An Exploration of Handwriting Correlates in Children with Autism Spectrum Disorders

A DISSERTATION SUBMITTED TO THE FACULTY OF THE CURRY SCHOOL
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Abstract

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Handwriting deficits in children with autism spectrum disorders have been increasingly recognized in the literature. This study sought to compare handwriting legibility in children with ASD to a control group of typically developing, age and gender matched peers. Twenty-two children (11 per group) participated in this study. Statistically significant differences in letter and word legibility were found between groups. Children with ASD demonstrated poorer performances on letter and word legibility. Graphomotor control was correlated with word and letter legibility in children with ASD. A sensory processing measure of proprioception was also found to be a predictor of letter legibility in children with ASD.

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APPROVAL OF THE DISSERTATION

This dissertation, An Investigation of Handwriting Correlates in Children with Autism Spectrum Disorders, has been approved by the Graduate Faculty of the Curry School of Education in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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Date of Defense

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My journey at the University of Virginia commenced many moons (and three children) ago with the desire to be challenged intellectually, to gain the skills necessary to become an academician, and (more esoterically) to develop a fuller understanding of motor performance in children with disabilities and autism, in particular. In each of these respects, I am deeply indebted to Dr. Martin Block for his willingness to take me under his wing and for his invaluable support throughout this endeavor. Dr. Block's classroom instruction and management have inspired and guided my approach to teaching; moreover, he has provided me with numerous opportunities to lecture and hone my skills. Additionally, his patience, insight and assistance throughout the dissertation process were essential to its completion. Simply put, I could not have had a better advisor and committee chair.

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CHAPTER ONE

Introduction

The clinical observation of an apparent paradox in children with autism spectrum disorders (ASD) was the seminal force behind this project: why did so many children with ASD demonstrate such difficulty with handwriting when, taken as a whole, their performances on tests of visual perception were average to above average? Motor performance that paralleled cognitive development in individuals with intellectual disability was understandable. Motor deficits in students with diagnoses such as cerebral palsy and spina bifida were understood and expected. In contrast, children with ASD generally do not present overt evidence of motor impairment such as tremulous movement, spasticity, or impaired range of motion. Thus, the difficulty demonstrated by many students with ASD with elemental writing skills when visual perception was often of average to above average ability was perplexing. These clinical observations, which were initially made over a decade ago by the primary researcher, laid the foundation for the research described herein.

The review of literature elucidated patterns of performance consistent with the clinical observations noted above; visual perception of static forms tends to be an area of strength (Happe & Frith, 2006; Mottron, Dawson, Soulieres, Hubert, & Burack, 2006;) whereas motor performance has been recognized as a weakness (Berkeley, Zittel, Pitney, & Nichols, 2001; Dowell, Mahone & Mostofsky, 2009; Dziuk et al, 2007; Fabbri-Destro, Cattaneo, Boria & Rizzolati, 2009; Fournier, Hass, Naik, Lodha & Cauraugh, 2010; Jansiewicz et al., 2006; Teitelbaum, Teitelbaum, Nye, Fryman & Maurer 1998; Weimer, Schatz, Lincoln, Ballantyne, & Trauner, 2001). However, as limited research has been identified with regard to handwriting and ASD, questions remain concerning the associations between motor performance, visual perception, and handwriting in this population. This project was undertaken to gain a better understanding of the relationships between specific aspects of motor performance, visual perception, sensory processing, and handwriting in children with ASD.

The number of children diagnosed with Autism Spectrum Disorders (ASD) has increased dramatically over the past 35 years (DSM III, 1980; Kogan et al., 2009). In 1980 approximately 2 to 5 in 10,000 children were diagnosed with autism (DSM III). In 2009, Kogan et al. (2009) reported that as many as 1 in 91 children between the ages of 3 and 17 years were diagnosed with an ASD. More recently, the prevalence of autism in 8-year-old children was reported to be 1 in 68 with the ratio of boys to girls with ASD being 4.5:1 (Centers for Disease Control and Prevention [CDC], 2014).

Autism is recognized as a neurological condition with numerous studies identifying atypical neuroprocessing and/or neuro-morphology (Chang et al., 2014; Just, Keller, Malave, Kana, & Varna, 2012; Marco, Hinkley, Hill, & Nagarajan, 2011; Minshew & Williams, 2007). Atypical neurological processing has been associated with motor performance (Mostofsky, Burgess, & Gidley Larson, 2007; Mostofky et al, 2009; Muller, Kleinhans, Kemmotsu, Pierce & Courchesne, 2003; Muller, Pierce, Ambrose, Allen, & Courchesne, 2001), visual perception (Ring et al., 1999), and sensory processing (Chang et al., 2014). More specifically, ASD has been hypothesized to result from impaired connections within the brain (Just et al., 2012; Minshew &Williams, 2007). Furthermore, it has been hypothesized that deficits in interconnectivity between brain regions may facilitate enhanced localized processing; moreover, this phenomenon has been hypothesized to explain perceptual performance in ASD (Just et al., 2012). Also in regard to visual-perceptual functioning, Spencer et al. (2000) hypothesized that individuals with ASD may have impaired dorsal visual stream functioning. The dorsal visual stream has been hypothesized to be associated with the visual guidance of movement (Milner & Goodale, 1995).

Although the principle characteristics of ASD involve deficits in communication, social interaction, repetitive behaviors, and/or limited interests, atypical sensory processing is now recognized as a common and salient feature of this diagnosis (American Psychiatric Association, 2013). Findings that describe atypical patterns of sensory processing in children with ASD have been noted in the literature (Kern et al. 2006; Koenig & Rudney, 2010; Tomchek & Dunn, 2007;) and have been related to adaptive behavior (Lane, Young, Baker, & Angley, 2010), academic performance (Ashburner, Ziviani, & Rodger, 2008) and activities of daily living (White, Mulligan, Merrill, & Wright, 2007). Research investigating the relationship between sensory processing and handwriting performance in children with ASD has not been identified in the literature.

An extensive body of research demonstrates that a significant number of individuals with ASD also exhibit deficits in motor function (Berkeley et al., 2001; Teitelbaum et al., 1998). Deficits have been noted in speed of movement (Glazebrook, Elliott, & Szatmari, 2008; Jansiewicz et al, 2006; Nazarali, Glazebrook, & Elliott, 2009), motor planning (Dowell, Mahone, & Mostofsky, 2009; Dziuk et al, 2007; Fabbri-Destro et al., 2009) and kinesthesia (Weimer et al., 2001).

The performance of fine motor skills, including handwriting, has been reported to occupy a significant portion of a child's day in school with 30% to 60% of a student's day being occupied with fine motor tasks (McHale & Cermak, 1992). With regard to the percentage of time engaged in fine motor activities, McHale and Cermak (1992) noted that, "85% of the time was spent on paper-and-pencil tasks and 15% was spent on manipulative tasks" (p. 900). Graham et al. (2008) conducted a survey of handwriting teaching practices in kindergarten through third grade teachers and found that, on average, children in these grades participated in handwriting tasks an average of two hours and 33 minutes per week. Additionally, the majority of teachers in this study reported that poor handwriting resulted in decreased writing output, lower grades, and additional time to complete assignments (Graham et al, 2008). Thus, the need to acquire and utilize handwriting skills is integral to academic participation and achievement. Furthermore, Harris and Handleman (2000) found that students with ASD with intelligence quotients (IQ) above 80 were often placed in regular education classrooms. Given the dramatic increase in number of children diagnosed with autism and the likelihood that many of these students will be educated in regular classrooms, a better understanding of handwriting difficulties in children with ASD is needed.

The relationship between handwriting performance and abilities such as visual motor integration and fine motor coordination has been investigated in several studies (Cornhill & Case-Smith, 1996; Tseng & Murray, 1994; Volman, van Schendel, & Jongmans, 2006;). However, results have yielded inconsistent findings with regard to correlations between handwriting performance and underlying abilities. For example, visual perception, visual motor integration, fine motor coordination, hand function, and hand writing grip have all been associated with handwriting performance (Berninger & Rutberg, 1992; Cornhill & Case-Smith, 1996; Schneck, 1991; Tseng & Murray, 1994; Volman et al., 2006; Weil & Cunningham Amundson, 1994). Additionally, research has demonstrated that the relationships between motor abilities and handwriting vary in differing diagnostic populations (Feder et al, 2005; Levine, Oberklaid & Meltzer, 1981; Zivani, Hayes & Chant, 1990).

With regard to ASD, research has demonstrated deficits in handwriting quality (Fuentes, Mostofsky, & Bastian, 2009; Fuentes, Mostofsky, & Bastian, 2010; Hellinckx, Roeyers, & Van Waelvelde, 2013), legibility (Henderson & Greene, 2001; Myles et al., 2003) and letter formation (Cartmill, Rodger & Ziviani, 2009; Fuentes et al., 2009). Additionally, children and adults with ASD have demonstrated handwriting that is larger than that produced by typically developing peers (Beversdorf et al., 2001; Myles et al., 2013).

Researchers have also sought to identify correlates and predictors of handwriting performance in children with ASD: the findings have varied. Cartmill, Rodger, and Ziviani (2009) found that visual perception, oral spelling, verbal memory, and "spelling with different allographs" (p. 113) were found to be significantly correlated with legibility: correlations ranged between .40 and .46. Using stepwise multiple regression, Fuentes, Bastian, and Mostofksy (2009) found that handwriting quality in children with ASD was predicted by "timed movement scores" (p. 1534) using the Physical and Neurological Examination for Subtle (Motor) Signs (Denkla as cited in Fuentes, Bastian, & Mostofsky, 2009). In contrast, these same authors identified a different predictor of handwriting performance in adolescents with ASD (Fuentes et al., 2010). In adolescents, deficits in handwriting quality were also identified when the writing of participants (age 12 - 16 years) with ASD was compared to an age and IQ matched control group; however, the only predictor of handwriting was Perceptual Reasoning Index performance (Fuentes et al., 2010). Hellinckx, Roeyers, and Van Waelvelde (2013) also sought to identify predictors of handwriting performance in children with ASD: age, gender and visual-motor integration were found to be significant predictors of handwriting quality. Additionally, these authors also identified differences in handwriting quality and speed between children with ASD and a control group of typically developing peers (Hellinckx, et al., 2013).

In summary, handwriting deficits in children with ASD have been identified in several studies (Cartmill et al., 2009; Fuentes et al., 2009; Fuentes et al., 2010; Hellinckx et al., 2013; Henderson & Greene, 2001; Myles et al, 2003). However, consensus has not been established regarding the identification of correlates or predictors of handwriting in children with ASD. Moreover, for therapists, educators, and parents addressing handwriting in children with ASD, findings noted in the literature do not necessarily provide or suggest a clear starting point for the remediation of handwriting deficits.

Statement of the Problem

At present, no studies have been noted in the literature in which the relationships between motor performance, sensory processing, and handwriting in children with ASD have been investigated. Furthermore, no studies have been identified in the literature in which handwriting grip has been assessed in children with autism. Given the rate of inclusion of students with ASD in regular education classrooms (Harris & Handleman, 2000) and the importance of handwriting performance to academic participation and progress (Graham et al., 2008), the need for further study of handwriting performance in individuals with ASD is warranted.

Purpose of the Study

The present study has three primary purposes. The first is to determine the percentage of handwriting legibility in a sample of children with ASD between the ages of 8 years and 12 years 11 months using a standardized handwriting assessment tool, the Evaluation Tool of Children's Handwriting (Amundson, 1995) and to determine if this rate differs from a control group of age and gender matched typically developing peers. The second purpose is to determine the correlations of various abilities associated with handwriting performance in a sample of children with ASD and a control group. Based upon the findings of previous research these abilities will include the following: 1) visual-motor integration as measured by the Beery-Buktenica Developmental Test of Visual-Motor Integration (6th ed.) (Beery VMI); 2) visual perception as assessed by performance on the Beery VMI Visual Perception test; 3) graphomotor control as measured by the Beery VMI Motor Coordination test; 4) object manipulation as measured by a test of in-hand manipulation; 5) sensory processing as assessed by the Sensory Processing Measure - Home Form; and 6) type of handwriting grip utilized. The third purpose is to utilize stepwise multiple regression to identify the contribution of variance in handwriting legibility attributed to the various abilities mentioned above.

It was also the intention of the present study to identify potential tasks that could be used in future research to assess efficacy of treatment with regard to handwriting. For example, if visual-motor integration were found to be highly correlated with good handwriting performance in children with ASD, future research could assess the impact of participation in visual-motor integration tasks upon handwriting performance to determine if the relationship extended beyond statistical correlation.

The research questions were as follows:

1. Does the legibility percentage of handwriting in children with ASD differ from typically developing children?
2. Are there statistically significant relationships between performance on the ETCH (Amundson, 1995) and the following in children with ASD: visual motor integration as measured by the Beery VMI; graphomotor control as measured by the Beery VMI Motor Coordination test; object manipulation as measured by the Nine Hole Peg Test; visual perception as measured by the Beery VMI Visual Perception test; sensory processing as quantified by the Sensory Processing Measure - Home Form (Parham & Ecker, 2007) and handwriting grip as determined via photographic identification of typical vs. atypical grips.
3. Using stepwise multiple regression, which abilities will predict handwriting legibility as measured by the ETCH (Amundson, 1995) in children with ASD?

Definitions

Visual-motor integration refers to “the degree to which visual perception and finger-hand movements are well coordinated” (Beery & Beery, 2004, p. 12). Furthermore, in this context, visual-motor integration refers specifically to the ability to draw or copy presented forms.

Graphomotor control refers to the ability to complete a tracing or path-drawing task with accuracy. Examples of tests that measure this ability include the Beery Motor

Coordination subtest (Beery & Beery, 2010) and the Motor Accuracy Test (Beery & Beery, 2010).

Object Manipulation is defined as the ability to manipulate objects with the hand(s) with speed and/or precision. Assessments of object manipulation include peg tasks and in-hand manipulation.

Manual movement refers to the ability to complete hand and/or finger movements to produce a particular hand position or to produce as many repetitions of a movement as quickly as possible (e.g., finger tapping). Manual movement tasks do not utilize objects.

CHAPTER TWO

Review of Literature

The literature review begins with an overview of autism spectrum disorders with particular attention to motor function, perceptual abilities, and sensory processing. This will be followed by a review of handwriting research with an emphasis on studies that investigated the influence of various underlying abilities on handwriting performance. The review of literature will conclude with a review of studies examining handwriting deficits in children with different disabilities with an emphasis on ASD.

Autism Spectrum Disorders

Autism was first described in the literature by Kanner (1943) in the seminal article “Autistic Disturbances of Affective Contact” in which he described the behaviors of eleven American children. The behavior of these children was marked by impaired social interactions, atypical verbal communication, limited interests, and sterotypies. In this same period, Hans Asperger described similar behaviors in a group of children in Germany (Frith, 1991). Asperger’s behavioral descriptions were similar to those of Kanner, although Asperger, to a much greater degree, highlighted the presence of motor deficits. (Asperger's descriptions of motor function will be discussed in greater length later in this paper.)

Prior to 1980, the Diagnostic and Statistical Manual of Mental Disorders published by the American Psychiatric Association (APA) did not recognize autism as a specific disorder (Sanders, 2009). In 1980, the APA recognized autism as a unique disorder in the Diagnostic and Statistical Manual of Mental Disorders (Third edition) (DSM-III) and provided six specific criteria to be met in order to obtain a diagnosis of infantile autism.

In 1987, the APA published a revised edition of the DSM-III in which a diagnosis of autism required a child to demonstrate 8 of 16 listed behaviors, which were divided into three clusters (DSM-III-R, 1987). It was also required that each cluster be represented with at least one behavior. Additionally, the name of the disorder was changed from "infantile autism" to "autistic disorder." In 1994, the APA again changed the diagnostic criteria for an autism disorder diagnosis; in this version it was required that the child demonstrate six of twelve described behaviors and that at least one behavior be present from one of three clusters (DSM-IV, 1994). It should also be noted that the DSM-IV was the first version in which variations of autism such as Asperger's syndrome and Pervasive Developmental Disorder – Not Otherwise Specified (PDD-NOS), were also included (DSM-IV, 1994). Two key differences in diagnostic criteria between autism and Asperger's disorder were 1) differences in language development and 2) the criteria requiring an absence of cognitive deficits in the diagnosis of Asperger's syndrome (DSM-IV, 1994). These criteria were maintained for the DSM-IV Text Revision (DSM-IV-TR) that was published in 2000. In the recently published DSM-V (APA, 2013), distinctions between autism, Asperger's syndrome, and PDD-NOS were eliminated; all diagnoses are considered to be *autism spectrum disorders*. As with previous versions, diagnostic criteria include deficits in communication, social interactions, and limited interests or repetitive behaviors. Additionally, an inclusion criterion was added to address sensory processing. To clarify, there need not be evidence of sensory processing dysfunction; however, sensory processing dysfunction may be utilized in the determination of an ASD diagnosis.

Motor Performance and ASD

A review of the diagnostic criteria for autism spectrum disorders reveals that the presence of motor deficits is not, nor ever has been, a criterion for diagnosis. However, the presence of motor deficits in individuals with ASD is well documented; deficits have been identified in areas of motor development (Berkeley et al., 2001; Teitelbaum et al., 1998), balance (Minshew, Sung, Jones & Furman, 2004; Weimer et al., 2001) gross motor performance (Berkeley et al., 2001; Ghaziuddin, Butler, Tsai & Ghaziuddin, 1994; Provost, Lopez & Heimerl, 2007), fine motor performance (Ghaziuddin et al.,1994; Provost et al., 2007), and motor planning (Dowell et al., 2009; Dziuk et al., 2007; Fabbri-Destro et al., 2009). Additionally, research has demonstrated relationships between motor deficits and atypical neuroprocessing (Mostofsky et al., 2009; Muller et al., 2001; Muller et al., 2003) and differences in motor cortex composition (Mostofsky et al., 2007) in comparisons of individuals with ASD and typically developing peers.

In his landmark article, Asperger made numerous references to motor deficits in the children he observed (Frith, 1991). The following quotes come from his early descriptions of three different children:

> Apart from his intransigence to any requests, he was not good at PE because he was motorically very clumsy. He was never physically relaxed. He never swung in any rhythm. He had no mastery over his body (Frith, 1991, p.44).
>
> The clumsiness was particularly well documented during PE lessons. Even when he was following the group leader's instructions and trying for once to do a particular physical exercise, his movements would be ugly and angular. He was never able to swing with the rhythm of the group. His movements never unfolded

> naturally and spontaneously – and therefore pleasingly – from the proper coordination of the motor system as a whole. Instead, it seemed as if he could only manage to move those muscular parts to which he directed a conscious effort of will (Frith, 1991, p.57).
>
> As is to be expected from his whole appearance, he was clumsy to an extraordinary degree. He stood in the midst of a group of playing children like a frozen giant. He could not possibly catch a ball, however easy one tried to make it for him. His movements when catching and throwing gave him an extremely comical appearance. The immobile dignity of the face which accompanied this spectacle made the whole even more ridiculous. He was said to have been clumsy in all practical matters from infancy, and has remained so ever since (Frith, 1991, p. 66).

Comparisons of motor performance in ASD diagnoses. Researchers have investigated the presence of motor deficits in children with autism and Asperger's syndrome to determine if motor dysfunction could be utilized as a marker to distinguish these two manifestations of ASD (Ghaziuddin et al.,1994; Manjiviona & Prior, 1995). Collectively, findings indicated that motor function was not a distinguishing characteristic in these ASD variants.

Ghaziuddin et al. (1994) utilized the Bruininks-Oseretsky Test of Motor Proficiency to compare motor performance among 10 males with Asperger's syndrome (AS) and nine males with high functioning autism (HFA). The mean age of the AS group was 13.6 years; the mean age of the HFA group was 12.9 years. Individuals with IQ scores lower than 70 were excluded from the study. Motor deficits were found in both groups, although no significant differences were found in gross motor, fine motor, limb coordination, or composite scores between the AS and HFA groups. Findings of no statistically significant differences between AS and HFA in motor performance have also been reported in other research (Jansiewicz et al, 2006; Ming, Brimacombe & Wagner, 2007).

Green et al. (2009) investigated the presence of motor deficits in children by ASD subtype and in relation to IQ. This research utilized the Movement Assessment Battery for Children to assess prevalence and type of motor impairment in 101 children with ASD. The research participants had a mean age of 11 years 4 months and included 89 males and 12 females. The authors reported that, "The proportion of children with definite movement problems was similar between the autism group (82.2%) and the broader ASD group (76.8 %)" (Green et al, 2009, p. 313). However, the findings also indicated that children with IQ's of <70 had a significantly higher rate of motor dysfunction than children with ASD and IQ's of greater than 70. Additionally, it was reported that performances on a timed pegboard task and balance board task were significantly worse than all other tasks (Green et al., 2009).

Movement speed and ASD. Mari, Castiello, Marks, Marraffa, and Prior (2003) completed a kinematic assessment of reach-to-grasp in 20 children with ASD (age range 7.4 to 13.1 years) and a typically developing (TD) control group which was also comprised of 20 participants (age range 8 to 12.5 years). Findings indicated that the reach-to-grasp movement was completed more slowly in the ASD group than in the TD control group. However, the authors attributed this difference to the segment of the ASD group that they referred to as *low ability*; this group, with IQ scores that ranged from 70-

79, comprised ten of the twenty participants in the ASD group (Mari, Castiello, Marks, Marraff & Prior, 2003).

Freitag, Kleser, Schneider, and von Gontard (2007) also demonstrated slower performance in ASD participants on a timed pegboard task when compared to typically developing controls. It should be noted that the ASD group in this study was comprised of males between the ages of 16 and 22 years with diagnoses of either high functioning autism or Asperger's syndrome and a mean full scale IQ of 98.7. Thus, this study also demonstrated that deficits in motor function in autism are not only associated with lower IQ ranges (Freitag, Kleser, Schneider & von Gontard, 2007). Slower motor performances have also been demonstrated in both reaction time and movement time when individuals with autism have been compared to typically developing peers (Glazebrook, Elliot, & Szatmari, 2008; Nazarali et al., 2009).

Jansiewicz et al. (2006) utilized the The Physical and Neurological Assessment of Subtle Signs (PANESS) to measure performance of motor control to determine if differences existed in motor signs in males (age 6 – 17 years) with high functioning autism (HFA), Asperger's syndrome (AS), and a control group of typically developing (TD) males. The ASD groups consisted of a total of 40 participants; the control group included 55 participants. Inclusion in the study was limited to individuals with full-scale IQ scores greater than 80. The authors noted that, "These cut-off criteria allowed us to specifically examine the development of motor functioning in children with HFA and AS, not associated with mental retardation" (Jansiewicz et al., 2006, p. 615). No significant differences in motor performance, as measured by the PANESS, were found between the group with HFA and AS. As such, these two groups were combined into an

ASD group for comparison with the TD group. Significant differences were found between the ASD and TD groups in balance, dysrhythmia, overflow, gait, and timed repetitive movements (Jansiewicz et al., 2006).

Research utilizing kinematic analysis of reaching tasks has also demonstrated slower reaction and movement times when individuals with ASD (n = 9, mean age 26.9 years) were compared to typically developing peers (n = 9, mean age 25.1 years) (Glazebrook et al., 2006): Not surprisingly, peak acceleration and peak velocity were significantly slower in the ASD group. Additionally, the ASD group was found to demonstrate more spatial variability at the point of peak acceleration; however, there was not a significant difference in spatial variability upon reaching the target. The authors noted, “Thus, although their movements are characteristically slower, and more variable over the initial ballistic phase of movement execution (especially for movements of greater length, or to larger targets), individuals with autism were able to achieve the same endpoint accuracy as their chronologically aged matched peers” (Glazebrook et al., 2006, p. 260).

Motor planning and ASD. Fabbri-Destro et al. (2009) utilized reach to grasp to assess the performance of an object placement task in children with ASD (n = 12, mean age 10.00 years) and a control group of TD peers (n = 14, mean age 7.6 years) who were matched by non-verbal cognition. The task involved reaching for and grasping an object prior to placing it into a large or small container, depending upon the experimental condition. The TD group responded to the container size in both phases of the process (i.e., the reach for the object and the placement component). In contrast, the ASD group did not modify their initial reach time in relation to the demand of the subsequent step. The authors summarized their findings by stating that, “Most importantly, the present study shows that, in contrast to TD children, children with autism are unable to translate their motor intention into an action, but program single motor acts independently from one another" (Fabbri-Destro et al., 2009, p. 524). These findings provide further support for the notion that motor planning dysfunction appears to be a factor in motor performance deficits in individuals with ASD (Fabbri-Destro et al., 2009).

Ming et al. (2007) investigated the prevalence of different types of motor disorders in a sample of 154 children with ASD between 2 and 18 years of age. Hypotonia and apraxia were the two most common motor disorders reported with prevalence rates of 51% and 34%, respectively. More specifically, the authors reported the presence of *oral motor apraxia* and *hand apraxia* (Ming et al., 2007). The authors stated further that "In children with apraxia, hand muscle apraxia was evident when children performed acts such as holding a pen, placing pieces of a puzzle, folding a paper, etc." (Ming et al., 2007, p. 568). This research also investigated the extent to which ASD subtype was associated with motor disorders: the authors reported that, "No significant association was found to indicate that a specific ASD subtype (autistic disorder, PDD-NOS or Asperger's syndrome) was a risk for motor deficits" (Ming et al., 2007, p. 568).

Further support for deficits in motor planning in ASD comes from a study that investigated the relationship between motor skills and praxis (Dziuk et al., 2007). A total of 94 children between 8 and 14 years of age participated in this study; 47 of the participants were diagnosed with an ASD. Praxis was measured via the Florida Apraxia Screening Test (Revised) (FASTR), which was adapted for use with children. The FASTR was used to assess the participant's ability to complete transitive and intransitive gestures. Transitive gestures were those that utilized an object; intransitive gestures did not require the use of an object (e.g., waving). Furthermore, transitive gestures were performed under three conditions: by verbal request, imitatively, and with an object. For example, one may be asked to show how to use a toothbrush when asked, after a modeled performance, and with an actual toothbrush. In addition to the evaluation of praxis, The Physical and Neurological Assessment of Subtle Signs (PANESS) was utilized to measure motor control. Motor skills assessed with the PANESS involved timed movements such as "…finger tapping, hand patting, and toe-tapping – on right and left sides…" (Dzuik et al. 2007, p. 736). Results revealed that the ASD group performed more poorly on measures of motor control and praxis. Additionally, hierarchical regression analysis revealed that the ASD group demonstrated significantly poorer praxis than controls, even when the effect of motor ability (as measured by timed performance of repetitive movements) was taken into account. These results suggest that motor performance in individuals with ASD is impacted not only by motor control processes affecting speed of movement, but also by motor planning deficits (Dzuik et al., 2007).

Weimer et al. (2001) compared motor performance of 10 children and teens with Asperger's syndrome (mean age = 15.7 years) to 10 typically developing peers who were matched on age, gender, socioeconomic variables, and verbal IQ. Results revealed differences in praxis, finger-thumb opposition, balance, and tandem gait. Praxis was assessed via a 26-item test that included tasks obtained from other tests of apraxia as well as those the authors referred to as "…novel items…." (Weimer et al., 2001, p. 95). Types of apraxia were categorized as ideomotor, buccofacial, and ideational. Ideomotor apraxia tests consisted of *transitive limb*, *intransitive limb*, and *whole body*. *Transitive limb* tasks involved demonstration of use of an object (Weimer et al., 2001). *Intransitive limb* tasks required performance of upper limb gestures that do not require an object (Weimer et al., 2001). *Whole body* tasks required the participant to demonstrate a particular position and/or movement that utilized the whole body (e.g., a baseball player's stance when at bat or the movements needed to shovel) (Weimer et al., 2001). Buccofacial movements required facial gestures such as demonstrating how to blow out a match or sniff (Weimer et al., 2001). Tests of ideational apraxia necessitated performance of a sequence of movements (e.g., "stand up, turn around once, and sit down" (Weimer et al., 2001, p. 95). When performances of the two groups were compared, only differences in ideomotor/whole body apraxia reached statistical significance. The authors interpreted their findings as implicating the role of proprioception deficits as the participants with AS did worse on a balance task with eyes occluded, with producing whole body positions, and with finger-thumb opposition (Weimer et al., 2001).

Stone, Ousley, and Littleford (1997) also demonstrated deficits in whole body movements when assessing imitation in children with autism. Imitation of whole body movements was more impaired than imitation of movements with objects when children with autism were compared to children with developmental disabilities who were matched on mental and chronological age (Stone, Ousley & Littleford, 1997).

Mostofsky et al. (2006) investigated dyspraxia in children between 8 and 12 years age with and without ASD (ASD n = 21, control group n = 24). An adapted version of the Florida Apraxia Screening Test was utilized to investigate the ability for children to use gestures in response to three different stimuli: verbal command, imitation, and tool use. The children with autism made significantly more errors when completing motor gestures in all three scenarios. The authors concluded that "The findings, therefore, suggest that impaired performance of skilled gestures in autism is unlikely secondary to processes specific to imitation (e.g., self-other mapping); rather, it is likely due to abnormalities in processes common to all three conditions, such as mapping the precise kinesthetic/spatial aspects of movement…and/or planning of goal directed actions…" (Mostofsky et al., 2006, p.322). Additionally, comparisons were made between ASD participants with HFA and Asperger's syndrome; no differences were observed in performance of motor gestures between these groups (Mostofsky et al. 2006).

Dowell et al. (2009), in referencing the work of Heilman and Rothi (1993), noted the following:

> There appear to be three potential contributors to dyspraxia in autism: (a) impairments in the storage of learned time-space movement representations, mediated by parietal regions; (b) impairments in transcoding of these movement representations in the premotor cortex; and (c) impairments in execution and basic motor skills (mediated at the cortical level by the motor cortex) (p. 564).

In order to assess the influence of each of these potential factors upon motor performance, Dowell et al. (2009) investigated differences in motor performance (via the PANESS described previously), *postural knowledge* and praxis in children with high functioning autism (HFA) (n = 37, mean age = 10.26 years) and a control group of typically developing peers (n = 50, mean age = 10.55). Postural knowledge (Mozaz, Rothi, Anderson, Crucian, & Heilman, 2002) refers to the ability to create and store representations of learned movements and was assessed via an adaptation of the Postural Knowledge Test created by Mozaz, Rothi, Anderson, Crucian, & Heilman (2002). This test involved the presentation of drawings of a person engaged in various motor acts (e.g., hammering); however, the hand involved in the task was omitted from the picture. The participant was then shown three pictures of different hand positions and asked to point to the picture that demonstrated the appropriate position given the depicted task. This was completed for both transitive (tool use) and intransitive gestures. Therefore, if the child was able to adequately create and store a conceptualization of the correct hand position for the given gesture, he or she could demonstrate this knowledge without having to execute the motor act. Praxis was assessed via a modified version of the Florida Apraxia Battery (Gonzalez, Rothi, Raymer, & Heilman (1997) as cited in Dowell et al., 2009). Results indicated that children with ASD demonstrated deficits in both postural knowledge and motor control when compared to typically developing peers (Dowell et al., 2009). However, the authors also stated that, "these deficits do not entirely account for the observed dyspraxia in ASD. Both measures of basic motor skill and postural knowledge were significant predictors of praxis performance. Nevertheless, the HFA group continued to show significantly poorer praxis than did controls after accounting for these abilities" (Dowell et al., 2009, p. 567). The authors concluded that, "…the combined contributions of parietal, premotor, and motor systems to dyspraxia in autism suggest that abnormalities in connectivity between these regions may contribute to difficulties with acquisition and performance of skilled gestures" (Dowell et al., 2009, p. 567-568).

Kinesthesia and motor performance in ASD. Atypical sensory processing has been identified in children with autism when compared to typically developing peers (Ashburner et al., 2008; Kientz & Dunn, 1997; Kern et al., 2006). Furthermore, deficits in proprioception have been hypothesized to contribute to impaired motor performance in children with ASD (Mostofsky et al, 2006; Weimer et al., 2001). Researchers have also suggested the need to more fully investigate the role of proprioception in regard to handwriting performance in children with ASD (Fuentes et al., 2009).

The effect of vision and proprioception upon reaching to a target in individuals with autism was investigated by Glazebrook, Gonzalez, Hansen, and Elliot (2009). This study compared the performance of individuals with autism and typically developing peers in reaching tasks that were completed with vision and with vision occluded. The findings revealed that individuals with autism were able to reach to a target accurately in either experimental condition; however, slower movement times and greater variability in performance were demonstrated in the group with autism when compared to the control group (Glazebrook, Gonzalez, Hansen & Elliot, 2009). The authors reported "that individuals with an autism spectrum disorder produce coordinated eye–hand movements with less integration between the ocular and manual systems" (Glazebrook et al., 2009, p. 430) and that "the individuals with ASD were able to use proprioceptive feedback during their movement to successfully reduce the variability of their manual aiming movement" (Glazebrook et al., 2009, p.430).

Molloy, Dietrich, and Bhattacharya (2003) found that vision was a crucial factor in the performance of standing balance when comparing children with ASD to typically developing peers. Their results indicated that the group with ASD depended heavily upon the use of vision in maintaining balance and minimizing postural sway, regardless of variations in standing surface stability (Molloy, Dietrich & Bhattacharya, 2003). Similarly, Weimer et al. (2001) identified deficits in motor performance when participants with autism engaged in tasks in which vision was occluded. These results were interpreted as being suggestive of proprioceptive deficits in individuals with ASD (Weimer et al., 2001).

The role of proprioception in motor performance in autism was also assessed in an investigation of participants' abilities to generalize learned motor patterns in a joystick task (Haswell, Izawa, Dowell, Mostofsky, & Shadmehr, 2009). Results indicated that the autism group developed a "much stronger than normal association between motor commands and proprioceptive feedback" (Haswell et al., p. 970). Additionally, the authors noted that "We found that the greater the proprioceptive-driven generalization in our task, the greater the impairments in general motor function, social interaction and imitation/praxis" (Haswell et al., 2009, p. 971).

Although the research addressing kinesthetic performance in children with ASD is limited, the importance of the role of kinesthesia in the motor performance of individuals with ASD has been highlighted. Further investigation into the role of kinesthetic function in the performance of specific tasks, such as handwriting, is needed (Fuentes et al., 2009).

The preceding literature review concerning motor performance and autism revealed several important themes. First, the influence of IQ upon motor performance is significant when IQ scores approach or fall below 70. Second, when IQ is taken into account, motor performance among ASD diagnostic categories is commensurate. Third, motor performance in ASD is influenced by processes of motor control and motor planning. Finally, there appears to be a relationship between kinesthesia and motor planning as hypothesized by Mostofsky et al. (2006).

Visual Perception and ASD

In contrast to the motor and sensory processing deficits noted in individuals with ASD, certain aspects of visuo-perceptual function have been shown to be of normal to superior functioning in children with autism (O'Riordan, Plaisted, Driver, & Baron-Cohen, 2001: Mitchell & Ropar, 2004; Shah & Frith, 1983). These areas of visuo-perceptual strength have typically been demonstrated in the perception of static forms (O'Riordan et al., 2001; Shah & Frith, 1983). In contrast, deficits in the visual perception of biological movement have been reported (Blake, Turner, Smoski, Pozdol, & Stone, 2003; Oberman et al, 2005).

O'Riordan et al. (2001) demonstrated that children with autism had superior visual search abilities in the performance of feature and conjunction search tasks. Feature search tasks involved identifying a target shape from a display containing numerous other distractor shapes (e.g., identifying an oblique line amongst a display of vertical lines). Conjunction search tasks involved the identification of a target stimulus that shares features of the distractors (e.g., finding a red 3 amongst red 5's and green 3's). This research was conducted in two experiments that addressed feature search tasks and conjunction search tasks separately. In each experiment, the performance of 12 children with autism (age range = 6 years 5 months to 10 years 9 months) was compared to 12 typically developing children of comparable ages and cognition (O'Riordan et al., 2001).

Shah and Frith (1983) reported that children with autism demonstrated superior performance on a test of embedded figures when compared to controls matched by mental age. The Children's Embedded Figures Test was utilized and required the participants to identify a target form within the context of various depictions. Participants included 20 children with autism, 20 typically developing peers, and 20 children with intellectual disability. The results demonstrated that the children with autism performed significantly better than the other two groups (Shah & Frith, 1983). However, it is interesting to note that the decision to match students by mental age resulted in a four year difference in mean age between the group with ASD (mean age = 13.30) and the group comprised of typically developing individuals (mean age = 9.30) (Shah & Frith, 1983).

The two studies described previously demonstrated that participants with ASD exhibited a strength in identifying component features of a given visual presentation. Frith (as cited in Happe & Frith, 2006) proposed that perceptual function in autism results from *weak central coherence*. Weak central coherence described the general finding that individuals with autism tend to process parts of stimuli, objects or the environment rather than the gestalt.

However, not all research findings have supported the weak central coherence paradigm. Deruelle, Rondan, Gepner, and Fagot (2006) investigated global and configural processing strategies and found that children with autism responded similarly to typically developing peers in tasks of global processing. The global processing task utilized a target shape (e.g., a circle) that was comprised of several other shapes (e.g., squares). Below the target form, two choices were presented: one choice depicted the outline of the target shape comprised of different component forms; the other choice was a different outline than the target shape, though comprised of the same forms as the target. Thus, the participant was forced to make a choice that was dependent upon an observation of the form's outline (i.e., gestalt) or its component forms. The performances of three separate groups were compared: an ASD group (n = 13, mean age 9 years 1 month), a group matched on chronological age (n = 13, mean age 10 years), and a group matched on verbal mental age (n = 13, mean age 7 years 7 months). No differences were found between groups, as results indicated that all groups demonstrated a tendency to utilize global processing (Deruelle et al., 2006). This finding ran counter to the weak central coherence hypothesis as the responses of children with ASD showed a preference for a form's gestalt rather than constituent similarities (Deruelle et al., 2006).

With the same group of participants noted above, Deruelle et al. (2006) also assessed configural processing. This was assessed via another task in which the participants were asked to select one of two choices that most resembled a target form. However, instead of differences in outline or shape, the choice was between 1) variations in spatial relationships (i.e., the space between forms was varied, but the component forms were the same as the target) or 2) identical spatial relationships with different component forms. Findings indicated that "…only the clinical group showed a significant response bias, and this bias was clearly in favour of the local match" (p. 103). Thus, the ASD group demonstrated choice preferences based upon the component features rather than spatial relationships. This finding, although seemingly in contrast to the results of the previous experiment, supports the weak central coherence paradigm by demonstrating a response preference for constituent features. In discussing the contradiction in results in these two experiments, the authors suggested that these tasks did not assess the same constructs; moreover, it was stated that "...the hypothesis may be advanced that Experiment 1 emphasized the analysis of global gestalts while Experiment 2 emphasized a consideration of the inter-elemental distances (and thus an analysis of spatial relationships)" (Deruelle et al., 2006, p. 104).

Despite findings which do not support the weak central coherence perspective, there is consensus among researchers that individuals with autism generally present a local bias in visual perception and that visual perception of form is a relative strength (Blake et al., 2003; Mitchell & Ropar, 2004; O'Riordan et al., 2001; Shah & Frith, 1983).

Neurological studies have also demonstrated differences in brain activity between individuals with autism and controls during perception tasks and visuomotor tasks (Muller, Kleinhans, Kemmotsu, Pierce, & Courchesne, 2003; Ring et al., 1999; Samson, Mottron, Soulieres, & Zeffiro, 2012). Ring et al. (1999) utilized fMRI to assess brain activity in individuals with autism and controls during performance of an embedded figures task. Although certain areas of response were noted in both groups, results revealed that the group with autism utilized visual areas to a greater extent than the control group; in contrast, the control group utilized cortical areas associated with working memory to a greater extent than the autism group (Ring et al., 1999).

Regarding seemingly enhanced perception of static forms, researchers have suggested that this may arise as a byproduct of hypo-connectivity between frontal and posterior regions of the brain (Just et al., 2012). More specifically, Just et al. (2012) stated, "underconnectivity theory proposes that a visual processing style may emerge in autism because of decreased availability of frontal processing resources, leading to increased reliance on posterior processing, particularly visuospatial processing" (2012, p. 1303).

Although the perception of static forms is considered a relative strength, deficits in the perception of biological motion and human movement have been reported. Blake et al.

(2003) investigated dorsal stream function relative to the perception of human movement. Human movement was portrayed via point-light displays that portrayed motion for 1 second. Following the presentation, the child was asked to report whether or not the depiction was a person. The performance of the autism group was significantly poorer than the controls (Blake et al., 2003). Moreover, performance on the motion task was significantly correlated with severity of autism (as measured by scores on the Autism Diagnostic Observation Scale – Generic and the Childhood Autism Rating Scale) (Blake et al., 2003). Additionally, Oberman et al. (2005) found evidence of diminished mirror neuron function in individuals with ASD as EEG activity in the ASD group was found to be significantly different from controls when observing a video of human movement.

In summary, individuals with autism tend to demonstrate relative strengths in the perception and identification of static forms and this perception is generally characterized by heightened local processing. However, perception of biological movement has been found to be impaired. Additionally, perceptual research using neuroimaging and measures of neural activation has found differences in individuals with ASD when compared to controls. Given the deficits in motor function and motor planning reviewed previously, the identification of deficits in the perception of movement is particularly intriguing.

Sensory Processing and ASD

Atypical sensory processing has been found to exist in over 90% of children with ASD (Tomchek & Dunn, 2007) and is widely recognized in research literature (Ashburn, et al., 2008; Kern et al., 2006; Kientz & Dunn, 1996). Accordingly, sensory processing dysfunction was included as a potential diagnostic criterion of ASD in the DSM-V (APA,

2013) with the inclusion of the following passage: "Hyper- or hyporeactivity to sensory input or unusual interests in sensory aspects of the environment (e.g., apparent indifference to pain/temperature, adverse response to specific sounds or textures, excessive smelling or touching of objects, visual fascination with lights or movement)" (APA, 2013, p. 50).

Kientz and Dunn (1996) compared sensory processing in children with ASD to children without ASD using the Sensory Profile. Their findings demonstrated sensory processing differences in all assessed categories, including *body position*, movement, touch, vision, auditory, and activity level (Kientz & Dunn, 1996). Kern et al. (2006) investigated sensory processing in individuals between 3 and 56 years of age by comparing persons with autism to age and gender matched individuals who were not diagnosed with ASD. Results showed significant differences in sensory processing between the groups in all areas assessed via the Sensory Profile: auditory, visual, touch, and oral sensitivity (Kern et al., 2006). However, the findings also suggested that sensory processing deficits decrease over time in persons with ASD (Kern et al., 2006).

Ashburner et al. (2008) also compared sensory processing in children with ASD to age and intelligence matched typically developing peers. Using the Short Sensory Profile, group findings indicated differences in sensory processing in all categories except movement sensitivity: thus, findings were noted in areas such as tactile sensitivity, taste/smell sensitivity, visual/auditory sensitivity, and auditory filtering (Ashburner et al., 2008). Furthermore, it was reported that, "underresponsiveness/seeks sensation and auditory filtering were significantly negatively associated with academic performance and attention to cognitive tasks..." (Ashburner et al., 2008, p. 570). In a review of research investigating children with sensory processing deficits, Koenig and Rudney (2010) stated that "Evidence from several studies found that children and adolescents with difficulties processing and integrating sensory information showed lower participation in school activities; children from diagnostic groups associated with difficulties processing and integrating sensory information demonstrated decreased academic achievement and were at a higher risk for learning difficulties" (p. 436-437).

The relationship between sensory processing and performances of activities of daily living in children has also been investigated (White et al., 2007). Areas of sensory processing (e.g. auditory, visual, touch, etc.) were found to correlate with the motor performances involved with the performance of activities of daily living; however, the correlations were generally low (e.g. between $r = .28$ and $r = .31$) (White et al., 2007). This study included children with sensory processing dysfunction, but did not state explicitly whether or not the participants had ASD diagnoses (White et al., 2007).

Roley et al. (2015) investigated the relationship between sensory processing and praxis in children with autism and reported that, "behaviors indicating praxis problems and difficulty with sensory reactivity across multiple sensory systems are evident in the contexts of both home and school" (p. 5). A statistically significant correlation between the Sensory Processing Measure *Social Participation* score and Sensory Integration and Praxis Tests' *imitation praxis* was reported (Roley et al., 2015). Furthermore, the authors noted that, "our study shows that children with ASD have strengths in visuopraxis and major deficits in somatopraxis" (Roley et al. 2015, p. 5).

Researchers have also identified deficits in tactile discrimination when comparing children with ASD to typically developing peers; more specifically, deficits in stereognosis and finger touch recognition were reported (Abu-Dahab, Skidmore, Holm, Rogers, & Minshew, 2012). In contrast, differences in *simple touch* (as measured via the Luria-Nebraska tests of Simple Touch), *sharp-dull discrimination*, and *Fingertip Number Writing* were not found (Abu-Dahab et al., 2012). In discussing the contrasting findings, the authors noted that, "the tactile-perceptual skills that required the greatest higher cortical circuitry integration were impaired as compared to those based on subcortical elementary tactile abilities" (Abu-Dahab et al., 2012, p. 2246). With regard to sensory processing and neurological function, recent research has demonstrated a relationship between specific neural tracts of the brain and performance on assessments of sensory processing in children with ASD (Pryweller et al., 2014).

In summary, the review of literature demonstrates consistent findings of atypical sensory processing in children with ASD. Moreover, relationships have been reported between atypical sensory processing and academic performance, activities of daily living, and praxis. Research has also identified correlations between specific neural structures and measures of sensory processing in children with ASD.

Handwriting

Handwriting performance has received considerable research attention and many studies have investigated correlations between performance factors (e.g. visual motor integration, in-hand manipulation, handwriting grip, and visual perception), handwriting legibility, and handwriting speed (Cornhill & Case-Smith, 1996; Tseng & Murray, 1994; Weintraub & Graham, 2000). Additionally, the impact of kinesthesia and grip use upon handwriting performance has also been addressed (Laszlo & Bairstow, 1983; Schneck, 1991). Handwriting performance has also been assessed in special populations (Feder et al., 2005; Ziviani et al., 1990).

Handwriting and Performance Correlates

The relationship between visual-motor processes, hand function, and handwriting in 48 first-grade children was investigated by Cornhill and Case-Smith (1996). This study utilized the Minnesota Handwriting Test (MHT) to assess handwriting performance. Correlations were obtained between scores on the MHT and the Motor Accuracy Test (MAC), the Beery VMI, and *in-hand manipulation*. As described by the authors, "The Motor Accuracy Test (MAC) is a tracing task that measures a child's accuracy in tracing a curved black line" (Cornhill & Case-Smith, 1996, p. 733-734). As this test is also timed, speed also factored into the scoring. In-hand manipulation was comprised of two tasks: *translation* and *rotation* (Exener, 1992 as cited in Cornhill & Case-Smith, 1996). *Translation* involved picking up pegs from a pegboard, moving them into the palm of the hand so that the pegs could not be seen, and then returning them to the pegboard (Exener, 1992 as cited in Cornhill & Case-Smith, 1996). This was completed in three separate trials in which three, four, and five pegs were used. The score for data analysis was the summed time of the three trials. *Rotation* was assessed by having participants grasp a peg from a pegboard, turn it over, and return it to the original hole (Exener, 1992 as cited in Cornhill & Case-Smith, 1996). Five pegs were used in each trial and the participants completed four trials of this task. For data analysis, the scores of each trial were summed. Results indicated that participants classified as having good handwriting scored significantly higher in all assessments; moreover, significant correlations were noted between each performance area and the MHT (Cornhill & Case-Smith, 1996). The two highest correlations with the MHT, which were nearly identical, were found with translation ($r = -.798$) and rotation ($r = -.770$) (Cornhill & Case-Smith, 1996). Stepwise multiple regression was completed with MHT score as the criterion variable and performance tests as predictor variables. Results indicated that translation, which was entered first, accounted for 63.7% of the variance, VMI performance accounted for an additional 5.9%, and rotation, which was entered last, accounted for 3.3% of the variance (Cornhill & Case-Smith, 1996).

The impact of gender, orthographic processes, finger function, and visual motor integration on cursive handwriting in fifth grade students ($n = 55$) was assessed by Weintraub and Graham (2000). Group comparisons were made between children having good or poor handwriting. The Test of Legible Handwriting was utilized as the assessment tool; a performance which fell one or more standard deviations above the mean classified a child as having good handwriting, while a score one standard deviation or more below the mean classified a student as having poor handwriting (Weintraub & Graham, 2000). The authors reported that *finger function* and visual motor integration (as measured by performance on the VMI) "…significantly and uniquely contributed to the prediction of handwriting status…" (Weintraub & Graham, 2000, p. 131). Finger function scores were created from a composite of finger apposition (successively touching each finger to the thumb as quickly as possible), isolated finger extension, and *finger recognition* (Weintraub & Graham, 2000). Finger recognition was assessed by having students identify which finger was touched with a paper clip without the use of vision; thus, finger function included apposition (opposition), isolated movements, and localization of tactile input (Weintraub & Graham, 2000). Berninger and Rutberg (1992) also reported a significant association between finger function and handwriting.

Volman et al. (2006) determined correlations between handwriting performance and visual perception, visual-motor integration, dexterity, fine motor coordination, and *cognitive planning* (p. 454). This study investigated the handwriting performance of two groups of second and third grade students: those with handwriting deficits (n = 29) and those without (n = 20) (Volman et al., 2006). The Concise Assessment Scale for Children's Handwriting was utilized to quantify handwriting quality. When these groups were combined, only manual dexterity was significantly correlated to handwriting quality (Volman et al., 2006). Dexterity was measured via two unimanual subtests of the Movement Assessment Battery for Children (M-ABC). These M-ABC tasks included a pegboard activity and "drawing a line into a trail" (Van Waelvelde, De Weerdt, De Cock, & Smits-Engelsman, 2004, p. 53). However, when data analysis was completed with the handwriting deficit group only, a significant correlation was only found between handwriting quality and visual motor integration as measured by the Beery VMI (Volman et al., 2006). In the control group, the only significant correlation with handwriting quality was with fine motor coordination (Volman et al., 2006). This was assessed via the Motor Control subtest of the Beery VMI which requires graphomotor control as participants to complete path drawing tasks with precision. The authors stated that "These results suggest that two different mechanisms underlie the handwriting performance in both groups, and that the underlying mechanism responsible for quality of handwriting in children with handwriting difficulties is related more to visual-motor integration processes than to fine-motor-control processes as such" (Volman et al., 2006, p. 457).

The impact of visual motor integration, as measured by the Beery VMI, was also investigated by Weil and Cunningham Amundson (1994) in kindergartners' (n = 60) performance on the Scale of Children's Readiness in Printing (SCRIPT). The SCRIPT requires participants to copy all 26 lower case letters and 8 capital letters. The findings revealed a statistically significant relationship between performance on the VMI and letter writing (Weil & Cunningham Amundson, 1994). Daly, Kelley, and Krauss (2003) replicated these findings with regard to the correlation between the VMI and kindergartners' performance on the SCRIPT.

The influence of motor and perceptual skills on handwriting in children from grades three through five in Kaohsiung, Taiwan was analyzed by Tseng and Murray (1994). Participants were classified as having good or poor handwriting based upon teachers' ratings. Seven perceptual motor tests were utilized to determine predictors for classification of good or poor handwriting. These tests assessed visual motor integration (Beery VMI), visual perception (Test of Visual Perception, non-motor) (TVPS), speed and coordination, motor accuracy (via a tracing task), finger position, kinesthesia, and finger movement. The assessment of finger position was purported to be a test of motor planning as participants were required to correctly imitate finger positions demonstrated by the examiner as quickly as possible. However, the authors did not clarify how increased movement times in this task were attributable to motor planning rather than processes of motor control. Kinesthesia was assessed via the kinesthesia subtest of the Sensory Integration and Praxis Tests (SIPT). The Kinesthesia subtest of the SIPT involves the following: with vision occluded, participants' hands were guided to a target location by the examiner and then returned to the starting position. The participant was then required to move his or her finger to the target location. Scoring was obtained by measuring the distance between the target and the participants' finger placement. Results indicated that the good handwriting group performed better than the poor handwriting group in six of the seven tests; performances on the kinesthesia subtest did not differ significantly between groups (Tseng & Murray, 1994). With regard to correlations between legibility and performance tests, visual motor integration and finger position imitation yielded the only significant correlations within the poor handwriting group (Tseng & Murray, 1994). Significant correlations in the good handwriting group were reported for visual motor integration (Beery VMI) and visual perception (TVPS) (Tseng & Murray, 1994).

Handwriting and Kinesthesia

Although the findings of Tseng and Murray (1994) indicated a lack of statistical significance with regard to the impact of kinesthesia on handwriting performance, Laszlo and Bairstow (1983) emphasized the importance of kinesthetic function in the performance of functional tasks such as handwriting. Moreover, they designed tests for assessing *kinaesthetic sensitivity* and *kinaesthetic perception and memory*. The test of *kinaesthetic sensitivity* required participants whose vision was occluded to differentiate limb positions. After each arm was moved up and down separate ramps that varied in height, the participant was asked to report which limb went higher than the other (Bairstow & Laszlo, 1980). The *kinaesthetic perception and memory* test required that the participant hold a stylus while his or her hand coursed around a grooved pattern with vision occluded. The patterns were imprinted upon a circular disc and were looped such that the ending and starting points were the same. Following the passive movement phase of the test, the disc was rotated such that the pattern was not in its original orientation. Next, the participant viewed the pattern imprinted on the disc and was required to rotate the disc such that it matched the orientation presented for the initial passive movement phase of the test. Each of these tasks was completed with 180 subjects; 20 subjects (10 male, 10 female) were included with participants 5 to 12 years of age (a total of 8 groups) and an additional group comprised of adults (mean age 22 years). The findings revealed, "that by the age of seven children have developed a kinaesthetic acuity equivalent to that of adults" (Bairstow & Laszlo, 1980, p. 459). Findings regarding the kinesthetic memory task revealed that performance fell into one of three age bands: 5 – 7 years, 8 to 12 years, and adult (Bairstow & Laszlo, 1980). The studies findings were well summarized by the following comment:

> While kinaesthetic acuity seems to be fully developed by the age of seven years, the ability to integrate and memorise kinaesthetic information increases markedly beyond this age. It is apparent that the ability to perceive sensory information and the ability to integrate and remember that information are distinct and separate functions of the perceptual process (Laszlo & Bairstow, 1980, p. 462).

Bairstow and Laszlo (1981) utilized the kinesthetic sensitivity test and kinesthetic memory test in a follow-up study under passive, rather than active, movement conditions. Thus, rather than actively moving one’s hands up and down the ramp or through the circuit, the participant’s hands were moved passively along the ramp or pattern circuit. The performances of participants in this study (n = 475) were compared to the results obtained in the previous study (Laszlo & Bairstow, 1980) under active movement conditions. When these two conditions were compared (passive vs. active movement), there was no difference in performance in the kinesthetic sensitivity task (Laszlo & Bairstow, 1981). However, performance on the kinesthetic memory task was demonstrated to be better in the passive condition when compared to the active condition (Laszlo & Bairstow, 1981).

In a subsequent study, Laszlo and Bairstow (1983) utilized the kinaesthetic acuity and kinaesthetic memory tasks to teach kinesthetic perception to children 6 to 8 years of age who were identified as having deficits in kinesthesia. Results indicated that statistically significant improvement could be demonstrated in both tasks of kinesthetic perception (Laszlo & Bairstow, 1983). Additional assessment was conducted to assess the impact of kinesthetic training on drawing tasks. Training involved kinaesthetic acuity and/or kinaesthetic memory task practice (depending upon the individual's performance in initial testing). Results indicated statistically significant improvement in performance of drawing tasks following kinaesthetic training (Laszlo & Bairstow, 1983). Additionally, improvement in handwriting was reported via anecdotal teacher report for ten of the sixteen participants in the experimental group, which was comprised of participants with low kinesthetic testing scores (Laszlo & Bairstow, 1983).

Sudsawad, Trombly, Henderson, and Tickle-Degnen (2002) also assessed the effectiveness of kinesthetic training on handwriting using the Laszlo and Bairstow (1980; 1983; Bairstow & Laszlo, 1981) kinesthetic acuity and kinesthetic memory tasks described above. Participants were 6 to 7 year old children (n = 45) who had scored at the 25th percentile or lower on the Kinesthetic Sensitivity Test (KST) and had a teacher report of handwriting deficits. Participants were divided evenly into one of three groups: kinesthetic training group, handwriting practice group, and a control group. The control group participated in their typical school activities. The kinesthetic training group participated in kinesthetic acuity and kinesthetic memory tasks. The third treatment group participated in handwriting practice. Handwriting performance was assessed via the Evaluation Tool of Children's Handwriting (ETCH) and a teacher questionnaire prior to and following participation in the study. While some improvement was noted on the KST, there were no statistically significant differences among the three groups (Sudsawad et al., 2002). Additionally, when subtests were analyzed independently, no difference in performance on the *kinesthetic acuity* subtest was reported. Statistically significant improvement was noted on the *kinesthetic memory and perception* subtest, although this improvement did not differ among groups. The authors hypothesized that this may have been the result of previous task exposure at the time of pre-test (Sudsawad et al., 2002). Statistically significant differences in performance on the ETCH were not found when comparing pre-test and post-test performances. Improvement in writing was reported when measured via the teacher questionnaire, but this improvement did not differ among groups (Sudsawad et al., 2002). In attempting to explain the curious findings regarding a lack of improvement in ETCH scores by any group, the authors suggested that the ETCH may not be sensitive enough to measure improvement in handwriting that was evident to the teachers (Sudsawad et al., 2002). For example, the authors stated that "Upon examination of the ETCH scoring criteria, certain aspects of handwriting, such as the ability to write on the line, letter size, alignment, and the consistency of letter size and alignment within a sentence, would not be reflected by the ETCH scores, which reflect only global legibility…" (Sudsawad et al., 2002, p. 31).

The role of kinesthesia in the handwriting performance of children with disabilities has also been investigated. The results have suggested that relationships exist between kinesthetic function and handwriting performance in children with spina bifida (Zivani, et al., 1990) and *developmental output failure* (Levine et al., 1981). Additionally, kinesthetic function has been hypothesized to relate to handwriting grip (Schneck, 1991). The relationships between kinesthesia and writing in special populations and handwriting grip are discussed at greater length in the following sections.

Handwriting and Special Populations

The relationships between handwriting and constituent abilities have also been assessed in special populations. However, these lines of research appear to be limited. Additionally, disparity has been noted with regard to research methods and investigated factors. Diagnoses have included spina bifida, prematurity of birth, and developmental output failure (Feder et al, 2005; Levine et al., 1981; Ziviani et al., 1990).

Ziviani et al. (1990) investigated handwriting deficits in 34 children with spina bifida between the ages of 6 and 13 years. The impact of visual perception, tactile perception, kinesthesia, motor planning (via the Motor Accuracy Test), grip strength and grip type on handwriting legibility and speed was assessed. Kinesthesia was measured via the Kinesthesia subtest of the Southern California Sensory Integration Tests (Revised). Additionally, the authors assessed the influence of age, gender, handedness, the extent of disability (which included level and severity of spinal lesion), scholastic aptitude (as measured via Peabody Picture Vocabulary) and behavior (assessed via Conner's Revised

Teacher Rating Scale) on handwriting performance (Zivani et al., 1990). Components of handwriting legibility included alignment, formation, spacing and size. Results revealed that, "Alignment, however, proved to be explained substantially by kinesthesia, handedness, age and scholastic aptitude (R^2 = .55). Letter formation was primarily determined by kinesthesia, age, and scholastic aptitude (R^2 = .71)" (Zivani et al. , 1990, p. 19).

Feder et al. (2005) assessed handwriting performance in 48 children six to seven years of age who were born preterm. This group's performance was compared to a control group of gender and age matched peers (n = 69). Findings revealed that visual perception (as measured via the Test of Visual Perceptual Skills -non-motor (TVPS)) was significantly correlated at the .01 level with word legibility in the preterm group (Feder et al., 2005.) Visual motor control (as assessed via the Bruininks-Oseretsky Test of Motor Proficiency), visual motor integration (measured via the Beery VMI), visual perception (Test of Visual-Perceptual Skills - Non-motor), and motor control (as measured via the Motor Accuracy subtest of the Sensory Integration Praxis Tests) had significant correlations at the .01 level with letter legibility in the preterm group (Feder et al., 2005).

Levine et al. (1981) observed that students with *developmental output failure* demonstrated fine motor deficits and difficulty with pencil grasp. Children in this study were determined to have *developmental output failure* if they had an IQ that was average to above average, reading achievement commensurate with or near grade level, and reports of underachievement on parent and teacher questionnaires. Statistically, the authors reported that 72% of the 26 participants had difficulty with fine motor tasks and

72% had *finger agnosia* (Levine et al., 1981). Levine et al. (1981) expounded upon the influence of finger agnosia as follows:

> Children with finger agnosia may have difficulty receiving or perceiving proprioceptive-kinesthetic feedback to localize their fingers while writing. They may require intensive visual monitoring of fine motor or written output, keeping their eyes very close to the page, needing to see whether they are at the top of a letter to know when it is time for a motor descent...It is possible that their poor proprioceptive-kinesthetic feedback either resulted in or aggravated difficulties with fine motor output (1981, p. 21).

Additionally, it was reported that 80% of the participants had difficulty with *visual retrieval,* which was described as being "…unable to reproduce age-appropriate forms from memory following a five-second exposure to the designs" (Levine et al., 1981, p. 21).

Handwriting Grip

Researchers have also investigated the influence of writing grip on handwriting legibility. Schneck and Henderson (1990) investigated the development of handwriting grip in children from 3 years to 6 years 11 months of age. Handwriting grips were classified into one of three categories: primitive, transitional, or mature. Utilization of mature grips was noted in 47.5% of the students between 3 years and 3 years 5 months of age; in contrast, mature grips were noted in 95% of the children aged 6 years 6 months to 6 years 11 months (n = 40) (Schneck & Henderson, 1990). The mature grips were the *lateral tripod grasp* (Schneck, 1987 as cited in Schneck & Henderson, 1990) and the *dynamic tripod grasp* (Rosenbloom & Horton, 1971 as cited in Schneck & Henderson, 1990).

In addition to the dynamic tripod grasp and lateral tripod grasp, Tseng (1998) proposed that the quadrapod grip also be considered a mature grip. Koziatek and Powell (2003) found that the *lateral quadrapod grasp* produced speed and legibility performances in cursive writing in fourth grade students that were not statistically different than those produced by the three grip patterns Tseng (1998) considered to be mature. As such, the authors suggested that these grip patterns (lateral tripod, quadrapod, and lateral quadrapod) "…should be considered mature pencil grips equal in function to the dynamic tripod" (Koziatek & Powell, 2003, p. 287).

Schneck (1991) investigated grip patterns in first grade children with good and poor writing. A standardized handwriting assessment was not utilized in this study. Instead, teachers were asked to rate the participants' handwriting based upon classroom performance. Schneck (1991) reported that "The criteria for rating handwriting were based on six characteristics: legibility, accuracy of letter formation, uniformity of letter size, uniformity of letter slant, spacing between letters and words, and alignment of lines of writing (Rubin & Henderson, 1982)" (Schneck, 1991, pg. 704). Each participant's handwriting grip was given a score from 1 to 5 depending on developmental maturity. In addition to type of grip, strength of hand preference, and performance on The Imitative Finger Movement Subtest of the Pediatric Early Elementary Examination were also assessed. The Imitative Finger Movement Subtest was utilized as a measure of "…proprioceptive-kinesthetic finger awareness" (Schneck, 1991, p. 703). This subtest assessed kinesthetic function by having the participants produce hand positions that are modeled by the examiner. Results indicated that the poor handwriting group had significantly lower grip scores than the good handwriting group when completing a drawing task (Schneck, 1991). Additionally, findings indicated that participants with lower proprioception scores had significantly lower grip scores (Scheck, 1991). Findings also indicated that the poor handwriting group had lower hand preference scores; thus, handwriting grip, proprioception and hand preference all differed between the two groups (Scheck, 1991). However, with regard to grip scores, Schneck (1991) noted that, "…those children with poor handwriting and with good proprioceptive-kinesthetic feedback demonstrate scores equal to the children with good handwriting" (p. 705).

Handwriting Summary

In summary, research investigating performance factors and handwriting in children with and without disabilities has demonstrated a range of findings. Relationships have been noted between handwriting and visual-motor integration, kinesthesia, graphomotor control, object manipulation, manual movements, visual perception, and grip. One interesting commonality in many of the studies was the Beery VMI as a measure of performance of visual motor integration.

In contrast, evaluation of many of the other performance factors lacked common assessment procedures and common terminology. For example, the ability to utilize one's hands and/or fingers effectively was measured with tasks as disparate as isolated finger movement, opposition, or object manipulation. Moreover, terminology differences create confusion with understanding the particular task being utilized. For example, Volman et al. (2006) used the phrase *fine motor coordination* to refer to performance on the Motor Coordination subtest of the Beery VMI. However, as this is a path-drawing task, the ability measured by this assessment is similar to the ability measured by the Motor Accuracy Test that was utilized by Cornhill and Case-Smith (1996) and described as *eye-hand coordination* (p. 735). Using the terminology described in Chapter 1, each of these tasks would be referred to as graphomotor control.

By using the terminology suggested previously in Chapter 1, the findings of the preceding literature review can be more easily summarized. An association between visual-motor integration and handwriting was reported in seven studies (Cornhill & Case-Smith, 1996; Daly, Kelley, & Krauss, 2003; Feder et al, 2005; Tseng & Murray, 1994; Volman et al., 2006; Weil & Cunningham Amundson, 1994; Weintraub & Graham, 2000). Three studies demonstrated relationships between handwriting and graphomotor control (Cornhill & Case-Smith, 1996; Feder et al, 2005; Volman et al., 2006), while two studies indicated an association between handwriting and object manipulation (Cornhill & Case-Smith, 1996; Volman et al., 2006). A relationship between handwriting and manual movements was reported in three studies (Berninger & Rutberg, 1992; Tseng & Murray, 1994; Weintrab & Graham, 2000) while an association with kinesthesia was identified in two studies (Laszlo & Bairstow, 1983; Ziviani et al., 1990). Finally, a relationship between visual perception and handwriting was also noted in two reports (Feder et al, 2005; Tseng & Murray, 1994).

Handwriting and Graphomotor Skills in Autism Spectrum Disorders

A developing body of research has been identified in the literature regarding handwriting and ASD. Interestingly, Asperger's original accounts reported handwriting difficulties in the children he observed (Frith, 1991). Furthermore, research has demonstrated deficits in graphomotor function and handwriting in individuals with ASD

(Beversdorf et al, 2001; Cartmill et al., 2009; Fuentes et al., 2009; Henderson & Green, 2001; Mayes & Calhoun, 2007; Myles et al, 2003).

Specific descriptions of handwriting difficulties were reported in three of the four children Asperger observed (Frith, 1991). The quotes concerning these deficits are provided below.

> Writing was an especially difficult subject, as we expected, because his motor clumsiness, in addition to his general problems, hampered him a good deal. In his tense fist the pencil could not run smoothly. A whole page would suddenly become covered with big swirls, the exercise book would be drilled with holes, if not torn up. In the end it was possible to teach him to write only by making him trace letters and words which were written in red pencil. This was to guide him to make the right movements. However, his handwriting so far has been atrocious (Frith, 1991, p. 49).
>
> His handwriting, as to be expected from his general clumsiness, was very poor. He carried on writing carelessly and messily, crossing out words, lines going up and down, the slant changing. (Frith, 1991, p. 55)
>
> His most blatant failure was in writing. Like almost all autistic individuals, this motorically clumsy boy had atrocious handwriting. The pen did not obey him, it stuck and sputtered; he corrected without concern for appearance and would simply write new letters on top of the old ones; he crossed out, and his letters varied in size. However, this was not the worst aspect of his writing. Even when copying – where he drew letter by letter with painful effort – he could make many spelling mistakes. In dictation, one could hardly recognise what the words were

> meant to be: letters were omitted, inserted, or put in the wrong order, and some could not be recognised at all (Frith, 1991, p.63).

Myles et al. (2003) investigated handwriting performance in children with Asperger syndrome (n = 16) and a control group of typically developing children (n = 16) between the ages of 8 and 16 years; significant difference in handwriting legibility as assessed via the ETCH were reported. Differences were found in both letter and word legibility (Myles et al., 2003). Additionally, differences were reported with regard to letter formation, letter size and letter alignment (Myles et al., 2003). Furthermore, this research also investigated the linguistic content of written compositions. In this regard, the authors reported that "students with AS demonstrated that they can produce sentences similar in number to their peers, but sentences generated are brief and not as complex as demonstrated by the number of morphemes, t-units, and words" (Myles et al, 2003, p. 368).

Fuentes et al. (2009) compared the writing of children with ASD (n = 14) to a control group (n = 14) matched by gender, age, and IQ. The ages of participants ranged from 8 to 13 years. Handwriting quality was assessed via a standardized handwriting evaluation tool, the Minnesota Handwriting Assessment (MHA). The findings indicated that children with ASD had significantly lower letter formation scores than the control group (Fuentes et al., 2009). Significant differences in letter formation and overall handwriting quality were noted; however, differences were not identified in other elements of handwriting such as size, spacing, legibility, and alignment (Fuentes et al., 2009). Additionally, correlations were sought between handwriting performance on the MHA and motor performance and visuo-perceptual ability. Motor performance was assessed via the Revised Physical and Neurological Examination for Subtle (Motor) Signs (PANESS). Visuo-perceptual ability was measured via the Block Design Test and Perceptual Reasoning Index of the Wechsler Intelligence Scale for Children-IV (WISC-IV). Motor abilities assessed via the PANESS included balance, *stressed gait tasks*, timed movements, and patterned movements. Balance tasks included standing and hopping on one leg. Stressed gaits included heel walking, toe walking, and others. Timed movements included tasks such as finger tapping and foot tapping. Patterned movements included diadokokinesis and finger apposition (i.e. touching each finger to the thumb in specified order). The PANESS composite and timed movement scores were significantly correlated to handwriting performance in the ASD group; however, the authors reported that timed movement had a higher correlation with handwriting performance (Fuentes et al., 2009). Visuo-perceptual skills were not significantly correlated with handwriting performance in the ASD group (Fuentes et al., 2009). The only factor that correlated with handwriting quality in the control group was gender (Fuentes et al., 2009).

The finding of no statistically significant difference in size of handwriting between the control and ASD groups in the Fuentes et al. (2009) study are in contrast to the findings of Beversdorf et al. (2001) and Myles et al. (2003) who found that individuals with ASD had significantly larger handwriting than controls who were matched by age and IQ. However, it should be noted that the Minnesota Handwriting Assessment, which was used by Fuentes et al. (2009), was designed to assess handwriting in first and second grade students. As such, the writing space was larger than that utilized by Beversdorf et al. (2001) which was reported to be one-quarter inch. The disparity in writing space may have influenced the differences in findings regarding letter size in these two studies.

Correlates of handwriting performance and legibility of eight-year-old children with ASD were investigated by Cartmill et al. (2009); findings of statistically significant differences were not found in legibility or handwriting speed between children with ASD and an age, gender and IQ matched control group of typically developing children (n = 56). However, letter formation was poorer in the sample of children with ASD (Cartmill et al., 2009). With regard to handwriting speed, "consistency of letter formation...was significantly correlated with handwriting speed. Specifically, faster writers produced handwriting with less consistent letter formation" (Cartmill et al., 2009, p. 112). Significant correlations were found between visual perception, oral spelling, letter formation accuracy and "spelling with different allographs" (Cartmill et al., 2009, p. 113).

Hellinckx et al. (2013) sought to find abilities that correlated with handwriting performance in children with ASD: these included visual motor integration, visual perception, manual dexterity and reading ability. To assess handwriting, these researchers used the Systematic Screening of Handwriting and noted that it is a Dutch assessment used to identify "graphomotor disorders in children" (Hellinckx et al., 2013, p. 178). Significant differences between groups were found in visual motor integration, visual perception, manual dexterity and reading ability, as the group with ASD performed worse than the control group on each of these measures (Hellinckx, 2013). In the ASD group, handwriting quality was significantly correlated with age and visual motor integration (Hellinckx, 2013). It is also interesting to note that handwriting quality and speed were negatively correlated such that writing that is produced more rapidly is produced with less quality (Hellinckx, 2013). With regard to handwriting quality, the best predictors were found to be age, gender and visual motor integration; the regression model including these abilities predicted 55% of the variance in handwriting quality in the ASD group (Hellinckx, 2013). Handwriting speed was correlated with age and reading ability in the ASD and control groups; the regression model predicting handwriting speed in ASD accounted for 75% of the variance and included the following attributes and abilities: age, gender, reading ability, and manual dexterity (Hellinckx, 2013).

In contrast to the findings of Fuentes et al. (2009) with children with ASD between 8 and 12 years of age, Fuentes, Mostofsky and Bastian (2010) found perceptual reasoning to be the only predictor of handwriting function in children with ASD between 12 and 16 years of age. Handwriting performance as assessed via the Minnesota Handwriting Assessment and "total handwriting scores were lower in the ASD group than the control group" (Fuentes et al., 2010, p. 1826). Significant differences between groups were also reported in *spacing*, which concerns the adequacy of spatial relationships between letters and words (Fuentes et al., 2010).

Research has also revealed deficits in non-writing graphomotor performance in children with ASD (Mayes & Calhoun, 2007; 2003). For example, Mayes & Calhoun (2007) reported that children with ASD had significantly lower scores on the Beery VMI when compared to control groups of typically developing children. Additionally, Mayes and Calhoun (2003) reported a significant difference between graphomotor performance as measured via the Beery VMI and full scale IQ in school aged children with ASD.

Moreover, it is interesting to note that the authors reported significant differences between graphomotor performance and visual reasoning (Mayes & Calhoun, 2003). These findings corroborate those of Fuentes et al. (2009) in suggesting that deficits in graphomotor performance, including handwriting, do not arise from deficits in perceptual function.

Research regarding handwriting performances in children with ASD has demonstrated deficits in handwriting quality and legibility, as well as increased size when compared to the writing of typically developing peers. Additionally, correlations of handwriting performance have suggested links with motor performance, visual motor integration, perceptual reasoning, reading level, age, writing time, and gender.

CHAPTER 3

Methodology

The purpose of the present study was threefold. The first was to compare handwriting legibility in a sample of children with ASD to a peer group of typically developing children matched by age and gender. The second purpose was to identify correlations of abilities associated with handwriting performance in this sample of children with ASD. These abilities included the following: 1) visual-motor integration; 2) visual perception; 3) graphomotor control; 4) object manipulation; 5) sensory processing; and 6) type of handwriting grip utilized. Additionally, correlations with various aspects of sensory processing, as determined by the Sensory Processing Measure - Home Form (Parham & Ecker, 2007) were assessed. The third purpose was to utilize stepwise multiple regression to identify the contribution of variance on handwriting performance attributed to the aforementioned factors.

It should be noted that the abilities identified above were determined via extensive review of the literature. However, when seeking to identify correlates of handwriting performance, it is suggested here that assessed tasks should offer insight into potential therapeutic interventions. As such, this study sought to assess motor performance via tasks that lend themselves to active engagement in therapy sessions. For example, object manipulation, in contrast to measures such as isolated finger extension or finger tapping, could be more easily incorporated into challenging and meaningful activities to develop the hand function necessary to improve handwriting. The desire to follow this line of thought, in conjunction with the findings from previous handwriting research, contributed to the selection of assessment measures in this study. The Institutional Review Board for the Social and Behavioral Sciences approved the research protocol (SBS# 2011034400).

Recruitment

Participants with ASD between the ages of 8 years and 12 years 11 months years were recruited from autism parent and support groups, private schools, and via word of mouth. Introductory letters explained the purpose of the study and the tasks to be completed. Parents signed consent forms and all participants signed assent forms. Additionally, parents completed participation checklists which attested that their son or daughter met the following participation criteria: 1) an ASD diagnosis; 2) non-verbal/performance IQ of 80 or above; 3) absence of other diagnoses that may directly impact motor performance (e.g., cerebral palsy, Fragile X, etc.); 4) absence of hearing impairment; and 5) corrected or uncorrected vision of 20/30 or better. Parents were provided the option of receiving a written report of their child's performance on the ETCH, the Beery VMI, Beery VMI Visual Perception test, Beery VMI motor coordination test, and the Sensory Processing Measure.

The determination to utilize this age range was made based upon several factors. First, research indicates that IQ scores in children with autism may not stabilize until the age of eight years (Mayes & Calhoun, 2003). Second, it is logical to predict that eight-year-old students would typically be in second or third grade. Thus, one could assume that, at a minimum, the children in this study would have had at least 3 to 4 years of writing education and instruction.

The decision to include students with any form of ASD (i.e., Asperger’s, autism, or PDD-NOS) was based upon motor research that demonstrated comparable performances between these groups when IQ scores were comparable (Ghaziuddin et al., 1994; Green et al., 2009; Manjiviona & Prior, 1995;). The recent DSM-V changes regarding ASD diagnostic criteria confirmed the logic of this approach (APA, 2014).

Age and gender matched peers were sought to comprise a control group of typically developing peers. Recruitment of these participants took place via word of mouth. In addition to consent forms, parents were asked to complete a checklist indicating that the following criteria were met: 1) absence of an ASD diagnosis; 2) participant is not currently receiving occupational therapy, physical therapy, or speech pathology services; 3) placement in a regular education classroom; 4) absence of hearing impairment; and 5) uncorrected or corrected vision of 20/30 or better. Additionally, parents were offered the opportunity to receive a written report regarding their child's performance on the Evaluation Tool of Children's Handwriting (ETCH), Beery VMI, Beery VMI visual perception test, Beery VMI motor coordination test, and the Sensory Processing Measure - Home Form. All participants and parents of participants signed assent and consent forms, respectively.

Participants

Eleven participants with ASD participated in this study, as well as 11 control group participants. Each group consisted of 10 males and 1 female. One participant in the ASD group was also reported to have ADHD. One participant in the control group received speech therapy services for articulation; this information was obtained after testing had been completed and, given that the participant's performances were commensurate with other control participants, the data obtained from this participant was included for analysis. Participants were matched on age (within 6 months) and gender. Participants' ages and genders for each group are presented Table 1. Ages are based upon the Beery VMI age procedure, which rounds ages to the nearest month (e.g., an age of 9 years 5 months and 19 days would become 9 years 6 months). With regard to gender, the male to female ratio of 10:1 in this study was higher than recent estimates of a male to female ratio of 4.5:1 in children with ASD (Centers for Disease Control and Prevention [CDC], 2014).

Table 1.

Participant Ages & Genders by Group.

Participants Ages & Genders	
ASD	TD Control
8 years 7 months	8 years 1 months
8 years 9 months	9 years 1 months
9 years 8 months	9 years 6 months
10 years 0 months	10 years 4 months
10 years 10 months	10 years 7 months
11 years 1 months	11 years 5 months
11 years 6 months*	11 years 5 months*
12 years 10 months	12 years 5 months
12 years 10 months	12 years 7 months
12 years 10 months	12 years 10 months
13 years 0 months	12 years 10 months

* Female participants.

Settings

Research sessions were completed in locations convenient for parents and participants. Therefore, the settings for data collection included participants' homes, a public library, churches, the primary researcher's residence, and schools. An adjustable height chair was utilized when needed to ensure that seating height was conducive to completion of the research tasks.

A picture schedule was utilized during research sessions to provide participants an understanding of the sequence of tasks. Six simple drawings depicting the different assessments were presented on a sheet of cardstock. Each drawing was removed from the cardstock following the completion of that particular assessment. The picture schedule was utilized for all participants in the ASD group and all but two participants in the control group. All participants demonstrated an understanding of the tasks to be completed.

Tasks

Participants took part in a battery of assessments and tasks that assessed handwriting, visual-motor integration, visual perception, graphomotor control, object manipulation, and handwriting grip. Directions were repeated or paraphrased as needed to ensure that each participant understood what he or she was being asked to do. Each participant's response indicated an understanding of the task; therefore, the obtained results are considered accurate estimations of each participant's abilities.

The order of assessments was the same for all sessions. As handwriting legibility was the dependent variable of interest, the handwriting assessment was completed first. Second, per the manual, the Beery VMI and its subtests were to be completed in a specific order. Lastly, in consideration of the potential for fatigue, writing assessments were alternated with non-writing assessments. Thus, the order of assessments was as follows: 1) ETCH; 2) in-hand manipulation; 3) Beery VMI 4) Beery VMI Visual Perception 5) Beery VMI Motor Coordination 6) Handwriting grip photograph. The primary investigator, who is an occupational therapist with over 20 years experience in the field, administered all assessments.

Handwriting. Handwriting was assessed via the Evaluation Tool of Children's Handwriting (Amundson, 1995). This assessment tool includes the following writing tasks: writing the lower and upper case alphabet from memory; writing numerals 1 to 12 from memory; near-point copying; far point copying, dictation, and sentence composition.

The ETCH manual provides instruction regarding legibility scoring criteria. Additionally, the manual includes practice items and proficiency quizzes to enable raters to demonstrate aptitude with scoring legibility. Once a rater passes a competency quiz with a score of 90% or better, he or she is considered to be prepared to use the ETCH. In the case of the primary investigator, a score of 90% or better was not achieved (competency scores = 80%). As such, the author of the ETCH, Dr. Susan Amundson, was contacted via email and the rationale behind the primary researcher's scoring decisions were provided. Dr. Amundson replied via email and stated that, "the competency quizzes were a vehicle for therapists to practice and learn some aspects of the scoring. Anyone who passes with an 80% and understands the scoring as best s/he can is ready to go!" (Personal communication, May 13, 2014).

According to the ETCH manual, the intraclass correlation coefficient (ICC) is .84 for letters, .82 for numerals, and .48 for words (Amundson, 1995). Several criteria are provided to determine legibility. For example, a letter is considered illegible if "...it is not easily recognized out of context and at first glance" or "parts are omitted or improperly closed" (Amundson, 1995, p. 62). The ETCH has been utilized in other research investigating handwriting (Myles et al., 2003; Sudsawad et al., 2002).

Handwriting samples were scored by two licensed occupational therapists who work in school-based pediatric settings. For the purposes of data analysis, the average legibility percentage of the two ratings was utilized. The average measure intra-class correlation coefficient between raters for letter legibility was .847. Given the inherent subjectivity in determining the legibility of handwriting, the utilization of mean legibility scores strengthened scoring validity when compared to utilizing scores obtained from only one rater. Moreover, the use of mean scores, rather than a consensus score, enabled each rater to maintain his or her initial scoring without compromise. Prior to rating and scoring the samples, the second rater was not provided information regarding group assignment. At no time was the second rater provided identifying information regarding the participants.

Visual-motor Integration. Visual-motor integration was assessed via the Beery-Buktenica Developmental Test of Visual-Motor Integration (6^{th} ed) (Beery & Berry, 2010). The Beery VMI has been used in numerous studies investigating handwriting (Cornhill & Case-Smith, 1996; Daly et al, 2003; Feder et al, 2005; Hellinckx et al, 2013; Tseng & Murray, 1994; Van Waelvelde et al, 2004; Weil & Cunningham Amundson, 1994; Weintraub & Graham, 2000).

The Beery VMI (6th ed.) consists of 30 forms that are copied in the examination booklet. The forms increase in complexity as the test progresses. Specific scoring criteria for each form are provided in the test manual. The raw score is calculated by summing the number of correct responses achieved prior to 1) completing the test or 2) reaching the ceiling of three consecutive missed items. Raw scores may be converted to standard scores that were derived from age-based normative date. The Beery VMI (6th ed.) manual provides an extensive overview of this test's validity and reliability. The interested reader is referred to the Beery VMI (6th ed.) manual for a full review.

Visual Perception. Visual-perception was assessed via the Beery VMI Visual Perception test. This test assesses visual discrimination, as participants are required to identify a target form from a group of 4 to 6 forms, which are similar but differ in some way. The target forms, although smaller in size, are the forms included in the Beery VMI. Raw score is calculated by summing the number of correct responses. As with the Beery VMI, the raw score may be converted to a standard score based upon developmental norms.

Graphomotor Control. Graphomotor control was assessed via the Beery VMI Motor Coordination test. This test required participants to complete path-drawing versions of the forms included in the Beery VMI. An item was scored as incorrect if the participants drawing crosses the path's border. The raw score for this test is comprised of the number of accurately traced forms that are completed in 5 minutes or less. The raw score may be converted to a standard score derived from age-based data.

Object Manipulation. Object manipulation was assessed via a test of in-hand manipulation similar to a task that was found to correlate with handwriting performance in previous research (Cornhill & Case-Smith, 1996). To complete this task, participants were asked to use only their dominant hand to remove a peg from a peg board, turn the peg over, and place it back into the pegboard as quickly as possible. Participants completed one practice trial and three additional trials; the three trials were timed and averaged for purposes of data analysis.

Sensory Processing. Sensory processing was assessed via a parent questionnaire, The Sensory Processing Measure - Home Form (SPM-HF) (Parham & Ecker, 2007). The SPM-HF consists of 65 questions that address various types of sensory processing: vision, hearing, touch, taste and smell, *body awareness*, *balance and motion*, and *planning and ideas*. Additionally, 10 questions are included which address *social participation*. Responses to questions were provided via a four choice Likert scale, which indicates if the queried behavior occurs *never*, *frequently*, *often*, or *always*. A total sensory processing score was obtained, as well as sensory systems scores for vision, hearing, touch, body awareness, and *balance and motion*. Additionally, scores are provided for *social participation* and *planning and ideas,* which "represent higher level integrative functions that are strongly influenced by sensory inputs while encompassing other cognitive and contextual factors" (Parham, Ecker, Kuhaneck, Henry, & Glennon, 2009, p. 19). Raw scores are converted to t-scores 59 or below indicate typical sensory processing. T-scores between 60 and 69 indicate probable differences in sensory processing while t-scores that are 70 or higher indicate a definite difference in sensory processing. The SPM was developed for use with children from 5 to 12 years of age. In regard to construct validity, the SPM manual notes that "the SPM Home Form scale scores show the expected strong and consistent relationship with the scores of the

Sensory Profile, a measure of children's sensory processing function" (Parham, Ecker, Kuhaneck, Henry, & Glennon, 2009, p. 71).

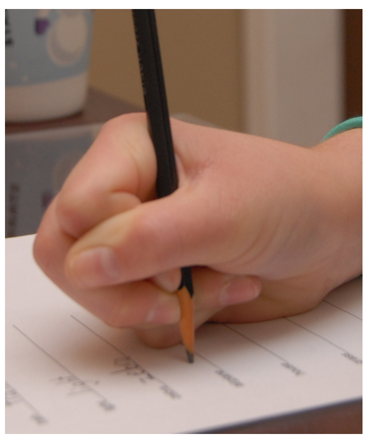
Handwriting Grip. Handwriting assessment was assessed via photographs taken while participants were writing. Secondary to concerns that the taking of photographs may distract from or otherwise impact writing performance, the handwriting photograph was not taken during the completion of the ETCH. Moreover, the handwriting grip task was the last activity completed and its written output was not assessed for legibility. During this task, each participant was asked to copy words while the researcher took photographs of the participant's handwriting grip.

Handwriting grips were scored categorically as being either t*ypical* or *atypical* via visual analysis of the photographs taken of each grip. Typical grip patterns included the tripod grip, lateral tripod grip, quadrapod grip, and lateral quadrapod grip. Based upon previous research, these four grip patterns are considered comparable and functional (Schneck & Henderson, 1990). A grip pattern was considered atypical if it was not one of the four aforementioned patterns. The four typical grip patterns are presented in Figure 1 below.

Figure 1. The four typical handwriting grip patterns.

Lateral Tripod Grip

Tripod Grip



Lateral Quadrapod Grip

Quadrapod Grip

Procedures

In the majority of situations, the sessions began with the researcher being introduced to the participant by a parent. In many of these sessions, this was also the parent's first opportunity to meet the primary researcher, as most pre-session communication took place via email. The sequence of tasks was presented via a picture schedule. As the researcher set up the picture schedule by affixing drawings of task representations to a sheet of cardstock, the activities depicted by each drawing were explained to the participant. This provided the participant with an opportunity to understand what he or she would be doing while also enabling rapport to be established with researcher prior to testing. Additionally, prior to initiating the research tests, the participant was asked to sit at the table to be used to allow for assessment of positioning. Sessions concluded with the completion of the photograph task and participants were thanked for their involvement. Session notes are provided in the Appendix.

Data Analysis

Data analysis was completed with SPSS (Version 22.0) in accordance with the research questions. First, in order to determine if differences exist in handwriting and performance variables between children with ASD and typically developing peers independent t-tests (Hinkle, Wiersma, & Jurs, 2003) were utilized to compare means. A Chi square test was used to determine if significant differences existed between groups in the frequency of use of atypical handwriting grips. Second, correlations were sought between handwriting legibility and measures of visual motor integration, visual perception, graphomotor control, in-hand manipulation, and sensory processing. Due to the use of categorical data to analyze handwriting grip, point-biserial correlations were sought to examine the relationship between handwriting grip and legibility (Hinkle et al., 2003). Finally, stepwise multiple regressions (Hinkle et al., 2003) were utilized in an effort to identify significant predictors of handwriting in children with ASD.

CHAPTER 4

Results

Prior to comparing group means, descriptive statistics were obtained for each group of participants in order to assess the distribution of data across variables and to determine if any outliers were present. Outliers were defined as scores that fell three or more standard deviations from the mean. Within the ASD group, one outlier was identified in letter legibility. Outliers were also found with regard to writing time; one outlier was identified in each group. As each of these outliers represented poorer performance than was observed in its respective group, the values were adjusted in order to reduce the extent of impact upon group means. These outliers were adjusted in a manner similar to Winsorizing in which their values are replaced with the next lowest, non-outlying value (Obsborne & Overbay, 2004).

Five outliers were also noted in particular areas of sensory processing in the ASD group. However, 4/5 of these outliers were indicative of typical sensory processing rather than atypical sensory processing. Therefore, these scores were not adjusted. One outlier was indicative of significant atypical sensory processing in SPM-HF category Planning and Ideas; this value was adjusted by being assigned the value of the next numerically adjacent score, as described in the preceding paragraph.

Assumptions were assessed to determine the appropriateness of conducting independent t-tests to compare group means (Independent T-Tests in SPSS, n.d.). Due to the large number of independent variables, the following discussion will address performance variables first and a discussion of sensory processing variables will follow.

As noted previously, outliers were modified as deemed appropriate for this data set. Normality was assessed with the Shapiro-Wilk test and Levene's test was utilized to assess homogeneity of variance (Independent T-Tests in SPSS, n.d.). Shapiro-Wilk testing indicated that the null hypothesis of normal distributions could not be rejected except for ETCH word legibility in the control group ($p < .0005$). With regard to homogeneity of variance, Levene's test indicated that homogeneity of variance could not be assumed for ETCH time or ETCH word legibility (Independent T-Tests in SPSS, n.d.). As ETCH word legibility lacked a normal distribution in the control group and homogeneity of variances could not be assumed between groups, a Mann-Whitney U Test was used to compare groups on this variable. Independent t-tests were utilized for all other group comparisons, as each group was comprised of equal sample sizes (Independent T-Tests in SPSS, n.d.).

Bonferroni corrections were made for each family of comparisons, rather than on an experiment-wise basis. This was done for two reasons. First, a Bonferroni correction utilizing the total number of comparisons completed in this research ($n = 16$) increases the likelihood of Type II error. Second, as argued by Armstrong (2014), the probability value for identifying differences in one test should not be influenced by the administration of other tests. Thus, in this study, the established probability value for ETCH performances should not be influenced by the administration of the Beery VMI battery of tests. Therefore, in order to decrease the likelihood of Type I errors, Bonferroni corrections were completed, but on a family-wise basis rather than experiment-wise. The families of comparisons for tests of performance measures were defined as follows: 1) ETCH letter legibility, ETCH word legibility, and ETCH total time and 2) VMI tests and in-hand Manipulation. In addition to these comparisons, the mean ages of each group were compared.

The ASD group had a mean age of 11 years and 1 month and the TD group had a mean age of 11 years 0 months; differences in mean ages between groups were not statistically significant. Group mean ages and standard deviations are presented in Table 2.

Table 2.

Independent t-test: Age

	ASD		TD				
	Mean	(SD)	Mean	(SD)	t	df	*p*
Age	11y 1m	(1y 8m)	11y 0m	(1y 7m)	.108	20	.915

With regard to ETCH letter legibility, the ASD group had a mean legibility of 82.26 with a standard deviation of 8.87. The TD group's mean letter legibility was 91.46 with a standard deviation of 4.62. An independent t-test was used to compare these means and statistically significant differences were noted. With regard to time of completion, the ASD group completed the timed ETCH writing tasks with a mean time of 3:14 and a standard deviation of 1:19. The TD groups mean completion time was 2:22 with a standard deviation of 0:41. Differences in group means with regard to time of completion were not statistically significant. Findings with regard to ETCH performance are presented in Table 3.

Table 3.

Independent t-tests: ETCH

	ASD Mean	ASD (SD)	TD Mean	TD (SD)	t	df	*p*
ETCH Letter Legibility Percentage	82.26	(8.87)	91.46	(4.62)	-3.062	20	.006*
ETCH Word Legibility Percentage	81.79	(18.88)	97.71	(3.41)	----	----	----
ETCH Total Time (Min: sec)	3:14	(1:19)	2:22	(0:41)	1.919	14.949	.074

*Significant at p < .016 (.05/3)

With regard to word legibility, the ASD group had a mean legibility percentage of 81.79 with a standard deviation of 18.88; the TD group's mean word legibility was 97.71% with a standard deviation of 3.41. As Levene's test indicated statistically significant differences in variance (p = .001), the Mann-Whitney U test was used to compare groups with regard to word legibility; statistically significant differences were found, as presented in Table 4.

Table 4.

Mann-Whitney U Test for Word Legibility

	ASD Mean Rank	TD Mean Rank	Mann-Whitney U	Z	p
ETCH Word Legibility	8.05	14.95	-.388	-2.585	.010*

*Significant at p < .016 (.05/3)

With regard to the Beery VMI test battery, statistically significant differences were found with the Beery VMI and the Beery VMI Motor Coordination test. In each of these tests, the TD group demonstrated superior performances. Statistically significant differences were not noted in the Beery VMI Visual Perception test. Differences in group performances on the test of in-hand manipulation were not statistically significant. These results are presented in Table 5.

Table 5.

Independent t-tests: Beery VMI Tests & In-Hand Manipulation

	ASD		TD				
	Mean	(SD)	Mean	(SD)	t	df	*p*
VMI	85.36	(6.41)	95.18	(5.12)	-3.972	20	.001*
VMI Visual Perception	102.09	(7.54)	103.73	(10.13)	-.430	20	.672
VMI Motor Coordination	68.73	(14.64)	87.73	(12.63)	-3.259	20	.004*
In-hand Manipulation	17.36	(5.82)	14.26	(3.17)	1.550	20	.137

*Significant at $p < .0125$ (.05/4)

Prior to completing comparisons between group means on the Sensory Processing Measure - Home Form, normality was assessed with the Shapiro-Wilk test and Levene's test was utilized to assess homogeneity of variance. Shapiro-Wilk testing indicated that the null hypothesis of normal distributions could not be accepted for the control group for social participation, vision, hearing, balance and motion, and body awareness; the null hypothesis of normal distributions could not be rejected in any area of sensory processing for the ASD group. With regard to homogeneity of variance, Levene's test indicated that the null hypothesis of no differences in variance between groups could not be rejected, except for touch ($p = .042$). Given that, in no one measure of sensory processing were assumptions of both normality of distribution and homogeneity of variance violated, and that groups were comprised of equal sample sizes, independent t-tests were utilized (Independent T-Test Using SPSS, n.d.). Bonferroni corrections were made for the SPM-HF family of comparisons. As demonstrated in Table 6 below, statistically significant differences between groups were found in all areas of sensory processing except for vision and body awareness. Group means, standard deviations, and t-tests results are provided in the tables below.

Table 6.

Independent t-tests: Sensory Processing Measure - Home Form

	ASD		TD				
	Mean	(SD)	Mean	(SD)	t	df	*p*
Sensory Processing Total	62.36	(7.51)	49.46	(7.80)	3.953	20	.001[2]
Touch[1]	64.00	(5.49)	50.18	(8.36)	4.579	17.277	< .0005[2]
Hearing	62.82	(5.83)	47.91	(7.05)	5.406	20	< .0005[2]
Vision	57.18	(9.76)	47.64	(8.12)	2.495	20	.021
Planning and Ideas	63.09	(4.89)	47.55	(5.89)	6.737	20	< .0005[2]
Body Awareness	60.64	(9.62)	49.55	(8.07)	2.931	20	.008
Balance	59.09	(9.97)	46.91	(7.84)	3.184	20	.005[2]

1 Equal variances not assumed.

2 Significant at p = .007. (This represents the Bonferroni correction of .05/7.)

Chi square analysis was utilized to compare the frequency of grip pattern use between groups. Atypical grip patterns were observed in 4/11 participants in the ASD group and no participants in the control group. The association between grip pattern and group was found to be significant $\chi^2(1) = 4.889$, $p = .027$. Within the ASD group, statistically significant differences were not noted between participants who used typical and atypical grip patterns with regard to mean ETCH letter legibility or ETCH word legibility. Table 7 below presents the ASD group legibility data by grip type.

Table 7.

Independent t-tests: Grip Type and Legibility within the ASD group

	Typical Grip		Atypical Grip				
	Mean	(SD)	Mean	(SD)	t	df	*p*
ETCH Letter Legibility	82.91	(5.50)	81.12	(14.11)	.243	3.531	.821*
ETCH Word Legibility	87.08	(12.06)	72.55	(26.79)	1.03	3.71	.367*

* Equal variances not assumed.

Bivariate correlations were assessed between all independent variables and the dependent variables ETCH letter legibility and ETCH word legibility for the ASD group. Assumptions regarding bivariate correlations were met. Linear relationships were reviewed visually via scatter plots and outliers were not observed (Pearson's Product-Moment Correlation using SPSS, n.d.). Additionally, Shapiro-Wilk tests indicated that the null hypothesis of normal distributions could not be rejected. No statistically significant correlations were found between ETCH letter legibility, ETCH word legibility, age, in-hand manipulation, grip and ETCH total time.

Table 8.

ASD Group ETCH Pearson r Correlations with Age, IHM, Grip, & ETCH Total Time

	Age	IHM	Grip	ETCH Letter Legibility	ETCH Total Time
ETCH Letter Legibility	-.006	-.398	-.102	--	.108
ETCH Word Legibility	-.056	-.187	-.388	.744	.020

No correlations significant at $p < .05$.

Correlations were also assessed between ETCH letter and word legibility and the Beery VMI test battery. Statistically significant correlations were found between Beery

VMI Motor Coordination and ETCH letter and word legibility. These findings are presented in Table 9 below.

Table 9.

ASD Group ETCH Pearson r Correlations with Beery VMI Tests

	VMI	VMI Visual Perception	VMI Motor Coordination
ETCH Letter Legibility	.530	.269	.793*
ETCH Word Legibility	.257	.164	.732*

* p < .05

Bivariate correlations were assessed between ETCH Letter and Word legibility and the SPM-HF. No statistically significant correlations were found. These findings are presented in Table 10.

Table 10.

ASD Group ETCH Pearson r Correlations with SPM-HF

	Total	Hearing	Vision	Touch	Body	Planning	Balance
ETCH Letter Legibility	-.152	-.066	-.175	.243	-.129	.009	-.459
ETCH Word Legibility	-.151	-.264	-.211	.199	.027	.149	-.251

No correlations significant at $p < .05$.

In order to determine if there were significant correlations between in-hand manipulation and the other measures of graphomotor performance completed in this study, correlations were obtained between In-hand Manipulation and the Beery VMI and Beery Motor Coordination test. As shown in Table 11, statistically significant correlations were not found.

Table 11.

ASD Group Pearson r Correlations for In-hand Manipulation & Beery VMI & Beery VMI Motor Coordination.

	VMI	VMI Motor Coordination
In-hand Manipulation	-.363	-.152

No correlations significant at $p < .05$

Control group bivariate correlations were assessed between all independent variables and the dependent variables ETCH letter legibility and ETCH word legibility. Assumptions of bivariate normality, as assessed via Shapiro-Wilk's test, rejected the null hypothesis of normal distributions for ETCH word legibility and SPM-HF social participation, vision, hearing, body awareness, and balance; as such, Spearman's rho rank-order correlations were obtained for the control group (Spearman's Rank Order Correlation using SPSS Statistics, n.d.). No statistically significant correlations were found between ETCH letter or word legibility and age, in-hand manipulation or ETCH total time. These findings are presented in Table 12.

Table 12.

Control Group ETCH Spearman's rho Correlations with Age, IHM, & ETCH Total Time

	Age	IHM	ETCH Letter Legibility	ETCH Total Time
ETCH Letter Legibility	.251	-.445	--	.497
ETCH Word Legibility	-.005	-.305	.358	-.111

No correlations significant at $p < .05$.

With regard to ETCH letter and word legibility and the Beery VMI battery, a statistically significant negative correlation was found between VMI Visual Perception and ETCH letter legibility ($r_s = -.610$). These findings are presented in Table 13.

Table 13.

Control Group ETCH Spearman's rho Correlations with Beery VMI Tests

	VMI	VMI Visual Perception	VMI Motor Coordination
ETCH Letter Legibility	.428	-.610*	.009
ETCH Word Legibility	.580	-.554	-.413

* = $p < .05$

Control group correlations were also assessed between ETCH Letter and Word legibility and sensory processing. The only statistically significant correlation was found with ETCH Word legibility and Hearing (r_s = -.703).

Table 14.

Control Group ETCH Spearman's rho Correlations with SPM-HF

	Total	Hearing	Vision	Touch	Body	Planning	Balance
ETCH Letter Legibility	-.450	-.470	-.422	-.032	-.334	-.381	.254
ETCH Word Legibility	-.425	-.703*	-.294	-.043	-.243	-.054	-.050

* = $p < .05$

To identify predictors of legibility in the sample of children with ASD, stepwise multiple regressions were completed using ETCH letter legibility and ETCH word legibility as the dependent variable. All Beery VMI tests, In-Hand Manipulation, grip, age, and all measures of the SPM-HF were entered. Assumptions regarding linearity, independence of residuals, and normality of residuals were met (Multiple Regression Analysis using SPSS Statistics, n.d.). One outlier was noted with regard to studentized deleted residuals (> 3 SD); this participant's ETCH average legibility score was higher than the other participants in the ASD group. However, this score did not result in a Leverage value greater than .5 or a Cook's *d* value of greater than 1; as such, the data was not modified and multiple regression was performed (Multiple Regression Analysis using SPSS Statistics, n.d.). The findings revealed that VMI Motor Coordination and SPM-HF Body Awareness were significant predictors of ETCH letter legibility, $F(2,8) = 51.649$, $p < .0005$, $R^2 = .928$, adj. $R^2 = .910$. Thus, VMI Motor Coordination and SPM-HF Body

Awareness accounted for 91% of the variance in ETCH letter legibility. Regression coefficients and standard errors are presented in Table 15 below.

Table 15.

ASD Group Stepwise Multiple Regression for ETCH Letter Legibility

Variable	B	SE_B	β	Sig.
Intercept	71.977	5.639		
VMI Motor Coordination	.648	.064	1.070	< .0005
SPM - Body Awareness	-.565	.098	-.613	< .0005

ETCH word legibility stepwise multiple regressions identified VMI Motor Coordination as the only predictor, $F(1, 9) = 10.364$, $p = .011$, $R^2 = .535$, adj. $R^2 = .484$. Assumptions regarding independence of residuals, linearity, homoscedasticity, multicollinearity and outliers/influential data points were met (Multiple Regression Analysis using SPSS Statistics, n.d.) Additionally, data plots revealed an approximately normal distribution. Regression coefficients and standard errors are presented in Table 16.

Table 16.

ASD Group Stepwise Multiple Regression for ETCH Word Legibility

Variable	B	SE_B	β	Sig.
Intercept	16.975	20.548		
VMI Motor Coordination	.943	.293	.732	.011

CHAPTER 5

Discussion

Evidence of handwriting deficits in children with ASD was first reported in Asperger's seminal article in 1944 (Frith, 1991). The review of literature revealed a growing body of research identifying handwriting deficits in children with ASD (Cartmill et al., 2009; Fuentes et al., 2009; Fuentes et al., 2010; Henderson & Green, 2001; Hellinckx et al., 2013; Myles, 2003). Furthermore, research seeking to identify correlates of handwriting performance in persons with ASD has highlighted associations between handwriting performance and motor ability (Fuentes et al., 2009), visual motor integration (Hellinckx, 2013), perceptual reasoning (Fuentes et al., 2010), and language skills (Cartmill et al, 2009; Hellinckx, 2013). However, studies were not identified that investigated the relationship between handwriting, sensory processing, and other performance abilities, such as in-hand manipulation, found to correlate with handwriting performance in other populations. Therefore, the purpose of this study was to determine, in a sample of children with ASD, the correlations between handwriting performance and the following: 1) visual-motor integration, 2) graphomotor control, 3) in-hand manipulation, 4) handwriting grip, and 5) sensory processing.

In order to assist professionals and parents in addressing handwriting deficits in children with ASD, another goal of the present study was to suggest ways to apply the findings of this research to clinical and educational practice. It was also a goal of the present study to provide suggestions for future research.

The remainder of this chapter is divided into four sections: 1) discussion of findings; 2) application of findings to practice; 3) limitations and implications; and 4) conclusion.

The discussion section includes three subsections that address: a) group comparisons; b) correlates and predictors of handwriting in children with ASD; and c) correlates of handwriting in typically developing children.

Discussion of Findings

Statistically significant differences in handwriting performance were found between groups in ETCH letter legibility (ASD $\bar{X}$ = 82.26; TD $\bar{X}$ = 91.46) and ETCH word legibility (ASD mean rank = 8.05; TD mean rank = 14.95). In each case, the sample of children with ASD demonstrated decreased mean legibility scores when compared to typically developing age and gender matched peers.

Mean legibility percentages for ETCH word legibility (ASD mean = 81.79; TD mean = 97.71) were slightly lower in the ASD group and higher in the TD group as compared to ETCH letter legibility (ASD mean = 82.26; TD mean = 91.46). With regard to the TD group, these differences may stem from the ETCH scoring criteria regarding letter and word legibility. For example, it is possible for a word to be scored as legible even though it may be comprised, in part, of illegible letters. If a child wrote the word "tiger" with an illegible "g" and "r" it is possible that the word would still be recognizable. This is quite plausible, given the ETCH scoring criteria for letter legibility. For example, letters with "descenders" (g, j, p, q, y) must course below the writing line to be considered legible. Therefore, if the lower case "g" were written without descending below the writing line, it is possible that one could score the *word* "tiger" as legible, even though the letter legibility percentage for this particular word would be 60%. Thus, deficits in letter legibility may not necessarily be significant enough to impact word legibility scores. Mean ETCH letter legibility (82.26%) and mean ETCH word legibility (81.79) were quite similar in this sample of children with ASD. This may suggest that ASD group letter formation deficits were more significant than those demonstrated by the TD group and that these deficits in letter formation impacted word legibility. Conversely, this finding may indicate that the ASD group had more difficulties with the spacing of letters between and within words. For example, according to ETCH scoring criteria, a word scored as illegible could be comprised of all legible letters. This may result from inadequate spacing between letters or words. For example, if each letter in "thecatran" or "t h e c a t r a n" were scored as legible, the ETCH letter legibility score would be 100%. Therefore, due to errors in spacing, the ETCH word legibility score in these examples would be 0% (0/3). However, this hypothesis is in contrast to the findings of Fuentes et al. (2009) who reported that spacing was comparable between children with ASD and a typically developing control group.

The difference in mean total time of completion of ETCH handwriting tasks was not found to be statistically different between groups (ASD $\bar{X}$ = 3:14; TD $\bar{X}$ = 2:22). Given the principal researcher's clinical observations and experiences, this finding was somewhat surprising. However, ETCH tasks involving dictation and composition were not included in the calculation of this mean. Therefore, it is logical that tasks requiring the writing of memorized information (e.g., the upper case and lower case alphabet) and copying may be completed more quickly, as there are fewer demands on language processing. Furthermore, the finding of no difference in writing speed has been reported in other research of handwriting performance in children with ASD (Cartmill et al., 2009).

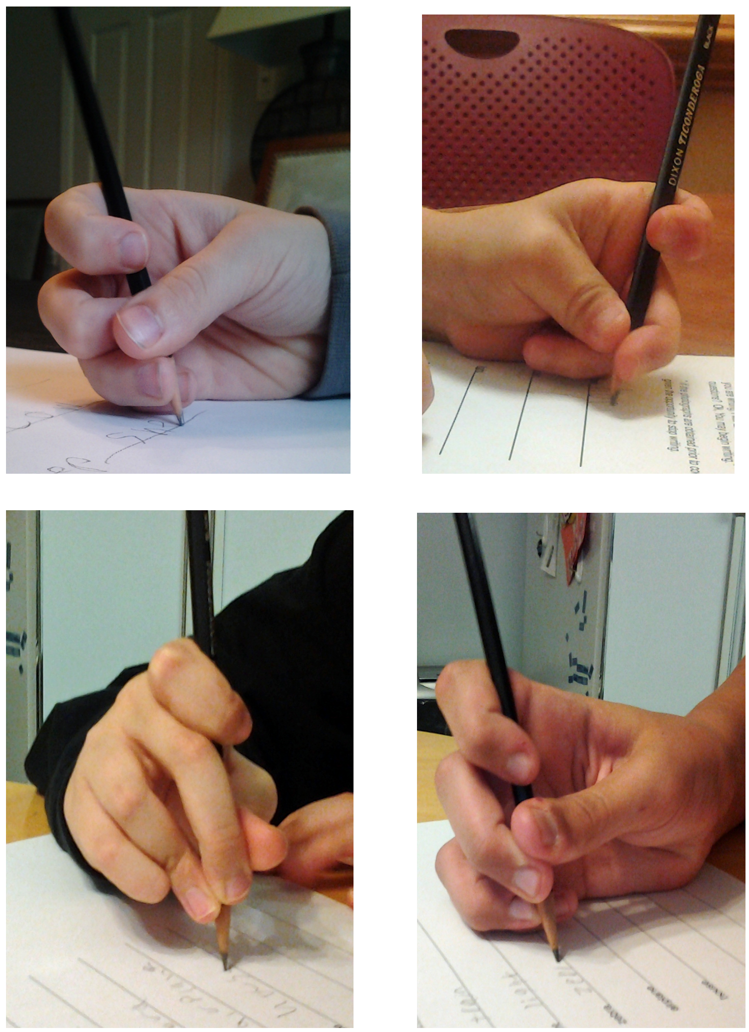
Group performances were compared with regard to the Beery VMI, Beery Visual Perception test, Beery Motor Coordination test, and a test of in-hand manipulation. Statistically significant differences between groups were found in the Beery VMI (ASD $\bar{X}$ = 85.36, TD $\bar{X}$ = 95.18) and Beery Motor Coordination (ASD $\bar{X}$ = 68.73, TD $\bar{X}$ = 87.73). The finding of a statistically significant difference in Beery VMI scores is consistent with previous research that has demonstrated poorer performance in children with ASD on this assessment when compared to typically developing peers (Hellinickx, 2013). These findings indicated that this sample of children with ASD exhibited poorer performance in visual-motor integration and graphomotor control than typically developing age and gender matched peers. The finding of no statistically significant difference in Beery Visual Perception performance is also consistent with previous research indicating that children with ASD have relative strengths in certain aspects of visual perception (Mottron et al., 2006).

These findings support the hypothesis that dorsal stream processing of visual information may be impaired in children with autism. Milner and Goodale's *dual streams* hypothesis proposes that visual processing of information is comprised of a ventral stream and a dorsal stream (Goodale & Milner, 1992; Milner & Goodale, 1995; Milner & Goodale, 2008). Although both visual streams originate in the primary visual area of the occipital lobe, the dorsal stream terminates in the posterior parietal lobe and is proposed to be responsible for visually based movement (Milner & Goodale, 1995). In contrast, the ventral stream terminates in the temporal lobe and is hypothesized to be responsible for object identification (Milner & Goodale, 1995). Spencer et al. (2000) investigated visual stream processing in children with autism and found "that children with autism show a particular deficit on tasks that require processing predominantly attributed to the dorsal stream" (p. 2766-2777). With regard to graphomotor control, it may be hypothesized that inefficient dorsal stream processing impairs the performance of visually guided tasks. As such, the findings of this study, which demonstrate deficits in letter formation, graphomotor control, and visual-motor integration in children with ASD, may be interpreted as providing support for deficient dorsal stream processing.

The findings of comparable performances between the ASD group and control group on the Beery VMI Visual Perception test (ASD $\bar{X}$ = 102.09; TD $\bar{X}$ = 103.73) provide support for the hypothesis of enhanced localized processing resulting from deficits in interconnectivity between frontal and posterior regions of the brain (Just et al., 2012). More directly, Just et al. (2012) stated that, "underconnectivity theory proposes that a visual processing style may emerge in autism because of decreased availability of frontal processing resources, leading to increased reliance on posterior processing, particularly visuospatial processing" (2012, p. 1303). However, it could also be posited that these results provide further evidence of deficits in dorsal stream processing in children with ASD; when the motor demands of perceptual tasks are removed, performance is comparable to typically developing peers.

Chi square analysis found statistically significant differences in the use of atypical grip patterns between the ASD group and control group of typically developing peers (χ^2 (1) = 4.889, p = .027). In this sample of children with ASD, 4/11 utilized grip patterns that are considered to be atypical, while no children in the group of typically developing peers demonstrated atypical grip patterns. The four atypical handwriting grip patterns observed in this study are pictured below in Figure 2.

Figure 2. Atypical Handwriting Grips

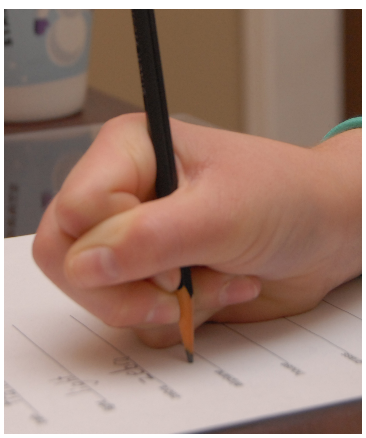


For purposes of comparison, handwriting grip photographs depicting the four typical grip patterns are provided below in Figure 3.

Figure 3. The four typical handwriting grip patterns.

Lateral Tripod Grip

Tripod Grip



Lateral Quadrapod Grip

Quadrapod Grip

The mean ETCH letter legibility scores of participants in the ASD group who utilized atypical grip patterns was not statistically different from the scores of children who used typical grip patterns (Atypical Grip $\bar{X}$ = 81.12, Typical grip $\bar{X}$ = 82.91). However, the two lowest letter legibility scores (53.81% and 70.08%) and the highest letter legibility score (99.57%) in children with ASD were found in participants with atypical grip patterns. This disparity in ETCH letter legibility performance was reflected in the differences in variance in letter legibility (Atypical Grip SD = 14.11, Typical Grip SD = 5.50, p = .033). Mean ETCH word legibility percentages did not differ with regard to statistical significance (Atypical Grip $\bar{X}$ = 72.55, Typical Grip $\bar{X}$ = 87.08). However, as with ETCH letter legibility, ETCH word legibility variances differed significantly (Atypical Grip SD = 26.79, Typical Grip SD = 12.06, p = .014).

The similarity in "atypical" grip patterns was striking as each of these grips involved 2nd digit PIP and DIP flexion at a relatively high contact point on the pencil. Benbow (1992) reported that this type of handwriting grip is indicative of "extreme laxity of the metacarpal-phalangeal joint of the thumb" (p. 273). This statement suggests that the use of this grip pattern is not the result of deficient sensory processing, such as impaired tactile or proprioceptive input. Thus, although sensory processing may impact handwriting in other ways, it is not necessarily the impetus behind the development and utilization of this unusual grip pattern.

Significant differences in sensory processing were noted in all areas assessed via the SPM-Home Form except for body awareness and vision. (See Table 6, p. 70.) Differences in body awareness approached significance as p = .008 and the Bonferroni adjusted value for this family of comparisons was p = .007. Differences in visual sensory processing between children with ASD and control groups of typically developing peers have been reported in other research (Kientz & Dunn, 1997). The lack of significant differences between groups in visual processing and body awareness in this study may be a product of the small sample size. Differences in SPM-HF Total Sensory Processing scores between children with ASD and typically developing children is consistent with previous research demonstrating differences in aggregate scores of sensory processing (Tomchek & Dunn, 2007). Moreover, the recognition of differences in sensory processing in persons with ASD was reflected in the inclusion of sensory processing deficits as a potential diagnostic criterion in the DSM-V (American Psychiatric Association, 2013). Differences in sensory processing in children with ASD have been hypothesized to emanate from atypical neurological processing (Marco et al., 2011; Pryweller et al., 2014).

Correlates and Predictors of Handwriting in Children with ASD

With regard to correlates of handwriting in children with ASD, ETCH letter legibility was found to be significantly correlated with Beery VMI Motor Coordination ($r = .793$). ETCH word legibility was also significantly correlated with Beery VMI Motor Coordination ($r = .732$). These findings provide further support for the notion that handwriting legibility in children with ASD is associated with motor function. Moreover, these findings are consistent with previous research that has identified correlations between handwriting, motor performance (Fuentes et al., 2009), and visual-motor integration (Hellinckx, 2013) in children with ASD.

More specifically, in children with ASD, these findings suggest a stronger association between handwriting legibility and graphomotor control than in-hand manipulation. Thus, from these findings, it appears that handwriting legibility in children with ASD is not necessarily correlated with any measure of fine motor performance, but more specifically with graphomotor control. This statement is further supported by the lack of statistically significant correlations between in-hand manipulation and ETCH letter and word legibility.

Graphomotor control tasks present a unique set of demands when compared to other fine motor tasks, such as the test of in-hand manipulation. For example, graphomotor control necessitates the integration of tactile, proprioceptive, and visual-motor demands. The writer must process sensory feedback emanating from contact with the pencil and the pencil's contact with the writing surface; moreover, this feedback is used to gauge force and movement. Additionally, proprioceptive input regarding movement and stability of the joints of the hand and upper extremity must be also processed. Furthermore, graphomotor control may require constant visual monitoring of the performance. This is especially true with the Beery VMI Motor Coordination test, as it requires participants to complete path-drawing tasks without crossing the borderlines that form the path. Thus, continual monitoring of the pencil and the drawn output are required. In contrast, the test of in-hand manipulation requires an integration of visual and motor processes, but constant visual monitoring is not required. For example, after picking up the peg and rotating it, the participant identifies the target and uses visual information regarding target location to guide his or her movement to place the peg into the pegboard. The participant does not, however, need to watch his or her hand as it moves to the target; vision is used to identify the location of the target, but not to directly monitor the movement of the hand as it moves toward the pegboard. In contrast, constant visual feedback regarding movement is required in certain graphomotor tasks, such as the Beery VMI Motor Coordination test. The lack of significant correlations between in-hand manipulation test scores and two other graphomotor tasks, the Beery VMI and Beery

VMI Motor Coordination test, provides further evidence that these tasks present unique perceptual-motor demands. (See Table 11, p. 75.)

The ability to accurately control pencil movements, as required by the Beery VMI Motor Coordination test, was found to be more highly correlated with ETCH letter and word legibility than visual-motor integration as measured by the Beery VMI. Furthermore, a post-hoc paired samples t-test comparing Beery VMI Motor Coordination standard scores ($\bar{X} = 68.73$) to Beery VMI standard scores ($\bar{X} = 85.36$) in this sample of children with ASD yielded statistically significant findings ($t(10) = 4.274$, $p < .002$). Thus, children with ASD performed worse on a task of graphomotor control than visual-motor integration and this difference was statistically significant. This finding may provide further support for the dorsal stream hypothesis regarding visual perception. When copying a form, as in the Beery VMI Test of Visual-Motor Integration, it is plausible that attention may be directed to the anticipated endpoint for a given stroke and to the gestalt of the drawing. Thus, as with the example of the pegboard task above in which one does not need to watch his or her hand as it moves to the target, one does not necessarily watch the writing stroke as it is being produced to copy a form. In contrast, the Beery VMI Motor Coordination test could be hypothesized to require continual visual processing of the movement of the pencil as it is moved between the borders of the path. This would be similar to Benbow's (1992) description of printing; "In manuscript writing the hand's output depends almost entirely upon the input and ongoing guidance of the visual system" (p. 260).

Furthermore, findings regarding correlations between legibility, visual motor integration, and graphomotor control suggest that handwriting deficits in this sample of children with ASD may be less related to the visual-motor integration demand of writing letters (e.g. forming the general gestalt of the letter) than in controlling the movements necessary to accurately form letter strokes. This hypothesis is supported by the findings of Fuentes et al. (2009) that identified differences in letter formation between children with ASD and typically developing peers. Letter formation deficits were scored if the following elements were not observed:

> "Overall letter quality must be good. Letters must not have gaps or extension greater than 1/16 of an inch. Curved segments cannot have sharp points, and pointed segments cannot be curved. Letters must not contain extra lines" (Fuentes et al., 2009, p. 1533).

Failing to meet these criteria is posited to be more consonant with deficits in graphomotor control than visual-motor integration, as impaired motor control would more likely lead to errors such as line extensions, gaps, and difficulties with forming pointed and curved lines. Moreover, these findings may be indicative of neurological deficits related to motor control. Dowell et al. (2009), in reviewing the work of Heilman and Rothi (1993), suggested the following:

> "there appear to be three potential contributors to dyspraxia in autism: (a) impairments in the storage of learned time-space movement representations, mediated by parietal regions; (b) impairments in transcoding of these movement representations in the premotor cortex; and (c) impairments in execution and basic motor skills (mediated at the cortical level by the motor cortex)" (p. 564).

The preceding passage highlights the potential impact of various processes on motor performance in persons with ASD. However, the most pertinent aspect of the preceding passage to the current discussion of graphomotor control in ASD is the assertion of "impairments in execution and basic motor skills" (Dowell et al., 2009, p. 564). Thus, although impaired dorsal stream processing has been considered as a possible explanation for deficits in graphomotor control in children with ASD, it is also possible that impairments in graphomotor control emanate from basic motor control processes associated with the motor cortex.

Stepwise multiple regression was utilized to determine predictors of handwriting legibility in children with ASD. The model that accounted for the greatest variance in handwriting performance included Beery motor coordination and SPM-HF body awareness and yielded an Adjusted R^2 of .910. The only predictor of ETCH word legibility in the ASD group was Beery VMI Motor Coordination performance. These findings suggest that body awareness (proprioception) has an association with ETCH letter legibility. Schmidt's (1975) schema theory proposed that motor programs are developed for specific motor responses, such as throwing a football or writing the letter 'V.' As the task is practiced, the learner utilizes kinesthetic feedback to develop an internal model of how a successful effort "feels"; after completing the task, the kinesthetic "feel" is compared to the performance outcome and this information is used to guide subsequent productions of the task. Thus, in the example of learning to write letters, one develops a kinesthetic sense with practice and this sense is coupled with a visual analysis of each trial's outcome. With practice, the kinesthetic sense is refined and more fully developed. The findings of this study indicated that kinesthetic sense, as measured by the SPM-HF body awareness score, was one of only two predictors of handwriting legibility in children with ASD. Thus, in Schmidt's (1975) theoretical model of motor learning, deficits in writing legible letters may be associated with inadequate kinesthetic processing, which then leads to inadequate schema formation.

Deficits in proprioception in persons with ASD have been reported in previous studies (Weimer et al., 2001) and researchers have alluded to the potential influence of proprioception on handwriting (Fuentes et al., 2009). Benbow (1992) highlighted the role of kinesthesia by stating, "In writing, an internal sensitivity that a letter movement feels correct reduces a child's need to visually monitor the fingers or pencil point while moving across the line" (p. 265).

However, one study that attempted to assess kinesthesia via direct assessment rather than caregiver questionnaire did not find a significant correlation between handwriting and proprioception (Cartmill et al., 2009). Although the present study identified a measure of proprioceptive function as being a predictor of handwriting performance in children with ASD, research is needed to further explore the relationship between handwriting and kinesthesia in children with ASD.

Handwriting performance, as discussed above, requires and is influenced by the integration of numerous sensory and motor processes. The underconnectivity theory of autism postulates that observed performance deficits in autism arise from deficient interconnectivity between various regions of the brain (Just et al., 2012). More specifically, Just et al. (2012) asserted that, "the theory posits that the communication bandwidth among cortical areas, particularly between frontal and posterior areas, is lower in autism than in typical participants. Thus, any facet of psychological or neurological function that is dependent on the coordination or integration of frontal brain regions with more posterior regions is susceptible to disruption, particularly when the computation demand is large (i.e. the task is complex and requires integration of different types of cortical computations)" (p. 1297). A meta-analysis of studies investigating the neurological bases of handwriting identified 12 areas as "constituting an extensive brain network of writing" (Planton, Jucla, Roux, & Demonet, 2013, p. 2777). This network included the frontal lobes, parietal lobes, left temporal lobe, right cerebellum, and left thalamus (Planton et al., 2013). Thus, in addition to the involvement of frontal and posterior regions of the brain, writing also requires integration of input from the left and right hemispheres of the brain. As such, the growing body of evidence regarding handwriting deficits in persons with ASD may be considered as further support of the underconnectivity theory of autism.

Correlates of Handwriting in Typically Developing Children

Correlations between ETCH letter legibility and all performance and sensory variables were also assessed in the control group of typically developing age and gender matched peers. ETCH letter legibility was found to be negatively correlated with VMI visual perception. ETCH word legibility was found to be significantly correlated with the SPM-HF hearing score.

The findings of a negative correlation between ETCH letter legibility and VMI Visual Perception ($r = -.610$) may be the result of assessing a relatively large number of correlations with a small sample size. Similarly, the control group finding of a negative correlation between SPM-HF Hearing and ETCH Word Legibility ($r = -.703$) may also be the product of assessing a number of correlations with a sample size as a logical explanation for these findings is not apparent. However, inconsistent findings with regard to correlations between handwriting and measures of perceptual and motor performance in typically developing children have been noted in the literature. For example, Fuentes et al. (2009) found that the only significant predictor of handwriting performance in typically developing children between 8 and 13 years of age was gender. Gender analysis was not completed in this study since there was only one girl in each group. In contrast, Hellinckx et al. (2013) found that age and Beery VMI scores had significant correlations with handwriting quality in typically developing children between the ages of 7 and 12 years. Volman et al. (2006) found that in children with good handwriting the only significant predictor of handwriting performance was graphomotor control, as measured via the Beery VMI motor coordination test. Thus, in typically developing children in this age range, there does not appear to be a consistent pattern with regard to correlates of handwriting. This may indicate that there is considerable variability regarding performance abilities that underlie handwriting in typically developing children. Conversely, it may be that that common correlates have yet to be identified.

Application of Findings to Practice

As the data analysis completed in this study involved the investigation of correlations between handwriting performance and potentially associated abilities, one cannot infer causality. However, the findings indicated that children with ASD have deficits in graphomotor control when compared to typically developing peers and that these deficits are correlated with handwriting letter and word legibility. As such, the observed deficits in graphomotor control will provide the basis for suggestions regarding the applicability of the findings to clinical practice.

As there appears to be difficulty with utilizing a pencil with precision, it is recommended that children with ASD who are receiving services to address handwriting legibility practice tasks that specifically address graphomotor control. For example, completing pencil maze tasks with curved and angular paths may facilitate the improvement of graphomotor control. Additionally, it is recommended that the tasks be graded such that the space between the lines of the maze is large enough in the beginning to facilitate success and decrease the likelihood of frustration. As the child improves, the space between maze lines should be decreased incrementally in order to require greater precision. It is also recommended that the mazes being used in the beginning of practice be relatively short in the length. As the child progresses, mazes of greater length and complexity may be utilized to provide more challenge and to maintain the child's engagement with these tasks.

It is also recommended that handwriting instruction include specific directions regarding letter formation. Observationally, it appears that handwriting instruction has become less concerned with the *process* of writing letters than the outcome. This observation was corroborated by Asher (2006) who surveyed teachers regarding handwriting instruction and reported that, "some teachers expect students to copy the letters presented in class without addressing the directionality of the letter formation" (p. 466). Thus, if a child is able to write a legible 's' or 'r' by starting at the bottom of the letter and writing in an upward manner, this seems to be considered acceptable. However, in children with ASD, it may be beneficial to teach specific letter formation techniques. This approach may decrease variability in performance and assist in strengthening schema development. Furthermore, the utilization of a consistent approach to letter formation may facilitate the development of more accurate kinesthetic perceptions regarding letter formation. Additionally, it may also be effective to combine the use of maze or path-drawing approaches discussed above with letter formation, such that children learn a specific stroke sequence for writing letters while also working to develop graphomotor precision.

Additionally, in children with ASD, it may be appropriate and necessary to provide more practice opportunities to address letter formation than are typically provided in the classroom. As reported by Asher (2006), "Only 3 teachers (out of 13 teaching manuscript) reported having a daily practice schedule when teaching new manuscript letters" (p. 466). For children with ASD, who often present with deficits in visual-motor integration (Hellinckx, 2013; Mayes & Calhoun, 2007), motor skills (Jansiewicz et al., 2006; Ming et al., 2007), and sensory processing (Kern et al., 2006; Kientz & Dunn, 1997), it is recommended that ample practice opportunities and formal instruction regarding letter formation be provided. Moreover, additional practice opportunities may facilitate the development of neural pathways needed for effective handwriting.

Limitations and Implications

There are several limitations regarding the findings of this research. These include sample size, participant characteristics, and data collection processes.

The sample size of 22 total participants (n =11 per group) is considered small and necessitates a cautious interpretation and generalization of the findings. However, the sample size was comparable to other studies investigating handwriting performance in ASD. For example, published research regarding handwriting performance in ASD has included sample sizes of 2, 9, 12 and 14 participants with ASD (Beversdorf et al., 2001; Green & Henderson, 2001; Fuentes et al., 2009; Fuentes et al.; 2010).

Additionally, as there was not a random selection of participants, the recruitment process may have resulted in an over inclusion of children with ASD who have handwriting deficits. It is possible that this sample of parents with children with ASD were more willing to participate in this research because their children have handwriting difficulties. Thus, in this respect, this sample may not be representative of the at large population of children with ASD.

Another limitation of this study concerns the lack of independent determinations of IQ scores and ASD diagnoses, as this study relied on parent report of ASD diagnosis and IQ performance. Additionally, this study did not match participants on IQ. As such, it may be possible that the findings have been influenced by differences in levels of performance IQ.

Furthermore, although participants with non-verbal/performance IQ's of 80 or above were sought, two participants who did not meet this criterion were included in the ASD group. In the first case, a parent reported that her child's non-verbal IQ score was 79; given the standard error of measurement in IQ testing, it was deemed reasonable and appropriate to allow him to participate. In the second case, at the time of recruitment, the parent of the participant was uncertain of her child's non-verbal IQ score. However, after testing was completed, the results of psychological testing completed approximately 4 years prior were reviewed with the principal investigator. A composite non-verbal IQ was not provided in the report, although the results of the performance IQ subtests were provided. A school psychologist reviewed these scores and estimated that the composite non-verbal/performance IQ score derived from the subtest scores would probably fall in the upper 50's range. The decision to include the data obtained form this participant was based upon the following: 1) his letter legibility percentage was the fourth highest in the ASD group and 2) his Beery VMI, Beery VMI Motor Coordination, and In-hand manipulation test scores were all better than the ASD group average.

There are also limitations regarding data collection processes as the research settings varied among participants. As noted previously, testing was completed in participants' homes, churches, schools, and a library. Additionally, there was not uniformity with regard to the presence of other persons, ambient activity or ambient noise. As such, the data collected in these settings may vary from data obtained in a more clinical environment. However, it could also be argued that the settings in which data was collected were representative of the environments in which children complete their schoolwork and homework. Lastly, with regard to data collection, human error in the administration and/or scoring of collected data may have influenced the replicability of these findings.

Given this study's small sample size, a replication of this study with more participants is warranted. In particular, replication is needed to determine if the regression model identified in this study is able to predict handwriting performance in another, preferably larger, sample of children with ASD. Additionally, as graphomotor control was found to be a significant variable with regard to letter and word legibility in children with autism, further exploration of variables that may influence graphomotor control and handwriting are warranted. For example, it seems plausible that grip strength may be associated with graphomotor control and handwriting. Furthermore, differences in grip strength have been found in children with ASD when compared to typically developing peers (Kern et al., 2013).

The SPM-HF Body Awareness score was also identified as a predictor of letter legibility in children with ASD. However, this is an indirect measure of kinesthetic and proprioceptive function obtained via parent questionnaire. Therefore, further exploration of the relationship between kinesthesia and handwriting with a direct performance measure of kinesthetic function may shed more light on the nature of this relationship. Additionally, research investigating letter formation processes used by children with ASD may also yield beneficial information for developing strategies for handwriting instruction and remediation.

Summary

The findings of this research demonstrated significant differences in letter and word legibility between a group of children with ASD and an age and gender matched group of typically developing peers. Additionally, significant differences in graphomotor performance, visual-motor integration, and sensory processing were found between groups. In this sample of children with ASD, measures of handwriting letter legibility and word legibility were correlated with graphomotor control. Additional research is needed to further explore the nature of handwriting performance in children with ASD.

Appendix. Research Session Notes.

A-K = ASD Group; L-V = TD Control Group

A. Session completed in office room of school. No other persons present in the room. Ambient noises from outside the room noted at times. Used index finger with pencil tip on several letters of upper and lower case alphabet. Stated, "I never really learned what a lower case "q" looks like." Paper angled at 45 degrees. Used left index finger to guide pencil. Near point copying, tried to copy the shape of the letters on the page. Remarked that he didn't have his glasses for far point copying, but said he didn't need them to read the chart. Said he did not need them for near distance. Participant said it was impossible to write a sentence, but that he could write 5 words, though. Slouched at times. Complained of back pain in the adjustable height chair and was allowed to change seating to standard chair. Reported that he does not know or use cursive. Learned it once, but never went back to it. Took break after Beery VMI. Participant said he was getting tired and was encouraged to take a break. Coached on #19 of Beery VMI as acceptable per VMI manual. Did not complete full item on VMI Motor coordination #20, but should have been cued to attend to this per manual. Completed 5/6 circles fully and therefore, since he was not cued, was given credit for successful completion of this item. Session took 55 minutes. 2 break periods.

B. Session completed at student's home. Mother and siblings were present, but mother did not observe the testing session directly. Session took place at dining room table with protective pad. Ambient noises at times. Offered break after each change of task/test. Wanted to use his pencil. Good, erect posture. With dictation task, wrote all letters on different lines initially. Reminders not to use left hand when completing in-hand manipulation test. Cued to continue after completing first form of VMI. Consistent grip so far throughout testing. Feet on floor. Feet under posterior at times. Pencil between 4th and 5th digits.

C. Session completed in private reading room of public library. Mother present for testing session. Participant asked mother about correctness of upper case Q. Used adjustable height chair. Was incorrectly cued to attend to completeness of VMI Motor Coordination item #10. Appropriately cued to attend to completeness of VMI Motor Coordination #19.

D. Session completed in participant's home. Mother at home, but not present for entire session. Used adjustable height chair. Chair in home did not allow his feet to touch the floor. Used ulnar surface of hand to stabilize paper. Reminded to not use two hands to complete test of in-hand manipulation.

E. Session completed at participant's home. Mother and other family members were also home. Testing completed at dining room table. Good positioning. Occasionally, a family member passed through room. Used left hand to stabilize paper. With VMI, was cued for proper positioning and stabilization of test booklet. Researcher offered to stabilize VMI form for him, but he responded, "I'm good." At this point, researcher should have stabilized form, per VMI manual. However, it is the researcher's recollection that as the items became harder, the participant stabilized the VMI booklet with non-writing hand. Researcher adjusted position of Beery VMI Visual Perception test booklet twice. Researcher cued to attend to VMI Motor Coordination #19 per manual.

F. Session completed at participant's home. Mother and siblings at home. Mother present for entire testing session. Used adjustable height chair. Good positioning. Straightened test booklet for item #25. Student took break after VMI for water and restroom.

G. Session completed at student's school. Used speech pathologist's room. Mother was present initially to ensure that room was adequate. Student was waiting in room upon researcher's arrival. Participant was given second attempt with ETCH dictation task as he did not follow directions to write in lower case from the beginning of the task. Cued to keep going when pausing during completion of VMI. Wanted to sharpen pencil during completion of VMI Motor Coordination task and was permitted to do so. Participant expressed concern about getting to music class on-time. After session, it was realized that, inadvertently, breaks between tasks were not offered. In retrospect, this oversight was considered an unintentional response to the participant's wanting to be on-time for music class. Student did not demonstrate any evidence of distress during the research session.

H. Session completed at kitchen table of participant's home. Parents and others in the home during the session. Ambient noise present. Took break after in-hand manipulation test.

I. Session completed in participant's home. Good effort and attention to task. Mother present for testing. Off-hand not always used to stabilize paper. Good table height with chair. Break taken after each test. Student was given 5:00 breaks to play with his iPad. Beery VMI Motor Coordination test performance slowed on second page. Cued to straighten paper with visual perception test.

J. Session completed in participant's home. Mother present for testing. Excellent attention. Good positioning. Cued to attend to completeness of VMI Motor Coordination item #19 per VMI manual.

K. Session completed in participant's home at dining room table. Mother, father and sibling in home, but not always present in room or adjacent room during session. Used adjustable height chair. Participant indicated that he was comfortable in the chair. Put feet under chair with toes anchored on footrest. Used off-hand to stabilize paper during ETCH. ETCH dictation instructions were rephrased to facilitate comprehension. Researcher stabilized booklet during VMI. Participant asked his sister to watch him complete the VMI Visual Perception test. Asked his sister once during completion of the test to watch him. Was cued to attend to completeness of VMI Motor Coordination #9. Ate potato chips during break.

L. Session completed in researchers home. Others present, but not observing session. Ambient sounds. Completed at dining room table with pad. Used adjustable height chair. Secondary to concerns about the potential influence of the dining table pad for this participant and for participant B, this participant was retested approximately 1 month later with a different writing surface. The raw score difference in VMI Motor Coordination test performance was1 point. Base upon this finding, it was decided that the table pad did not appear to have a significant impact on performance and the data for each of these participants was included in data analysis.

M. Testing completed at participant's home at dining room table. Participant's father was present for the entire session. Picture schedule not utilized for this control participant.

N. Session completed in participant's home at his kitchen table. Picture schedule not utilized for this control participant. Slight rotation of torso and test paper with VMI Motor Coordination test, which was not addressed by researcher. Switched pencil on item #17 secondary to initial pencil becoming dull.

O. Testing completed in office of church. Others present in building, but not office. Ambient sounds at times. Cued to attend to completeness of VMI Motor Coordination test per manual. Participant delayed his initiation of writing after second page directions for VMI Motor Coordination were read. With VMI Motor Coordination item #24, participant asked if I "go around circles or fill in the circles."

P. Session completed in room of church. Mother and others present in the building, but did not observe session. Position adequate. Participant said seating position was similar to his school seating. Glasses on. When completing the ETCH, participant stated, "I'm used to cursive." Participant did not use L hand to stabilize VMI booklet. On VMI Motor Coordination task participant asked, "how do you do this one?" Participant was instructed to fill in the circles.

Q. Session completed at researcher's home. Others present in home, but did not observe session. Ambient sounds at times.

R. Session completed at researcher's home. Others present in home, but did not observe session. Ambient sounds at times.

S. Session completed at participant's home. Mother and other family members present, but did not observing testing process. Participant wore his glasses during the session. With Beery VMI Motor Coordination Test item #24, the participant asked, "Do I just fill in the dots?" Researcher responded "yes."

T. Session completed at participant's home. Session completed at kitchen table. Participant expressed that he wanted to use the chair in the kitchen. Positioning was acceptable. Ambient sounds. Others passed through room at times. With ETCH UC writing task, participant enquired about the direction of upper case "D" by asking "does it go this way?" while pointing to his right. Researcher responded "yes." Participant looked to his lower case alphabet writing to see what letter came next when writing the upper case alphabet. With numerals, participant asked, "which kind of 1, can I do both 1's?" (Response was not recorded. Student's written work shows that he wrote a single "1.") Used finger for spacing with writing of sentences. When completing Far Point Copying task, participant asked about where to write "our sky" (the last two words of this task.) Researcher repeated dictation instructions. Participant self corrected with regard to upper case to lower case. VMI Motor Coordination Test #24, participant asked "do I fill in the whole thing?" In-hand manipulation peg test, participant was cued to use one hand. Participant wanted to use both hands or body to stabilize the peg. Was encouraged to just use one hand. With trial 3, stopwatch was restarted secondary to use of both hands.

U. Session completed at participant's home. Mother present in home. Glasses on. No noise or distractions. Excellent attention/effort.

V. Session completed in participant's home at kitchen table. Stabilized paper with VMI, VMI Motor Coordination and ETCH. Was cued to completeness of VMI Motor Coordination item #18. Also cued to item #19, but did not see omitted portion and continued with the rest of the test. VMI Motor Coordination #24 participant asked "should I fill this in?" Researcher responded, "yes, make it look like the small one above." (In reference to the small depiction of how a completed tracing would appear.)

Turned VMI Motor Coordination paper two times.

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