HANDWRITING:
AN EXPLORATION OF FOUNDATIONAL SKILLS

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Abstract

Latent Class Analyses were used to identify two Latent Classes from a sample population of 200 students with slow handwriting who were referred to occupational therapy because of difficulties keeping up with the writing demands of the classroom. The underlying foundational handwriting skills of developmental hand skills, visual perception, visual motor skills, upper limb speed and dexterity, letter motor memory, handwriting legibility and letter formation skills were used to determine that Latent Class One and Latent Class Two exist within the data gathered from the students' occupational therapy clinical files. A one way Multivariate Analysis of Variance (MANOVA) revealed that Latent Class One and Latent Class Two were statistically different from each other. Univariate Analysis of Variance (ANOVA) as follow up to the MANOVA identified that Latent Class One was different from Latent Class Two in all of the foundational handwriting skill areas except upper limb speed and dexterity. Letter motor memory skills were associated with 79% of the variance between the Two Latent Classes. Letter formation skills were associated with 37% of the variance between Latent Class One and Latent Class Two. Handwriting legibility was associated with 27 % of the variance between the Latent Classes. Developmental hand skills, visual motor skills, and visual perceptual skills were associated with a smaller yet still significant percentage of the variance between the Latent Classes.

Students in Latent Class One tended to have very low letter motor memory, handwriting legibility and letter formation skills. Their developmental hand skills and visual motor skills were below average. They demonstrated low end average upper limb speed and dexterity skills,

while their visual perceptual skills were average. Students in Latent Class Two had below average handwriting legibility and letter formation skills. They had borderline upper limb speed and dexterity skills and borderline developmental hand skills. Their visual motor skills and letter motor memory skills were average. These students demonstrated very strong visual perceptual skills. The findings suggest that for students with slow handwriting, there are two Latent Classes with very distinct profiles of foundational handwriting skills.

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Chapter I

Introduction

The goal of handwriting instruction is to ensure children become automatic in the skill of handwriting. Automatic handwriting refers to the ability to write without thinking about letter formation, so that the cognitive resource of attention is available for the more complex tasks of putting ideas down on paper (Jones & Christiansen, 1999). Recent evidence suggests that a child's level of automaticity, measured by the number of letters that children can write in one minute and the quality of children's essays are correlated (Graham, Berninger, Abbott, Abbott, Whitaker, 1997). Slow handwriting, which is the inability to produce the number of letters per minute within one standard deviation of grade and age norms, can impact on classroom performance. Children who were slow handwriters were not automatic and produced essays of poor quality which lacked imagination, organization, aptness of word choice, and good sentence structure, when compared to those who wrote with greater speed (Graham et al., 1997).

A shift in handwriting instruction over the past 20 years has changed the way children are taught this skill and subsequently changed the way children are learning to handwrite. In the early 1970's teachers had clear guidelines for teaching handwriting in textbooks and provincial teaching manuals. The emphasis was on teaching the mechanics of handwriting including letter formation, pencil grip, proper postural positioning, and consistent teaching and practice. In the late 1970's the direct approach to handwriting was replaced with teaching practices that emerged from the child – centred or the whole language approach to learning (Simner, 2003). New handwriting instruction incorporated a more incidental focus on letter formation, taught only as needed when the children were engaged in the process of writing (Farris, 1991). This approach downplayed the importance of teaching handwriting mechanics in a formal way (Simner, 2003). This shift in emphasis on handwriting instruction changed the amount of time spent in the classroom on teaching and learning the skill. Formal handwriting instruction became more of an insignificant aside as opposed to a core component of the primary curriculum (Simner, 2003; Goldberg & Simner, 1999).

Despite this change in handwriting instruction, children continue to be expected to produce legible handwriting in the classroom and to use handwriting to demonstrate their knowledge. Occupational therapists continually assess and provide treatment for children referred to occupational therapy for difficulties with handwriting. A key question for an occupational therapist is "What are the foundational factors of handwriting skill development that ensure that skills are proficient to meet performance expectations in the classroom?" Occupational therapists need to be familiar with the foundational areas that contribute to this problem and the environmental conditions that may impact on the development of efficient handwriting skills. This knowledge will enable the development of assessment, intervention and prevention programs to promote foundational skill development in children who are at risk of developing handwriting problems or to intervene when students already have handwriting problems. Such programs would address the underlying factors associated with the development of automatic handwriting skills. This study is an exploration of these foundational skills.

Background Information

Most students acquire the skill of automatic or proficient handwriting and can easily execute handwriting as a means of getting ideas on paper. However there is a population of students who do not easily learn to handwrite or who cannot execute handwriting in a proficient manner. Handwriting difficulties are normally associated with speed and legibility and affect between 5% and 27% of the elementary school population. Handwriting difficulties are most commonly seen in boys (Hamstra-Bletz & Blote, 1993; Karlsdottir & Stafansson, 2002; Mojet, 1991). A student is considered to have slow handwriting if he or she does not meet the standard handwriting speed generally assessed by the number of letters written in one minute. Poor handwriting is a global term used to describe handwriting that is not legible or is of poor quality relating to inconsistent letter size, letter shape, spacing, letter formation or interchanging of upper and lower case letters. Some students have significant difficulty in expressing ideas on paper because of their failure to master legible handwriting skills to an automatic level. These difficulties may result in difficulties with learning to compose and edit written work, shortened written responses, poor legibility and slow speed in the completion of classroom work. All of these contribute to lower marks and reduced academic achievement (Berninger, Mizokawa & Bragg, 1991).

The failure to master handwriting skills at an automatic level impedes a student's ability to write spontaneously thereby limiting his/her ability to demonstrate knowledge and thoughts through the written word. This deficiency can cause students to focus on forming letters when writing rather than on the cognitive tasks of composing (Jones & Christiansen, 1999). Handwriting may require so much effort that some students develop an approach to writing that minimizes the use of other writing processes such as planning and revising because of the competing demands of forming letters on the page (McCutchen, 1996). If automatic handwriting is limited, a student's hand cannot keep up with his or her thoughts and writing becomes slow (Graham, Weintraub & Berninger, 2001). Academic failure may result from problems associated with poor handwriting (Tseng & Cermak, 1993).

For children in the early years of elementary school, the visual motor and letter formation skills involved in handwriting have a significant effect on their ability to generate written text (Jones & Christiansen, 1999). Children who do not develop efficient handwriting skills are not able to express their ideas to the same level as their student peers (Berninger, 1999). Automatic handwriting may also be connected to speed of writing stories and expressing ideas, which can affect a student's academic productivity. When students with good handwriting and those with poor handwriting were asked to copy a writing example, students with poor handwriting needed almost twice as much time to complete the copying tasks (Weintraub & Graham, 1998).

The integration of foundational developmental handwriting skills plays a role in the process of development of automatic handwriting. Curricular requirements and educational activities in the early grades both assist students in developing the skill of handwriting. Handwriting programs focus on letter formation, letter spacing, letter size consistency and letter alignment (writing on the line). Speed of handwriting is not taught specifically, but improves with handwriting practice, age and grade (Ziviani, 1984; Blote & Hamstra-Bletz, 1991).

The integration of foundational skills for handwriting occurs as a natural process of learning to handwrite. However, methods used for teaching handwriting skills may enhance the integration process. For example, automatic handwriting, like other motor skills, requires practice and over-learning in order to become rote or automatic (Benbow, 1995). If handwriting practice is not emphasized as part of a handwriting program it is probable that the skill will take longer to learn. Without the proper reinforcement and practice the skill may be less developed which would lead to slower overall ability and perhaps failure to develop automatic handwriting skills. The factors which contribute to the development of automatic skills have not been identified. The scarcity of research in the area of automatic handwriting development means that the full impact of slow handwriting performance on student outcomes is not yet clearly understood (Jones & Christiansen, 1999).

Difficulty with the completion of written tasks that require legibility and speed may not become evident until Grade 3 or later as the demands of written work increase. Since handwriting is the primary way in which elementary school students demonstrate their knowledge in all academic areas, students who can write with legibility and speed in an automatic manner will likely get more information on paper than students who are struggling with handwriting (Case-Smith, 2002). Handwriting ability may affect scores on academic standardized tests since the responses to these tests are mostly handwritten, so the academic implications of poor handwriting become very important to parents and educators.

Poor handwriting is a common complaint among teachers of children with learning disabilities and can appear with and without other academic difficulties. Cratty (1994) found that 30-40% of children with learning disabilities also had handwriting difficulties. Dysgraphia is a handwriting disorder observed as a disturbance in the production of written language related to the mechanics of writing (Hamstra-Bletz & Blote, 1990). Dysgraphia is manifested in poor handwriting among children who are of at least average intelligence and who have not been identified as having obvious neurological problems (Rosenblum, Weiss, & Parush, 2004). Many children referred to occupational therapy with handwriting difficulties do not have an underlying learning or medical diagnoses but continue to have problems completing classroom activities that require them to handwrite.

In a recent study Volman, van Schendel and Jongmans (2006) investigated the role of different processes, such as fine motor coordination, visual motor integration, visual perception and cognitive planning ability, and poor handwriting performance in a group of children with handwriting difficulties. Children with handwriting difficulties were less proficient on all of the standardized tests compared to a matched control group (no handwriting difficulties, same gender and grade). Stepwise linear regression analyses were used to identify visual motor integration as the best and only significant predictor for the students with handwriting problems. Unimanual dexterity (dominant hand skill) was the best and only significant predictor for students in the control group (no handwriting problems) (Volman et al., 2006). These results suggest that different foundational mechanisms underlie handwriting performance, in each group, that is, lack of visual motor skills was associated with poor handwriting while proficient hand and dexterity skills were associated with good handwriting.

Handwriting performance of slow speed and normal speed writers are different (Tseng & Chow, 2000). Slow hand writers were found to rely more heavily on visual processing, especially sequential memory and visual motor integration, while children with normal handwriting speed appeared to rely on skills related to upper limb coordination. As children get older their fine motor coordination improves. Age was found to strongly correlate with handwriting speed. Handwriting speed increases as children get older and move through the grades (Tseng & Chow, 2000). The correlation between handwriting speed and age is also supported in other research (Hanmstra-Bletz, & Blote, 1990; Tseng & Hseuch, 1997; Ziviani & Elkins, 1984).

Teachers and occupational therapists need an understanding of the underlying processes associated with the development of automatic handwriting if they are to provide students with remediation in handwriting and appropriate therapy to develop this skill. The acquisition of handwriting skills can be broken down into several foundational areas that are analyzed by occupational therapists. These may include visual perception, letter motor memory, fine and gross motor skills (hand skills, speed and dexterity, upper limb coordination, and posture), visual motor skills and kinesthesia. An understanding of the relationship among the factors as proposed in this study, may assist in developing therapy and teaching practices for handwriting intervention and the adoption of handwriting instruction methods that target the skills necessary to move handwriting development more effectively to an automatic level. Improved knowledge of the factors involved in developing automatic handwriting will enable researchers to investigate the process of this development.

Purpose of the Study

This study explored the foundational skills associated with handwriting development in primary grade students referred to occupational therapy for treatment of slow handwriting. The data used for these analyses were gathered from the students' occupational therapy clinical files. Using Latent Class Analyses, this study focused on:

1. Identifying the number of groups or Latent Classes that exit within a sample population of 200 students with slow handwriting. The Latent Classes cluster or hang together based on students' performance in foundational handwriting skill areas.
2. Specifying the nature of the Latent Classes by describing how the groups of students with slow handwriting are similar or different based on their skill performance on foundational handwriting skill measures.

Rationale

Many school age children referred to occupational therapy have handwriting difficulties. Research suggests that students who have handwriting problems or are slow with handwriting are unable to demonstrate their knowledge on paper, are unable to develop cognitively because they cannot get their ideas down on the paper quickly enough and cannot keep up with learning in the classroom (Graham et al., 1997). Children may have difficulties with handwriting because of problems in the underlying mechanisms such as fine motor control, bilateral and visual motor integration, motor planning/ motor memory, in hand manipulation, visual perception, kinesthesia and sensory awareness of the fingers on the pencil (Feder & Majnemer, 2007, Volman et al., 2006).

This study has explored the foundational skills of students with slow handwriting in the elementary grades to add to a body of knowledge about students' handwriting performance in the classroom. With a better understanding of foundational skills, occupational therapists and teachers can focus on particular problems in order to improve the development of automatic handwriting. Teachers and occupational therapists will be able to target the foundational handwriting skill variables that cause students to be "at risk" for not developing automatic handwriting in the early elementary grades.

Chapter II

Literature Review

The Foundations of Automatic Handwriting

Automatic handwriting is the skill that enables students to get their ideas down onto paper neatly and quickly. Elementary school children can spend up to 50% of the school day completing tasks that require them to write, and some of these tasks have time constraints (Amundson & Weil, 1996; McHale & Cermak, 1992; Tseng & Chow, 2000). Jones and Christenson (1999) suggest that students who have to think about how to form letters during a writing task cannot dedicate their thinking to what they want to say when they write. Therefore, they write less. The foundational components of automatic handwriting are complex and require integration of language, visual perception, letter motor memory, fine and gross motor skills, visual motor integration and kinesthesia (Benbow, 1995). The literature review presents research findings about the foundational skills associated with automatic handwriting and handwriting development. These foundational handwriting skills will be explored in detail as they relate to students who have not achieved automatic handwriting skills and have handwriting difficulties.

Automatic Handwriting

Automatic handwriting enables students to complete the task of printing or cursive handwriting without having to think about it so that the cognitive resource of attention is available for the more complex writing aspects of text generation such as ideation (formulating ideas for writing), sequencing of ideas (making sure ideas are in a particular order), and monitoring for accuracy (making sure that the information is correct and written as intended) (Jones & Christiansen, 1999). In all academic areas, handwriting constitutes the primary way in which elementary school students demonstrate their knowledge on paper. Therefore, automatic handwriting is vital to success in the classroom (Case-Smith, 2002). Students who cannot get ideas down on paper have demonstrated productivity problems, i.e., problems with the amount of written work completed. Satisfactory writing productivity is necessary for success in the classroom.

Blote and Hamstra-Bletz (1991) noted that when children learned to handwrite, the grade-related changes in handwriting were quantitative, not qualitative. They concluded that the structure of handwriting characteristics (letter quality) in primary school children was stable across the grades except when it was influenced by speed. Both the slow writers and the very fast writers performed poorly in form, quality, and smoothness of script. The authors speculated that the slow writers were lacking in skill, whereas the fast writers could have done better if they wrote more slowly (Blote & Hamstra-Bletz, 1991). This study suggests that for students with better automatic handwriting ability, quality decreases with speed, while slow writers continually have poor handwriting in both quality and speed.

Mojet (1991) used an electronic writing tablet to analyze 219 handwriting samples of children in elementary school to provide an objective evaluation of handwriting abilities as children developed the skill of automatic handwriting. The handwriting abilities measured were form, speed and movement quality (proficiency of writing strokes). The main findings of this study were:

1) Developmental changes in handwriting were greatest in Grades 1 to 4
2) Speed (production velocity) increased with writing experience
3) Movement quality rose and the number of writing strokes decreased with grade
4) Size of handwriting product decreased with grade
5) Regularity of timing of the up and down strokes in the handwriting improved
6) Regularity of shaping of letters increased
7) Handwriting pressure showed a moderate decrease over the grades
8) There was a correlation in the duration of handwriting education with production speed.

Based on these findings Mojet (1991) developed a matrix-based set of indices for assessing handwriting skill which was intended for use at any given grade level. Below are samples of the indices:

A) Index 1: The most proficient writers at any grade level; these students can write fast with good form.

B) Index 3: The less proficient writers include; slow writers with good product quality.

C) Index 7: Writers with less proficiency than in index 3 are the fast writers with poor quality.

D) Index 9: Writers with the least proficiency (opposite of index 1) are slow writers with poor letter shaping.

In some research, handwriting fluency is referred to as handwriting speed (Pontello, 1999). The rationale for this working definition is that the degree to which legible letters can be produced automatically and quickly will predict the degree to which one's attention can be devoted to the higher level aspects of composing rather than the mechanics of letter production (Graham et al., 1997). Graham et al. (1997) identified that alphabet letters are the building blocks of written comprehension. Ability to access letter forms rapidly in memory and to produce them automatically without conscious effort frees student attention for writing composition. Beginning and developing writers who have to devote more time to letter production will be less able to devote attention to the areas of composing (Graham et al., 1997). Fluency as measured by the number of legible letters produced in a specific time frame allows researchers to assess levels of automaticity.

Automaticity in handwriting has been researched for its relationship to writing skills; however, it has not been investigated as a separate process of development. Graham et al. (1997) explored the role of mechanics (handwriting and spelling) in compositional fluency and compositional quality. Measures of handwriting (defined as the number of legible letters produced within a time constraint), spelling and composing were administered to 600 children in grades one to six (100 at each grade level). They found that in the primary grades, the students with the better handwriting and spelling abilities, had better compositional fluency. In the intermediate grades, students with better handwriting fluency demonstrated better compositional fluency. Overall, handwriting fluency contributed directly to compositional fluency and compositional quality (speed of writing and quality of writing). The number of legible letters produced quickly by the students in this study contributed significantly to compositional fluency and compositional quality (Graham et al., 1997).

Tseng and Chow (2000) studied the underlying factors that correlate with handwriting speed in school age children. In this study, age (accounting for 42.4% of the variance), visual sequential memory (accounting for 13.1% of the variance) and visual motor integration (accounting for 6.5% of the variance) were the best predictors of slow handwriting. Visual motor integration was not a predictive factor in the normal handwriting speed group. This outcome was supported by a recent study in which Volman et al. (2006) concluded that poor quality of handwriting among children with handwriting problems was associated with visual motor integration.

The Role of Vision in Automatic Handwriting

Marquardt, Gentz and Mai (1996) explored the role of vision in skilled handwriting in adults. The first study demonstrated that the subjects produced smooth handwriting when completing handwriting with vision and with vision occluded. When asked to visually track the pen tip while writing, automatic handwriting was hampered. The subjects were found to slow down and had irregular handwriting. These irregularities were not found when writing under sighted conditions (Marquardt et al., 1996). Therefore, the findings of this study indicate that vision is not necessary to produce automatic handwriting movements and that directing attention from writing to visual feedback causes a shift from automatic to nonautomatic handwriting movements

The second experiment completed by Marquardt et al. (1996) revealed that visual feedback is effectively used in handwriting. To control the visual feedback, the written example was presented on the computer screen while the subject's view of the writing hand was occluded. The example was shown at eye level in the original size as written. The subjects were encouraged to use their normal style of quick handwriting and to practice handwriting until the velocity and acceleration signals of the script (kinematic characteristics) were equal to the subject's normal automatic handwriting on paper. The subjects were shown computer letters that were enlarged or minimized on the computer screen. Following this visual feedback, subjects reacted consistently by altering their handwriting. They were able to decrease the letter stroke to make the letter smaller on the page when given visual feedback. The reverse occurred when the letter size was minimized as the subjects made the letter bigger to account for the change. Visual feedback was found to play a role in the completion of stroke size when copying letters. In automatic handwriting, the researchers postulated that vision monitors the range of movement of the hand when writing and is used to adjust letter sizes (Marquardt et al., 1996).

The researchers suggest that during handwriting instruction, downgrading the accuracy of the letter forms in favour of writing speed may help to elicit automatic handwriting (Marquardt et al., 1996). In follow up research by Margquardt, Gentz and Mai (1999) the role of visual control of automated handwriting movements was tested using the same test methods. The authors concluded that the role of visual feedback in automated handwriting movements should be differentiated from visually guided slower handwriting movements.

The Relationship between Legibility and Speed in Handwriting

Studies support teacher and therapist observations of handwriting performance in the classroom. When students take their time to write, their work is neater and students who have handwriting problems will take a longer time to write in order for their work to be readable. When students need to increase their handwriting speed they tend to have difficulties maintaining legibility as well. Pontello (1999) found that Grade 1 students who had neater and more legible handwriting in a timed test were slower in handwriting speed. The speed of handwriting improved as students became more familiar with letter formation and appeared to improve toward the end of Grade 1 (Pontello, 1999).

There is a relationship in the development of legibility and speed in handwriting as children progress through the grades. Hamstra-Bletz and Blote (1990) found that Grade 2 students with slower handwriting had better letter formation and accuracy than the faster writers but there were more irregularities with respect to the size of letters and alignment of letters on the writing line. In Grade 3 students, fast and slow writers were similar in terms of letter formation and spacing but the handwriting of the fast writers was more legible. A variation in the proficiency of handwriting skills exists between the grades (Hamstra-Bletz & Blote, 1990).

Graham, Berninger, Weintraub, and Schafer (1998) explored the development of handwriting speed and legibility in Grade 1 to Grade 9 students (900 students - 50 girls and 50 boys in each grade). They found that handwriting legibility when copying improved from Grade 1 to Grade 6. As expected, the children's handwriting speed typically increased from Grade 1 to Grade 6 and plateaued in Grade 7 to Grade 9. The handwriting of girls was more legible than that of boys on all three writing tasks during each grade (Graham et al., 1998).

Graham et al. (1998) presumed that younger students who have to devote increased attention and time to the composing processes (generating ideas and planning) have fewer attentional resources for handwriting neatly. This assumption was the basis of the instructional practice of allowing young children to delay attention to legibility until the preparation of the final draft (Graham et al., 1998). In the study, handwriting speed was found to be of little value in predicting legibility, as there was a trade off between these two skills when children attempted to write faster or slower. When children were asked to write neatly, their speed decreased. Additional research would be needed to identify factors that contribute to the development of speed and legibility (Graham et al., 1998).

The results of Graham et al. (1998) are supported in another study that assessed the speed and legibility of writing using a Modern Cursive Alphabet. They also found that young children write at slower speeds than older children. These studies support the learning process for handwriting where letter formation skills are emphasized over the development of handwriting speed particularly in the primary years (Ziviani & Watson Will, 1998). As in the Graham et al. (1998) study, girls were also reported to maintain a higher degree of legibility than the boys

In a longitudinal study, Blote and Hamstra-Bletz (1991) investigated handwriting development of children assessing once a year from Grade 2 to Grade 6, (37 boys, 26 girls; N= 63 students), using a consistent assessment battery. They found that for both boys and girls, handwriting started as irregular and unsteady and progressed to handwriting that was steady and smooth (Blote & Hamstra-Bletz, 1991). Improvement in handwriting skill was greatest in Grade 2 to Grade 4. After Grade 4 there was very little change, however, formal handwriting instruction for this sample did not go beyond Grade 4.

Legibility

Automatic handwriting is not useful unless the handwriting can be easily read by others. Legible handwriting is important if students need to demonstrate their knowledge on paper. Handwritten work that is legible and easy to read is marked more favourably than work that is not as neat and legible. When occupational therapists assess students' performance in handwriting, legibility is a primary component evaluated. Legibility, as described by Ziviani and Elkins (1986), is a component skill of handwriting that cannot be evaluated without considering elements like letter formation, letter slant, letter size, letter and word spacing, letter alignment and smoothness of letter stroke.

Graham, Berninger and Weintraub (2001), identified the legibility of each letter as an essential ingredient in the development of handwriting competence. The primary focus of their study was to examine the legibility of 26 lower case letters of the manuscript alphabet (Graham et al., 2001). They sampled 300 students from Grade1 to Grade 3 including 50 boys and 50 girls at each grade level. The students completed a series of four handwriting tasks. The first test required the students to print 26 letters of the alphabet as quickly as possible. The time for completion of the task was recorded. Then, three handwriting samples were collected. In the first, students were asked to copy a short paragraph as quickly as possible without making any mistakes for a period of 1.5 minutes. The other two were expository and narrative compositions. The students were given 5 minutes to complete each handwriting composition. Legibility was assessed according to quality criteria that included: presence of all parts of the letter, no breaks in the letter, no additional lines or strokes, letters correctly proportioned, letters correctly formed, and no reversals or reversed parts. The quality criteria components were analyzed using correlational statistics. Nonhierarchical linear regression analyses were completed for each of the other scores of letter legibility in each of the handwriting tasks (Graham et al., 2001).

The researchers found that students in the second half of the school year in first grade were likely to have mastered most of the lower case manuscript letters from memory. The students were able to write 4 out of every 5 (80%) of the letters of the alphabet using manuscript lower case letters in a legible manner. The first grade students were able to print 24.6 letters of the alphabet and they substituted an appropriate upper case letter if they did not know how to form the lower case letter (Graham et al., 1998).

By second grade, students' manuscript letter writing skills improved to the point where they were able to produce 24 out of 26 of the manuscript letters of the alphabet legibly (Graham et al., 2001). The second grade students were found to skip a letter rarely when writing the alphabet from memory (1% of the time). The findings were similar for the grade three students as a letter was rarely missed when printing the alphabet from memory (Graham et al., 1998).

The results identified that six letter quality skills (i.e., letter legibility, no additions, correct proportion, correct formation, no rotations and alphabet fluency) were found to be significantly related to overall legibility when each variable was considered alone. Two of these variables, letter legibility and correct proportion, continued to make a significant and unique contribution to the prediction of text legibility after all of the other letter writing skills, grade, gender, and dominance were controlled for (Graham et al., 2001).

Graham et al. (2001) found that a letter does not have to be formed perfectly to be considered legible. Ninety percent (90%) of the lower case manuscript letters produced by the students in this study were only observed as being correctly formed 64% and 79% of the time. This inexactness serves a useful function as writers gradually modify how they form letters in an effort to increase speed (Meulenbrock & van Galen, 1986; Sovik & Arntzen, 1991). Measures of overall handwriting legibility should take into account the legibility of individual letters, as this measure made a significant and unique contribution to the prediction of this construct after all other predictors were controlled (Graham et al., 2001).

Graham, et al. (2001) concluded that letter legibility can be added to a growing list of attributes that contributed significantly to the prediction of text legibility in previous studies. These include neatness, letter formation, uniformity of slant, size of letters, compactness of space between letters and words, steadiness of letter and word alignment lightness and darkness of print, type of script, gender, assignment and examiner variables (Anderson, 1969; Graham, 1986; Graham, Berninger, & Weintraub, 2001; Graham, Boyer-Shick, & Tippetts, 1989; Graham & Weintraub, 1996).

The Minnesota Handwriting Assessment (Reisman, 1999) is a norm reference assessment that is used to assess grade one and grade two students in handwriting ability in the areas of rate, legibility, form, alignment, size and spacing. Research for the standardization of this assessment was conducted to determine handwriting performance on a population of 2000 ethically diverse students in grades one and two during two test periods during the 1st school year and three test periods during the 2nd school year. The first grade students were tested during the first two weeks in January and April. The second graders were tested in October, January and April. The students in first grade did not have a test period during October as they were just learning to form letters at that time period. Independent group *t-tests* revealed that there were no score differences for boys and girls and for right and left handed students. Age also did not appear to make a difference for students during any marking period (Reisman, 1999).

For the students in grade one, the only difference in handwriting abilities from January to April was in rate of speed. There were no other statistical differences in abilities with regard to legibility, form, alignment, spacing and size. For the students in second grade, the rate of handwriting changed from October to April but the quality indicators were unchanged during this time period. From these findings, the norms are outlined as follows; students in grade one who are performing like their peers, copy 33-34 / 34 letters of the alphabet legibly, 30-34/34 letters were formed accurately, 29-34/34 letters were aligned appropriately to the baseline and middle line, 27-34/34 letters were of consistent size and 30/34 letters had appropriate letter and word spacing (Reisman, 1999).

For students in grade two who were functioning like peers had the following scores; 34/34 of the letters were copied legibly, 31-34/34 were formed accurately, 31-34/34 letters were resting on the baseline and appropriate to the middle line, 27-34/34 of the letters were of consistent size, and 32-34/34 were spaced appropriately as outlined in the manual (Reisman, 1999).

Handwriting Instruction

Handwriting practice and instruction improves students' performance in the classroom and appears to be a fundamental component for learning the skill of handwriting. Handwriting instruction has changed over the last 20 years with the focus moving from teaching the mechanics of handwriting to a whole language child – centred approach (Simner, 2003). Jones and Christiansen (1999) found that recent curricula reforms focused on whole language approaches reduce the emphasis on practice activities to improve letter formation skills. This has affected the development of automatic handwriting for some students.

Jones and Christensen (1999) hypothesized in their study, that persistent poor performance in written tasks will affect students' cognitive and affective development. They identified that lack of automaticity in writing meant that students focused on letter formation rather than the cognitive aspects of text generation. They studied an intervention intended to enhance children's automaticity in writing so that their letter formation became quick, smooth and effortless (Jones & Christensen, 1999). The intervention was designed to improve proficiency in letter motor memory (number of letters formed correctly in a set timeframe) of students who had handwriting difficulties. Initially, children with good handwriting skills in the control group were significantly better than the children who demonstrated poorer handwriting skills in the experimental group. Following the intervention for handwriting, no difference between the groups in handwriting skills was noted. The researchers concluded that difficulties in handwriting are amenable to instruction and that improvement in handwriting will result in comparable improvement in written expression (Jones & Christensen, 1999).

Karlsdottir and Stafansson (2002) report that handwriting dysfunction can result from insufficient time spent in primary handwriting instruction particularly in teaching proper letter formation. This type of dysfunction requires remediation or systematic repetition of letter formation to improve the skill (Karlsdottir & Stafansson, 2002). As in the research by Jones and Christiansen (1999), these researchers found that repetition and practice of proper letter formation is required to develop efficient letter formation skills and is a factor in functional handwriting development.

Graham et al. (1997) found that individual differences in handwriting were predictive of individual differences in compositional fluency and quality. The authors suggested that researchers and educators need to examine the processes leading to the writing product. These include instructional intervention studies designed to shed light on the causal mechanisms between handwriting fluency and development of composition skill (Graham et al., 1997). The authors identify that instruction in handwriting can contribute to increasing achievement in composing for children in the elementary grades.

Teacher expectations of students' handwriting are also important in the process of learning to handwrite. Teachers who receive formal training in a handwriting program have better handwriting outcomes in their classrooms (Peck, Askov, & Fairchild, 1980). If a teacher does not emphasize handwriting as an important part of a student's work early in school, the student may not receive enough reinforcement and consistency to establish effective automatic handwriting (Alston & Taylor, 1987).

In an examination of the use of two handwriting programs with Grade 1 students, a structured handwriting program which included handwriting books, specific instruction, practice and emphasis on letter formation using similar letter formation groups made a difference in printing development for the students in the study. One class used the *Handwriting Without Tears Program* (Olsen, 1997) while the control group used a ball and stick method for teaching letter formation. The findings suggested that one type of handwriting instruction program may be more beneficial than another in teaching Grade 1 students to print (Pontello, 1999).

Graham, Harris and Fink (2000) examined handwriting to determine if it was a causal factor in learning to compose. They found that first grade students struggling with learning to handwrite who participated in supplemental handwriting instruction outperformed a control group of their peers. The authors' state, "explicit and supplemental instruction that helps young children to write letters accurately and quickly can increase the probability that they will become skilled writers" (Graham et al., 2000, p. 631).

Karlsdottir and Stafansson (2002) evaluated the development of functional handwriting skills to determine the extent of handwriting dysfunction among primary school children. They found a link between handwriting instruction methods for teaching automatic skills and identified that visual cues and memory retrieval strategies used in handwriting instruction are effective at improving handwriting quality and writing speed. These findings have implications for the teaching and learning of automatic handwriting skills especially since there has been a shift away from formal teaching of handwriting in recent decades (Alston & Taylor, 1987).

Berninger, Vaughan, Abbott, Abbott, Rogan, Brooks, Reed and Graham (1997) conducted an instructional intervention study to investigate potential relationships between handwriting and compositional fluency in 144 first grade students identified as at risk for handwriting dysfunction. Correlational statistics on twenty potential predictors of treatment outcomes identified two variables that had a correlation with handwriting. Both were teacher variables, i.e. the teacher rating of the importance of handwriting instruction (noted at pre-test only), and teacher treatment of handwriting difficulties (noted from mid-test to post-test after the effect of treatment had an opportunity to exert itself). The results support the hypothesis that treatment of handwriting difficulties has an impact on handwriting outcomes (Berninger et al., 1997). The treatments associated with the best performance in handwriting were the combination of teaching of visual cues and memory retrieval that improved seven handwriting and compositional fluency tasks. The results show transfer from training in handwriting to compositional fluency, and thus from transcription to text generation on standardized testing (Berninger et al., 1997).

Berninger et al. (1997) identified that traditional handwriting instruction emphasized penmanship (encouraging production of letters that conform to an idealized letter form) rather than automaticity of letter production. They suggest that practicing the handwriting of all letters of the alphabet only a few times, helps students create more precise representations of alphabet letters in memory. This practice also avoids habituation, which occurs when children write the same letter over and over again (Berninger et al., 1997). They found that through frequent but explicit instruction, young children learn to automatize letter production and retrieve letter forms rapidly from memory, likely increasing their probability of becoming skilled writers (Berninger et al., 1997).

Studies of the Components of Automatic Handwriting

Visual Perception. When handwriting, students need to differentiate the letters of the alphabet and know that each letter has a unique shape. They must recall shape and form of letters and numbers when writing. Children need to recognize that letters are the same size, that letters need to be written in a particular position on the writing line and letters need to be spaced appropriately to make words on the page. Visual perception allows for increased awareness of spatial organization and is needed for students to understand the language of handwriting instruction. For example positional prepositions such as: over, under, beside, up and down, are words often used in handwriting to describe letter formation (Benbow, Hanft & March, 1992).

Visual perception includes visual memory, visual discrimination, spatial relationships, visual figure ground, visual sequential memory, visual form constancy, visual closure and laterality. Visual memory enables students to recognize letters and letter shapes. Visual discrimination means that students can differentiate among different shapes and letters. Spatial relationships enable students to know how to place letters on the line and helps with letter formation. Spatial relationships also assist students in knowing how to intersect lines to form letters, where to start forming letters in relation to the writing line and enables students to place letters on the page in relation to the margin, other letters and words. Visual figure ground enables students to pick out information from a busy black board and pick out words and letters on a page. Visual sequential memory assists students with remembering the order of letters in words. This is especially important when copying from the black board. Good visual sequential memory skills enable a student to look at the blackboard less frequently when copying information. Visual form constancy enables a student to understand that although a different style is used to form a letter the letter is the same. This is seen in some children who have difficulty reading cursive handwriting as they do not understand that a printed "a" and cursive "a" are the same. Visual closure enables a student to piece letters and pictures together to make them whole for recognition. Visual closure enables a child to recognize objects when parts of the object are missing or hidden. A child would use visual closure to complete a letter or picture in the classroom when presented with a part of the letter or picture. Laterality enables a student to differentiate between the left and right sides of a picture, their body and on the page. This is especially important for left to right awareness when reading and writing.

Laterality is the internalized awareness of the knowledge of right and left sides and is associated with spatial awareness (Alston & Taylor, 1987). This skill enables students to orient themselves to the world around them. When laterality is not well established it may cause directional confusion (Alston & Taylor, 1987). In handwriting, particularly printing, many of the letters are similar except for details related to laterality (i.e. "b" and "d" or "p" and "b"). Children who have difficulties with laterality demonstrate increased reversals and inversions of letters (Alston & Taylor, 1987), although reversals are common until age seven (Chapman, & Wendall, 1972)

Although occupational therapists identify that visual perception plays a role in handwriting development previous research is inconclusive about the influence of visual perceptual skills on handwriting. Graham and Weintraub's (1996) review of handwriting research suggests that children's handwriting performance cannot be reliably predicted on the basis of a visual perceptual skills assessment. Similarly, Yost and Lesiak (1980) did not find a correlation between the handwriting of first grade students and their scores on a test of visual perception. As well, Maeland and Karlsdottir (1991) found that the handwriting quality of sixth grade students was not related to their performance on a visual perceptual assessment in the area of figure ground. In contrast, Tseng and Murray (1994) found a significant difference between poor and good hand writers on the scores from the Test of Visual Perceptual Skills (Gardner, 1992).

Tseng and Chow (2000) compared visual perception, including visual memory, visual spatial relation, visual form constancy, visual sequential memory, and visual figure ground and found differences between children with slow handwriting speed to children with normal handwriting speed but there were no differences between the groups in discrimination and visual closure. Visual perception may be a factor that affects the speed of handwriting. The performance of the slow hand writers was identified as relying heavily on visual processing, whereas the students with normal handwriting speed relied more on motor based skills (Tseng & Chow, 2000).

Letter Motor Memory. The term "letter motor memory" in this research refers to the skill of using letter memory (recalling mental image of letter) and letter formation (memory of letter formation) without a visual prompt or cue. Letter motor memory has been referred to in other research as "orthographic coding" and "kinesthetic memory" (Weintraub & Graham, 2000; Ziviani, 1995). Letter motor memory requires the skill of procedural memory. Procedural memory assists one in knowing "how to do something" and plays a role in the acquisition of handwriting skills (Graham et al., 1999). The first component of procedural memory is the ability to store automatic processes for routine actions and skills. Simple processes such as brushing teeth and tying shoes require procedural memory. More complex skills, such as driving a car, handwriting or decoding words, also require procedural memory. These skills, once practiced by students in the learning process, are automatic in adults. After much repetition and practice, the skill can be performed without conscious thinking (Wolfe, 2001). Therefore, by the time a student writes on paper, he/she has retrieved the letter image and motor plan for forming the letter on the paper (van Galen & Teulings, 1993).

Children in the early stages of learning to handwrite seem to experience difficulties remembering what some letters look like. The ability to recall how a letter looks is part of letter knowledge. Jones and Christensen (1999) examined the relationship between handwriting and the ability to produce written text in Grade 1 students. In this study, the term of orthographic motor integration was used instead of letter motor memory to describe the number of letters formed correctly in alphabetic order in a 15 second time frame. More than half of the variance (53%) in written expression was accounted for by forming letters and writing them on the page when reading was controlled. For children in the early years, orthographic-motor skills of letter formation and speed involved in handwriting had a significant effect on their ability to generate written text (Jones & Christensen, 1999). This meant that children with these skills were able to put more of their ideas down on paper. The authors anticipated that there would be a significant relationship between orthographic motor integration and the ability to express ideas in writing, but the magnitude of the effect was surprising (Jones & Christiansen, 1999).

There is a positive correlation between letter knowledge and handwriting function (Karlsdottir & Stafansson, 2002). When a student is learning to handwrite, the letter can be recalled more easily if the student is given a verbal cue (Alston & Taylor, 1987). Visual, auditory, motor and sequential skills, laterality and directionality all constitute part of the memory bank needed for learning and establishing letter formation (Alston & Taylor, 1987). For each letter, an internal model of how it is formed needs to be remembered so that it can be automatically and quickly recalled. Memory for letters will be extended into letter strings as the student learns to write and compose meaningful sentences (Alston & Taylor, 1987). The internalized model of each letter established within one's memory for automatic printing is the key step leading to automatic handwriting skills.

As children learn to handwrite a letter, an internal model of the letter is being developed through proprioceptive and kinesthetic processes (Benbow, 1995; Alston & Taylor, 1987). A clear image of the letter must be firmly established for the child to "know" what the letter looks like and how to form the letter. Initially, children rely heavily on visual input to assist with letter formation, however, as the kinesthetic memory of letters develop, children rely on proprioceptive and kinesthetic input from their joints during the movement when handwriting. This increased awareness allows handwriting legibility and speed to improve (Ziviani, 1995).

Weintraub and Graham (2000) identify orthographic coding as the ability to develop an intact representation of the letters of the alphabet, and rapidly and accurately encode and reproduce letters from memory. They predict that failure to develop this ability may constrain the development of handwriting legibility. Despite their prediction, the results of their study did not support this hypothesis. Weintraub and Graham (2000) investigated orthographic coding, with Grade 5 students who had good and poor handwriting. Three tests for orthographic coding were conducted and through correlation analyses they found that orthographic coding did not make a significant nor unique contribution to the prediction of handwriting legibility. The authors postulated that these processes may not have been found to contribute to handwriting legibility because the orthographic skills of Grade 5 students (and possibly even younger students) are so accurate and fluent that they do not constrain handwriting development (Weintraub & Graham, 2000). With a younger grade sample (Grade 1 or Grade 2), the findings may have been different. A possible explanation provided by Weintraub and Graham (2000) was that their assessment procedure for general legibility using the *Test of Legible Handwriting*, (Larson & Hammill, 1989) was too global.

In contrast, Abbott and Berninger (1993) found that orthographic coding skills accounted for a significant proportion of the variance in handwriting fluency of children in grades 1 to 6 and may be more important to handwriting development than fine motor skills. The students demonstrated significant correlations between handwriting and orthographic coding skills (producing alphabet symbols) but they did not have the same findings for fine motor skills (finger function) (Abbott & Berninger, 1993).

Berninger, Yates, Cartwright, Rutberg, Remy, and Abbott, (1992) evaluated a battery of predictive measures of writing given to 300 students in the first, second and third grades. The influence of neuromotor development, orthographic knowledge, visual motor integration, syllable and phoneme segmentation, word finding, sentence syntax, reading and verbal intelligence were explored for their impact on writing. The findings suggest that rapid coding of orthographic information, rapid automatic writing of alphabet letters and sequential finger movement were the best predictors of writing composition. This research leads to the argument that low-level developmental skills as well as component skills of handwriting and spelling may provide critical foundation in the early stages of writing. These foundational skills may influence the degree to which a child may subsequently develop higher level writing skills (Berninger et al., 1992).

Fine and Gross Motor Skills. Fine motor skills are critical in the development of handwriting skills (Graham & Weintraub, 1996). Good hand function is dependent on the balance between the intrinsic and extrinsic muscle of the hand and forearm. The small intrinsic muscles permit the thumb and index and middle finger to flex and straighten, and complete rotary strokes with a pencil to print or cursive write (Hanft & Marsh 1993). The muscles of the hand or the intrinsic muscles are used to guide and grade the movement of the fingers and thumb when manipulating and gripping small objects like pencils and crayons. These small hand muscles allow the fingers to spread out and move together (Hanft & Marsh, 1993). The larger muscles of the forearm that cross the wrist and attach to the small bones in the hand are known as the extrinsic muscles. Their function is to move the fingers and the thumb in larger hand movements, for example, flexing all fingers or fisting, or using a power grip (Hanft & Marsh, 1993).

A recent study conducted by Naider-Steinhart and Katz-Leurer (2007) described upper extremity proximal and distal muscle activity in typically developing children during handwriting tasks. As part of this study they explored the relationship between muscle activity and speed and quality of writing. The study included 35 participants in grades three and four who were assessed for muscle activity while completing the Alef-Alef Ktav Yad Hebrew Handwriting Test. The muscle activity was measured using surface electromyography and measured the activity of the trapezius muscle in the shoulder and the muscles of the thumb. The results indicate that the shoulder muscles had less variability than the thumb muscles. Less variability of the shoulder muscles was associated with decreased variability of the thumb muscles and this combination was associated with faster handwriting. The findings suggest that decreased muscle variability of the shoulder muscle (proximal) and thumb muscles (distal) are more economical for handwriting and allow for faster handwriting. The results of this study support the premise that a stable base of support in the proximal upper extremity is necessary for efficient distal control during writing (Naider-Steinhart & Katz-Leurer, 2007).

Weintraub and Graham (2000) found that finger function made a unique and significant contribution to the prediction of good and poor handwriting skills. The finger function tasks employed in this research involved finger succession (thumb to finger touching), finger lifting (raising fingers touched by researcher) and finger recognition (identification of the finger touched by researcher with vision blocked) as described by Weintraub and Graham (2000). Finger function in their research involved the accurate placement or identification of fingers based on tactual or kinesthetic cues, as these were found to be the most predictive cues of handwriting status identified in a previous study by Berninger and Rutberg (1992). Weintraub and Graham (2000) found that finger function contributed to the prediction of handwriting status in students who were good and poor handwriters. This result supports the premise that finger functioning is related to handwriting legibility even after the variance attributed to other factors (gender and letter motor memory/ orthographic coding) was accounted for (Weintraub & Graham, 2000).

The gross motor skills associated with handwriting development include shoulder stability, posture and balance. The development of a dexterous hand depends on the interaction of all the joints of the upper extremity (Benbow, 1995, p. 256). Each joint including the neck, shoulder, elbow and wrist, must be developed and move freely. Sometimes children tighten their muscles or use their muscles inefficiently which leads to difficulties in handwriting (Benbow, 1995). The smooth range of motion noted in the shoulder, elbow and wrist provide a stable base of support for the control of the joints in the hand (Benbow, 1995). Good posture and effective ergonomic positions decrease overall fatigue and allow for effective use of the large muscles of the shoulder, elbow and wrist to support the use of the writing tool (pencil, pen, marker, crayon) in the hand (Benbow, 1995).

Developmental hand skills are required for skilled fine motor control. These hand skills are present in students of 5 and 6 years of age (Benbow, 1995). Development of the thumb index web space, hand arches, in hand manipulation, finger and thumb isolation, motoric separation of the two sides of the hand and wrist stability are all necessary for developing an efficient pencil grasp (Benbow, 1995). The development of the thumb and hand arches is essential for proper pencil grasp and distal movement of the pencil on the paper (Benbow et al., 1992). In hand manipulation skill is required for controlling the pencil position in the hand, primarily picking it up and placing it into the writing position. It is also needed for adjustment of a grasped object within one hand while it is being held in that hand (Benbow, 1995). Correlations between in hand manipulation for rotational (pencil turning from writing side to eraser side) and translation movements (moving pencil down fingers to place them in the writing position on the pencil) are predictive in relation to handwriting skills (Cornhill & Case-Smith, 1996).

In hand manipulation skills were studied by Pehoski, Henderson and Tickle-Degnen (1997) to observe the development of in-hand translation skills in young children (the ability to move a small object from the fingers into the palm and from the palm to the fingers). A peg board task was used to measure this ability in 154 right handed children between the ages of 3 years 0 months to 6 years 11 months. The children's skills were then compared to adults' skills. The results showed that boys and girls had similar abilities, however, at times the girls had better skill performance. Age was found to be a significant factor in both the number of pegs held in the hand and the method used to move the peg from palm to fingers and fingers to palm. The older children tended to place more pegs successfully and were most likely to use methods most commonly used by adults. The majority of the children between the ages of 3 and 6 were able to pick up and hold several small objects in their hand one at a time. Getting the object out of the hand while only using one hand was harder but by the age of 6 years the majority of the children in the study could place at least 2 out of the 5 pegs. The authors identify that an older child's inability to perform a similar task might be suspect of difficulties (Pehoski et al., 1997).

Fine motor abilities in handwriting are integrated and precise, and affect the way in which the pencil is used during the task. Fine motor skills will affect how much and how smoothly the pencil will move in the hand and how the pencil is manipulated in the hand and adjusted between the writing tip of the pencil and the eraser end of the pencil (Benbow, 1995). Motor function (motoric separation) of the two sides of the hand refers to the differing functions of the little finger and the thumb side of the hand (Benbow, 1995). The function of the little finger side of the hand is to hold and stabilize an object while the thumb side of the hand is used to manipulate the object (Benbow, 1995).

A child must be able to hold the pencil efficiently in the dominant hand to write. When the child has an efficient pencil grasp with proper writing posture at the desk, the hand can easily maintain its position on the pencil to allow for skilled movements of the fingers. The child must be able both to hold the pencil and move the pencil into the grasp for writing. The fingers must be able to assist with pencil pressure on the paper. If a child makes a mistake and wants to use the eraser on the pencil, the child needs to be able to easily turn the pencil over to the eraser side and back to the lead side.

One of the most important components of an effective pencil grasp is the rounded open web space in the hand between the thumb and the index finger (Benbow et al., 1992). This allows for opposition of the fingers and the thumb so that objects can be manipulated freely with the finger tips (Benbow et al, 1992). Another important consideration of an efficient pencil grasp is the dynamic ability of the grasp or movement of the fine muscles of the hand. This allows for simple flexion and extension movements of the wrist and fingers to make vertical pencil strokes while the horizontal wrist action moves the hand across the paper (Benbow et al., 1992).

The dynamic tripod grasp is the most developmentally mature method of pencil grasp identified in the literature. This grasp allows for increased speed and the most sustained and dexterous control of the pencil in the hand (Connolly, 1973). The lateral tripod grasp is commonly used by children and is characterized by the pencil being stabilized against the radial side of the middle finger, with the index finger on top of the pencil and the thumb adducted and braced over or under anywhere along the index finger (Schneck & Henderson, 1990, p. 896). The lateral tripod grasp was observed to be one of the most commonly used grasps along with the dynamic tripod grasp. A recent study reported that fourth graders using the lateral quadrupod and lateral tripod pencil grasps performed better than the dynamic tripod and dynamic quadrupod grasps, for total word and letter legibility. However, the speed of handwriting for all of the children with the various mature grips was equal (Koziatek & Powell, 2003). This finding has been supported by others (Tseng, 1998; Parush, Leveanon-Erez & Weintraub, 1998; Dennis & Swinth, 2001). Tseng and Chow (2000) found that children who had normal handwriting speed depended more on motor skills than vision when handwriting.

Visual Motor Integration. Visual motor integration is the coordination of visual information with movement (Henderson & Pehoski, 1995). This ability is assessed in children by having them copy geometric diagrams. Visual motor skills associated with the development of handwriting follows a typical sequence of skills. The sequence moves from a preprinting stage to the handwriting stage. This sequence is outlined as follows:

1. At almost 3 years old, most children can copy a vertical line (Beery & Buktenica, 1989).
2. At 3 years old, most children can copy a horizontal line and a circle (Beery & Buktenica, 1989).
3. At just over 4 years old, most children can copy a cross (Beery & Buktenica 1989).
4. During the 4 years old period, children move from copying a cross to copying a diagonal line (/) , a square, another diagonal line (\), and by the end of age 4, most children can copy an oblique cross(X) (Beery & Buktenica, 1989).

5. By the end of age 5 most children can copy a triangle. Design copying ability starts to increase at this stage particularly in the level of detail copied, the ability to intercept shapes when copying, the ability to put shapes together and reproduce size and spatial organization (Beery & Buktenica, 1989).
6. At six years of age, children can copy a triangle, print their names, and copy most lower case and upper case letters (Amundson & Weil, 1996, p. 525).
7. At age eight, children can copy a diamond placed vertically on paper (Beery, 1989).
8. After this period the design copying becomes more involved including putting shapes together, intersecting shapes and adding detail. This development occurs up to 13 years of age (Beery & Buktenica, 1989).

Formal pencil and paper work should be postponed until a child can easily copy an oblique cross, an ability usually achieved at 5.5 years of age (Beery & Bultenica, 1989; Benbow, 1995). The oblique cross requires the child to have the ability to cross the midline using diagonal visual guidance. This integrated skill is necessary to produce several manuscript letters (Benbow, 1995).

Karapetsus and Vlachos (1997) found that a child's ability to copy designs develops specifically between ages seven and twelve, and there may be a difference between the development of boys and girls. They reported that at younger ages boys demonstrated lesser abilities in design copying when compared to girls. The authors hypothesized that different rates of human cerebral hemispheric maturation in the brain may be part of the reason why girls exhibit more advanced skills at certain developmental stages (Karapetus & Vlacos, 1997). Similarly, Judd, Siders, Siders, and Atkins (1986) found that boys in Grade 1 demonstrated weaker skills than girls in rate and accuracy of copying symbols. These differences may be related to information processing of symbols at this young age (Judd et al., 1986).

Visual motor skills have been found to correlate with handwriting abilities (Weil, Cunningham-Admunsun, 1994; Weintraub & Graham 2000; Karlsdottir & Staffansson, 2002). The Developmental Test of Visual Motor Integration (Beery & Buktenica, 1989) is used to identify children's readiness to start formal handwriting instruction in school. Reisman (1999) explored the correlation between scores on the Minnesota Handwriting Assessment (MHA) (Reisman, 1999) and the Test of Visual Motor Skills- Revised (TVMS-R) (Gardener, 1997) used by therapists and psychologists to assess visual motor skills in children The findings suggest that as children's visual motor skills mature, the relationship between handwriting and design copying become less strong indicating that these skills becomes more integrated and automatic in older children (Reisman, 1999).

Benbow (1995) suggests that shape copying tests such as the Developmental Test of Visual Motor Integration (VMI) (Beery & Buktenica, 1989) which provides a visual motor age for students, are useful in predicting a student's potential ease and potential difficulty in learning to print. They are less helpful in predicting the ease in a student's ability in learning cursive handwriting (Benbow, 1995).

Graham and Weintraub (2000) used the Developmental Test of Visual Motor Integration (Beery & Buktenica, 1989) to assess grade five students for comparison of their visual motor skills and fine motor skills. The results indicate that the scores on the VMI correlated significantly and uniquely contributed to the prediction of handwriting skills. This study supports the correlation between visual motor skills and handwriting ability in older children.

More recent studies (Tseng & Chow 2000; Volman et al., 2006) identified a relationship between visual motor ability, slow handwriting and handwriting quality. Tseng and Chow (2000) reported a 6.5% correlation between visual motor skills and slow handwriting. There was no correlation for children who had normal handwriting speed (Tseng & Chow, 2000). Volman et al. (2006) concluded that the poor quality seen in children who have handwriting problems was correlated with poor visual motor skills.

Kinesthesia. Kinesthesia is the conscious perception of the amount of joint movement and direction of joint movement and of the weight and resistance of objects being used in the hand (Benbow, 1995). All precise movements and integrated abilities are influenced by kinesthesia (Zion, 1996). Kinesthesia is considered part of the sensory system that makes movement of any kind possible and is the basis for understanding how the body operates (Zion, 1996). Through kinesthesia, one can determine where body parts are in space and how they are moving in relation to each other and the environment. Kinesthetic ability in handwriting is the most controversial foundational skill and appears to pervade all other foundational areas of automatic handwriting. Researchers and therapists understand that kinesthesia plays a role in automatic handwriting development, however, they have been unable to pinpoint the best way to measure it or the best tool for assessing kinesthetic ability in students (Benbow, 1995).

As a student initiates writing on paper, he or she holds the pencil in a way that enables the pencil to move freely, looks at what is to be copied, applies enough pressure with the pencil, and knows how to form words on paper quickly without thinking. As a student's experience in handwriting broadens, the actions become unconscious patterns that are stored in the brain, and called upon to execute a motor plan for letter formation. These automatic patterns only develop after many repetitions and are directed by kinesthetic planning or motor planning (Benbow, 1995). The development of these automatic patterns would seem important in the development of letter motor memory. Benbow (1995) identifies that handwriting is a kinesthetic skill and becomes automatic once the kinesthetic abilities for this skill are developed. This premise is inherent in Benbow's (1990) handwriting program (Loops and Other Groups ®) which was developed as a kinesthetic handwriting program to develop automatic cursive handwriting skills.

Efficient handwriting depends on kinesthetic ability (Benbow, 1995). Handwriting involves the "feeling" of the movement of the fingers in forming the letters without the need for visual guidance and enhances speed in learning cursive handwriting. Handwriting naturally accelerates over time leading to functional speed without the reduction of performance quality (Benbow, 1995).

The legibility of handwriting that relies on vision instead of kinesthetic ability may be neat and readable but will not be functional because the methodological execution of handwriting is too slow and too consuming of cognitive abilities. The motor activity of writing must be fairly automatic to free up cognitive abilities to writing and spelling. The human nervous system is able to focus clearly on only one complex task at a time. Therefore handwriting must be sufficiently automatic to be carried out as an associated skill within the writing process (Benbow, 1995). Kinesthetic ability makes the movement of the pencil on the page when handwriting fast and effortless (Benbow, 1995). The correlation of kinesthetic ability and handwriting speed and automatic handwriting as Benbow (1995) described it, has not been established in the research.

A study completed by Bairstow and Laszlo (1981) indicated that children at ages of six and seven with poor kinesthetic ability will find it difficult to perceive errors in their movement when printing, particularly when finger movements are quick and fine. Children need the ability to interpret kinesthetic information for refinement of fine motor skills (Bairstow & Laszlo 1981). A student's ability to pick out errors in movement is quicker than using visual feedback. If students have difficulty interpreting the joint positions of their elbow, wrist and fingers (kinesthesia), difficulty will be experienced even with visual input (Bairstow & Laszlo, 1981). The findings suggest that kinesthetic ability, perception and memory develop gradually and differences in ability are found at various ages (Bairstow & Laszlo, 1981).

In a later study, Bairstow and Laszlo (1983) identified a positive correlation between paper and pencil skills and kinesthetic sensitivity in 6 and 7 year old children. Using a Kinesthetic Sensitivity Test, the children who had poor kinesthetic ability, showed improvement on a drawing skill (copying geometric shapes) after kinesthetic sensitivity training but not after drawing training alone (Laszlo & Bairstow, 1983). The kinesthetic sensitivity training consisted of five 10 – 12 minute daily sessions using two runway apparati which could be set at different angles to each other. Two pegs, each mounted on a wooden base were placed on the starting platform of the runways. The child held a peg in each hand. The trainer guided the child's arms up and down the runways concurrently. The child's training task was to reliably discriminate arm position when vision was occluded and the arm position was moved. During the test period children who relied on kinesthetic ability alone found it extremely difficult or were unable to tell which of their arms/hands was higher, however, when the masking box was removed and the children used vision to assist them they could identify with ease which of their arms/ hands were higher with sensitivity to a 1 to 2 degree runway separation (Laszlo & Bairstow, 1983; Laszlo & Bairstow, 1984). As the child's kinesthetic skill improved the training task difficulty was increased. Following the runway task, the children underwent drawing practice using an increasingly complex picture for three times and by gradually increasing the difficulty of the drawing task over five training sessions (Lazlo &

Bairstow, 1983; Laszlo & Bairstow, 1984). The findings showed that kinesthesic ability in these children influenced drawing ability and could improve handwriting ability. Further research was recommended in order to draw conclusions about a possible relationship between kinesthesia and handwriting.

A follow up study by Laszlo and Bairstow (1984) investigated the results of the same type of kinesthetic training with eight and nine year old children who were diagnosed as clumsy and were found to suffer from dyskinesthesia (severe kinesthetic incompetence). They found that kinesthetic training made a marked improvement in drawing and writing for these children. A high percentage of the population of clumsy children in this study had dyskinesthesia (74%) and kinesthetic training showed favourable results in treating this clinical group. The findings indicated that one third of children at ages five and six years old are developmentally unprepared for paper and pencil tasks which may increase frustration (Laszlo & Bairstow, 1984). The authors provided three suggestions to narrow the gap between the required perceptual skills for handwriting and the demands placed on students by the writing task which requires full kinesthetic development.

1. The child's kinesthetic readiness could be identified by testing every five and six year old on the Kinesthetic Sensitivity Test (Bairstow & Laszlo, 1981).
2. General kinesthetic training could precede the teaching of pencil- paper skills. General training could include gymnastic type movement as Bairstow and Laszlo (1981) found that ballet dancers and gymnasts develop significantly finer kinesthetic perception and memory than subjects in other sport activities.

3. Formal teaching of fine paper-pencil skills could be postponed until the age of seven, by which time normal kinesthetic development has reached the level necessary for the performance and acquisition of this skill (Laszlo & Bairstow, 1984).

Laszlo and Bairstow (1984) identified that the latter is the most feasible suggestion in dealing with the development of kinesthetic ability in children. They suggested that classroom activities focus on reading and verbal skills rather than tasks that require writing.

A comparison of the effects of practice in kinesthetic acuity (accuracy), kinesthetic perception (interpretation of movement) and memory on handwriting performance of 124 kindergarten and grade one students with poor handwriting showed that kinesthetic ability may improve as the child matures (Harris & Livesey, 1992). The students were assigned to three groups with differing practice conditions. Practice consisted of six 15 minute sessions per subject, one session per day over consecutive school days. No feedback was give to students during the training group sessions.

The training group sessions are described:

A) Handwriting Practice Group: Students in this group were presented with different seven and eight word sentences to copy for 15 minutes in each practice session. Handwriting remediation was not emphasized but only handwriting practice in a time period.

B) Kinesthetic Acuity Training Group: The students used two arm runways that were placed at different angles with vision occluded. During 32 trials (equal trials to the students' right and left hands) the students had to indicate which hand was higher than the other. The percentage of correct responses was the kinesthetic acuity for that subject.

C) Kinesthetic Perception and Memory Training Group: A subject was shown six pictures and asked to describe the pictures. Following this, the subject's vision was occluded and holding a stylus in the preferred hand, the experimenter moved the subject's hand with stylus twice around the pattern with a pause at the start point. The experimenter then rotated the picture clockwise or counter-clockwise, 45, 90, 135, 180 degrees and the subject was asked to look at the pattern and to reorient it to the original position. The mean error (in degrees) was recorded indicating the subject's kinesthetic perception and memory. Thus, a lower score indicated better performance. (Harris & Livesey, 1991, p. 25).

The children in the handwriting practice only intervention demonstrated no apparent practice effect for the age group. The children who received kinesthetic acuity practice demonstrated a strong practice effect for the older group but not the younger group. There was a strong practice effect for kinesthetic perception and memory practice for the Grade 1 students and a much weaker effect for the senior kindergarten students. The results of this study indicate that children may develop better kinesthetic acuity (accuracy) and kinesthetic perception and memory skills as they mature. The older group of students showed the greatest improvement in handwriting from training in kinesthetic acuity and kinesthetic perception and memory practice. The students that were younger and just learning to handwrite showed little improvement with the training. It was postulated that the effect of kinesthetic practice may have little demonstrated effect until a level of proficiency in handwriting is achieved, or until the sensory system matures and the students have a better awareness of these skills (Harris & Livesey, 1992).

In a similar study, Sudsawad, Trombly, Henderson and Tickle-Degnen (2002) investigated the effect of kinesthetic training on handwriting performance in first grade students who demonstrated kinesthetic deficits and handwriting difficulties. The study sample consisted of 45 Grade 1 students who were randomly assigned to one of three treatment groups: kinesthetic training group, handwriting practice group and no treatment group. Treatment began one week after a pre-test and lasted for two weeks. The treatment included the following protocol.

A) *Kinesthetic Training Group.* Two training tasks were presented over a 6 day training period lasting 30 minutes. The runway task training had students differentiate with vision occluded the height of his or her arms on two table top runways. The angles of the runways differed starting at 20 degrees, and reduced to 16, 12, 8, and 4 degrees over the six day period. This task training lasted 15 minutes. In the pattern task training, students was asked to reorient one of six stencil patterns presented in order of the least to the most complex. The student used a stylus that was guided by the trainer through a cutout on a stencil pattern while the student's vision was blocked. The trainer then rotated the stencil and asked the student to put it back in its original position.

B) *Handwriting Practice Group.* Students participated in six training sessions that included copying letters, words and sentences. Verbal and visual feedback were provided for letter size, alignment and spacing.

C) *No Treatment Group.* The students in this group continued to participate in their usual academic activities in the classroom. They participated in the pretest and posttest assessments (Sudsawad et al., 2002).

In a post-test completed one week after treatment ended, significant improvements of kinesthesia and handwriting legibility were found as judged by the teachers but no significant improvements of handwriting legibility or handwriting speed as measured by the standardized handwriting measure were found. The students who received kinesthetic training did not improve significantly more in either kinesthesia or handwriting performance than the students who received handwriting practice or no treatment. The effectiveness of the kinesthetic training on handwriting performance was not demonstrated in this research (Sudsawad et al., 2002).

Levine (1987) suggested that students with impaired kinesthetic function demonstrated awkward and inefficient pencil grasps. He also proposed that impaired kinesthetic ability would be observed through slow writing that would not achieve automaticity. Other research has supported the relationship of kinesthetic function to handwriting. Ziviani, Hayes, and Chant (1990) found that kinesthesia (as measured by the Southern California Sensory Integration Test (SCSIT) (Ayres, 1972) was related to letter formation and letter alignment in children with spina bifida. This study proposed new views on handwriting legibility and identified that alignment, for children with spina bifida, is not as readily influenced by poor perception and visua-motor difficulties as previously thought but is influenced greatly by kinesthesia. Letter formation is also considered at risk if kinesthetic insensitivity is present (Ziviani, Hayes, & Chant, 1990).

Tseng and Murray (1994) found that kinesthesia did not emerge as a significant contributor to handwriting legibility and was not significantly different in children with good and poor handwriting. They studied a group of 143 students in grades three to five. Seventy one students were identified by their teachers as having poor handwriting while 73 students were identified by their teachers as having normal handwriting skills. Overall handwriting performance was assessed by having the students copy a paragraph of a story from a beginning grade three Chinese textbook (Tseng & Murray, 1994). The students were asked to copy for 10 minutes and use their normal handwriting without rushing. Following completion of the handwriting sample, teachers sorted the samples for legibility on a scale of 1 (poorest) to 7 (best). The mean was calculated and students who scored within the middle range were excluded to make sure the two groups (good and poor handwriters) were well represented. Those handwriting samples that scored above the mean were classified as good handwriters and those samples that scored below the mean were classified as poor handwriters. Once the two groups of students were identified from the sample, perceptual motor tests were completed with each student. The students were assessed in visual motor skills, upper limb speed and dexterity skills, visual perceptual skills, kinesthetic skills, eye hand coordination, finger identification and position.

The results suggested that kinesthesia did not emerge as a significant contributor to handwriting legibility. The researchers felt that perhaps the kinesthetic skills required for printing in English versus Chinese may be different and difficult to measure (Tseng & Murray, 1994).

Poor kinesthesia can be associated with poor motor planning skills (Cornhill & Case-Smith, 1996). Children with motor planning difficulties often have difficulties in their ability to plan and direct sequences of hand movements which can affect handwriting (Ayres, 1972; Benbow, 1995; Cunningham-Admundson, 1992). A child with limited kinesthetic ability must rely heavily on visual guidance when writing because of the lack of kinesthetic feedback during joint movement (Cornhill, & Case-Smith, 1996). That is, vision is used more when a student is lacking kinesthetic function (Benbow, 1995; Tseng & Cermak, 1993).

Summary

As children learn to handwrite, they must utilize foundational skills in an integrated manner. The specific order or hierarchy of the foundational skills is known based on developmental milestones and observations of children's behaviour. The correlation of such skills and their relationship to handwriting development was the area considered in this review of the literature.

The development of automatic handwriting starts with the foundational developmental skills of handwriting but can be influenced by students' ages, grades and the handwriting instruction methods used by teachers. Handwriting legibility and speed are an integrated component of automatic handwriting skills. The underlying premise for automatic handwriting is that automatic handwriting is a tool that enables a student to write within a reasonable time frame, to keep up with the classroom expectations, take notes for his or her own needs in learning and to handwrite with a degree of legibility that enables the student and others to read without effort the information that is written. We know that factors like fine motor skills, visual motor skills, visual perception, letter motor memory and kinesthesia play a role in a student's ability to learn to handwrite. The specific influence of these factors on automatic handwriting has not been well researched or the results of such research are not consistent. The influence of each factor associated with handwriting development in students with handwriting difficulties, particularly slow handwriting in the classroom, is the focus of this research.

Chapter III

Research Question and Methodology

Occupational therapy focuses on improving handwriting skills by implementing programs intended to target the foundational skills assessed as being problematic. In this study, data from existing occupational therapy clinical charts for students who were referred to therapy because of slow handwriting were used for statistical analyses of foundational skills areas associated with handwriting development.

Handwriting problems are among the major identified reasons for students being referred to occupational therapy by the school system (Chandler, 1994; Clark-Wentz, 1997; Vreeland, 1999). As reported earlier, foundational developmental skills all play a part in learning to handwrite, however, their impact on the development of automaticity is not very clear. In this research the foundational skill areas of developmental hand skills, visual perception, letter motor memory, upper limb speed and dexterity skills, fine and gross motor skills, visual motor skills and kinesthesia were targeted for exploration.

The specific questions guiding this research were:

1. How many groups of students or Latent Classes exist within the data gathered from the occupational therapy clinical files for 200 students with slow handwriting based on their performance in foundational skills associated with handwriting development?

2. What is the specific nature of each group of students or Latent Class in the foundational handwriting skill areas?

Students with slow handwriting are frequently referred to occupational therapy for intervention to improve handwriting in the classroom. During the occupational therapy assessment, children are identified as having difficulties in one or more of the underlying foundational skills. Many are also diagnosed with a learning disability (language or non- language based) or a medical diagnosis such as attention deficit disorder (ADD) or attention deficit hyperactivity disorder (ADHD) that impacts their learning. Some children have a visual perceptual problem, a fine motor problem or a motor coordination difficulty that co-exists with the handwriting problem. Others do not have a diagnosed learning disability or medical diagnosis but continue to have handwriting difficulties and slow handwriting in the classroom and in therapy.

The specific medical diagnoses on the charts were not analyzed as variables in the research because of the difficulty in differentiating which diagnoses impact on the difficulties with handwriting. Many students have several diagnoses such as central auditory processing, attention deficit disorder and visual perceptual dysfunction. Students diagnosed with a developmental delay were excluded from the study, but all others, regardless of the diagnoses were included.

Research Design

This research used a cross sectional research methodology based on a retrospective review of the charts of students referred to occupational therapy because of difficulties completing the writing demands of the classroom. As standard practice, students receiving occupational therapy services in the school system undergo an initial assessment of visual perceptual skills, letter motor memory, fine motor skills, visual motor skills, kinesthesia and handwriting speed. Data for this study were gathered from initial assessments from two hundred (200) student files. The data were then analyzed using Mixture Modeling/ Latent Class Analyses.

Mixture Modeling / Latent Class Analyses

Mixture modeling is a data analysis method used to identify homogeneity in a population (Nylund, Asparouhov & Muthen, 2007). Profile analysis is a generic term for all methods of statistics concerning the grouping of people according to their scores on particular variables (Ding, 2001). A Latent Class in mixture modeling is a description of the group of people identified. In this case, Latent Class Analyses (LCA) was used to identify/describe the nature of a group of students with slow handwriting.

LCA was used to discover groups of students that "hang together" or "cluster" with the same performance in particular foundational skill areas (Ding, 2001). The students that cluster together with similar skill performance are considered to be a Latent Class. Once the Latent Classes are identified, further analyses are undertaken to define the population based on the differences and similarities of the means for each variable or factor used for the Latent Class Analyses. The Latent Classes that are identified present a profile of skills or variables that define the group.

Consent and Confidentiality

All student clinical files used in the study were from students referred for an occupational therapy assessment and intervention. According to the Privacy Act, clients' files can be used for research as long as all identifying information is removed. Clinical files brought into the study were closed and inactive files as the students were no longer receiving occupational therapy services. As the attending therapist, I was the only person to have access to the names of students and all students' clinical files. All student files were assigned a number to track them and were kept in a locked cabinet to which access was controlled and confidential. The student clinical files will be stored for 10 years following the students' eighteenth birthday as required by legislation for storage of paediatric medical records. The data collected from the clinical files and used for entry of statistics to be analyzed will be kept for 5 years in keeping with criteria for storage of research data.

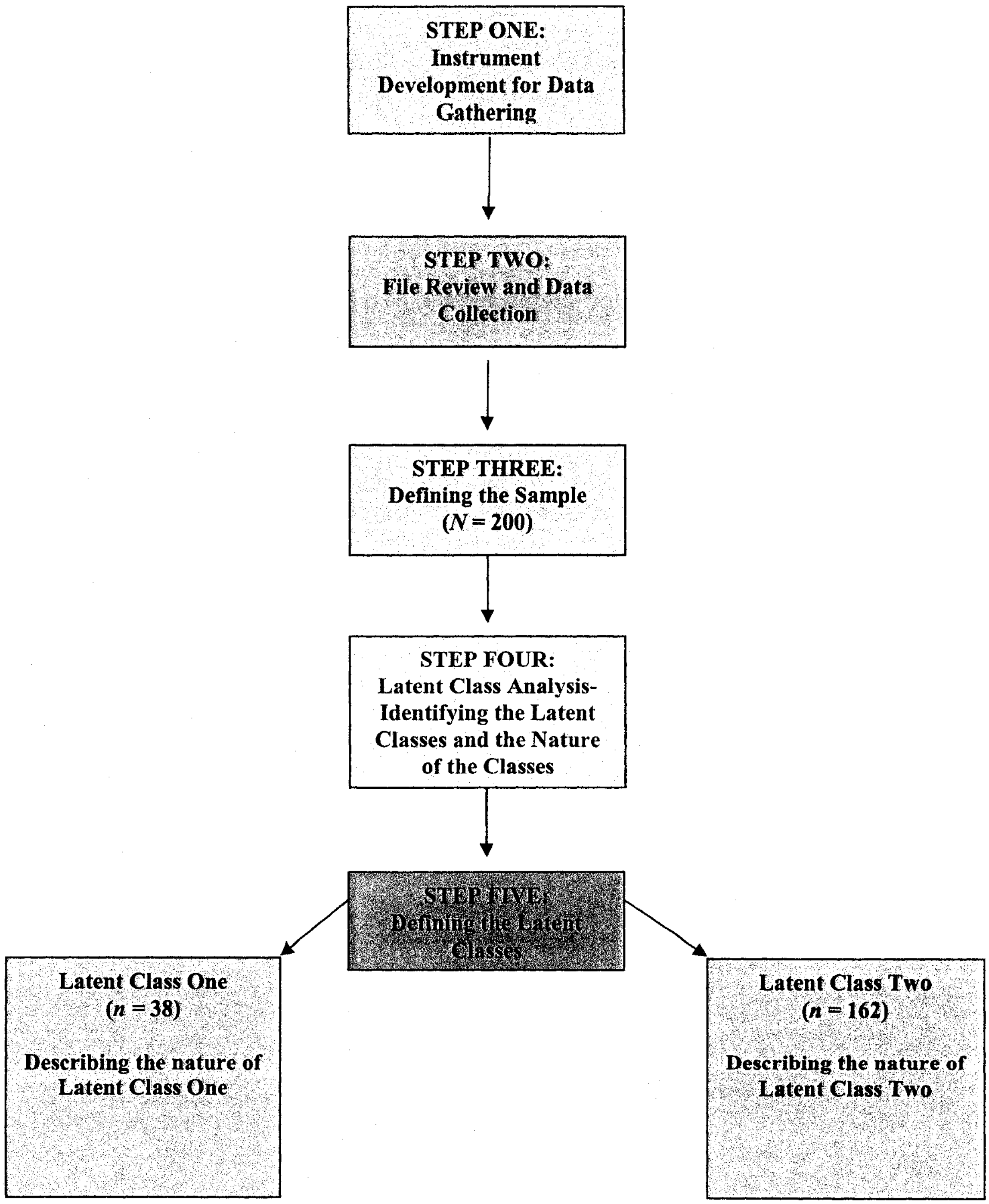
Methodology

A preliminary examination of several clinical files confirmed the availability of a wealth of data. The task was to make the data useable for statistical purposes. The data necessary for latent class analyses needed to be gathered from the files using a standard method for consistent data marking. Therefore, the first stage of the study included the development of data collection instruments. An initial file inclusion criteria list was developed. Based on this list, a draft raw data collection sheet was prepared. These were used on a pilot assessment of 15 clinical files. Qualitative notes were taken during the pilot to guide the development of the statistical data markers and three data gathering protocols were established; a) a list of criteria for file inclusion, b) a raw data collection sheet, c) a set of statistical markers used to standardize the data for statistical analyses.

Next, the clinical files were examined using a random file selection process in which files were first previewed to see if the inclusion criteria were met. Data from those files that met the inclusion criteria were gathered onto raw data sheets using the developed standardized data markers. When 200 raw data sheets had been completed, data from them were entered in a data spreadsheet to be statistically analyzed. The instrument development and data gathering stages are described in Chapter IV.

The data spreadsheet that resulted from these first stages was used for two forms of data analyses. First the spreadsheet data were converted into an SPSS file for descriptive and comparative statistical analyses, and then it was used for Latent Class Analyses. The data analyses are described in Chapter V. The Latent Classes that were identified through Latent Class Analyses were defined using multivariate analysis of variance (MANOVA). Based on these findings, the Latent Classes were described and underwent further statistical exploration using follow up analysis of variance (ANOVA) to the MANOVA. The discussion in Chapter VII focuses on the impact of foundational handwriting skill variables on handwriting performance for Latent Class One and Latent Class Two. Figure 1 illustrates the road map used for the research methodology.

Figure One: Flow chart for the research methodology. "Handwriting: An Exploration of Foundational Skills".



Chapter IV

Instrument Development and Data Gathering

STEP ONE: Instrument Development for Data Gathering

1. **Determine file inclusion criteria.**
2. **Develop raw data sheet.**
3. **Standardize data markers.**

Instrument Development

The goal of this research was to determine what students with slow handwriting "look like" in terms of foundational skills associated with handwriting development. The raw data used for statistical analyses were collected from clinical files containing student scores from a battery of assessments completed by occupational therapists. The students were referred to occupational therapy because teachers identified students as having difficulty keeping up with written work.

From the literature we know that children develop the foundational skills for handwriting before they enter the classroom with the development of hand dominance, in-hand manipulation skills, visual perceptual skills and the ability to integrate visual perception and hand coordination in visual motor integration skills. For children proficient with handwriting, these skills develop in an integrated manner. Children learn to recognize letters, print letters from a copy and then from memory. They can copy print from a paper next to them or from the black board. As handwriting matures, the motor aspect of this skill becomes less cognitively demanding as handwriting becomes more automatic. The goal of efficient handwriting is for students to easily put their ideas down on paper to communicate their ideas without having to think about the motor skill of printing in the writing process.

We do not know exactly why some children do not develop automatic handwriting skills. Children who have difficulty with handwriting are unable to demonstrate their knowledge on paper because the handwriting task is too complex for them. These children become less able to perform in the classroom as the demands of the classroom increase. There is evidence to suggest foundational skills are lacking in children who have handwriting difficulties. We do not, however, have a "profile" of these students and their level of foundational skills to use as a starting point for further research on appropriate therapy and compensatory strategies. This research has been set up to identify "profiles" for students who cannot keep up with the writing demands of the classroom.

During occupational therapy assessment some children demonstrate average skills in all of the foundational areas of handwriting as assessed through standardized assessments and through observational assessments. Others do not have the necessary motor skills. Some lack the memory skills needed to remember how to form letters without a visual sample. How do these types of students differ statistically when scored on assessments of foundational skills? This question is where the exploratory process for understanding students with slow handwriting begins.

Three interconnected data collection instruments were needed in order to extract the data to be used for latent class analysis from the student files. These were:

1. Criteria for File Inclusion. A measure by which to assess whether or not a specific clinical file contained the necessary information and criteria for rejection of those that did not have the necessary information.

2. Raw Data Sheet. A coherent format for documenting the information selected for inclusion in the analyses.
3. Standardized Data Markers. Criteria used to quantify the data to make them reliable for data analyses.

These three instruments were developed through trial and error in a pilot data collection exercise. Qualitative notes were made throughout the pilot assessment.

Pilot File Review

As the file review process started, qualitative information based on the occupational therapists' notes available in the student charts and the referral information from the teacher were identified. Clinical ideas based on the qualitative information helped to finalize the inclusion criteria and raw data sheet for data gathering and helped identify areas that needed to be highlighted in the data gathering process.

There seemed to be two groups of students referred to occupational therapy for handwriting difficulties. Those students who proved to be slow in occupational therapy testing and students who were slow in the classroom but within the average ranges for their grade for handwriting speed when tested by the occupational therapist. Many of the students whose files were included in this study had an average handwriting speed in a one to one situation but had slow handwriting performance in the classroom. This finding indicated that the student had difficulties maintaining a skill level in the classroom that was not evident in a one to one situation. Many reasons could account for this problem particularly, attention difficulties. Because of this finding, the raw data sheet was changed to include information about the student's attention skills in the classroom.

Attention issues diagnosed or not, could impact classroom productivity, including slow handwriting.

Several questions emerged concerning the relationship among foundational skills which suggested the use of particular data analyses. In particular, the questions were centred on correlations between letter motor memory and visual motor skills, handwriting quality and visual perceptual skills, or letter formation skills and speed of handwriting. These correlations could possibly be factors in the profile of students with handwriting difficulties and subsets within that profile that may or may not be divided between those with perceptual skill difficulties and those with motor difficulties. The pilot chart review process resulted in adaptations to allow for statistical analyses around these questions.

Development of File Inclusion Criteria

Criteria necessary for a student's file to be included in the study were identified to ensure that the information needed to explore the foundational skills associated with poor handwriting was available. The initial criteria used for the pilot file review were as follows:

1. The information provided to OT in the referral by the teacher indicated that the student was slow with handwriting and demonstrated poor handwriting that affected classroom performance.
2. The file included a handwriting speed test completed by the Occupational Therapist .
3. Handwriting legibility and quality indicators were included in the file. These were handwriting quality characteristics (letter formation, letter and word spacing, letter alignment, letter size and legibility) and kinesthesia (identified as pencil pressure).

4. Standardized assessments and ranking assessment in foundational skill areas associated with handwriting development were present on the chart. These areas include gross and fine motor skills, visual perception, visual motor skills, and letter motor memory.

The results of the pilot file review, the development of the final version of the raw data sheet, and the development of data makers all contributed to the confirmation of final chart inclusion criteria. In the end, a chart was included in this study if all of the inclusion criteria identified below was present. If not, the file was not used.

1. Handwriting problems related to slow handwriting in the classroom were identified by the teacher. Teachers use a checklist as part of the referral process. On this checklist there is a place to indicate that the student is slow to complete handwritten work in the classroom. The file was included in this study if the teacher identified the student as having handwriting difficulties or if a comment about slow handwriting, was included in the comments of the teacher on the referral.

2. Handwriting speed was assessed by the occupational therapist during the formal assessment process. A speed assessment completed by the occupational therapist is a standard assessment protocol for referral to occupational therapy in the school system. The results of this speed test indicated whether the student was slow in a 1:1 situation or slow in the classroom situation. Handwriting speed is normally determined by having the student copy a sentence for two minutes from a near copy sample, that is, the sample to be copied is on the student's desk, or the student is asked to do a far copy sample in which the sample to be copied is written on the blackboard. The standard sentence used is "the quick brown fox jumped over the lazy dogs" since it includes all the letters of the alphabet. The protocol from the Resource Book on Handwriting Assessment (Chedoke- McMaster Hospital, 1992)

is usually used as a reference for the therapist in determining handwriting speed in letters or words written per minute. The handwriting protocol was developed in Hamilton, Ontario and used with a population of "normally developing" students in the public school system in that city/ district. It was used as a guideline for the occupational therapist in determining handwriting speed. It is not a norm-referenced handwriting assessment.

3. Pencil grasp was assessed, identified/ labeled and hand dominance noted. As part of the assessment, occupational therapists report the type of grasp that a student uses to hold the pencil. Also, hand dominance of the student is usually noted. Hand dominance information was not necessary for the file to be included but pencil grasp was a necessary component.

4. Completion of a developmental hand skills assessment. Occupational therapists complete a developmental hand skills assessment using an object manipulation assessment developed by Benbow (1980). The skills assessed using this observational hand assessment include wrist stability, in-hand manipulation, hand arches, finger isolation, motoric separation of the two sides of the hand and thumb\ index web space. These skills are observed in children who are in Senior Kindergarten and Grade One, if they are developing in the typical manner. The therapist ranks the skill level of the student in each of these developmental areas. If this was present in the file, the file was included.

5. Completion of the Test of Visual Motor Skills Revised Alternate Scoring Method (Gardner, 1997). This test is used by occupational therapists to determine if a child is able to copy accurately various shapes and forms in a developmental order. Initially students are asked to copy a horizontal line, then a vertical line, a circle, and a diagonal line. As the student continues to copy each shape from the booklet the shapes get more detailed and difficult to

copy. The student copying is scored according to various details including but not limited to the intersection of lines, closure of lines, basic shape similarity and size. The raw score is calculated and then translated into a motor age, percentile rank, standard score and stanine for interpretative purposes. All students whose charts were included in this study completed this assessment in a one to one situation with an occupational therapist and the standard score was available in the file.

6. Completion of the Test of Visual Perceptual Skills Revised (Gardner 1996). Student charts included in this study included results of a thorough visual perceptual test with several perceptual subtests. The whole assessment needed to be completed for the chart to be included in the study. The visual perceptual quotient (VPQ) based on the sum of scaled scores for each perceptual subtest (visual discrimination, visual memory, visual spatial relations, visual form constancy, visual figure ground, visual sequential memory and visual closure) was the score used in this study.

7. Completion of the Bruininks Oseretsky Test of Motor Proficiency – Upper Limb Speed and Dexterity Subtest (Bruininks, 1978). Students referred to occupational therapy is assessed for their ability to complete manual tasks in a quick and proficient manner using one and two hands together. Tasks include turning pennies, drawing lines, placing pegs, shuffling and placing cards and stringing beads. This is a timed test and all students are scored for the number of items placed or turned in 15 seconds.

8. Alphabet handwriting sample identifying letter motor memory upper and lower case. As part of the occupational therapy assessment each student is asked to print or handwrite the alphabet from memory. This test is not a timed test but is used to observe letter formation

and a student's ability to remember how to print a letter. Each student in this study had an assessment completed of their letter motor memory.

9. An observational assessment of kinesthetic ability was present on the OT assessment. A rating chart was used if the occupational therapist noted the student's pencil pressure was too light, too heavy or not fluid during the handwriting assessment. The therapist usually rated the student's pencil pressure descriptively.

10. The quality of handwriting is rated in the student file to include handwriting legibility, handwriting quality and handwriting letter formation. As part of the standard OT assessment protocol, an assessment of handwriting quality is completed in the area of overall quality, legibility and letter formation. The therapist rated each handwriting quality component based on guidelines developed for the OT assessment. The handwriting assessment of quality was not standardized or norm referenced.

Once the inclusion criteria were established, each file was reviewed for the information required for inclusion in the study. If one of the inclusion criterion was not present, the chart was not included for final systematic review of the variables.

Development of the Raw Data Sheet

A draft raw data collection sheet was completed based on information gathered through a literature review and adapted following the pilot test. The working definitions for the variables are found in the glossary in Appendix 2. During the pilot, data were identified as either continuous (along a continuum) or categorical (falling into a slot or category). The continuous variable measures were recorded to include the raw score, standard score, scaled score, stanine and percentile range and skill age (motor age, perceptual age). Standardized clinical observations and a working definition of each variable were used to establish the parameters of each variable. Figure 2 is a copy of the final raw data sheet used in this research. Data on all of these variables were collected but all variables were not used in the final analyses.

Figure 2. Raw Data Sheet.

Figure 2:	Raw Data Sheet					(page 1)
Client Number:						
Sex:	Male					Female
Grade:	SK 1 2 3 4 5 6					Age:
Learning or Medical Diagnoses: (Diagnosed by)						
Other Information (Re: Writing Productivity)						
Foundational Skills	Scoring					Comments
Hand Dominance						
Pencil Grasp						
Developmental Hand Skills:	Wrist Stability /5 Finger / Thumb Isolation / 5 Thumb Index Web Space / 5					Motoric Separation / 5 Hand Arches / 5 In Hand Manipulation / 5
Upper Limb Speed and Dexterity (Bruininks)	RS	Std	Scld	PR	Stan	
Upper Limb Coordination (Bruininks)	RS	Std	Scld	PR	Stan	
Strength (Bruininks)	RS	Std	Scld	PR	Stan	

Figure 2 Continued: Raw Data Sheet (page2)						
Balance (Bruininks)	RS	Std	Scld	PR	Stan	
Posture when handwriting (postural control)						
Visual Motor Skills – TVMS Revised (Gardener)	RS	Std	Scld	PR	Stan	
Visual Perceptual Skills-Revised (Gardener)	RS	Std	Scld	PR	Stan	
VP- Visual Discrimination	RS	Std	Scld	PR	Stan	
VP – Visual Memory	RS	Std	Scld	PR	Stan	
VP- Visual Spatial Relations	RS	Std	Scld	PR	Stan	
VP – Visual Form Constancy	RS	Std	Scld	PR	Stan	
VP – Visual Sequential Memory	RS	Std	Scld	PR	Stan	
VP – Visual Figure Ground	RS	Std	Scld	PR	Stan	
VP – Visual Closure	RS	Std	Scld	PR	Stan	

Figure 2 Continued:	**Raw Data Sheet**	**(page 3)**
Letter Motor Memory	**Upper Case:** **Lower Case:**	
Kinesthesia		
Handwriting Speed		
Handwriting Legibility		
Consistent letter size, spacing and alignment (Baseline)		
Letter Formation		
COMMENTS:		

Development of Data Marking System for Chart Review

Data marking was completed by defining the variable with a working definition and giving a number to each piece of data. For example, a data marker of 1 for right handedness, 2 for left handedness or 3 for hand dominance not established. Each foundational skill was represented by a standard score for rankings from standardized assessment or by a designation score for categorical data. Continuous scores were accommodated for age for comparison by using the corresponding standard score for each assessment.

Data Markers

1. <u>Handwriting Speed.</u>

Students who scored one standard deviation (SD) below average for handwriting speed for age and grade during the occupational therapy handwriting assessment received a designation of "1". Those above the 1 SD cut off range, functioning at an average level, were assigned a designation of "2".

2. <u>Pencil Grasp.</u>

A five point system was used to designate pencil grasp and its efficiency during the handwriting task (5 for mature pencil grasp and a 1 for a primitive pencil grasp). The point system used for designating a score was based on research by Schneck & Henderson, 1990; Erhardt, 1992 Tseng, 1998; Amundson, 1995; Edwards, Buckland, & McCoy-Powlen, 2002; Yakimishyn & Magill-Evans, 2002. Most children will develop a mature grasp for pencil use. Although some children may develop less mature pencil grasps, these pencil grasps are not always problematic for handwriting however the pencil grasps that are very tight and static will cause difficulties for functional handwriting (Benbow, 1995). Table 1 provides the scoring for each pencil grasp, the type of grasp, and a description of the grasp properties used by the therapist in ranking students' pencil grasps.

Table 1. Description of Pencil Grasps.

(page 1)

Table 1. MATURE PENCIL GRASPS
Designation of 5

Teachers and therapists work towards helping children achieve mature pencil grasps as they are the most efficient for writing. When using this grasp, the fingers guide the pencil in a smooth and fluid manner with good use of all hand skills. Pencil pressure is regulated and muscle effort is minimal on observation. Students who have a mature pencil grasp were given a rank score of 5 during the occupational therapy assessment. The grasp itself could be one of the following types:

The **dynamic tripod grasp** is a three finger pencil grasp with the thumb and index finger in opposition. The pads of the index finger and thumb touch the pencil while the middle finger supports the pencil on the side of this finger. The dynamic pencil grasp is thought to be the most efficient and skilled pencil grasp due to the intrinsic movement of the muscles in the hand (Benbow, 2002).

The **alternate tripod grasp or the interdigital grasp** looks unusual. The pencil rests in between the index and middle finger with the thumb in opposition. All three fingers are rested on the pencil shaft while the index finger and thumb are in opposition and the pencil rests on the side of the middle finger. This is an efficient grasp and places a minimal amount of physical stress on the joint of the thumb (Benbow, 1995).

The **dynamic quadrupod pencil grasp** offers more stability to control the pencil as it provides increased surface contract between the fingers and the pencil shaft (Benbow, 2002). Three fingers (index, middle and ring finger) rest on the pencil along with the thumb in opposition. The web space between the thumb and index finger is open.

The **lateral tripod grasp** is characterized by the stabilization of the pencil against the radial side of the middle finger with the volar surface of the index finger (middle joint of index finger to finger pad) placed on top of the pencil shaft. The thumb index web space is narrowed with this grasp. The pencil is less diagonal with this grasp (Schneck & Henderson, 1990; Bergmann, 1990; Schneck, 1991; Myers, 1992; Admundson, 1995; Benbow, 1995; Dennis & Swinth, 2001; Summers, 2001).

(page 2)

Table 1 Continued. STATIC PENCIL GRASPS WITH MATURE PENCIL HOLD
Designation of 4

These pencil grasps look the same as the grasps described above however the fingers hold the pencil in place while the movement of the pencil comes from the forearm and shoulder instead of the hand. On observation, the fingers do not move to control the pencil in a fluid manner. Pencil pressure is usually increased and children complain of fatigue in their hands during writing tasks. Students, who have this grasp, demonstrate some emerging properties of the dynamic grasp in the fingers but finger movement is not smooth and muscle effort is observed. The dynamic properties of the grasp are intermittent and not maintained during the writing task.

The **static tripod grasp** looks identical to the mature dynamic tripod grasp until the hand is observed when writing. This pencil grasp is seen when the hand moves as a unit during the writing task and the fingers do not routinely move freely to control the pencil however some movement of the fingers is noted but not consistent. Three fingers hold the pencil in position with the thumb and index finger in opposition. This grasp is typically identified as a transitional grasp (Benbow, 2002).

The **static quadrupod** grasp is a four finger hold of the pencil. It looks identical to the mature dynamic quadruped grasp until the student starts to write. When writing the hand generally moves as a unit and the movement of the pencil comes from the wrist and forearm. Some movement is noted in the hand but not consistent. The fingers told the pencil tightly without moving freely to control the pencil. This grasp will typically develop into a dynamic grasp as it is mostly transitional (Benbow, 2002).

The **cross thumb grasp** is characterized by flexion of all of the fingers into the palm of the hand against the thumb side of the index finger. The thumb is crossed over the pencil to the index finger (Schneck & Henderson, 1990; Schneck, 1991). The wrist and the flexed fingers move the pencil as a unit as the forearm rests still on the table (Schneck, 1991). This is also a transitional grasp.

(page 3)

Table 1 Continued. **FIXED STATIC GRASPS**
Designation of 3

These pencil grasps are awkward and inefficient. The fingers hold the pencil tightly so that the fingers cannot move freely to control the pencil. The movement of the pencil comes the forearm and shoulder. The hand moves as a unit when handwriting. The student complains of hand fatigue. Pencil pressure is increased when using these grasps.

The **locked grip** is characterized by a tight fisted hand with the thumb crossing over the index finger or tucked under the index finger. The hand moves as a unit and tires easily (Benbow, 2002)

The **Index Grip** is characterized by 5 fingers having contact with the shaft of the pencil. The wrist is slightly flexed with the wrist in a neutral position. The index finger wraps around the shaft while the pads of the thumb, middle and ring finger support the shaft. The little finger supports the shaft on the thumb side of the finger. This grasp is seen in with laxity of ligaments in the hand (Benbow, 2002).

The **lateral pinch grip** is characterized by a tight pencil grasp with a hyper extended wrist. The thumb index web space is closed and the hand moves as a fixed unit (Benbow, 2002)

The **grasp with extended fingers or 4 fingered grip** is characterized by the pencil being held on the thumb side of the index finger and thumb with the fingers observed to be straight. Four fingers rest on the pencil shaft. This grasp is less stable and the forearm moves as a unit to control the pencil (Benbow, 2002).

(page 4)

Table 1 Continued. DEVELOPMENTALLY IMMATURE GRASP
Designation of 2

Developmentally immature pencil grasps are not functional for writing. These pencil grasps look very awkward. The wrist is not in contact with the table and the heel of the hand is usually in the air. Pencil control is minimal and pencil pressure can be light or heavy. These grasps are naturally observed in very young children under the age of three (Yakimishyn & Magill-Evans, 2002). When these grasps are observed in school age children, intervention to develop the grasp is needed.

The **digital pronate** grasp is developmentally immature and is characterized by the end of the pencil or crayon extending past the palm of the hand with the index finger on the crayon in an extended position. The thumb is close to the hand and the movement of the pencil is a result of whole arm movements. This grasp is usually seen in children around two years old (Yakimishyn & Magill-Evans, 2002). This grasp is not mature and requires intervention to develop into a mature grasp.

The **interdigital grasp (Variation 1)** is observed with the fingers fisted into the palm. The pencil lies across the palm and projecting on the little finger side (ulnar side) of the hand from between the index and middle fingers. Movement comes from the fingers and the wrist (Tseng, 1998).

The **interdigital grasp (Variation 2)** is characterized as a fisted grasp with fingers fisted into the palm, pencil across the palm and projecting on the ulnar side of the hand between the middle and ring fingers (Tseng, 1998).

he **interdigital grasp (Variation 3)** is characterized as a fisted grasp with fingers fisted into the palm, pencil across the palm and projecting on the ulnar side of the hand with the tip of the pencil projecting between the ring and little finger (Tseng, 1998).

Table 1 Continued.	PRIMITIVE GRASP Designation of 1	(page 5)
The grasp is very primitive and observed early in hand development. **Radial Cross Palmar Grasp** is observed by the pencil being held across the palm of the hand with the lead of the pencil and the thumb of the hand toward the paper. The hand is fisted and the forearm is in full pronation. The child uses full arm movement to scribble (Shneck & Henderson, 1990).		

4. Developmental Hand Skills.

In this research the score (out of 5) on each of 6 developmental hand skills was gathered from the student file for a total score (out of 30) based on wrist stability, motoric separation of the two sides of the hand, finger and thumb isolation, hand arches, in hand manipulation skills and the maintenance of thumb index web space. These hand skills are expected to be observed in children who are 6 years old who are developing as expected in fine motor areas (Benbow, 1995). Most of the developmental hand skills are noted in children younger than 6 years old (Erhardt, 1992; Pehoski et al., 1997). In this study, the individual developmental hand skills scores were also used in the analyses to determine if one skill had more impact on handwriting than another. Table 2 outlines the numerical designation allotted for each hand skill ranging from the highest score of 5 to the lowest score of 1.

Table 2. Description and Designation of Developmental Hand Skills

	(page 1)
Table 2.	**DEVELOPMENTAL HAND SKILLS**
WRIST STABILITY	The ability of the wrist to remain in extension when holding the pencil. This provides support during handwriting.
Designation of 5	**Normal Skill:** Wrist in extension for all handwriting activities and offers support of hand and fingers for handwriting.
Designation of 4	**Intermittent Skill:** Wrist in neutral position and slightly flexed at times during handwriting task some mature wrist extension observed without verbal cuing from therapist.
Designation of 3	**Developing Skill:** student needs reminding to position the wrist in extension and with reminding can keep it extended. Can achieve wrist extension but not observed during task unless reminded by therapist
Designation of 2	**Emerging Skill:** Wrist extension can be maintained for very short periods during task with constant reminding of therapist. Wrist is mostly neutral or flexed and wrist extension only occurs with support.
Designation of 1	**Skill Not Present:** The wrist is not observed to extend during task. Student is not aware of how to extend wrist.

(page 2) Table 2 Continued. DEVELOPMENTAL HAND SKILLS	
MOTORIC SEPARATION OF THE TWO SIDES OF THE HAND	The ability of the hand to move the front of the hand while the heel of the hand offers support as when using scissors or snapping fingers.
Designation of 5	**Normal Skill:** The front of the hand can support utensils such as scissors while the little finger (5th finger) side of the hand offers support. Tasks snapping fingers, using scissors efficiently, moving pencil while heel of hand supports wrist hand on table.
Designation of 4	**Intermittent Skill:** The front of the hand can support utensils but control of utensil is less smooth and fluid. Movements are not as definite. Needs more stability on the 5th finger side of the hand.
Designation of 3	**Developing Skill:** The student needs to position hand and wrist to offer more support of the utensil in the hand. Rests forearm on table for support. Needs reminding to stabilize in hand for movement of fingers. Awkward movement noted.
Designation of 2	**Emerging Skill:** Cannot snap fingers but has the posture for snapping fingers. Not able to cut with scissors but can snip.
Designation of 1	**Skill Not Present:** Cannot control scissors or snap fingers. Hand works as a unit.

(page 3)

Table 2 Continued. DEVELOPMENTAL HAND SKILLS

FINGER AND THUMB ISOLATION	The ability to isolate or separate the fingers individually for pointing and keyboarding.
Designation of 5	**Normal Skill:** Fingers can separate for pointing and keyboarding. The student does not need to look at fingers. Able to use fingers independently. Good keyboarding skills observed.
Designation of 4	**Intermittent Skill:** Student tends to use same fingers for pointing. Is able to separate fingers for keyboarding but uses index finger primarily. When reminded to use all fingers, can use them for typing but goes back to index finger use.
Designation of 3	**Developing Skill:** Student needs reminding to position fingers on keyboard and to separate fingers. Will try to scoop items into hand without using tip to tip finger grasping. Needs reminding to use fingers in an individual manner.
Designation of 2	**Emerging Skill:** Difficulty moving fingers separately in a coordinated manner. Will use fingers together without reminding. Needs physical support to hold fingers into position. When pointing middle finger extends also.
Designation of 1	**Skill Not Present:** The student cannot isolate fingers. Fingers move together and scoop items.

Table 2 Continued. DEVELOPMENTAL HAND SKILLS (page 4)	
HAND ARCHES	Enables and supports the roundness or cupping position of the palm of the hand.
Designation of 5	**Normal Skill:** The hands can form a spherical position that looks cup like in the palm of the hand. The hand can accommodate placing the fingers evenly around a quarter so that all fingers touch the quarter with the finger pads. The skin and muscles in the palm of the hand bulk when the thumb opposes the little finger. No flattening is noted on either side of the hand.
Designation of 4	**Intermittent Skill:** Cupping of the hands is observed but not as spontaneously as normal skill. Some limited creasing noted on the 5^{th} finger side of the palm of the hand.
Designation of 3	**Developing Skill:** student needs reminding to place palms in cupping position when items are being poured into the hand. Can ensure that cupping position is held if student pays attention to it.
Designation of 2	**Emerging Skill:** Support of positioning is needed to initially place hands in position. Once placed in position the student can hold it for a short period but loses the position quickly. Needs hands on support to facilitate position at all times. Very flat hands in the palm area.
Designation of 1	**Skill Not Present:** Student cannot maintain cupping of the palms of the hands even when hands are placed in this position by the therapist.

Table 2 Continued. DEVELOPMENTAL HAND SKILLS (page 5)	
IN HAND MANIPULATION	The ability of the hand to move objects from the palm to the fingers and to rotate objects in the hand.
Designation of 5	**Normal Skill:** Student can easily and quickly bring items when placed in the palm of their hand to the finger tips and back. Can hold items in hand to pick up others and place the others in palm while still holding onto items. Smooth fluid movement noted. Student can rotate pencil from lead side to eraser side without dropping pencil.
Designation of 4	**Intermittent Skill:** Student is able to bring objects from the palm to the fingers in a less coordinated manner. Needs some cuing to pick up speed.
Designation of 3	**Developing Skill:** Student drops items at times but is able to bring items from palm to finger tips with slow movement and conscious effort. Some limited coordination noted.
Designation of 2	**Emerging Skill:** The student wants to use the other hand when trying to pick up items and when trying to move items from palm to finger tips. Items drop during task. Needs assistance and guidance to follow through with proper skill. Skill just starting to develop,
Designation of 1	**Skill Not Present:** Unable to move objects from palm to fingers and back. Cannot stabilize items in hand while picking up items in same hand.

(page 6) **Table 2 Continued. DEVELOPMENTAL HAND SKILLS**	
THUMB INDEX WEB SPACE	The space between the index finger and the thumb generally seen in an open position when the pencil is held properly.
Designation of 5	**Normal Skill:** The space between the thumb and index finger is maintained in a round open position during the writing task. No collapsing of space is noted.
Designation of 4	**Intermittent Skill:** The space between the thumb and index finger is present at the start but with handwriting particularly increased speed, the space starts to collapse.
Designation of 3	**Developing Skill: The** student needs reminding to position the thumb index web space in a round open position. Needs cuing to initiate and maintain this during activity. Does not start with position until reminded.
Designation of 2	**Emerging Skill:** The student requires hands on support to put fingers in position to demonstrate thumb index web space. The student has difficulty maintaining position and it tends to collapse or the thumb starts to wrap around the pencil or finger to close the space.
Designation of 1	**Skill Not Present:** There is no thumb index web space observed usually in developmentally immature grasps. No awareness of position of thumb and index finger to demonstrate a-ok sign with fingers. Cannot maintain even after fingers are positioned in proper position by therapist.

5. Visual Motor Skills. Visual motor skills were assessed by having students copy shapes in a student test booklet from the Test of Visual Motor Skills – Revised (Gardner, 1997). The shapes follow a developmental sequence and range from easy to more difficult. A student's raw score is determined by the score given to each shape based on resemblance of the copied shape to the sample shape, the amount of detail observed and the quality of the copy. This raw score is converted into a standard score and then into a visual motor age. The standard score was the statistic used for comparison in this study. Table 3 includes the standard score and the corresponding student ability for visual motor skills as well as visual perceptual skills and upper limb speed and dexterity skills.

Table 3. Standard Scores for Visual Motor Skills, Visual Perception and Upper Limb Speed and Dexterity Skills.

Visual Motor Skills, Visual Perception and Upper Limb Speed and Dexterity			
Variable	**Below Average (Below 16%)**	**Average (16% to 85%)**	**Above Average (Above 85%)**
Visual Motor Skills	Standard score is below 85	Standard Score is between 85 and 115	Standard Score is above 115
Visual Perception	VPQ is below 85	VPQ is between 85 and 115	VPQ is above 115
Upper Limb Speed and Dexterity	Scaled Score 0-11	Scaled Score 12 - 16	Scaled Score 17-20

6. Visual Perceptual Skills. Visual perceptual skills were assessed using a non motor test entitled Test of Visual Perceptual Skills-Revised (Non Motor) (Gardener, 1997). For this assessment, students use visual skills to identify shapes when given specific directions. For example in the component to test visual memory, the student looks at a shape and tries to remember the shape. Then, the page is turned and the student is asked to point to the shape among several they just saw on the previous page (Gardner, 1996). The visual perceptual quotient (VPQ) is the cumulative scaled score of each visual perceptual sub-test including visual discrimination, visual memory, visual spatial relations, visual form constancy, visual sequential memory, visual figure ground and visual closure. The VPQ provides a value for the total visual perceptual ability of the student. For a student with visual perceptual skills in the 50^{th} percentile range, the standard score for the VPQ is 100. Table 3 outlines the student ability that corresponds with the Visual Perceptual Quotient (VPQ).

7. Upper Limb Speed and Dexterity. The motor skills of the arm and hand were assessed using the Bruininks - Oseretsky Test of Motor Proficiency – Upper Limb Speed and Dexterity Subtest (BOTMP) (Bruininks, 1978). The scaled scores for this test are adjusted for age and range from 0 to 20. A scaled score of 15 is equivalent to a T-Score of 50 and the 50^{th} percentile on a normal population distribution. Table 3 provides a description of the scaled score and the skill associated with this score.

8. Letter Motor Memory. Letter motor memory scores for upper and lower case letter formation were taken from the student chart and were out of 26 or 1 for each correct letter. A total

of 26/26 is a perfect score for letter motor memory lower case and 26/26 for letter motor memory upper case.

9. Kinesthetic Ability. Kinesthetic ability as it relates to handwriting was determined by the pencil pressure the student used during the handwriting task. Table 4 presents the designation and description for pencil pressure representative of kinesthesia in this study.

Table 4. Description and Designation for Kinesthetic Ability.

Kinesthetic Ability		
VARIABLE	**Designation**	**DESCRIPTION OF PENCIL PRESSURE**
Kinesthesia	**1**	heavy pencil pressure noted consistently
	2	light pencil pressure noted consistently
	3	normal regulated pencil pressure noted consistently
	4	pencil pressure is inconsistent and not fluid consistently

10. Handwriting Legibility, Quality and Letter Formation. Students' handwriting quality, legibility and letter formation do not stay constant but students were observed and their handwriting assessed to fall within a range of skill. Table 5 outlines the designation score and description for handwriting legibility, overall handwriting quality and letter formation.

Table 5. Handwriting Assessment and Designation for Legibility, Quality, and Letter Formation.

Handwriting Assessment for Legibility, Quality and Letter Formation.		
VARIABLE	**Designation**	**DESCRIPTION OF HANDWRITING QUALITY**
Handwriting Legibility	**1**	1-10/26 letters of the alphabet handwritten are readable
	2	11-15/26 letters of the alphabet handwritten are readable
	3	16-20 /26 letters of the alphabet handwritten are readable
	4	21-25/ 26 letters of the alphabet handwritten are readable
	5	26/26 letters of the alphabet handwritten are readable
Handwriting Quality	**1**	1 -10/26 letters are consistent with spacing, size and alignment
	2	11-15/26 letters are consistent with spacing, size and alignment
	3	16-20 letters are consistent with spacing, size and alignment
	4	21-25 letters are consistent with spacing, size and alignment
	5	26/26 of the letters are consistent with spacing, size and alignment
Handwriting Letter Formation	**1**	1-10/26 letters are formed correctly
	2	11-15/26 letters are formed correctly
	3	16-20/ 26 letters are formed correctly
	4	21-25/ 26 letters are formed correctly
	5	26/26 letters are formed correctly

The final data marking guidelines used during chart review are presented in Table 6.

Table 6. Data Marking Guidelines.

(page 1)

Table 6. Data Marking Guidelines for Student File Review

VARIABLE	DESIGNATION AND DESCRIPTION
Client / Student #	Number of student from 1-200 in a total sample of 200 students
Group	**1**= students who score lower than -1 SD (below average) on a timed handwriting test **2** =Students who score higher than -1 SD (average) on a timed handwriting test
Sex	**1**= Male **2**= Female
Grade	Students who participated were in elementary grades SK to 7 (SK, 1, 2, 3, 4, 5, 6, 7)
Age	Student ages were recorded to include the year only i.e. (5, 6, 7, 8, 9, 10, 11, 12). Months were not included as they were rounded off i.e. 7 years, 2 months was recorded as 7 years.
Term Assessed	**1**= Fall **2**= Winter **3**= Spring
Birth Month	**1**= January **2**= February **3**= March ....**12**=December
Medical Diagnoses	**0**= No diagnosis **1**= ADD/ADHD **2**= Premature birth **3**= LD **4**= Multiple diagnoses (LD, ADD, Preterm, CAP etc) **5**= Meningitis **6**= Behavioural Issues **7**= Seizure Disorder **8** =Central Auditory Processing, **9**= Distractibility OT noted / Teacher noted not diagnosed **10**=ODD **11**=Asperger's Syndrome **12**=Birth Trauma/Birth Distress **13**= Low average cognitive ability **14**= Hearing loss
Hand Dominance	**1**= right handed **2**= left handed **3**=dominance not established

Table 6. Data Marking Guidelines for Student File Review Continued (page 2)	
PENCIL GRASP	
Pencil Grasp Score	**5**=Dymanic Mature Grasp **4**=Static mature position with dynamic properties emerging **3**=Fixed static grip **2**=Developmentally immature grasp
Pencil Grasp Type	**Mature Grasps (5 score)**: DT= Dynamic Tripod, DQ=Dynamic Quadrupod, LTR= Lateral Tripod **Static Mature Positions (4 score)**: Dynamic Emerging: ST= Static Tripod, SQ= Static Quadrupod, CrTh= Cross Thumb **Static Fixed Grips (3 score)**: LockT= Locked grip with thumb wrap or thumb tuck, IND= Index grip, LatPi= Lateral Pinch Grip, 4 fin= 4 Finger Grip **Developmentally Immature (2 score):** DigitP=Digital Pronate
DEVELOPMENTAL HAND SKILLS	
Wrist Stability	**5**= Normal Skill **4**= Intermittent Skill **3**= Developing Skill **2**= Emerging Skill **1**= Skill not present
Motoric Separation	**5**= Normal Skill **4**= Intermittent Skill **3**= Developing Skill **2**= Emerging Skill **1**= Skill not present
Finger Isolation	**5**= Normal Skill **4**= Intermittent Skill **3**= Developing Skill **2**= Emerging Skill **1**= Skill not present
Hand Arches	**5**= Normal Skill **4**= Intermittent Skill **3**= Developing Skill **2**= Emerging Skill **1**= Skill not present
In Hand Manipulation	**5**= Normal Skill **4**= Intermittent Skill **3**= Developing Skill **2**= Emerging Skill **1**= Skill not present
Thumb Index Web Space	**5**= Normal Skill **4**= Intermittent Skill **3**= Developing Skill **2**= Emerging Skill **1**= Skill not present
Developmental Hand Skills Total Score	Total score of all 6 skills (all should be present by the end of grade one)/ out of 30.

Table 6. Data Marking Guidelines for Student File Review Continued (page 3)	
GROSS MOTOR SKILLS	
BOTMP-Upper Limb Speed and Dexterity Subtest	RS= Raw Score Scld Score= Standard score PR= Percentile Rank
BOTMP- Strength	RS= Raw Score Scld Score= Standard score PR= Percentile Rank
BOTMP- Balance	RS= Raw Score Scld Score= Standard score PR= Percentile Rank
BOTMP-Upper Limb Coordination	RS= Raw Score Scld Score= Standard score PR= Percentile Rank
Postural Control-Sitting Posture	**5**= Normal Skill **4**= Intermittent Skill **3**= Developing Skill **2**= Emerging Skill **1**= Skill not present
VISUAL MOTOR INTEGRATION SKILLS	
Visual Motor Skills	Statistical numbers are inserted from test score sheet - (VMS) – Raw Score (RS), Standard Score (Std), Scaled Score (Scld), Percentile Rank (PR), Stanine (Stan) were all collected but the standard score was used for the analyses.

Table 6. Data Marking Guidelines for Student File Review Continued (page 4)	
VISUAL PERCEPTUAL SKILLS	
Visual Perceptual Skills Visual Perceptual Quotient (VPQ)	Statistical numbers were inserted from test score sheet The visual perceptual quotient was used for a score of overall visual perceptual ability of each student. The VPQ is determined by adding the scaled scores from each of the subtests together. The subtests are identified below.
VPS- Visual Discrimination – Subtest	Standard Score, Scaled Score, Percentile Rank, Stanine from the test score sheet.
VPS – Visual Memory Subtest	Standard Score, Scaled Score, Percentile Rank, Stanine from the test score sheet.
VPS – Visual Spatial Relations Subtest	Standard Score, Scaled Score, Percentile Rank, Stanine from the test score sheet.
VPS – Visual Form Constancy Subtest	Standard Score, Scaled Score, Percentile Rank, Stanine from the test score sheet.
VPS- Visual Sequential Memory Subtest	Standard Score, Scaled Score, Percentile Rank, Stanine from the test score sheet.
VPS – Visual Figure Ground Subtest	Standard Score, Scaled Score, Percentile Rank, Stanine from the test score sheet.
VPS- Visual Closure Subtest	Standard Score, Scaled Score, Percentile Rank, Stanine from the test score sheet.

Table 6. Data Marking Guidelines for Student File Review Continued	(page 5)
LETTER MOTOR MEMORY	
Letter Motor Memory – Upper Case	The number of capital letters that a student can print from memory out of 26 letters of the alphabet. The score is out of 26.
Letter Motor Memory – Lower Case	The number of lower case letters that a student can print from memory out of 26 letters of the alphabet. The score is out of 26.
KINESTHESIA	
Kinesthesia	1= heavy pencil pressure 2=light pencil pressure 3=normal regulated pencil pressure 4= pencil pressure inconsistent and not fluid
HANDWRITING ABILITY	
Handwriting Speed	1= slow speed (on or below -1 Standard Deviation on a timed test) 2= handwriting speed is greater than the cut off at -1 Standard Deviation
Handwriting Legibility	1= 1-10/26 letters are readable 2= 11-15/26 letters are readable 3= 16-20 letters are readable 4= 21-25 letters are readable 5 = 26/26 all letters are readable
Handwriting Quality	1= 1-10/26 letters are consistent with spacing, size and alignment 2= 11-15/26 letters are consistent with spacing, size and alignment 3= 16-20 letters are consistent with spacing, size and alignment 4= 21-25 letters are consistent with spacing, size and alignment 5 = 26/26 all letters are consistent with spacing, size and alignment
Handwriting Letter Formation	1= 1-10/26 letters are formed correctly and efficiently 2= 11-15/26 letters are formed correctly and efficiently 3= 16-20 letters are form correctly and efficiently 4= 21-25 letters are formed correctly and efficiently 5 = 26/26all letters are formed correctly and efficiently

Collation of Data

STEP TWO: File Review and Data Collection

1. **Review clinical files.**
2. **Determine if inclusion criteria are met.**
3. **If all inclusion criteria are present, complete data collection using raw data sheet. If not, the file is not included in study.**
4. **Stop file review and data collection once the data from 200 clinical files are gathered.**

The target sample size for this research was 200 student clinical files. To achieve this number, more than 200 student charts were reviewed since the files that did not meet the inclusion criteria were rejected. Approximately one in five were accepted into the study. The file review for one student file took approximately 15 to 20 minutes.

All files were closed files of students who were no longer receiving occupational therapy services. Clinical file selection started with those files created in the year 2007 and selection was completed from among files going back to 2003. Once the data had been entered on the Raw Data Sheets, the files were returned to storage and the raw data sheets were used for further statistical analyses.

Chapter V

Data Analyses

STEP THREE:	Define the Sample
	1. Complete descriptive statistics to describe the sample of 200 students with slow handwriting. 2. Complete correlation coefficient statistics to determine if any of the foundational handwriting variables are related. 3. Determine which variables will be used for further exploration using Latent Class Analyses.

The data collected on the 200 Raw Data Sheets were used for several stages of data analyses. First the data were transferred to an Excel file (Microsoft Excel, 2003) to be used to retrieve the descriptive statistics. The file was then converted into an SPSS data sheet (SPSS 10, 1999) for further statistical analyses, and finally it was used for Mixture Modeling- Latent Class Analyses (LCA) using the MPlus Statistical Program (Muthen & Muthen, 2007). This chapter discusses the descriptive statistics and the comparative analyses. The results of the Latent Class Analyses are described in Chapter VI.

Descriptive Statistics

The students whose charts were included in this study were from 46 schools in a Northern Ontario city with a population just over 100,000 people. Children who attended both the Catholic and Public School Boards were included. Frequency tables are provided here for each categorical variable that was gathered from the student file.

All students whose charts were included in this study were slow with handwriting. The information in the areas of age, grade, gender, handwriting speed, reading ability, medical diagnosis, hand dominance and pencil grasp was analyzed to provide baseline information and a description of the sample population.

Gender and Age of Students. Of the 200 student charts included in this research, 164 (82%) were charts of boys and 36 (18%) were charts of girls. The ratio is consistent with occupational therapy referrals in general. The children's ages ranged from 5 years old to 12 years old, in kindergarten or grades 1-7, but 92% of the children were between ages 6 to 10, and the majority were in grades 1 to 3 (79 %). Most of the students, over 80%, were boys between the ages of 6 and 8.

Table 7 presents the frequency table for the ages, grades and gender of the students whose files were included in the study.

Table 7. Frequency Table: Student Age, Grade, and Gender.

Age (yrs)	Grade (#/Gr)	Frequency (Age)	Girls	Boys	Percentage of Sample
5	2-SK/ 1-Gr1	3	1	2	1.5
6	1-SK/ 54-Gr1	55	9	46	27.5
7	23-Gr1/ 32-Gr2/ 3-Gr3	58	11	47	29.0
8	8-Gr2/ 26-Gr3/ 1-Gr4	35	9	26	17.5
9	7-Gr3/ 13-Gr4/ 1-Gr5	21	3	18	10.5
10	4-Gr4/ 8-Gr5	12	0	12	6.0
11	3-Gr5/ 6-Gr6	9	2	7	4.5
12	4-Gr6/ 3-Gr7	7	1	6	3.5

$N = 200$

Handwriting Speed. All students in this study were referred with handwriting difficulties in the classroom. Some students were identified by the teacher as slow in the classroom and were also slow during the handwriting speed test done by the occupational therapist (Group 1). Others were identified as slow in the classroom but tested within normal limits on the handwriting speed test (Group 2). Although, all were reported to have slow handwriting, two thirds of them were in Group 2 with no measurable handwriting speed difficulties. The ratio of boys to girls was approximately the same in each group. See Table 8.

Table 8. Frequency Table: Handwriting Speed.

Handwriting Speed	Total Frequency	Percentage of Sample
Group 1- Both slow in class and slow on handwriting speed assessment	68 Student charts 56 boys / 12 girls	34 % of 200 charts
Group 2- Slow in class but average on handwriting speed assessment	132 Student charts 108 boys / 24 girls	66 % of 200 charts

Medical / Learning Diagnoses. Some of the students included in the study had a medical diagnosis such as attention deficit disorder (ADD) or attention deficit hyperactivity disorder (ADHD) (24 students for these two combined). Some students were not diagnosed with any medical condition (78 students). Fourteen students were born prematurely, while 12 students had multiple problems including ADD, ADHD, learning disability and prematurity. Fifty six (56) students demonstrated attention difficulties in the classroom according to their teacher, but were not diagnosed with an attention deficit disorder. Other diagnoses included Asperger's Syndrome (2 students), Learning Disabilities (8 students), Meningitis (1 student), Behavioural Issues (4 students), Central Auditory Processing (4 students), Birth Distress (1 student), Hearing Loss (1 student). Table 9 outlines the frequencies of medical or learning diagnoses in order of frequency.

Table 9. Frequency Table for Medical/Learning Diagnoses

Diagnosis	Frequency N=200	Percentage of Sample
No Diagnosis	78	36
Distractibility Issues / no ADD or ADHD Diagnosis	56	28
ADD / ADHD	24	12
Pre Term	14	7
Multiple Diagnoses (Preterm, ADD/CAP/LD)	12	6
Learning Disability	8	4
Behavioural Diagnosis (Not specified)	4	2
Central Auditory Processing (CAP)	4	2
Asperger's Syndrome	2	1
Meningitis	1	0.5
Oppositional Defiance Disorder (ODD)	1	0.5
Birth Trauma/Distress	1	0.5
Hearing Loss	1	0.5

Students were included under one diagnostic category only as outlined in their clinical file. At least 46 % of the students were identified on their clinical files as having difficulties paying attention in the classroom and it is probable that the students with behavioural difficulties, central auditory processing disorders, learning disabilities, Asperger's Syndrome and ODD would also have attention difficulties so well over half of the population was likely experiencing some level of attention difficulties.

Hand Dominance and Pencil Grasp. There were 153 students (77%) who were right handed, 25 (13%) who were left handed and 22 (11%) who had not demonstrated hand dominance. There are slightly more students in this sample with left handedness (13%) than in a normal distribution since 90% of the population is right handed (Murray, 1995). Seventy eight percent of the children had an immature pencil grasp. See Table 10.

Table 10. Frequency Table: Pencil Grasps.

Pencil Grasp – Type	Frequency (n=200)	Percentage of Sample
<u>Mature Grasp</u> – Dynamic Tripod / Dynamic Quadrupod / Lateral Tripod	43	21.5
<u>Transitional / Static Grasps</u> Four Finger Grasp / Static Tripod/ Cross Thumb	84	42
<u>Developmentally Immature Grasps</u> Immature Higher Level: Grasp with Extended Fingers/ Brush Grasp	72	36
<u>Developmentally Immature Grasps</u> Immature Lower Level: Interdigital	1	0.5

Kinesthesia. Kinesthesia was measured by pencil pressure and fluidity of movement during handwriting sample tasks (quality and smoothness of line). In this population, there were 71 (35.5%) students with heavy pencil pressure, 22 (11%) students with light pencil pressure and 52 (26%) with fluctuating pencil pressure during handwriting tasks. Only 55 (27.5%) students had regular pencil pressure with good line quality.

Letter Formation. Only 5 students (2.5% of the population) had perfect letter formation. 42 students (21%) were able to produce 21 to 25 letters of the alphabet using proper letter formation. Over half of the student population (105 or 52.5%) was able to produce 16 to 20 letters of the alphabet, 35 students (17.5%) were able to form 11 to 15 letters of the alphabet correctly. Thirteen students (6.5%) produced fewer than 10 letters of the alphabet using correct letter formation. Based on this information the majority of the population had difficulties forming letters accurately.

Handwriting Legibility. Handwriting legibility was evaluated using lower case letters that were copied from a far copy sample placed on the blackboard. These letters were compared with the lower case letters written from memory in an alphabet sample that the student completed. If one of the letters was easy to read it was counted as legible. Nearly half (49% or 98 students) produced 16- 20 letters of the alphabet that were identifiable. There were 9 students (4.5%) who produced only 1-10 letters that were easy to identify, 39 students (19.5%) were able to produce 11-15 legible letters, and 49 students (24.5%) produced 20 to 25 letters that were easy to identify. Only 5 students (2.5%) had 26/26 letters that were legible.

Foundational Handwriting Skills of Student Population

The descriptive statistics for the foundational handwriting skills (variables) scored by the occupational therapists during the occupational therapy assessment have been placed in separate charts below.

Developmental Hand Skills. Children are expected to have mature hand skills by the end of grade one (Benbow, 1980). Skills that are mature would be expected to be close to 30/30. Some of the students in this study would be at age appropriate levels with scores below 30 particularly if they are in senior kindergarten and grade one. Students who present with less than 30/30 may be functionally limited and require therapy particularly if they are in grades two and higher. Overall, the students represented in the study were found to have limited developmental hand skills in all areas. Students scored, on average between, 3.4-4 /5 on each skill individually with a total score of 23/30 which indicates skills at 24% lower than normal. Table 11 describes the developmental hand skills for this population.

Table 11. Descriptive Statistics: Developmental Hand Skills.

Variable	*Mean*
Wrist Stability	3.89 / 5
Motoric Separation	3.82 / 5
Finger Isolation	4.06 / 5
Hand Arches	4.29 / 5
In-Hand Manipulation	3.86/ 5
Thumb Index Web Space	3.53 / 5
Total for Developmental Hand Skills	23.39 / 30

N = 200

Upper Limb Speed and Dexterity. The mean scaled score for the sample of 200 students with slow handwriting was 12.41on a test assessing the speed and dexterity of the hand and arm. The equivalent scaled score is 15 when compared to the 50th percentile or to a T-Score of 50. The highest scaled score for this assessment is 20 while the cut off for average is 11. A scaled score below 11 is below average in ability while any scaled score above 16 is above average in ability. The mean scaled score of 12.41 for this population of students with slow handwriting in the classroom indicates that these students have skills on the low end of average for their age. The students in this study have some difficulties manipulating objects with speed and accuracy in tasks requiring the use of one hand and two hands together.

Visual Motor Skills. The average skill range of a normal standard score for visual motor skills falls between 85 and115. A below average standard score is 85 and less (below the 16th percentile). A standard score of 100 would place a student at the 50th percentile for visual motor skills. Above average skills are indicated by a standard score higher than 115 or above the 85th percentile. The students in this study have an average standard score of 88.87. This indicates that the students have visual motor skills at the low end of average ability.

Visual Perceptual Skills. The average range for visual perceptual skills indicated by the Visual Perceptual Quotient (VPQ) is between 85 and 115. A VPQ of 100 is average. The mean and standard deviation for the total visual perceptual ability (VPQ) and each visual perceptual skill as identified individually are outlined on Table 12.

Table 12. Descriptive Statistics: Visual Perceptual Skills.

Average VPQ and Average Standard Score = 85-115

Variable (Standard Score 100=50th percentile)	*Mean*	*Standard Deviation*
Visual Discrimination	101.35	18.80
Visual Memory	98.06	17.40
Visual Spatial Relations	107.63	17.27
Visual Form Constancy	97.80	18.65
Visual Sequential Memory	98.51	21.97
Visual Figure Ground	106.53	17.53
Visual Closure	94.32	19.88
Visual Perceptual Quotient (VPQ) TVPS Revised	100.92	19.12

$N = 200$

The students appear to be strongest in the skills of visual spatial relationships (107.63), visual figure ground (106.53) and visual discrimination (101.35). Visual discrimination skills had a mean standard score of 101 (slightly greater than 50%). The overall visual perceptual skills of this population are at or near the 50^{th} percentile which demonstrates a very solid skill level in visual perception.

Letter Motor Memory. Letter motor memory is a count of the letters a student remembers and reproduces. In order to achieve automaticity a student would need to remember how to write all letters, both upper and lower case. In the area of letter motor memory the students in this study remembered how to print an average of 25/26 upper case letters and an average of 21/26 lower case letters.

Descriptive Profile for Students with Slow Handwriting

The descriptive data indicate that the students in this study will slow handwriting were primarily boys in grades 1-3. They could usually complete a handwriting speed test within an average range in a one to one test situation with an occupational therapist but had difficulties completing written work in the classroom. Most did not have a medical or learning diagnosis but did have some attention difficulties observed by their teachers in the classroom and at least 50 percent had some difficulties reading. In foundational skill areas, these students had limited developmental hand skills and borderline upper limb speed and dexterity skills. Their visual motor skills were below the 50^{th} percentile but within the average range. The students had good visual perceptual skills that fell solidly within the average range. These students as a whole remembered how to print some but not all the letters of the alphabet from memory and demonstrated the ability to print 21/ 26 letters from memory.

Correlation Statistics

Pearson Correlation Coefficients using the Statistical Package for the Social Sciences, Version 10 (1999), were used to identify correlations among the foundational handwriting skills to better understand the relationships among the variables. In this section, the correlation coefficients are shown with tables for each of the foundational handwriting skills. Asterisks (*) indicate whether a particular correlation is significant at the .05 level (*) or the .01 level (**), and p values associated with the significance tests are reported at the bottom of each table. The significant correlations and predictive variables were used for Mixture Modeling – Latent Class Analyses. Only those with significant results are included in the tables that follow. See appendices 3 to 6 for all of the correlation results. A small correlation coefficient is associated with $r = .10$ and indicates a small effect size for the relationship. A medium correlation coeffiecient is associated with $r = .30$ and indicates a moderate effect size for the relationship. A large correlation is associated with a correlation coefficient of .50 and indicates a large effect size for the relationship (Green & Salkind, 2005).

Visual Perception. Correlation coefficients were computed among visual perceptual skills and each of the handwriting foundational skills of letter formation, handwriting quality, handwriting legibility, letter motor memory (upper and lower case), visual motor skills, developmental hand skills, and upper limb speed and dexterity, handwriting speed, pencil grasp, and kinesthesia. The correlation results show that visual perception correlates with the foundational handwriting skills of letter formation, handwriting quality, handwriting legibility, letter motor memory, visual motor skills, developmental hand skills and upper limb speed and dexterity. The significant correlations range from small correlation coefficients for developmental hand skills to medium correlation coefficients for visual motor skills. Pencil grasp, kinesthesia and handwriting speed do not significantly correlate with visual perception for this sample of students. The results are presented in Table 13. Appendix 3 includes all of the correlation statistics for visual perceptual skills.

Table 13. Visual Perception: Correlation Coefficients *(r)* among the Foundational Handwriting Skills.

Foundational Handwriting Skills	Visual Perception
	r
Letter Formation	.23**
Handwriting Quality	.30**
Handwriting Legibility	.29**
Letter Motor Memory Lower	.28**
Visual Motor Skills	.40**
Upper Limb Speed & Dexterity	.26**
Developmental Hand Skills	.16*

N = 200

*. Significant at the . 05 level (two- tailed).
**. Significant at the . 01 level (two-tailed).

Visual Motor Skills. Correlation coefficients were computed between the students' visual motor skills and levels of foundational skill in the areas of letter formation, handwriting quality, handwriting legibility, letter motor memory (lower case), visual perceptual skills, developmental hand skills, and upper limb speed and dexterity, handwriting speed, pencil grasp, and kinesthesia. The foundational handwriting skills of letter formation, handwriting quality, handwriting legibility, letter motor memory, visual perceptual skills, developmental hand skills, upper limb speed and dexterity and pencil grasp correlate significantly with visual motor skills ranging from small to medium coefficients for pencil grasp, letter motor memory and developmental hand skills to medium to large coefficients for handwriting legibility, handwriting quality, letter formation and visual perceptual skills, respectively. Handwriting speed, kinesthesia and upper limb speed and dexterity do not correlate with visual motor skills in this group of students. Table 14 presents the correlation statistics for visual motor skills.

Table 14. Visual Motor Skills: Pearson Correlation Coefficients *(r)* among Foundational Handwriting Skills.

Foundational Skills	Visual Motor Skills
	r
Letter Formation	.40**
Handwriting Quality	.36**
Handwriting Legibility	.34**
Letter Motor Memory Lower Case	.27**
Visual Perceptual Skills	.40**
Developmental Hand Skills	.29**
Pencil Grasp	.21**

$N = 200$

*. Significant at the .05 level (two- tailed).
**. Significant at the .01 level (two-tailed).

Letter Motor Memory Lower Case Letters. Letter motor memory skills significantly correlated with many of the foundational skills associated with handwriting development and handwriting quality. The correlation coefficients were large for letter formation skills, handwriting legibility and handwriting quality. There was a medium correlation coefficient between letter motor memory and handwriting speed and age. Small correlations were found between letter motor memory and developmental hand skills, visual motor skills and visual perception. The results are summarized on Table 15.

Table 15. Letter Motor Memory Lower Case: Pearson Correlation Coefficients (r) among the Foundational Handwriting Skills.

Foundational Skills	**Letter Motor Memory Lower Case**
	r
Handwriting Speed	.41**
Letter Formation	.61**
Quality of Handwriting	.49**
Handwriting Legibility	.56**
Visual Perception	.28**
Visual Motor Skills	.27**
Developmental Hand Skills	.22**
Age	.38**

N = 200

*. Significant at the .05 level (2-tailed).
**. Significant at the .01 level (2-tailed).

Upper Limb Speed and Dexterity. Upper limb speed and dexterity skills were found to correlate significantly with visual perceptual skills, $r(198) = 0.26, p < .00$, and pencil grasp, $r(198) = 0.24, p < .00$. The correlation coefficients were small to medium. Upper limb speed and dexterity did not correlate significantly with handwriting speed, letter formation, handwriting quality and legibility, kinesthesia, letter motor memory, visual motor skills and developmental hand skills. Appendix 5 includes all of the correlational findings for upper limb speed and dexterity.

Developmental Hand Skills. Correlation coefficients were computed among the foundational hand skills and developmental hand skills. Developmental hand skills were found to correlation with pencil grasp with a large correlation coefficient. Developmental hand skills correlated with a medium coefficient with handwriting quality, handwriting legibility, letter formation and visual motor skills. Visual perceptual skills and developmental hand skills correlated with a small coefficient. Developmental hand skills did not statistically correlate with handwriting speed, kinesthesia and upper limb speed and dexterity. Appendix 5 includes all of the findings for the correlational analyses. Table 16 outlines the significant findings.

Table 16. Developmental Hand Skills: Pearson Correlation Coefficients (r) among Foundational Handwriting Skills.

Foundational Skills	Developmental Hand Skills
	r
Letter Formation	.33**
Handwriting Quality	.38**
Handwriting Legibility	.34**
Letter Motor Memory Lower Case	.22**
Visual Motor Skills	.29**
Visual Perceptual Skills	.16*
Pencil Grasp	.43**

N = 200

*. Significant at the .05 level (2- tailed).
**. Significant at the .01 level (2-tailed).

Pencil Grasp. Students' pencil grasps were analyzed for statistical correlation to the other foundational skills. Pencil grasp did not significantly correlate with handwriting speed, letter formation, handwriting quality and legibility, letter motor memory and visual perceptual skills but it did correlate with kinesthesia (medium coefficient), visual motor skills (small to medium coefficient), upper limb speed and dexterity (small to medium coefficient) and developmental hand skills (medium to large coefficient). Table 17 summarizes the results of the correlational analyses. Appendix 5 includes all of the correlational analyses results for pencil grasp.

Table 17. Pencil Grasp: Pearson Correlation Coefficients(r) among the Foundational Handwriting Skills.

Foundational Skills	Pencil Grasp
	r
Kinesthesia	.26**
Visual Motor Skills	.21**
Upper Limb Speed & Dexterity	.24**
Developmental Hand Skills	.43**

N = 200

*. Significant at the .05 level (2- tailed).
**. Significant at the .01 level (2-tailed).

Handwriting Legibility. Handwriting legibility and the foundational skills associated with handwriting were analyzed for correlational significance. Large correlation coefficients were observed between handwriting legibility and letter formation, letter motor memory lower case and overall handwriting quality. Medium correlation coefficients were found between handwriting legibility and handwriting speed, visual motor skills, visual perceptual skills and developmental hand skills. Handwriting legibility did not correlate with kinesthesia and upper limb speed and dexterity. Appendix 6 includes all of the results of the correlational analyses for this variable. Table 18 summarizes the results of the correlation analyses.

Table 18. Handwriting Legibility: Pearson Correlation Coefficients *(r)* among the Foundational Handwriting Skills .

Foundational Skills	Handwriting Legibility
	r
Handwriting Speed	.25**
Letter Formation	.64**
Handwriting Quality	.74**
Letter Motor Memory Lower Case	.56**
Visual Motor Skills	.34**
Visual Perceptual Skills	.23**
Developmental Hand Skill	.34**
Age	.42**

$N = 200$

*. Significant at the .05 level (two- tailed).
**. Significant at the .01 level (two-tailed).

Kinesthesia. Kinesthesia was found to have a small to medium correlation coefficient with pencil grasp, $r(198) = 0.26, p < .01$. There were no other observed significant correlations with this foundational skill. Appendix 6 includes all of the correlational statistics for this variable.

Handwriting Speed. Handwriting speed was analyzed for correlational significance with other foundational skills associated with handwriting development. Medium correlation coefficients were observed between handwriting speed and letter motor memory lower case, letter motor memory upper case, letter formation, handwriting legibility, and handwriting quality. No other significant correlations were found between handwriting speed and each of the other foundational skills. Appendix 6 includes all of the results of the correlational analyses between handwriting speed and each of the foundational skill variables. Table 19 summarizes the results of the analyses.

Table 19. Handwriting Speed: Pearson Correlation Coefficients (r) among the Foundational Handwriting Skills

Foundational Skills	**Handwriting Speed**
	r
Letter Formation	.30**
Handwriting Quality	.29**
Handwriting Legibility	.25**
Letter Motor Memory Lower	.41**

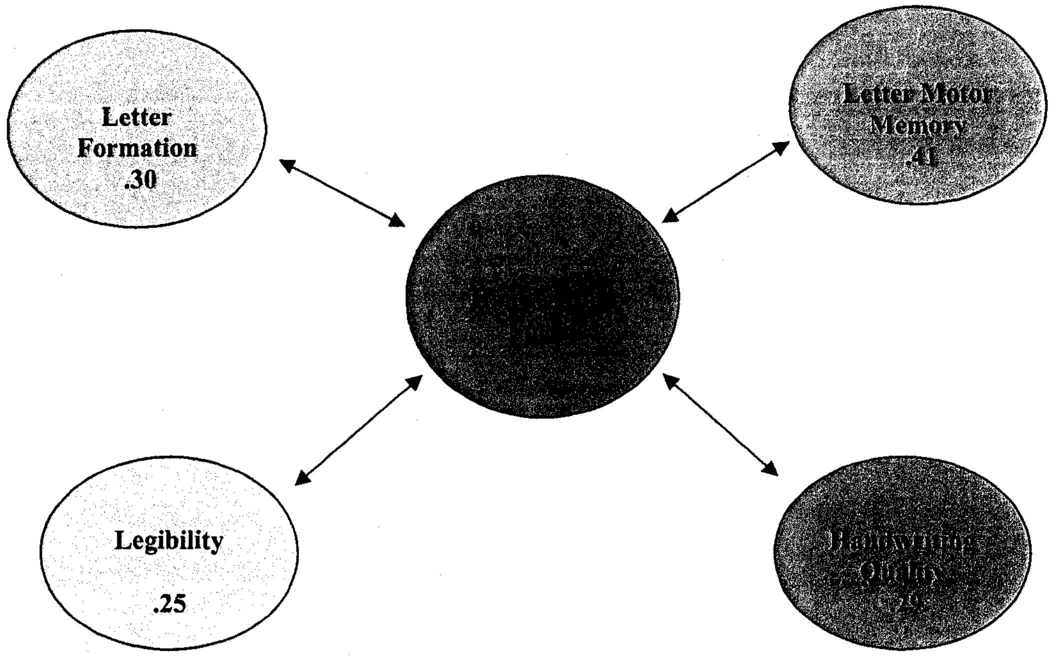
N = 200

*. Significant at the .05 level (2- tailed).
**. Significant at the .01 level (2-tailed).

Foundational Skills Selected for Latent Class Analyses

The foundational skills of letter formation, handwriting legibility, letter motor memory and handwriting quality were the foundational skills that were statistically correlated with handwriting speed for this population. For this reason, these variables were selected for further analyses using Latent Class Analyses. Latent class analyses will identify whether or not groupings of students can be identified based on their performance in skill areas and if the latent classes exist, whether or not the population of students with slow handwriting has similar or different skills in these areas. Figure 3 was developed to represent the correlations between handwriting speed and the other variables.

Figure 3. Graphic Representation of the Significant Pearson Correlation Coefficients *(r)* among Handwriting Speed and Other Foundational Handwriting Variables.



The correlational analyses provided information about how each of these variables is related to handwriting performance and other foundational handwriting skills. The correlation coefficient was highest for letter motor memory lower case, medium for letter formation and handwriting quality and lowest (small to medium) for handwriting legibility. These findings assisted in the selection of the variables that were used to further investigate the foundational handwriting skills using Latent Class Analyses.

The foundational handwriting skills selected for further analyses were based on the identified relationship that each of these appeared to have on handwriting performance speed. The foundational handwriting skills chosen were:

1. developmental hand skills
2. visual perceptual skills

3. visual motor skills
4. upper limb speed and dexterity
5. letter motor memory lower case
6. handwriting legibility
7. letter formation

Summary

This chapter described the sample of 200 students who have slow handwriting whose charts were included in this study. The results of the correlational analyses assisted in identifying the foundational skills selected for further analyses. These foundational handwriting skills appeared to capture a global foundational skill set that is related to handwriting. The foundational handwriting skills that were selected for further analyses using Mixture Modeling- Latent Class Analyses were: developmental hand skills, visual perception, visual motor integration skill, upper limb speed and dexterity, letter motor memory (lower case), letter formation and handwriting legibility. These skills appear to correlate with handwriting performance for the population of students with slow handwriting.

Chapter VI

Results

STEP FOUR:	**Latent Class Analyses – Identifying the Latent Classes and the Nature of the Latent Classes** **1. Complete Latent Class Analyses on the variables of developmental hand skills, visual perception, visual motor skills, upper limb speed and dexterity, letter motor memory lower case, handwriting legibility and letter formation, to determine if there are groupings for students with slow handwriting that exist in the sample of 200 students.** **2. Determine which profile of Latent Classes best fits the data by using Tests of Model Fit.** **3. Determine how the Latent Classes differ or are similar to each other based on the one way multivariate analysis of variance (MANOVA).** **4. Compare the Latent Classes to normative data to see if the Latent Classes are different than what is expected of students without difficulties on measures for foundational handwriting skills.**

Mixture Modeling: Latent Class Analyses

Latent Class Analyses (LCA) are methods by which a population is described in statistical terms to designate the number of groups that exist within the population and to describe the parameters of each group. This chapter will present the model that identifies distinct Latent Classes within the data set for 200 students with slow handwriting. Data on the foundational handwriting skill variables of developmental hand skills, visual perception, visual motor skills, upper limb speed and dexterity, letter motor memory (lower case), letter formation and handwriting legibility were used.

LCA were completed by running a series of statistical comparisons "asking" the MPlus program (Muthen & Muthen, 2007) to cluster the group of 200 students with slow handwriting into two, then three, four, five, and more than five classes to determine which number of Latent Classes best represents the data set. Each output from the latent class analyses was tested for model fit to determine which model "made sense" by comparing the variables, means, and variances for each latent class within the models identified. In this case, a statistical comparison used to assist in determining the best model fit was the Vuong -Lo –Mendell – Rubin Likelihood Ratio Test (LMR-LRT) (TECH 11) that compared the improvement in fit between the estimated model (k) and neighbouring models (k-1) (Muthen & Muthen, 2007). The LMR- LRT provided a *p*-value that was used to determine if there was a statistically significant improvement in the model fit for the inclusion of one more class in the model. Nylund, Asparouhov and Muthen (2007) reported that when using the LMR-LRT *p*-value the analysis should stop once the p-value is not significant as there is a tendency for the p-value to jump from being significant to nonsignificant and back to significant. They advise to stop the analysis at the number of classes that produces a nonsignificant p-value on the LMR-LRT and choose the model prior to that one that was found to have a significant finding.

Another statistic that was used to consider which model best described the population was the entropy summary statistic. The entropy summary statistic was used to indicate how well the model predicts class membership in values ranging from 0 to 1. Values closer to 1 represent good classification quality (Akaike, 1977; Muthen & Muthen, 2002). The entropy summary that indicates good classification quality should not be less than .80 (Muthen, 2007). Practically this means that the students who ended up in each group or latent class should "fit" the group in which they are placed.

For the purposes of this research, the following criteria were used to identify the number of classes or the model that best fits the data for the sample.

a) The LMR adjusted LRT *p*-value was significant for model fit ($p < .05$). This indicates that number of classes (k) in the current analysis fits the data better than the number of classes (k) minus 1 (k-1).

b) The entropy summary was greater than .80 for the model.

c) The model that was chosen had to "make sense" and have theoretical application to handwriting development.

Latent Class Analyses (LCA) were completed for variables that represented an overall foundational skill model for this population. Profiles of student performance on foundational skills for the sample of 200 students with slow handwriting were identified. It is hypothesized that there were possibly a few groups or classes that exist within the sample. LCA were used to test this hypothesis by estimating a model using two, three, four and five classes. Statistical comparisons were used to determine whether the estimated model fit the data better than the model with one less class. Table 20 summarizes the output for the LCA using a general model for foundational handwriting skills.

Table 20. General Model for Foundational Handwriting Skills: Output for Latent Class Analyses.

Number of Classes	LMR Adjusted LRT Test	LMR-LRT (p-value)	LMR-adjusted LRT (p-value)	Entropy
1				
2	334.63	.000	.000	.980
3	61.75	.041	.044	.827
4	22.91	.187	.190	.862
5	34.27	.012	.013	.881

Criteria for determining number of classes: Lo Mendel Rubin Log Likelihood Ratio Test (LMR-LRT) with significant p-value greater than 0.05; Entropy greater than .80.

In analyzing the results shown in Table 20, it was determined that the estimated model of two classes best fit the data. The 3 class model also had significant results, however, based on the mean scores, the groupings did not demonstrate clinical/ practical differences among the classes in some of the foundational skill areas and, therefore, did not make clinical sense. The models with four and five classes were not favourable as they did not meet the criteria for the best model fit. The two-class model met all the criteria for model fit including the LMR-LRT (significant p value) and the LMR adjusted LRT (significant *p*-value), an entropy summary of .98 and very high probabilities for group membership. The classification of individuals based on their most likely latent class membership was 38 students in Latent Class 1 and 162 students in Latent Class 2. The probabilities for most likely latent class membership were 98.9% for students in Latent Class 1 and 99.8 % for students in Latent Class 2. See Table 21.

Table 21. Latent Class Probabilities for Most Likely Class Membership.

Average Latent Class Probabilities for Most Likely Latent Class Membership (Row) by Latent Class (Column)

	1	**2**
1	.989	.011
2	.002	.998

The Tech11 output or p-value, Vuong-Lo-Mendell-Rubin Likelihood Ratio Test (LMR - LRT) for 1 (H0) versus 2 classes, was $p = .000$ and $p = .000$ (LMR adjusted). The low p-value indicated that the Two Latent Class Model best described the data.

Table 22 outlines the differences among the means and standard deviations for the two latent classes (Two Latent Class Model) when compared to the means and standard deviations for the sample of 200 students (One Class Model). Prior to conducting Latent Class Analysis, the One Latent Class Model described the 200 student sample.

Table 22. Means and (Standard Deviations) for the One Class and Two Class Model.

Variables	**One Class Model**	**Two Class Model**	
		Latent Class One	**Latent Class Two**
	***(N* = 200)**	***(n* = 38*)***	***(n* = 162*)***
Hand Skills	23.29 (4.37)	21.68 (4.51)	23.79 (4.27)
Visual Perception	100.92 (19.07)	89.92 (17.65)	103.50 (18.57)
Visual Motor Skills	88.87 (12.46)	81.87 (11.98)	90.51 (12.07)
Upper Limb Speed	12.41 (5.59)	11.87 (5.16)	12.53 (5.72)
Letter Motor Memory	20.89 (7.78)	6.58 (5.57)	24.25 (2.89)
Legibility	2.96 (0.86)	2.11 (0.73)	3.22 (0.73)
Letter Formation	3.01 (0.85)	1.87 (0.67)	3.21 (0.67)

Multivariate Analysis of Variance: Latent Class One and Latent Class Two

A one-way multivariate analysis of variance (MANOVA) was conducted to determine if the foundational handwriting variables associated with Latent Class One and Latent Class Two were statistically different from each. Significant differences were found in the dependent measures of developmental hand skills, visual perception, visual motor skills, upper limb speed and dexterity, letter motor memory lower case, handwriting legibility and letter formation, Wilks' $\Lambda = .20$, $F(1,198) = 111.35, p < .000$. The multivariate η^2 or effect size based on Wilks' Λ was strong and equaled .80. This indicates that 80% of the multivariate variance of the dependent variables was associated with Latent Class One and Latent Class Two. The Observed Power was equal to 1.00. The statistical differences reported in the MANOVA were computed using alpha $< .05$.

Analysis Of Variance: Latent Class One and Latent Class Two

Analyses of variances (ANOVA) on each dependent variable were conducted as follow up tests to the MANOVA. The independent variables were the two classes. The dependent variables were the student scores in foundational handwriting skill areas. The ANOVA was significant for each of the foundational handwriting skills for each group except upper limb speed and dexterity skills.

For developmental hand skills students in Latent Class One and Latent Class Two had significantly different developmental hand skill performance, $F(1,198) = 7.34, p < .01, \eta^2 = .04$. The effect size for developmental hand skills was not very strong with these skills associated with 4% of the variance. The strength of the differences between Latent Class One and Latent Class Two in visual perceptual skill areas was moderate with student visual perceptual skills associated with 8% of the variance between the groups, $F(1,198) = 16.76, p < 0.000, \eta^2 = 0.08$. Student performance in visual motor skill areas for Latent Class One and Latent Class Two was significantly different, $F(1,198) = 15.83, p < .000, \eta^2 = .07$, with a small effect size indicating that visual motor skills were associated with 7% of the variance. There were no differences between Latent Class One and Latent Class Two in upper limb speed and dexterity skills, $F(1,198) = .43, p = .51, \eta^2 = .00$. Student performance in letter motor memory was significantly different for students in Latent Class One and Latent Class Two, $F(1,198) = 762.99, p < .000, \eta^2 = .79$. Letter motor memory was associated with 79% of the variance among the groups indicating a very large effect size. Students in Latent Class One and Latent Class Two were significantly different in handwriting legibility, $F(1,198) = 72.02, p < .000, \eta^2 = .27$. The effect size was small and was associated with 27% of the variance. In letter formation abilities students in Latent Class One and Latent Class Two were significantly different from each, $F(1,198) = 117.66, p < .000, \eta^2 = .37$. The effect size was moderate and was associated with 37% of the variance between the Latent Classes.

The Observed Power was equal to .77 for the statistical differences identified in the foundational handwriting skills of developmental hand skills, and .98 for visual motor skills. For letter motor memory, handwriting legibility and letter formation skills the Observed Power was 1.00 indicating that there were very strong statistical differences in these foundational areas for Latent Class One and Latent Class Two. The Observed Power equaled .98 for visual perceptual skills. For upper limb speed and dexterity the Observed Power equaled .10 which is very low indicating that this foundational hand skill was not different between the groups. The statistical differences reported in the ANOVA were computed using alpha < .05.

Multivariate Analysis of Variance: Latent Class One, Latent Class Two and Normative Data

A one-way multivariate analysis of variance (MANOVA) was conducted to determine if Latent Class One and Latent Class Two were statistically different on the foundational handwriting skill variables, from each other and the Normative Data. Significant differences were found among Latent Class One, Latent Class Two and the Normative Data on the dependent measures of developmental hand skills, visual perception, visual motor skills, upper limb speed and dexterity, letter motor memory lower case, handwriting legibility and letter formation, Wilks' $\Lambda = .10$, $F(2,257) = 77.99, p < .000$. The multivariate η^2 or effect size based on Wilks' Λ was strong and equaled .67. This indicates that 67% of the multivariate variance of the dependent variables was associated with the group factor of Latent Class One, Latent Class Two and the Normative Data. The Observed Power was equal to 1.00 indicating that the Latent Classes are different from the Normative Data. The statistical differences reported in the MANOVA were computed using alpha $< .05$. Table 23 contains the means and the standard deviations for each dependent variable for Latent Class One, Latent Class Two and the Normative Data.

Table 23. MANOVA Results: Latent Class One, Latent Class Two and Normative Data.

Means and Standard Deviations (SD) for Latent Class One, Latent Class Two and Normative Data

Foundational Skill Variables	**Latent Class One (N=38)**		**Latent Class Two (N=162)**		**Normative Data* Added Sample**
	Mean	**SD**	**Mean**	**SD**	
Developmental Hand Skills	21.68	4.51	23.79	4.27	29.00
Visual Perception	89.92	17.65	103.50	18.57	100
Visual Motor Skills	81.87	11.98	90.51	12.07	100
Upper Limb Speed & Dexterity	11.87	5.16	12.53	5.72	15
Letter Motor Memory Skills lower case	6.58	5.57	24.25	2.89	25.50
Handwriting Legibility	2.11	.73	3.22	.73	4.50
Letter Formation skills	1.87	.74	3.21	.67	4.00

Note: Normative data was gathered for this comparison by using standard scores from standardized tests. These numbers represent the 50th percentile or a T-Score of 50 on a normative curve.

Developmental Hand Skills (Benbow, 1997; Exner, 1992, Pehoski, Henderson, Tickle-Degnen, 1997), Visual Perceptual Quotient, TVPS (Gardener, 1997), Visual Motor Skills – TVMS-Revised (Gardener, 1997), Upper Limb Speed and Dexterity -Bruininks-Ozerestsky Test of Motor Proficiency (Bruininks, 1978), Letter Motor Memory Lower Case (Admunson, 1995; Graham, Weintraub, Berninger, 2001), Letter Formation (Reisman, 1999), Handwriting Legibility (Reisman, 1999).

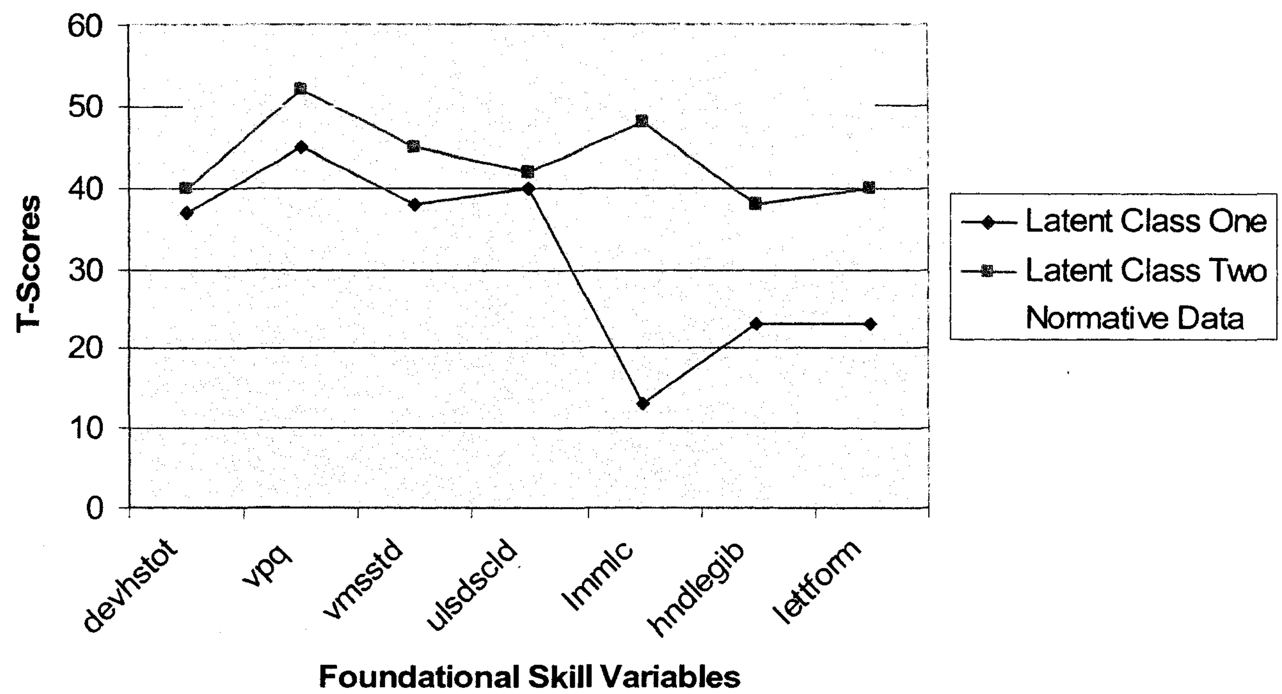
Analysis Of Variance: Latent Class One, Latent Class Two and Normative Data

For developmental hand skills students in Latent Class One and Latent Class Two had significantly different developmental hand skill performance from each other and the Normative Data, $F(2,257) = 55.41$, $p < .000$, $\eta^2 = .30$. The effect size for developmental hand skills was strong with these skills associated with 30% of the variance. The strength of the differences among Latent Class One, Latent Class Two and the Normative Data in visual perceptual skill areas was moderate (8% of the variance among the groups), $F(2,257) = 10.95, p < .000, \eta^2 = .08$. Student performance in visual motor skill areas for Latent Class One, Latent Class Two and Normative Data was significantly different, $F(2,257) = 35.81, p < .000, \eta^2 = .22$, with a strong effect size that was associated with 22% of the variance. The strength of the differences for upper limb speed and dexterity skills was considered small, with only 5% of the variance being associated with the Latent Classes, $F(2,257) = 6.67, p <.001, \eta^2 = .05$. Student performance in letter motor memory was significantly different for students in Latent Class One and Latent Class Two and the Normative Data, $F(2,257) = 542.46, p <.000, \eta^2 = .81$. Letter motor memory was associated with 81% of the variance among the groups with a very large effect size. Students in Latent Class One and Latent Class Two were significantly different in handwriting legibility from each other and from the Normative Data, $F(2,257) = 150.12, p <.000, \eta^2 = .54$. The effect size was strong and explained 54% of the variance. In letter formation abilities students in Latent Class One and Latent Class Two were significantly different from each other and statistically different from the Normative Data, $F(2,257) = 145.85, p <.000, \eta^2 = .53$. The effect size was strong with 53% of the variance associated with the Latent Classes.

The Observed Power was equal to 1.000 for the statistical differences identified in the foundational handwriting skills of developmental hand skills, visual motor skills, letter motor memory, handwriting legibility and letter formation skills. The Observed Power equaled .99 for visual perceptual skills and .91 for upper limb speed and dexterity. The statistical differences reported in the ANOVA were computed using alpha < .05.

Follow up tests were conducted for significant findings to evaluate differences among the means. The Dunnett's C test revealed that there were significant differences in the means of the Normative Data and Latent Class One and Latent Class Two for all foundational handwriting skill variables. For the foundational handwriting skill variables of upper limb speed and dexterity, Latent Class One and Latent Class Two were significantly different than the Normative Data but Latent Class One and Latent Class Two were not significantly different from each other at the $p<.05$ level. For visual perceptual skills, Latent Class Two had significantly better skills than Latent Class One and the Normative Data. Figure 4 plots profiles of each foundational variable for Latent Class One and Latent Class Two. The normative data were included for comparison.

Figure Four: Profiles for Latent Class One and Latent Class Two



Latent Class One (N=38) Latent Class Two (N=162)

devhstot= Developmental Hand Skills (total score)
vpq= Visual Perception
vmsstd= Visual Motor Skills
ulsdscld= Upper Limb Speed and Dexterity
lmmlc= Letter Motor Memory Lower Case
hndlegib= Handwriting Legibility
lettform= Letter Formation

Summary

Latent Class Analyses (LCA) were undertaken to identify how many homogeneous groups or latent classes existed within the sample of 200 students based on their scores for developmental hand skills, visual perception, visual motor skills, upper limb speed and dexterity skills, handwriting legibility and letter formation skills. The LCA revealed that there were Two Latent Classes that existed for this population of students with slow handwriting. The Two Latent

Classes (Latent Class One and Latent Class Two) demonstrated significantly distinct profiles based on the results of the accompanying univariate ANOVA. The Two Latent Classes were found to be statistically different on all of the selected foundational handwriting skill variables except upper limb speed and dexterity. Latent Class One had lower skill performance than Latent Class Two on all of the foundational measures except on upper limb speed and dexterity skill measures.

Further analyses were conducted to determine if each of these Latent Classes were significantly different from Normative Data on each of the selected variables. A one way multivariate analysis of variance (MANOVA) identified that Latent Class One and Latent Class Two were different from the Normative Data on all of the selected foundational handwriting skill areas. These findings indicated that Latent Class One and Latent Class Two were unique in their own profiles as well as, different from the norm. Both Latent Class One and Latent Class Two had lower skill performance than the norm on all of the foundational handwriting skill areas except for visual perceptual skills. Latent Class Two had better visual perceptual skills than the norms identified for this comparison.

The results of this LCA indicated that for the sample of students with slow handwriting Two Latent Classes were found with statistically distinct profiles in foundational handwriting skill areas.

Chapter VII

Discussion

STEP FIVE: Defining the Latent Classes

Describe Latent Class One and Latent Class Two based on foundational skill performance in developmental hand skills, visual perception, visual motor skills, upper limb speed and dexterity, letter motor memory, handwriting legibility and handwriting quality.

Defining the Latent Classes

The present study explored the role of foundational handwriting skills on handwriting performance in 200 elementary grade students with slow handwriting. The research used Latent Class Analyses (LCA) to identify how many groups of students existed within this population based on their performance in foundational handwriting skill areas. Using Latent Class Analyses, two distinct groups or classes of students were identified to describe the population. Each of the Latent Classes had statistically distinct skill performance in foundational handwriting skill areas.

Latent Class One had a membership of 38 students while Latent Class Two had a membership of 162 students. The MANOVA indicated that the skill performance of students in Latent Class One differed from Latent Class Two, Wilks' $\Lambda = .20$, $F(1,198) = 111.35$, $p < .000$. The effect size was strong with 80% of the multivariate variance of the foundational handwriting variables associated with Latent Class One and Latent Class Two. The power of this statistic was equal to 1.00 which indicated that the difference between these classes on the foundational variables was very strong.

The accompanying ANOVA for Latent Class One and Latent Class Two identified that letter motor memory lower case skills were very different for these Latent Classes, $F(1,198) = 762.99$, $p < .000$ with 79% of the variance associated with these Latent Classes. The power of this statistic was very strong and equal to 1.00. This indicates that letter motor memory lower case was an important foundational handwriting skill for the population of slow handwriters and that the skill performance for students in Latent Class One and Latent Class Two were very different.

The ANOVA for Latent Class One and Latent Class Two indicated that letter formation skills were very different for these classes, $F(1,198) = 117.66$, $p < .000$ with 37% of the variance associated with the groups. The power of the statistic was very strong and equal to 1.00. This finding suggests that slow handwriters in Latent Class One and Latent Class Two had very different letter formation skills. Based on the strength of the effect size, there would be noted clinical or practical differences in letter formation skills between the Two Latent Classes.

Handwriting legibility was different for students in Latent Class One and Latent Class Two as reported in the ANOVA, $F(1,198) = 72.02$, $p < .000$, with 27% of the variance associated with the Latent Classes. The power of this statistic was equal to 1.00 which indicated that the differences are very strong. The handwriting legibility was very low for students in Latent Class One and just below average for students in Latent Class Two. Handwriting legibility would affect handwriting performance in the classroom for both of these classes with very different skills for students depending on the Latent Class to which they belong.

The visual perceptual skills for Latent Class One and Latent Class Two were their strongest foundational handwriting skill in overall performance but very different between the classes. The

ANOVA indicated that the perceptual skills differed significantly for the Latent Classes, $F(1,198) = 16.76, p < .000$, and were associated with 8% of the variance between the Latent Classes. The power of the statistic was .98 indicating statistically strong differences. The students in Latent Class One had perceptual skills at the low end of average while the students in Latent Class Two had very strong skills above the 50^{th} percentile on a normative curve. These students were perceptually strong.

Visual motor skills were different for students in Latent Class One and Latent Class Two. The students in Latent Class Two demonstrated better skills than Latent Class One, $F(1,198) = 15.83, p < .000$, with 7% of the variance associated with the Latent Classes. Visual motor skills had a small effect on the differences between the groups but the variances that were present were very strong as identified by the power of this statistic which equaled .98. The students in Latent Class One had visual motor skills that fell just below the average range while the visual motor skills for Latent Class Two were lower end average.

The developmental hand skills for students in Latent Class One and Latent Class Two were different, $F(1,198) = 7.34, p <.01$. The effect of these skills on the differences among the Latent Classes was small and associated with 4% of the variance. The power of the statistic was high at .77 but not as high as other foundational handwriting skills. The students in Latent Class One and Latent Class Two had very different hand skills but they may be less obvious in the classroom.

The upper limb speed and dexterity skills between Latent Class One and Latent Class Two were not statistically different, $F(1,198) = .43, p =.51$. The students in Latent Class One and Latent Class Two did not appear to have very different skills with coordination and precision of their hands for manipulation and placing tasks. Students in both Latent Classes were on the low end average or borderline level which indicated that overall these students had slightly weaker dexterity skills than the norm but were not different from each other.

Normative Data was added for comparison among Latent Class One, Latent Class Two and a normal standard score. The MANOVA indicated that the skill performance of students in Latent Class One and Latent Class Two differed from each other, as well, differed from the Normative Data, Wilks' $\Lambda = .10$, $F(2, 257) = 77.99$, $p <.000$. The effect size was strong with 67% of the multivariate variance of the foundational handwriting skills associated with the group factor. The power of this statistic was equal to 1.00 indicating a very strong difference in foundational skills among the Latent Classes and Normative Data.

The accompanying ANOVA for Latent Class One, Latent Class Two and the Normative Data identified that:

1. Letter motor memory was associated with the variance at a very high level with 81% of the variance explained by the groups, $F(2,257) = 542.46$, $p <.000$.
2. Handwriting legibility was associated with the variances among the Latent Classes and the Normative Data at a strong level with 54% of the variance explained by the groups, $F(2,257) = 150.12$, $p <.000$.
3. Letter formation skills were associated with 53% variances among the Latent Classes and the Normative Data at a strong level, $F(2,257) = 145.85$, $p <.000$.
4. Developmental hand skills were associated with 30% of the variance among the Latent Classes and the Normative Data, $F(2,257) = 55.41$, $p <.000$.

5. Visual motor skills were found to explain the variances among the Latent Classes and the Normative Data at a medium level with 22% of the variance associated with the groups, $F(2,257) = 35.81, p <.000$.

6. Visual perceptual skills were associated with 8% of the variance among the Latent Classes and Normative Data, $F(2,257) = 10.95, p <.000$. Upper limb speed and dexterity skills were associated with 5% of the variance among the Latent Classes and the Normative Data, $F(2,257) = 6.67, p <.001$.

Foundational Skills Associated with Handwriting Development for Latent Class One and Latent Class Two

The students in Latent Class One and Latent Class Two were slow handwriters and referred to occupational therapy because of their problem keeping up with the writing demands of the classroom. Based on the results of this study, the underlying foundational handwriting skills for Latent Class One and Latent Class Two were different between the Latent Classes. The students with slow handwriting whose charts were included in this study had very different skill performance on all of the foundational handwriting skill areas from each other except for speed and dexterity skills. Letter motor memory lower case skills were associated with the variance between the Latent Classes with the strongest association statistically. Handwriting legibility and letter formation explained more of the variance between the Latent Classes with a strong statistical finding. Visual perception, visual motor skills and developmental hand skills, although different between Latent Class One and Latent Class Two, had a smaller association with the variance between the groups.

The students in Latent Class One were slow both in the classroom and in the one to one testing session. The students in Latent Class Two were slow in the classroom only but within the normal range for handwriting speed when tested individually. The findings of this research suggest that handwriting skill performance fell into two clinically different profiles. The findings from the present research also identified that the two Latent Classes were different from the norms.

Handwriting Speed and Handwriting Quality. There was no published research that looked at slow handwriters to define this population based on foundational skill performance. Furthermore, in the literature there was no agreement on whether children with handwriting difficulties had a slower speed of handwriting compared to matched controls. Pontello (1999) found that when students increased their handwriting speed they had difficulties maintaining legibility in a grade one sample population. Hamsta-Bletz and Blote (1990) found that Grade two students with slower handwriting had better letter formation and accuracy than the faster handwriters but the handwriting was more irregular with respect the size of the letters and alignment of the letters on the writing line. Graham et al. (1998) found that when children were asked to write neatly their handwriting speed decreased. Ziviani and Watson-Will (1998) identified that in the primary years, as students are learning to handwrite, legibility is emphasized over speed of handwriting.

Volman et al. (2006) found that students with handwriting problems were slower handwriters than students who did not have handwriting difficulties. Their finding is supported by this present research. For the students in the present study, the students with better handwriting legibility and handwriting quality had faster handwriting speed. This indicated that the students who were faster with handwriting had mastered letter formation and letter motor memory at a greater level than those students who were still struggling in these areas. The mean scores for Latent Class One and Latent Class Two were very different with the students in Latent Class Two demonstrating faster handwriting speed, better handwriting quality and better letter motor memory. Volman et al. (2006) found that visual motor integration and visual spatial memory were significant predictors of handwriting speed in a group of students with slow handwriting. For students without handwriting speed difficulties, upper limb speed and dexterity was a significant predictor of handwriting speed (Volman et al., 2006). In the present research, visual motor skills and visual perception explained some of the differences between Latent Class One and Latent Class Two at a small level, while upper limb speed and dexterity skills were not different between the Latent Classes. These findings indicate that for slow handwriters in Latent Class One and Latent Class Two, visual motor skills and visual perceptual skills were found to explain the variance between the Latent Classes at a small but significant level while upper limb speed and dexterity did not explain any the differences between the groups.

Visual Perceptual Skills. Research about the impact of visual perception on handwriting is inconclusive as some studies' results have indicated that visual perceptual test scores were not related to quality of handwriting (Graham & Weintraub, 1996; Yost & Lesiak, 1980; Maeland & Karlsdottir, 1991). Another study reported that there was a significant difference between poor and good handwriteres on the scores of visual perceptual tests (Tseng & Murray, 1994). These differences on perceptual tests of good and poor handwriters are supported by the current study as the students in both Latent Class One and Latent Class Two have average visual perceptual skills but still demonstrate poor quality of handwriting overall. The students in Latent Class One had low average visual perceptual skills while the students in Latent Class Two had average visual perceptual skills. Both of these Latent Classes had poor handwriting legibility and letter formation skills with students in Latent Class One having below average skills whereas students in Latent Class Two had just below average or borderline abilities. These findings support Tseng and Chow (2002) who identified that students with slow handwriting overrely on visual skills when handwriting. Volman et al. (2006) found that visual motor integration was more related to handwriting quality than handwriting speed. Latent Class One had very low skills in all motor areas but visual perceptual skills were within the average range. These students may use their strong visual perceptual skills to compensate for poorer motor skills. Further research is needed to explore this hypothesis.

Visual Motor Skills. Visual motor skills have been found to correlate with handwriting abilities in other research (Weil & Cunningham-Admunsun, 1994; Weintraub & Graham, 2000; Karlsdottir & Staffanson, 2002). Benbow (1995) identified that tests of visual motor ability are useful in predicting a student's potential ease or difficulty in learning to print. Reisman (1999) found that as children's visual motor skills mature, the correlation between handwriting and design copying becomes less strong. She postulated that the change in the relationship between handwriting and design copying may indicate that visual motor skills become more integrated and automatic in older children. Therefore, children rely less on visual motor abilities but on automatic abilities. The findings of the present research indicated that visual motor skills were associated with 22% of the variance among Latent Class One and Latent Class Two and the Normative Data. For the students in Latent Class One, it appears that perhaps the visual motor skills were not yet developed to the point of being useful in handwriting quality and that handwriting may be driven by visual perceptual abilities which could make handwriting less functional and much slower.

Latent Class Two had better visual motor skills overall than Latent Class One. This finding does not support the hypothesis that the different levels of functioning are a result of different underlying mechanisms affecting the handwriting quality for each of the Latent Classes, but indicates that the different levels of functioning were a result of different skill performance on the same underlying foundational handwriting skills within this population of slow handwriters. The research of Tseng and Chow (2002) identified that the handwriting performance of slow speed handwriters and normal speed handwriters was different. Volman et al. (2006) found that the underlying mechanisms that support handwriting quality for students with handwriting problems and those without were different. The present research found that the handwriting performance of slow speed handwriters was different from the Normative Data because there were two distinct groups of students with slow handwriting who have very different skill performance in the same foundational handwriting skill areas. This research found that the underlying mechanisms affecting handwriting performance for Latent Class One and Latent Class Two were the same but the skill performance for the Latent Classes in the foundational handwriting skill areas was different for the Latent Classes. The findings of this present research suggested that the underlying mechanisms that play a role in the handwriting performance of slow handwriters were the same but the skill levels for Latent Class One and Latent Class Two were very different from each other and from the Normative Data.

Letter Motor Memory. Other research identifies a positive correlation between letter knowledge and handwriting function (Karlsdottir & Stafansson, 2002). They identify that the time allotted to teach the letters of the alphabet is often not sufficient for children to learn the form ation of the letters. They recommend that verbal and visual prompting of specific features of letter forms during the first introduction of the letters along with systematic repetition is needed for mastering handwriting. Weintraub and Graham (2000) found that the ability to develop an internal representation of the letters of the alphabet, and rapidly and accurately encode and reproduce letters from memory was needed for handwriting fluency and legibility. They predicted that the failure to develop this skill may impede handwriting legibility and fluency. Abbot and Berninger (1993) found that printing the alphabet from memory was more important to handwriting development than fine motor skills. They found significant correlations were found between handwriting and alphabet coding (orthographic coding) by producing alphabet symbols and handwriting but this was not found for fine motor finger function. Latent Class One was very poor with letter motor memory which may have impeded handwriting quality for this population. All of the students in Latent Class One had poor letter motor memory. In the present study, letter motor memory lower case letters was associated with 79% of the variance between the Latent Classes and 81% of the variances among the Latent Classes and the Normative Data. This finding supported previous research that indicated letter motor memory impacts handwriting development and automaticity.

Developmental Hand Skills. The developmental hand skills for the students in Latent Class One were less mature and below average when compared to the skills of Latent Class Two and when compared to the norms. The students who had more mature developmental hand skills had better skills in the other areas explored as noted by the foundational skill differences between the Latent Classes. Past research suggests that hand skills play a part in handwriting performance. Weintraub and Graham (2000) reported that finger function made a significant impact on handwriting performance for good and poor handwriters. This finding supports those of Cornhill and Case-Smith (1996) who reported that in-hand manipulation skills, particularly those skills that help one turn the pencil from pencil side to eraser side and move fingers up and down the pencil shaft, were predictive of handwriting performance. The findings of this research suggested that developmental hand skills were different for slow handwriters. The variance in developmental hand skills for Latent Class One and Latent Class Two was small but significant. The hand skills for students in Latent Class One were weak when compared to those of Latent Class Two. The hand skills for Latent Class One and Latent Class Two were weaker than the Normative Data. Based on these findings, developmental hand skills play a role in handwriting performance for slow handwriters. Further research is needed to determine how much these skills influence handwriting.

Upper Limb Speed and Dexterity. There were no statistical differences between Latent Class One and Latent Class Two on measures of upper limb speed and dexterity. Both Latent Classes had weaker skills in this area. When compared with the Normative Data there was a small but significant difference between the Latent Classes and the Normative Data with Latent Class One and the Normative Data significantly different from each other and Latent Class Two and the Normative Data different from each other. Volman et al. (2006) found that unimanual dexterity or fine motor coordination was not a predictor for handwriting quality in students with handwriting problems but was a predictor in the handwriting quality of good handwriters. This research is supported in the present study as there were no significant differences among the Latent Classes in upper limb speed and dexterity skills but when the Normative Data was added, upper limb speed and dexterity skills were different between the slow handwriters and the Normative Data.

Description of Latent Class One and Latent Class Two

Table 24 presents a clinical description for Latent Class One and Latent Class Two for comparison.

Table 24. Foundational handwriting skill comparison between Latent Class One and Latent Class Two.

Latent Class One (*n* = 38)	**Latent Class Two (*n* = 162)**
Weak developmental hand skills.	Low average developmental hand skills.
Average visual perceptual skills.	Very strong visual perceptual skills.
Below average visual motor skills.	Average visual motor skills
Low average upper limb speed and dexterity skills.	Low average upper limb speed and dexterity skills.
Very low letter motor memory skills – lower case letters.	Average letter motor memory skills.
11-15/26 letters are legibly handwritten.	Below average handwriting legibility 16-20/26 letters are easily identified.
1-15/26 letters are formed correctly.	Borderline letter formation skills (16-20/26).

Latent Class One (*n* = 38)

1. **Describe the skill performance of Latent Class One in the foundational handwriting skill areas.**
2. **Provide a clinical picture of Latent Class One as seen in the classroom and on the occupational therapy assessment.**
3. **Use this information to better understand the population of student in Latent Class One.**
4. **Future research will focus on effective therapeutic interventions and teaching methods that target the needs of these students for developing automatic writing skills.**

When compared to the normative data, the students in Latent Class One were very different from the norms and had weaker foundational handwriting skills overall. Latent Class One differed from Latent Class Two on all variables except upper limb speed and dexterity. Latent Class One had the following skill performance in foundational handwriting areas.

a) Weak developmental hand skills. These students in Latent Class One had not achieved the developmental hand skills that should be fully developed by kindergarten / grade one (Exner, 1992; Benbow, 1995). All developmental hand skills, except for the in-hand manipulation skills, are normally observed in children younger than 5 years old (Exner, 1992).

b) Average visual perceptual skills. The students in Latent Class One had visual perceptual skills that fall within the average range but were below the 50^{th} percentile for their ages. Even so, the visual perceptual skills of these students were among their stronger skills compared to the other foundational areas considered.

b) Below average visual motor skills. The visual motor skills of students in Latent Class One are below average. These children had difficulty copying shapes that look like the sample. Because the visual perceptual skills of these students were within normal limits, the motor skills of this group may have impacted visual motor performance for Latent Class One. This finding was supported in other research that identified students with slow handwriting and handwriting problems have handwriting quality that was impacted by visual motor skills (Volman et al., 2006). Tseng and Chow (2000) suggested that slow handwriters rely strongly on visually directed processing including visual perception and visual motor skills which leads to slower handwriting.

c) Low average upper limb speed and dexterity skills. The students in Latent Class One had similar skills to those in Latent Class Two with upper limb speed and dexterity skills that were less proficient than the normative data. These students had difficulty moving items in their hands quickly and accurately to complete sorting and placing items.

d) Very low letter motor memory skills. These students were only able to produce 6 out of 26 letters of the alphabet from memory. Graham, Weintraub and Berninger (2001) reported that typically developing students in grade one were able to produce 24.7 out of 26 of the letters of the alphabet from memory with 90% legibility. By grade two the students rarely missed a letter when writing from memory (1% missed letters noted). The students in third grade rarely missed a letter (<1% of the time

The students in the present study in Latent Class One were found to perform far below the level outlined above in letter motor memory skills. Limited letter motor memory was associated with 79% of the variance between the Latent Classes. Jones and Christiansen (1999) found that letter motor memory impacted the amount of writing a student could produce in the classroom. The students in Latent Class One had difficulties producing written work in the classroom and during the occupational therapy assessment in a one to one situation. Karlsdottir and Stafansson (2002) identified a positive correlation between hand function and letter motor memory. The students in Latent Class One were found to have both hand function problems and motor memory difficulties when compared to Latent Class Two and the Normative Data.

e) Slow handwriting which is less legible than normal with poorly formed letters. The students in Latent Class One had less legible handwriting which supports the findings from another study that found that students with handwriting problems were slower handwriters (Volman et al., 2006). The letter formation skills of the students in Latent Class One were weaker than normal and weaker than the students in Latent Class Two.

A Clinical Picture of Latent Class One

Latent Class One had a distinct clinical picture that was defined based on the results of this study. Latent Class One included:

a) students who had hand skills that required cuing and support for correct pencil use and object manipulation in the classroom and in therapy,

b) students who had low average visual perceptual skills which could make visual interpretation slower in a busy classroom,

c) students who had visual motor skills that were below average which affected their ability to copy from the page or the blackboard,

d) students who had borderline coordination of their hand and upper extremities during tasks that required quick and coordinated use of one or two hands during fine motor tasks,

e) students who remembered how to print 6 letters of the alphabet from memory without copying,

f) students who could legibly handwrite 11-15 letters of the alphabet so they were easily identified,

g) students who correctly formed between 1 to 15 letters of the alphabet.

The students in Latent Class One could be defined as "Non Functional" handwriters. These students were unable to produce written work in the classroom and had difficulties with handwriting speed in a one to one situation. These students had immature developmental hand skills, below average visual motor skills, very low letter motor memory skills, poor handwriting legibility and poor letter formation skills. They had normal visual perceptual skills which fell below the 50th percentile and borderline upper limb speed and dexterity skills. These children have difficulties in the motor components associated with handwriting and with the memory components. The underlying factors that were found to be associated with the variance between Latent Class One and Latent Class Two were letter motor memory, handwriting legibility, letter formation skills, developmental hand skills, visual perception and upper limb speed and dexterity. The differences between the Latent Classes outlined in this study identified that Latent Class One performed at a much lower level than the students in Latent Class Two and the Normative Data in the foundational handwriting skill areas.

Latent Class Two (*n* = 162)

1. **Describe the skill performance of Latent Class Two in the foundational handwriting skill areas.**
2. **Provide a clinical picture of Latent Class Two as seen in the classroom and on the occupational therapy assessment.**
3. **Use this information to better understand the population of student in Latent Class Two.**
4. **Future research will focus on effective therapeutic interventions and teaching methods that target the needs of these students for developing automatic writing skills.**

Latent Class Two

The students in Latent Class Two performed better than those in Latent Class One in all foundational areas except for upper limb speed and dexterity. These students were found to have strong visual perception, moderate visual motor skills and borderline hand skills and handwriting quality. The students in Latent Class Two had the following skill level.

a) Low average developmental hand skills. The students in Latent Class Two had weak but borderline (low end of average) developmental hand skills. These hand skills were better than those in Latent Class One. These skills were different statistically from the Normative Data which indicated that the hand skills of students in Latent Class Two were less mature when compared to what is normally expected of children in elementary school.

b) Very strong visual perceptual skills. These students had very strong visual perceptual skills which indicated that these students could be stronger visual learners. The visual perceptual skills of Latent Class Two were better than the norm. These skills fell within the average range.

c) Average visual motor skills. The visual motor skills for students in Latent Class Two were on the low end of average. It appeared that these skills were impacted by weaker motor skills as the visual perceptual abilities for these students were very strong.

d) Borderline upper limb speed and dexterity skills. The upper limb speed and dexterity skills of the students in Latent Class Two were borderline. These students had difficulties manipulating objects in their hands accurately and proficiently and may have appeared clumsy and less coordinated with hand skills.

e) Below average handwriting legibility and borderline letter formation skills. Handwriting legibility and letter formation skills for students in Latent Class Two were significantly better than the students in Latent Class One but were less developed than what is expected based on the Normative Data. These students had slightly better letter formation skills than handwriting legibility. Both handwriting legibility and letter formation when compared to the normative data required improvement.

f) Average letter motor memory skills. The students in Latent Class Two had average letter motor memory skills however were weaker when compared to the Normative Data. These students continued to have some difficulties with remembering how to print 1 to 2 letters of the alphabet.

A Clinical Picture of Latent Class Two

Latent Class Two had a distinct clinical picture different from those students in Latent Class One. Their foundational skill profile was defined based on the results of this study. Latent Class Two included:

a) students who had hand skills that were used functionally at times in the classroom but were not maintained for the duration of the pencil – paper tasks or fine motor tasks,
b) students who had visual perceptual skills that were very good which enabled them to interpret information accurately and quickly,
c) students who had visual motor skills that were average which enabled them to copy from the page or blackboard at a functional level,
d) students who had low end average upper limb speed and dexterity skills which meant that they could manipulate objects in their hands with coordinated movement but might look somewhat clumsy,
e) students who could print 24 out of 26 letters of the alphabet from memory,
f) students who could print 16 to 20 letters of the alphabet that were easily identified by others,
g) students who could accurately form 16 to 20 letters of the alphabet.

The students in Latent Class Two could be defined as "Functionally Slow" handwriters. The students in Latent Class Two appeared to have the foundational handwriting skills that would enable them to complete work in the classroom. Despite this finding, they continued to have problems in the classroom with the completion of handwritten work. They were able to copy from a handwriting sample as needed but had difficulty keeping up with the handwriting expectations for their age and grade. These students were not slow on handwriting copying tests in a one to one situation but were slow in the classroom when completing written work. They had strong visual perceptual skills, lower average visual motor skills, and lower average letter motor memory skills, below average developmental hand skills, below average handwriting legibility and borderline letter formation skills. The handwriting performance of the students in Latent Class Two appeared to be impacted as well by the motor components of handwriting but not to the same extent as the students in Latent Class One. These students had better letter motor memory which may have enabled them to handwrite faster than the students in Latent Class One during the one to one assessment process. The students in Latent Class Two have different abilities in foundational handwriting skills of developmental hand skill, visual perception, visual motor skills, letter motor memory, handwriting legibility and letter formation skills than students in Latent Class One. The underlying foundational skills associated with handwriting were the same but the performance of the students in the Latent Classes was found to be much different.

Summary

This exploration of underlying foundational skills in students with slow handwriting in the classroom was intended to:

1. Identify how many groups of students or Latent Classes with slow handwriting that cluster together based on their performance in foundational handwriting skill areas.
2. Define each group of students based on their performance in each foundational skill area when compared to the other groups of students or Latent Classes.

The findings suggest that students with slow handwriting could fall into one of two Latent Classes based on their performance in the foundational skills associated with handwriting development. Table 25 presents a summary clinical picture of students in Latent Class One and Latent Class Two.

Table 25. Clinical Picture of Latent Class One and Latent Class Two

Latent Class One (*n* = 38)	**Latent Class Two (*n* = 162)**
Hand skills require cuing to be used correctly for object manipulation and pencil control.	Hand skills are functional but the quality of hand skills is not maintained during pencil / paper tasks.
Some difficulties with visual interpretation of information in a busy classroom.	Very good visual interpretation of information.
Difficulties copying information.	Can copy functionally from the page at the desk or from the blackboard onto the paper placed on the desk.
Borderline coordination of arm and hand skills making skills look clumsy.	Borderline coordination of arm and hand skills making skills look clumsy.
Can remember how to print approximately 6 letters of the alphabet from memory.	Can remember how to print 24 / 26 letters of the alphabet from memory
Can copy print 11-15 legible letters.	Can copy print 16-20 letters that are easy to read.
Can accurately form 1-15 letters of the alphabet when copying.	Can accurately form 16-20 letters of the alphabet.

The statistical definition and clinical definition of the Latent Classes indicate that the students in Latent Class One were impacted by poor performance in all areas except upper limb speed and dexterity when compared to Latent Class Two. They performed at the lower end of average in visual perceptual areas. The findings of the Latent Class Analyses suggest that the underlying foundational handwriting skills that impact on the performance of Latent Class One are different than Latent Class Two. The statistical definition and clinical definition of Latent Class Two indicate that these students function on the borderline of average or in the lower average range on all foundational skill areas except for their visual perceptual skill performance. These students were very strong in visual perceptual areas. In general, both Latent Classes of students could be defined as having average or strong visual perceptual skills which may indicate that these students rely on their visual skills rather than their motor skills for handwriting tasks. The students in Latent Class Two were more developed in the underlying foundational skill areas than the students in Latent Class One. Students in both Latent Class One and Latent Class Two perform lower than the Normative Data except the students in Latent Class Two had better visual perceptual skills than the Normative Data.

Through the identification and description of these Two Latent Classes, therapists and teachers can target intervention and remediation for students who have handwriting problems and slow handwriting. Therapists can determine where to intervene, develop outcomes measures suited for the particular profile the student demonstrates and monitor improvement of skill. The identification of Latent Class One and Latent Class Two enables the researcher and clinician to start to develop therapies targeting foundational skill areas. Based on the findings of this research, therapies would look different for the students in Latent Class One and the students in Latent Class Two.

Future Research

The results of this study warrant further exploration of the foundational handwriting skills using Latent Class Analyses and a control population of students who match the participants in age and grade but who are functioning normally in the classroom with handwriting speed and completion of written work. A control population would have provided more detail about how students without handwriting difficulties perform in specific areas when compared to a matched group of students with handwriting problems.

Replication studies would help to support the results of this research for application to the general population. Replication studies should include a population of students without handwriting problems.

The results of this study will assist in developing therapy to target the needs of each Latent Class. Effectiveness studies can then be completed to see which therapies are more effective for a particular Latent Class. Through further research, therapies that target the specific needs of a population can be developed to effect change and improve skills for students with slow handwriting. Handwriting instruction techniques can be developed and evaluated for these Latent Classes to see if a particular program benefits the students in the Latent Classes more than what is presently being used. Studies identifying the use of computers to increase written productivity could stem from the findings of this research as these students have stronger visual perceptual skills which are needed for computer use. Research on whether computers can assist one Latent Class over another would be interesting and warranted based on the results of this research.

Latent Class Analyses can enable researchers to ensure that participants are the same or very similar within a group being investigated or being tested for their response to particular treatments. By completing research using identified Latent Classes, effective approaches can be developed for particular groups. Latent Class Analyses can be helpful when preparing for research assessing the effectiveness of therapy and educational programs.

Further research on the impact of attention difficulties on handwriting performance is warranted. Attention difficulties can have an impact on student performance. In the present research 75% of the students could not produce written work in the classroom at a normal pace but could produce handwriting in a one to one situation. Difficulties with attention may have impacted on the findings of this study.

Limitations of this Research

The biggest limitation of this research was the lack of a control group of students without handwriting speed problems. Because this population was not part of the present research, Normative Data was added and was used to compare the means of Latent Class One and Latent Class Two.

The sample population was large enough to determine significance but a larger sample population would have provided more details about skill performance within each Latent Class. Once the Latent Classes were identified, the population of Latent Class One was small.

In assessing handwriting speed, the speed score was changed to a categorical number and should have been left at the rating of letters per minute. Using letters per minute may have provided more specifics related to the handwriting performance of the students with information about specific handwriting speeds. The students in this research were close to the low end of average in the norms, however, statistical analysis of the specific handwriting times was not completed because a designated score of 1 was given to students with slow handwriting in the classroom and a designation score of 2 was given to those students with slow handwriting in a one to one situation. A standardized test that assesses developmental hand skills would have tightened up this part of the assessment process. Occupational therapists are very limited in the variety of assessments that look at developmental hand skills. Most students are assessed through observation in this area.

The designated scores assigned to each component hand skill (wrist stability, motoric separation, finger and thumb isolation, hand arches, in hand manipulation and thumb index web space) in the students' clinical files were developed to provide a quantifiable number for each hand skill level associated with the total developmental hand skills of the student. The descriptions of each score for separate hand skills were based on the observations provided by Benbow (1995). The occupational therapists that completed the assessments of hand skills with the students whose clinical files were included in this study were trained on how to observe and designate the assigned score to each hand skill.

Many of the students were in grades one to three, with the greatest population in grade one. This may have had an impact on the lower ratings for letter motor memory as many of the children were just learning to handwrite. It was noted that as the grades and ages of the students increased the population of students decreased. This finding makes sense as many students eventually master the skill of handwriting or compensate for handwriting difficulties by using assistive technology. It is possible that students will develop functional handwriting even with difficulties in learning the skill.

Conclusion

Through the findings of this Latent Class Analysis, a population of 200 students with slow handwriting in the classroom was described more accurately. Based on these results, foundational handwriting skills have been identified that are statistically associated with the two Latent Classes of students with slow handwriting. This information will be useful in planning therapeutic intervention to increase handwriting performance and to develop compensatory strategies that may be helpful in the classroom for students who have difficulties getting their ideas down onto paper.

Students in Latent Class One need to focus on improving letter motor memory and developmental hand skills. Letter motor memory accounted strongly for the variance between the Latent Classes. Letter motor memory skills were very poor for this population of students in Latent Class One. The hand skills of this group were also very poor which could make them rely on visual perception rather than the motor components of printing. Once letter motor memory and hand skills are treated, letter formation and legibility can be the focus. The students in Latent Class One have poor foundational skills that need to be further developed before working on the more integrated skill of letter formation and handwriting legibility. Through clinical interpretation a therapist would start to improve letter motor memory and developmental hand skills for students in this Latent Class.

Students in Latent Class Two had more intact letter motor memory skills and better developmental hand skills than students in Latent Class One. These students had very strong visual perceptual skills which makes visual processing easier for them. For this population, targeting letter formation and handwriting legibility may assist to improve handwriting speed. By improving the proficiency of letter formation for Latent Class Two, handwriting quality could improve. Effectiveness studies could explore this hypothesis. Through clinical interpretation and based on the findings of the Latent Class Analyses the foundational skill of letter formation would be a place to target improvement in therapy and in the classroom for the students in Latent Class Two. Letter formation accounted for 37% of the variances between Latent Class One and Latent Class Two and 53% of the variances when the Normative Data was added for comparison.

Further research is required in replication studies so the findings can be generalized. As well, studies on the efficacy of therapy for particular latent classes in foundational handwriting skill areas would be helpful in identifying what type of intervention will enhance the development of automatic handwriting ability.

In summary, students with slow handwriting can fall into two clinically and statistically different Latent Classes based on their skill performance in the foundational areas of developmental hand skills, visual perception, visual motor skills, upper limb speed and dexterity skills, letter motor memory abilities, letter formation skills and handwriting legibility skills. This research suggests that for each group, there are different skill levels in foundational handwriting skills that play a role on handwriting performance for students with slow handwriting. As a clinician and researcher, knowing this information about students with slow handwriting will influence my learning in helping these students perform better in the classroom.

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Appendix 1

Glossary

Automatic handwriting refers to the ability to write without thinking about handwriting, so that the scarce cognitive resource of attention is available for the more complex tasks of putting ideas down on paper (Jones & Christiansen, 1999).

Cursive writing is the production of upper and lower case letters completed in a joined script form (Pontello, 1999).

Foundational Variables are the underlying developmental skills associated with the learning to handwrite.

Handwriting is the motor and perceptual task of printing and cursive writing.

Kinesthesia is the conscious perception of the amount of joint movement and direction of joint movement and of the weight and resistance of objects being used in the hand (Benbow, 1995).

Laterality is the internalized awareness of the knowledge of right and left sides and is associated with spatial awareness (Alston & Taylor, 1987)

Letter knowledge is the ability to identify letters of the alphabet by name, sound and letter formation (Lloyd, 1994).

Letter motor memory is the ability to recall the mental image of a letter and print or handwrite it on the page.

Manuscript printing is the production of upper and lower case letters in the printed form (Unconnected letters).

Orthographic coding is the ability to develop an intact representation of the letters of the alphabet, and rapidly and accurately encode and reproduce them from memory (Weintraub and Graham, 2000).

Orthographic motor integration is the visual representation specific to written symbols of letters, cluster of letters and words and writing them on the paper (Jones & Christiansen, 1996)

Penmanship is the style and skill of handwriting (Webster's, 1995).

Slow handwriting. Slow handwriting occurs when a student does not meet the standard handwriting speed generally assessed in the number of letters written in one minute. Various authors have norms for handwriting speed for grade. In this study, students who do not achieve the average handwriting speed for the grade level are identified to have slow handwriting.

Spatial awareness is one's ability to analyze geometric shapes, numbers and letters (Benbow,1995).

Visual Motor Integration is the coordination of visual information with movement. It is the ability to translate information received visually to a motor response. The term is often used to indicate the ability to copy geometric designs (Henderson & Pehoski, 1995).

Visual Perception Visual perception is a visual skill used for Interpreting stimuli through the eyes, including peripheral vision, and acuity, awareness of colour and pattern. Areas of visual perception that are of interest in this research include; visual memory (memory of information presented visually), visual sequential memory (memory of information presented visually and in a particular order), visual discrimination (ability to pick out similarities and differences in shapes, pictures or forms presented visually), visual form constancy (recognizing forms and objects as the same in various environments, positions and sizes), visual figure ground (differentiating between foreground and background forms and objects), visual spatial relations (determining the position of objects relative to each other), visual closure (identifying forms and objects from incomplete presentations), and laterality (using a preferred unilateral body part for activities requiring a high level of skill) (Dunn, 2000, p. 228-229).

Writing is the ability to commit ideas onto paper. It is the product of the integration of skills between handwriting and cognitive processes for communicating ideas on paper (Pontello, 1999).

Appendix 2

Glossary of Variables used on Data Sheet	
VARIABLE	**WORKING DEFINITION OF VARIABLE**
Sex	Identification of gender either male or female.
Grade	Grade level of the student from SK to Grade 7.
Age	Age of the student.
Reading Ability	Identification of reading ability as outlined on the teacher checklist of the referral to Occupational Therapy (OT).
Handwriting Issue	Identification of handwriting issues identified by the teacher on the teacher checklist portion of the referral to OT.
Term Assessed	Identification of the school term that the OT assessment took place. There are three terms in a school year.
Birth Month	The month that the student was born.
Medical Diagnosis	The medical diagnosis that was available on the student clinical chart diagnosed by a medical doctor or registered psychologist.
Hand Dominance	The predominant hand that the student uses for handwriting.
Pencil Grasp	The type of grasp that the student uses to hold the pencil.
Wrist Stability	The ability of the wrist to remain in extension when holding the pencil. This provides support during handwriting.
Motoric Separation	The ability of the hand to move the front of the hand while the heel of the hand offers support as when using scissors or snapping fingers.
Finger Isolation	The ability to isolate the fingers for pointing and keyboarding.

Glossary of Variables used on Data Sheet Continued	
Hand Arches	Supports the roundness or cupping position of the palm of the hand.
In hand Manipulation	The ability of the hand to move objects from the palm to the fingers and to rotate objects in the hand.
Thumb Index Web Space	The space between the index finger and the thumb generally seen in an open position when the pencil is held properly.
Upper Limb Speed and Dexterity	The ability of the hands to move quickly to complete tasks in one hand or in two hands together. Tasks include dealing cards, turning pennies, stringing beads, placing pegs.
Strength	The ability of the student to complete sit ups and push ups.
Balance	The ability of the student to stand on one leg and walk on a straight line and balance beam.
Postural Control	The seating position of the student at their desk as reported and assessed by the occupational therapist.
Visual Motor Skills	The ability to translate with one's hand what is perceived visually (Gardener, 1997). This skill involves looking at a shape or word and copying it accurately on a piece of paper.
Visual Perception	The ability to interpret or give meaning to visual information.
Visual Discrimination	The ability to match two forms from a choice of five similar forms.
Visual Memory	The ability to immediately recall all of the characteristics of a form presented in a group of similar forms.
Visual Spatial Relations	To determine which form is going in a different direction from a choice of five forms that are presented.
Visual Form Constancy	The ability to pick out a form that is the same even when it is rotated changed in size, backwards or hidden.
Visual Sequential Memory	The ability to immediately recall a series of forms in the same order from a group of five sequence choices.

Glossary of Variables used on Data Sheet Continued	
Visual Figure Ground	The ability to perceive a form visually when it is hidden or embedded in a conglomerated ground of matter.
Visual Closure	The ability to determine what a form looks like when it is presented unfinished like when connecting the dots.
Letter Motor Memory	The ability to remember the motor pattern for forming a letter in handwriting either printing or cursive style.
Kinesthesia	The ability to regulate pressure and movement.
Handwriting Speed	The ability to copy a written sentence in a timed test. It is identified as letters per minute.
Handwriting Legibility	The ability to produce handwriting that is easily read.
Handwriting Quality	The ability to produce handwriting with equal sized letters, spacing and alignment.
Handwriting Letter Formation	The ability to form letters with a consistent start and continuous motion that makes handwriting efficient for function and speed.

Appendix 3

Correlations Identified among the Handwriting Foundational Skills, Visual Perception and Visual Motor Skills

Foundational Skills	VPQ	VMSRSTD
Handwriting Speed (HNDSPEED)	.09	-.00
Letter Formation (LETTFORM)	.23**	.40**
Handwriting Quality (QUALITY)	.30**	.36**
Handwriting Legibility (HNDLEGIB)	.23**	.34**
Kinesthesia (KINESTH)	-.02	.01
Letter Motor Memory Lower (LMMLC)	.28**	.27**
Letter Motor Memory Upper (LMMUC)	.37**	.31**
Visual Motor Skills (VMSRSTD)	.40**	
Visual Perceptual Skills (VPQ)		.40**
Upper Limb Speed & Dexterity (ULSDSTD)	.26**	.10
Developmental Hand Skills (DEVHSTOT)	.16*	.29**
Pencil Grasp (PGRASPS)	.08	.21**

$N = 200$

*. Significant at the .05 level (2- tailed).
**. Significant at the .01 level (2-tailed).

Appendix 4

Pearson Correlation Coefficient (r) among the Handwriting Foundational Skills and Letter Motor Memory (Lower Case and Upper Case)

Foundational Skills	**LMMLC**	**LMMUC**
Handwriting Speed (HNDSPEED)	.41**	.34**
Letter Formation (LETTFORM)	.61**	.47**
Quality of Handwriting (QUALITY)	.49**	.40**
Handwriting Legibility (HNDLEGIB)	.56**	.38**
Kinesthesia (KINESTH)	.02	.12
Visual Perceptual Quotient (VPQ)	.28**	.37**
Visual Memory Skills (VPVMSTD)	.25**	.21**
Visual Discrimination Skills (VPVDSTD)	.36**	.35**
Visual Spatial Relations (VSRSTD)	.38**	.39**
Visual Form Constancy (VFCSTD)	.23**	.25**
Visual Sequential Memory (VSMSTD)	.31**	.30**
Visual Figure Ground (VFGSTD)	.05	.23**
Visual Closure (VCSTD)	.17**	.22**
Visual Motor Skills (VMSRSTD)	.27**	.31**
Upper Limb Speed Dexterity (ULSDSCLD)	.05	.12
Developmental Hand Skills (DEVHSTOT)	.22**	.25**
Thumb Index Web Space (WEBSPACE)	.06	.14
In Hand Manipulation (INHANDMA)	.27**	.30**
Finger Isolation (FINGERIS)	.11	.25**
Motoric Separation (MOTORSEP)	.26**	.27**
Wrist Stability (WRISTSTA)	.09	.04
Pencil Grasp (PGRASPS)	.06	.13
Letter Motor Memory Lower (LMM)		.59**
Age	.38**	.30**

N = 200

*. Significant at the .05 level (2-tailed).
**. Significant at the .01 level (2-tailed).

Appendix 5

Pearson Correlaton Coefficient (r) among Foundational Skills, Upper Limb Speed and Dexterity, Developmental Hand Skills and Pencil Grasp for Students with Slow Handwriting			
Foundational Skills	**ULSDSTD**	**DEVHSTOT**	**PGRASPS**
Handwriting Speed (HNDSPEED)	.12	.10	.08
Letter Formation (LETTFORM)	.03	.33**	.12
Handwriting Quality (QUALITY)	.07	.38**	.09
Handwriting Legibility (HNDLEGIB)	-.04	.34**	.06
Kinesthesia (KINESTH)	.08	.12	.26**
Letter Motor Memory Lower (LMMLC)	.05	.22**	.06
Letter Motor Memory Upper (LMMUC)	.12	.25**	.13
Visual Motor Skills (VMSRSTD)	.10	.29**	.21**
Visual Perceptual Skills (VPQ)	.26**	.16*	.08
Upper Limb Speed & Dexterity (ULSDSTD)		.14	.24**
Developmental Hand Skill(DEVHSTOT)	.14		.43**
Wrist Stability	.03	.52**	.17*
Motoric Separation	.10	.72**	.33**
Finger Isolation	.24**	.63**	.23**
Hand Arches	.26**	.61**	.42**
In Hand Manipulation Skills	.12	.68**	.21**
Thumb Index Web Space	.17**	.62**	.53**
Pencil Grasp (PGRASPS)	.24**	.43**	

N = 200

*. Significant at the .05 level (2- tailed).
**. Significant at the .01 level (2-tailed).

Appendix 6

Pearson Correlation Coefficient (r) among Foundational Skills, Handwriting Speed, Kinesthesia and Handwriting Quality for Students with Slow Handwriting			
Foundational Skills	**HNDSPEED**	**KINESTH**	**QUALITY**
Handwriting Speed (HNDSPEED)		.13	.29**
Letter Formation (LETTFORM)	.30**	.04	.65**
Handwriting Quality (QUALITY)	.74**	.07	
Handwriting Legibility (HNDLEGIB)	.25**	.03	.74**
Kinesthesia (KINESTH)	.13		.07
Letter Motor Memory Lower (LMMLC)	.41**	.02	.49**
Letter Motor Memory Upper (LMMUC)	.34**	.12	.40**
Visual Motor Skills (VMSRSTD)	-.00	.01	.36**
Visual Perceptual Skills (VPQ)	.09	-.02	.30**
Upper Limb Speed & Dexterity (ULSDSTD)	.12	.08	.07
Developmental Hand Skill(DEVHSTOT)	.10	.12	.38*
Pencil Grasp (PGRASPS)	.08	.26**	.09

N = 200

*. Significant at the .05 level (2- tailed).
**. Significant at the .01 level (2-tailed).