriting Measures**

Most of the tasks used in this study were developed previously and each had scoring protocols in place. The exception was the handwriting measure that involved copying a sentence, known here as the Quick Brown Fox (QBF). A scoring protocol was developed to capture all of the unique elements both required and produced when copying a sentence. The complete scoring scheme is shown in Appendix A. What follows is a brief summary of each of the five measures.

### **Letters**

A score was given for each letter in the sentence based on its form and legibility. Every letter in the sentence that was clearly identifiable by its orthographic features was awarded a point for a maximum of 36 points.

### **Words**

The legibility and structure of individual words that formed the written sentence were rated on a scale of 0 to 4. This rating was included to make note of whether or not the participants were able to provide structure to the words by correctly forming letters, recognizing such rules as words cannot be separated in the middle when writing is continued on another line, and they were also rated on legibility.

### **Sentence**

The entire sentence received a global score of 0 to 5 based on structure and legibility. This rating was included to note whether or not the participants' output resembled the appropriate form that a sentence should take on and if the sentence was legible.

**Punctuation**

Punctuation was rated on a scale of 0 to 2, based on whether or not the participant capitalized the first letter and finished the sentence with a period, included one of these criteria, or excluded all punctuation. This rating was added to note whether participants were familiar with all of the required aspects of creating a sentence or if they only produced the necessary letters.

**Word Boundaries**

Word boundaries were examined to determine whether or not the participant made appropriate separations in their letter copying to form individual words, rated on a scale of 0 to 3. This rating was included to determine whether participants were aware of the words in general and not just copying letters in a seemingly randomized order.

The QBF scoring protocol was developed to clearly display all aspects of the participants' understanding of letters, words, sentences, and punctuation at their individual developmental level.

To establish reliability for each measure, a second rater independently scored 10% of the total sample. Percentage agreement on this sample was 95%.

## CHAPTER FOUR: RESULTS

Presented in this chapter are the results that inform the hypotheses of the study. The chapter is organized around three sets of data analyses. First, a description of the sample participants and their performance on working memory and handwriting tasks are provided. Second, correlations between working memory and other cognitive variables and between working memory and measures of handwriting are reported. Finally, results of general linear modelling procedures for each of the handwriting measures (copying of letters, words and sentences) are presented.

### Sample Description

As shown in Table, 1, data was collected from 59 participants: 30 females and 29 males. Children in this study ranged in age from 60 to 81 months ( $M = 68.08$ ,  $SD = 5.30$ ) and had full-scale IQs ranging from 65 to 144 ( $M = 103.75$ ,  $SD = 14.90$ ). Analysis of Variance (ANOVA) of cognitive and handwriting measures found no statistically detectable gender differences except on the day-night Stroop task,  $F(1,55) = 3.72$ ,  $p = .05$ . Post hoc Tukey tests showed that girls performed better on this task than boys.

### Correlations

Prior to calculation of correlations to be used in general linear modelling of handwriting performance, all raw scores on measures were converted to z-scores, based on mean sample performance. By using z-scores, sampling variances among handwriting and cognitive measures are controlled and comparisons between correlations and



individual models of handwriting performance can be made. The association between age and children's ability to handwrite ( $r = .28, p < .05$  to  $r = .57, p < .01$ ) is clearly evident from the data. Older children outperform younger children on all handwriting measures. Correlations among measures of handwriting, working memory and cognitive processes are presented in Table 2. Several statistically detectable correlations were obtained from the data analysis. The magnitude of correlations obtained between all measures of handwriting and short term memory is weak to moderate ( $r = .28$  to  $.37, p < .01$ ). The association between handwriting and inhibitory control is significant for all handwriting measures ( $r = .28$  to  $.38, p < .01$ ) with the exception of letter copying accuracy. A similar pattern of correlations was found between measures of handwriting and orthographic awareness ( $r = .28$  to  $.36, p < .01$ ).

Correlations between handwriting and verbal working memory range from  $.26$  ( $p < .05$ ) on QBF sentences to  $.43$  on QBF punctuation. In comparison to handwriting-verbal working memory relations, the magnitude of correlations between measures of handwriting and visual working memory is greater and range from  $.31$  on QBF punctuation ( $p < .05$ ) to  $.52$  ( $p < .01$ ) on QBF letters.

In summary, analysis of the pattern of correlations demonstrates that letter memory accuracy is significantly related to all measures of working memory and cognition; however, correlations between sentence writing ability in terms of the measures QBF letters, QBF words, and QBF sentence, and working memory tasks differed in magnitude; a statistically significant relationship was found to exist among the variables. Additional analysis of the pattern of correlations demonstrates that age is significantly related to all measures of handwriting. Older children produced samples of

handwriting quicker and that were more legible than younger children. With the exception of the relation between age and orthographic awareness, which was non-significant, correlations between age and all cognitive measures showed a statistically significant relationship.

### **General Linear Model**

General linear modelling was performed on each of the handwriting measures to determine whether specific cognitive and/or memory variables reliably account for significant amounts of individual variation in young children's handwriting performance.

The general linear model of handwriting letters from memory, as reported in Table 3, revealed significant main effects for age and orthographic awareness,  $F(10, 45) = 5.11, p < .01$ . This indicates that age and orthographic awareness contribute to children's ability to handwrite letters from memory. The squared multiple correlation coefficient, or  $R^2 = .53$  suggests that about half of the variance in the criterion variable, handwriting letters from memory is explained by the age and orthographic awareness variables together. The general linear model of handwriting letter copying accuracy, as seen in Table 4, revealed significant main effects for age, visual working memory, and an interaction effect for age and visual working memory,  $F(10, 46) = 4.45, p < .01$ . Similarly, nearly half of the variance in letter copying accuracy,  $R^2 = .49$ , is explained by the independent effects of age, visual working memory and the interaction of age and visual working memory variables. Taken together, the main effect in each of these models indicates that older children with larger verbal/visual working memory capacities are more likely to be, successful on measures of letter copying accuracy than younger children with smaller verbal/visual working memory capacities. At the same time, the

interaction of age and verbal/visual working memory on letter copying accuracy suggests that young children with large verbal/visual working memory capacities produce more legible letters than older children with smaller verbal working memory capacities.

As shown in Tables 5 and 6, significant main effects for age, visual working memory, and the interaction of age and visual working memory were revealed in a general linear model for handwriting QBF letters,  $F(10, 46) = 6.67, p < .01$  and QBF words). Over half of the variance in children's handwriting of QBF letters and QBF words ( $R^2 = .59$  and  $R^2 = .53$  respectively) is explained by the age, visual working memory, and interaction of age and visual working memory. Once again, the interaction effect suggests that younger children with larger working memory capacities are likely to perform better on measures of QBF letters and QBF words than older children with smaller working memory capacities.

As shown in Table 7, the QBF sentence measure was examined through a general linear model, which revealed significant main effects for visual working memory and the interaction between age and visual working memory,  $F(10, 46) = 5.03, p < .01$ . This indicates that visual working memory and the interaction between age and visual working memory contribute to the successful performance of children's ability to legibly produce the QBF sentence. The variance in the QBF sentence writing performance,  $R^2 = .52$ , is approximately the same as that noted in the QBF word and letter measures and is explained by the visual working memory and the interaction of age and visual working memory variables. The similarities in these contributions and findings is logical as letters and words are the foundation to the production of a sentence and therefore success at letter and word production would likely lead to a successfully produced sentence.

A general linear model of QBF punctuation, as seen in Table 8, revealed a similar pattern of results. Significant main effects for visual working memory and the interaction of age and visual working memory,  $F(10, 46) = 3.05$ ,  $p < .01$  were found. This indicates that children's use of punctuation in a sentence is influenced by their visual working memory and the interaction of age and visual working memory. Under half of the variance in QBF sentence punctuation, ( $R^2 = .40$ ) is explained by the visual working memory and interaction of age and visual working memory variables.

Finally, a general linear model of QBF boundaries, as seen in Table 9, revealed significant main effects for age and visual working memory, ( $R^2 = .42$ ;  $F(10, 46) = 3.43$ ,  $p < .05$ ), however, in this case, no interaction effect between age and visual working memory was found. Compared to younger children with smaller visual working memory capacities, older children with greater visual working memory capacities are more likely to use word boundaries when copying sentences. Older children with smaller visual working memory capacities are still more likely to use word boundaries in sentence copying than younger children with large working memory capacities. Recognizing word boundaries in print is reflective of children's print knowledge and this knowledge appears to be less constrained by working memory limitations among older children than the act of handwriting legible copies of print.

### **Hierarchical Regression Analyses**

Results of general linear modelling suggest that working memory has a greater influence on handwriting performance than inhibitory control. However, one question posed in this study was whether inhibitory control mediated the effect of working memory on handwriting production. To test this hypothesis, two hierarchical regressions

were performed for the QBF sentence handwriting measure. The QBF Sentence measure was chosen because this is the handwriting copying measure that had the highest correlation with inhibitory control ( $r = .35, p < .01$ ). Visual working memory was entered into the equation because according to results of general linear modelling, visual working memory was a better predictor of performance on the QBF Sentence measure than verbal working memory. The correlation between visual working memory and inhibitory control is  $.26 (p < .05)$ . In the first prediction, age, visual working memory and inhibitory control variables were entered in a predetermined order using a forward selection procedure to the prediction of the QBF Sentence Handwriting measures. In the second model, inhibitory control and visual working memory were reversed. As shown in Table 10, in each model, visual working memory added significant variance (6%) to the prediction of handwriting beyond that explained by inhibitory control. Most importantly, however, the addition of inhibitory control to the model prior to the addition of working memory did not moderate the effect of working memory on handwriting performance. The hypothesis that inhibitory control mediates the role of working memory on handwriting performance is therefore, not supported by these results.

## CHAPTER FIVE: DISCUSSION

The purpose of this research was twofold. First, this study was conducted to investigate the role of working memory on handwriting performance of young, school-aged children. Second, the study sought to investigate whether the working memory system that underlies handwriting development operates in conjunction with, or independent of an executive system related to inhibitory control. In this chapter, key findings related to emergent handwriting, working memory, and inhibitory control are explored within the context of the literature related to each of these concepts. Additionally limitations, practical implications, and future directions will be discussed.

Findings of the study are discussed here as they relate to the purposes of the research:

1. Does working memory play a role in explaining young children's emergent handwriting abilities?
2. Does inhibitory control mediate the relationship between working memory and handwriting for young children?

Previous research documented the need for further examination of emergent handwriting abilities, working memory and inhibitory control in young children. Presently the bulk of this field of research concerning working memory and inhibitory control focuses more on young and older adult comparisons and concentrates less on the developmental impact these functions have on academic performance. In terms of handwriting, attention is paid to research on children's motor control; whereas

considerably fewer studies emphasize the effect of cognitive factors, such as attention and memory, on handwriting development even in conjunction with motor control (Brown & Donnenwirth, 1990). Research on children's development of executive function and subsequent handwriting development is important for the identification of learning difficulties early on in a child's school career.

Moreover, there seems to be adequate evidence to support the idea that even among very young children, executive function may have a role to play in early handwriting development. For example, research within the field of neurosciences has found that although the prefrontal cortex is not fully mature until an individual reaches puberty, it already subserves cognitive functions during early infancy (Diamond, Prevor, Callender, & Druin, 1997). More specifically, executive functions and their relevance to academics can be measured as early as preschool and rapid changes related to executive functions occur over the preschool years (Sonuga-Barke, Dalen, Daley, & Remington, 2002).

Results of this study confirm previous reports that handwriting is a cognitively demanding task for young children. Some studies of handwriting have found gender differences on handwriting tasks. Compared to girls, boys appear to have more difficulty managing the form aspects of their handwriting output (Blöte & Hamstra-Bletz, 1991). Results in this particular study did not uncover any significant gender differences in performance on handwriting or memory tasks. A statistically detectable gender difference was found to exist in performance on the day-night Stroop task, a measure of cognitive inhibition, revealing that girls outperformed boys. These findings corroborate previous research reports that suggest older children perform better on measures of

inhibitory control. In a study of inhibitory control among three and four year old children, Carlson and Moses (2001) found that girls significantly outperformed boys on at least half of the 10 measures of inhibitory control. Associations between inhibitory control and handwriting measures in the present study were weak to moderate for most of the handwriting measures except for letter memory accuracy. However, results of regression analyses suggest that the relationship between inhibitory control and handwriting performance is mediated by other variables, including working memory. When working memory was entered into the regression equation prior to inhibitory control, the variance in handwriting explained by inhibitory control was reduced to non-significant. These findings demonstrate a weak to moderate relationship exists between handwriting and inhibitory control, however these effects are not independent of working memory. In summary, results of hierarchical regression analyses indicated that working memory, not inhibitory control explained a greater portion of the variance in handwriting performance. Visual working memory was noted to contribute added significant variance to the prediction of handwriting beyond that explained by inhibitory control, suggesting that a visual domain specific working memory system underlies handwriting performance. Moreover, taken together, the results fail to support the hypothesis that inhibitory control mediates the working memory – handwriting relations.

Whereas visual working memory formed stronger associations than verbal working memory with most handwriting measures, this was not the case for measures of punctuation. Children with larger verbal working memory capacities were more likely to use punctuation in the sentences that they copied than children with smaller verbal working memory capacities. Some researchers have proposed that verbal working



memory is associated with assigning syntactic structure to a sentence and using that structure to construct meaning for that sentence (Caplan & Waters, 1999). Children with larger verbal working memory capacities are more likely to attend to markers of syntactic structure than children with small verbal working memory capacities

Weak to moderate correlations were found between measures of handwriting and short term memory. Short term memory is usually described as a function that holds small amounts of information passively and information is reproduced untransformed and short term memory is less important to high-level cognition (Swanson, 1993). The handwriting tasks in this study required participants to copy letters onto a sheet of paper which requires considerable cognitive effort. Thus the findings in this study are consistent with those reached by other researchers who have noted that working memory and short term memory reflect independent operations (Swanson & Berninger, 1996).

Results of general linear modelling procedures suggest that the best predictors of children's ability to print letters from memory are children's age and orthographic awareness. Significant main effects were noted for age and visual working memory. Analysis of interactions between visual working memory and age suggest that children with larger verbal/visual working memory capacities are more likely to perform better on measures of letter copying accuracy and handwriting letters from memory than age peers with smaller verbal/visual working memory capacities. Moreover, younger children with large working memory capacities are likely to handwrite letters from memory with better accuracy than older children with small working memory capacities. Similar findings were found when predicting children's performance on QBF letters, QBF words, and QBF sentence. These findings may reflect a developmental progression in working

memory-handwriting relations. Children with adequate working memory capacities appear able to first copy letters, then words, then sentences with accuracy. Moreover, older children with larger working memory capacities were more likely to use word boundaries when copying sentences. These findings are indicative of children's print-related knowledge which is highly associated with age and access to literacy activities (Hiebert, Coiffi, & Antonak, 1984; Lomax & McGee, 1987). Incidental learning precedes formal instruction of handwriting through exposure to such things as food labels, toys, and books. Children begin to become familiar with words and letters in preschool environments (Lomax & McGee, 1987) and by Kindergarten children begin to understand directionality and the difference between print and pictures (Gombert & Fayol, 1992; Lomax & McGee, 1987).

In conclusion, results of this study confirm that working memory plays a significant role in explaining young children's emergent handwriting abilities. Children who have larger working memory capacities perform better on measures of handwriting than those children with smaller working memory capacities. These findings are consistent with previous research that suggests that handwriting is an interactive process and the overall handwriting quality is limited by the writer's working memory resources as the writer must use memory-consuming cognitive executive routines to manage the handwriting enterprise (Swanson & Berninger, 1996). For young, emergent handwriters, the influence of working memory capacity on handwriting performance is clearly evident on letter copying and production tasks. Moreover, there is some indication that individual variation in children's working memory capacity, independent of the effect of age, moderates handwriting development. Older children with smaller working memory

capacities produced samples of writing that on average, were less legible than handwriting products of younger children with relatively larger working memory capacities.

## **Limitations**

Various limitations within this study need to be addressed. First, the participants in this study were not chosen randomly. Participants were recruited based on their already ongoing participation in a developmental study examining working memory and handwriting. Since the participants were already part of a sample involved in handwriting and working memory research, this sample may be viewed as one of convenience and results may be skewed based on their familiarity with the participatory process.

Second, this study employed a correlational design which is often used for studying problems in education. A drawback to using this type of design is that although this design allows for the inquiry of the presence of a relationship between two variables, causality cannot be assumed. This form of analysis is limited in regards to the depth of the information that is produced pertaining to the correlations between the variables. Follow-up studies or future analysis may be required to obtain more expansive explanations for the results obtained.

Third, the sample size in this study was relatively small, especially for utilizing regression analysis. In this study, reduced sample size and power may have resulted in a Type II error, which is the acceptance of the null hypothesis when it is actually false.

Fourth, independent variables were correlated with each other which results in the problem of multicollinearity. Multicollinearity occurs because two of the variables are related and essentially measure the same thing. This results in imprecise estimates of regression statistics as an overestimation of the influence of a particular variable which was entered into the regression and will have altered the effect.

Fifth, because this sample was chosen from a particular population of children who were all residents of the Lower Mainland in British Columbia, the results of this study cannot be generalized to other areas of Canada. SES differences were not examined to determine if variations in this factor resulted in significant differences on performance of measures of handwriting or cognitive ability.

Finally, use of the adapted day-night Stroop task may not be as reliable as the original measure in determining cognitive inhibition. This adapted Stroop-like task is relatively new and may not be an adequate measure of children's inhibitory control. Other additional measures of inhibitory control should be used in future research to replicate and confirm the findings of this study.

### **Practical Implications**

Results from this study indicate that for young children, handwriting is a cognitively demanding task. Acknowledgement of this information would be helpful for teachers as they could develop lessons that reduce the cognitive load experienced by young children. Until handwriting becomes a more automatic process, it is important for teachers to continue to focus their handwriting lessons on the basics of form as opposed to speed.

By recognizing the cognitive load learning to handwrite poses on children and focussing on form, children's handwriting legibility should improve. Activities to reduce cognitive load include methods such as keeping a sheet of paper with the letters children are working on at each of their desks or tables. This will allow them to use this paper as a referent as opposed to having to repeatedly look up at the blackboard. During writing tasks, interrupting children to emphasize legibility may interfere with text generation; therefore it would be beneficial to provide lessons in handwriting which are independent of composing tasks. Composing tasks can be used to demonstrate well formed letters and provide corrections or awareness to common errors in letters that are not well formed. It is also necessary to use explicit teaching methods that minimize cognitive load to help children learn letter forms and word boundaries.

Older children in the current study outperformed younger children on all handwriting measures. Older children's handwriting samples were produced more quickly and were more legible than those of younger children. These findings are similar to and support previous research which demonstrates that children between the ages of three and four are less able to handwrite forms clearly and accurately whereas by ages five and six, children are able to consistently incorporate word boundaries, recognize and handwrite large numbers of words, and understand more of the process of handwriting such as directionality and representation (Landsmann & Levin, 1987; Gombert & Fayol, 1992).

Attention paid to handwriting ability in young children may be beneficial in terms of recognizing learning disabilities among children. A child's written output or lack of improved development may be a sign of a learning disability. Unfortunately, writing

disabilities are often under recognized or not legitimized but written output may be one way in which cognitive or motor problems are recognized early on. Assessment within the classroom can involve providing children with multiple tasks that require different working memory load.

### **Future Directions**

Findings in this study corroborate research findings that handwriting ability is influenced by working memory capacity. Ongoing research is necessary to investigate several unresolved issues. Future studies are needed to replicate findings of this study and to provide converging evidence that emergent handwriting abilities are influenced by working memory capacity, independent of the effects of inhibitory control. However, it is also necessary to explore the relations of working memory and other executive systems on handwriting development. Moreover, more studies are needed to determine appropriate teaching methods that will minimize the cognitive load experienced by children with small working memory capacities as they learn and practice the act of handwriting.

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## APPENDICES

### Appendix A: Tables

**Table 1 Sample Description**

Variable	Mean	SD	Min	Max
Age in Months	68.08	5.30	60	81
Full Scale IQ	103	14.90	65	144
Short Term Memory				
Memory for Sentences	18.71	3.86	12	29
Working Memory				
Story Retelling	7.22	3.33	0	12
Visual Matrix	12.05	6.72	0	20
Rhyming	5.22	4.73	0	18
Spatial Organization	9.05	7.47	0	20
Orthographic Awareness	14.42	2.57	6	16
Handwriting				
Letter Copy Accuracy	27.56	4.31	12	30
Letter Memory Accuracy	7.84	3.52	0	12
QBF Letters	25.31	11.34	0	36
QBF Words	2.42	1.61	0	4
QBF Sentence	2.88	2.02	0	5
QBF Punctuation	0.95	0.54	0	2
QBF Boundaries	1.46	1.10	0	3
Inhibitory Control				
Day-Night	14.35	2.65	6	16

Note<sup>1</sup>: QBF refers to the sentence “The quick brown fox jumped over the lazy dog.”

**Table 2 Correlations Between Age, Working Memory, and Print**

Variable	Age	Letter Copy Accuracy	Letter Memory Accuracy	QBF Letters	QBF Words	QBF Sentence	QBF Punctuation	QBF Boundaries
Age	1.00							
Short Term Memory	0.45*	0.57*	0.56*	0.55*	0.52*	0.50*	0.28**	0.52*
Inhibitory Control	0.35*	0.39*	0.37*	0.32**	0.28**	0.30**	0.25	0.30**
Verbal Working Memory	0.39*	0.23	0.38*	0.28**	0.33*	0.35*	0.22	0.25
Visual Working Memory	0.56	0.24	0.39*	0.31**	0.33*	0.26**	0.43*	0.23
Orthographic Awareness	0.21	0.44*	0.46*	0.52*	0.49*	0.49*	0.31**	0.49
		0.23	0.36	0.28**	0.28**	0.28**	-0.01	0.29**

Note<sup>1</sup>: \*  $p < .01$ , \*\*  $p < .05$

Note<sup>2</sup>: QBF refers to the sentence "The quick brown fox jumped over the lazy dog."

**Table 3 General Linear Modelling of Handwriting Letters from Memory**

<b>Variable</b>	<b>Beta Weights</b>	<b>Partial F</b>
Age	0.07	6.70*
IQ	-0.01	0.71
Short Term Memory	0.15	1.00
Orthographic Awareness	0.32	6.52*
Inhibitory Control	-0.01	0.00
Visual Working Memory	2.66	1.40
Verbal Working Memory	1.74	0.94
Age* Verbal Working Memory	-0.02	0.84
Age* Visual Working Memory	-0.04	1.34
Inhibitory Control* Visual Working Memory	-0.17	0.89
Total R <sup>2</sup> = .53		
Note: * p < .01		

**Table 4 General Linear Modelling of Letter Copying Accuracy**

<b>Variable</b>	<b>Beta Weights</b>	<b>Partial F</b>
Age	0.10	13.98*
IQ	0.00	0.09
Short Term Memory	0.14	0.74
Orthographic Awareness	0.11	0.72
Inhibitory Control	0.01	0.00
Visual Working Memory	5.90	6.69*
Verbal Working Memory	1.68	0.81
Age* Verbal Working Memory	-0.02	0.84
Age* Visual Working Memory	-0.08	6.57*
Inhibitory Control* Visual Working Memory	0.22	1.33
Total R <sup>2</sup> = .49		
Note: * p < .01		



**Table 5 General Linear Modelling of Handwriting QBF<sup>1</sup> Letters**

<b>Variable</b>	<b>Beta Weights</b>	<b>Partial F</b>
Age	0.08	11.05*
IQ	-0.01	0.79
Short Term Memory	-0.09	0.46
Orthographic Awareness	0.13	1.48
Inhibitory Control	0.06	0.16
Visual Working Memory	8.74	20.10*
Verbal Working Memory	0.50	0.10
Age* Verbal Working Memory	-0.01	0.09
Age* Visual Working Memory	-0.12	18.94*
Inhibitory Control* Visual Working Memory	0.14	0.74
Total R <sup>2</sup> = .59		
Note: * p < .01		

Note<sup>1</sup>: QBF refers to the sentence “The quick brown fox jumped over the lazy dog.”

**Table 6 General Linear Modelling of Handwriting QBF<sup>1</sup> Words**

<b>Variable</b>	<b>Beta Weights</b>	<b>Partial F</b>
Age	0.06	6.11**
IQ	-0.01	0.79
Short Term Memory	-0.09	0.37
Orthographic Awareness	0.17	2.07
Inhibitory Control	0.20	1.41
Visual Working Memory	6.54	9.59*
Verbal Working Memory	2.13	1.53
Age* Verbal Working Memory	-0.03	1.42
Age* Visual Working Memory	-0.09	8.95*
Inhibitory Control* Visual Working Memory	0.23	1.74
Total R <sup>2</sup> = .53		
Note: * p < .01, ** p < .05		

Note<sup>1</sup>: QBF refers to the sentence “The quick brown fox jumped over the lazy dog.”

**Table 7 General Linear Modelling of Handwriting QBF<sup>1</sup> Sentence**

<b>Variable</b>	<b>Beta Weights</b>	<b>Partial F</b>
Age	0.06	4.72**
IQ	-0.01	0.44
Short Term Memory	-0.07	0.25
Orthographic Awareness	0.16	1.66
Inhibitory Control	0.33	3.79
Visual Working Memory	6.43	8.90*
Verbal Working Memory	2.37	1.81
Age* Verbal Working Memory	-0.03	1.80
Age* Visual Working Memory	-0.09	8.24*
Inhibitory Control* Visual Working Memory	0.37	4.31
Total R <sup>2</sup> = .55		
Note: * p < .01, ** p < .05		

Note<sup>1</sup>: QBF refers to the sentence “The quick brown fox jumped over the lazy dog.”

**Table 8 General Linear Modelling of QBF<sup>1</sup> Punctuation**

<b>Variable</b>	<b>Beta Weights</b>	<b>Partial F</b>
Age	0.02	0.35
IQ	0.00	0.20
Short Term Memory	0.01	0.01
Orthographic Awareness	-0.11	0.68
Inhibitory Control	0.06	0.11
Visual Working Memory	6.65	7.55*
Verbal Working Memory	2.99	2.30
Age* Verbal Working Memory	-0.04	1.77
Age* Visual Working Memory	-0.09	7.27*
Inhibitory Control* Visual Working Memory	0.22	1.25
Total R <sup>2</sup> = .40		
Note: * p < .01		

Note<sup>1</sup>: QBF refers to the sentence “The quick brown fox jumped over the lazy dog.”

**Table 9** General Linear Modelling of QBF<sup>1</sup> Word Boundaries

Variable	Beta Weights	Partial F
Age	0.07	5.72**
IQ	-0.01	0.72
Short Term Memory	-0.07	0.20
Orthographic Awareness	0.20	2.23
Inhibitory Control	-0.05	0.06
Visual Working Memory	4.47	4.12**
Verbal Working Memory	0.46	0.06
Age* Verbal Working Memory	-0.01	0.07
Age* Visual Working Memory	-0.06	3.62
Inhibitory Control* Visual Working Memory	-0.12	0.35
Total R <sup>2</sup> = .43		
Note: * p < .05		

Note<sup>1</sup>: QBF refers to the sentence “The quick brown fox jumped over the lazy dog.”

**Table 10** Hierarchical Regression Analysis of QBF<sup>1</sup> Sentence Copying

Variable	Proportion of Variance	F
<i>Model 1a</i>		
Age	0.26	5.57*
Visual Working Memory	0.06	4.99*
Inhibitory Control		2.43
<i>Model 1b</i>		
Age	0.26	3.71*
Inhibitory Control		2.43
Visual Working Memory	0.06	4.48*
<b>Note: * p &lt; .01</b>		

Note<sup>1</sup>: QBF refers to the sentence “The quick brown fox jumped over the lazy dog.”

## Appendix B: Scoring Protocol

Each writing sample of “The quick brown fox jumped over the lazy dog.” will be examined under five categories.

### Part A: Letters

- Score out of 36: Maximum score is 36 for clear legibility of all letters.
- 0 = a problem with legibility, form, reversal, capitalization, letters below guidelines
- 1 = well formed, clearly legible letter

### Part B: Words

- Rate words out of a score of 5, on a Likert-type scale.
- Errors in structure e.g. a word separated in the middle to continue on a different line

- 0 = incomplete
- 1 = illegible
- 2 = partially legible
- 3 = almost legible
- 4 = legible

### Part C: Sentence

- Rate the entire sentence on a Likert-type scale out of 5.

- 0 = incomplete
- 1 = indecipherable
- 2 = concentrated effort needed to decipher
- 3 = difficult to read on the first attempt
- 4 = legible at first glance
- 5 = clearly legible at first glance

### Part D: Punctuation

- Rate this out of 3, as most children will likely not include it.
- 0 = Did not use punctuation.
- 1 = Capitalized the first letter or used a period, but not both.
- 2 = Capitalized the first letter and used a period.

### Part E: Word Boundaries

- 0 = Partial response
- 1 = None
- 2 = Partial sentence
- 3 = Good