Sensorimotor and Executive Functioning Differences between Individuals with High-Functioning Autism and Typically-Developing Individuals

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Autism is a life-long neurodevelopment disorder affecting 1 in every 150 children in the United States. Along with the three major hallmarks of autism; impairments in social interaction, impairments in communication, and repetitive and restricted stereotypes of behavior, individuals with autism face a variety of impairments that affect their everyday functioning. These impairments include, but are not limited to, impairments in motor skills, impairments in sensory-perceptual skills, and impairments in executive functioning (EF) skills. This dissertation explored these aforementioned impairments in individuals with high-functioning autism (IHFA) in three studies. The first study explored simple and complex motor and simple and complex sensory-perceptual skills differences between IHFA and typically-developing individuals (TDI) for different age groups extending from childhood to early adulthood. The study found IHFA to be impaired compared to TDI on simple and complex motor skills across the continuum of age. However, for sensory-perceptual skills IHFA impairments were found only for complex sensory-perceptual skills for an older group of IHFA. The second study explored factors that were associated with good and poor complex fine-motor skills for IHFA and TDI. Two models were generated utilizing Exhaustive Chi-Square Automatic Interaction Detection (CHAID). In this study, we found different factors to be associated with complex fine-motor skills for IHFA versus TDI. The patterns of association for IHFA were also different from TDI. In the third study, we explored the factors that were associated with good and poor EF skills by generating

two models, one for IHFA and one for TDI, utilizing Exhaustive CHAID. In this study, we found similar factors to be associated with EF skills for both IHFA and TDI, however, the factors held different levels of association with EF in each group. Findings from the first study suggest the importance of early assessment and continuous re-assessment of simple and complex motor skills and complex sensory-perceptual skills for IHFA. Findings from the second and third study offer models that have the potential to establish priorities for assessment and intervention for IHFA.

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PREFACE

“'If you will be grateful, then I shall give you more” (Quran, 14:7)

“Whoever does not thank people, does not thank God” (Prophet Mohammad PBUH)

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1.0 INTRODUCTION

Autism is a life-long neurodevelopmental disorder characterized by three hallmarks; impairments in social interaction, impairments in communication, and the presence of restricted and stereotyped patterns of behavior (American Psychiatric Association [APA], 2000). In 2007, it was estimated that 1 in 150 children has autism (Centers for Disease Control and Prevention [CDC], 2007) making autism more common than pediatric cancer, diabetes, and AIDS combined (Autism Speaks, 2008). Autism has to be evident before age 3, but often diagnosed later, and it is 4 to 5 times more common in males than in females (APA, 2000, p.73). While a diagnosis of mental retardation is usually associated with autism (APA, 2000, p.71), a subgroup of autism, identified as individuals with high-functioning autism (IHFA), constitute about 20% of the autistic population (Fombonne, 1999). The number of IHFA is on rise due to enhanced diagnostic criteria and increased autism awareness. However, IHFA are still underdiagnosed because they may be mainstreamed in regular classrooms, home-schooled, or may not have been diagnosed by a professional at an early age (Yeargin-Allsopp et al., 2003). Studies involving IHFA are of great importance, as results obtained from such studies would better reflect characteristics associated with autism per se rather than autism and another disorder, such as mental retardation.

While an abundance of data is available as to how IHFA differ from typically developing individuals (TDI), there is a dearth of comparative information derived from homogeneous well-defined IHFA samples. In many studies heterogeneity of autistic samples has also led to ambiguous results. Heterogeneity has often been due to a wide IQ range and unclear diagnostic criteria. In our study, these sources of heterogeneity were controlled. To be included in the study, subjects had to have an IQ equal to or greater than 80. Two widely used standardized instruments for diagnosing autism were used to ascertain the autism diagnosis – the Autism Diagnostic Interview-Revised (ADI-R) and the Autism Diagnostic Observation Schedule (ADOS). Moreover, our TDI were matched to our IHFA sample by chronological age and IQ range. Thus, by controlling two factors that have detracted from the designs of previous studies, we were better able to discern differences between IHFA and TDI in the targeted variables.

The overall purpose of this dissertation is to extend knowledge about the similarities and differences of motor and sensory-perceptual skills of IHFA and TDI across childhood, adolescence, and early adulthood by examining the differences of these skills between the two groups, across different ages. This dissertation also aims to identify and model factors that are associated with good or poor fine-motor skills of IHFA and compare and those factors to ones in a TDI model. Also factors associated with good and poor executive functioning (EF) skills will be examined and modeled for the two groups. Establishing which factors are most strongly associated with good or poor motor or sensory-perceptual skills in the two groups will extend the body of knowledge about the differences and similarities between IHFA and TDI. In addition, identification of such factors could play a significant role in establishing priorities for assessment and intervention.

In Chapter 2 we provide a review of the literature on motor, sensory-perceptual, and executive functioning skills in IHFA. This literature review aims to identify what has been previously documented to serve as the foundation for the three aims in the chapters that follow.

In Chapter 3, motor skills and sensory-perceptual skills differences between a group of IHFA and a group of TDI are examined and compared across two different age groups; children and adolescents under the age of 12 years and adolescents and young adults between the ages of 12 and 21 years old. The aim of this study is to understand the natural course of motor skill and sensory-perceptual skill development in IHFA and how it differs from TDI.

In Chapter 4, the association between fine-motor skills and other components of functioning; namely, attention skills, motor skills, sensory-perceptual skills, language skills, memory skills, executive functioning skills, problem-solving skills, and visual-spatial skills is examined, and in Chapter 5 the association between these same exact components of functioning and executive functioning skills is examined. To explore these associations in both chapters we used Exhaustive Chi-square Automatic Interaction Detection (CHAID) analysis.

In Chapter 6, the results of the three studies are summarized and the implications of the results in relation to assessment and intervention planning are discussed.

2.0 AUTISM BACKGROUND AND SIGNIFICANCE

This chapter provides background information for the studies in this dissertation. First, autism is defined. Second, literature on the motor, sensory, and executive functioning skills of individuals with high-functioning autism (IHFA) is summarized.

2.1 DEFINITION OF AUTISM

The Diagnostic and Statistical Manual of Mental disorders – Text Revision (DSM-IV-TR) outlines main characteristics of autistic disorder under Pervasive Developmental Disorders (PDD): “qualitative impairment in social interaction, qualitative impairment in communication, and restricted repetitive and stereotyped patterns of behavior, interests, and activities” (American Psychiatric Association [APA], 2000). A recent report by the Autism and Developmental Disabilities Monitoring (ADDM) Network released by the Centers of Disease Control and Prevention (Centers for Disease Control and Prevention [CDC], 2007) estimated that 1 in 150 children has autism, with 51-91% of children with autism displaying developmental concerns before age 3, a requisite for the diagnosis of autism. Most children with autism also have mental retardation that can range from mild to profound (APA, 2000). Children with autism with an IQ of 70 or higher (i.e., do not have mental retardation) are considered high-functioning. Lack of delay or deviance in early language development is one of the DSM-IV-TR criteria that distinguishes Asperger's disorder, another form of PDD, from high-functioning autistic disorder, because individuals with Asperger's disorder have typical language development. Pervasive Developmental Disorders Not Otherwise Specified (PDD-NOS) is a term used when pervasive impairment in social interaction is present along with stereotyped behavior, interests, and activities, and impairment in communication, however, the criteria are not met for a specific PDD, Schizophrenia, Schizotypal Personality Disorder, or Avoidant Personality Disorder (APA, 2000, p.84). It is estimated that about 284,000 and up to 486,000 people under the age of 20 are diagnosed with PDD in the United States (Fombonne, 2005). Although females with autism tend to exhibit more severe mental retardation than males with autism, the rate of autism is 4 to 5 higher in males than in females (APA, 2000, p.73).

For the purposes of this dissertation we have restricted our analyses to individuals who have a Full Scale IQ (FS-IQ), Verbal IQ (V-IQ) and Performance IQ (P-IQ) of 80 and higher, thus focusing on IHFA. This decision was made to enhance the comparison between our IHFA and typically developing individuals (TDI), and to eliminate the effects of lower IQ levels/ mental retardation on test scores. Through this restriction, we have attempted to reduce the effect of confounding diagnoses.

2.2 MOTOR SKILLS

Voluntary motor actions, speicifically praxis and/or coordination, which will be the focus of our discussion, are defined as the ability to effectively plan and carry out unfamiliar motor actions (Ayres, 2005 , p. 87). This involves the ability to conceptualize what is to be done, plan, and execute a goal-directed action. Several studies have assessed voluntary motor skills in individuals with autism. This review is delimited to those studies carried out with IHFA.

Several studies have examined motor skills among IHFA across the age span. Studies with adults will be discussed first followed by studies with children.

As part of the neuropsychological battery in their study, Minshew, Goldstein, and Seigel (1997) compared 33 IHFA to 33 TDI, with 29 males and 4 females in each group, on the Finger Tapping (dominant hand), Developmental Test of Visual-Motor Integration (VMI; total points), Grooved Pegboard (GP; dominant hand, time in seconds), and Trial Making Test A (TMT A; time in seconds). The two groups were matched on full IQ, verbal IQ, and performance IQ measures. The mean age was 20.91 for the IHFA group, and 21.21 years for the TDI group. The IHFA group performed significantly worse on the GP and the TMT A. These two tests also significantly discriminated between the two groups (kappa = .52). Although the IHFA group performed worse on the VMI compared to the TDI group, the difference did not reach statistical significance. Performance on the Finger Tapping test was almost identical.

Performance on the TMT A was examined in a study comparing IHFA to TDI (Minshew, Goldstein, Muenz, & Payton, 1992). Both groups consisted of males only. The 15 IHFA (mean age = 21.13 years) performed significantly worse on the TMT A compared to the 15 matched TDI (mean age = 21.33 years).

Rumsey and Hamburger (1988) compared 10 men with HFA (mean age = 26.40 years) to 10 matched TD men (mean age = 28.40 years) on several measures including the GP and the TMT A. The two groups were matched on age, gender, IQ, level of education, and handedness. Although the results of the GP did not reach the statistical significance established for the study ($p < .025$), HFA participants were slower on the GP bilaterally ($p=.05$) compared to TD participants. The results for the TMT A were significant (p=.01), with HFA participants needing almost double the time of the TD participants to finish the test. Men with HFA (mean age: 26.40 years) were found to be significantly slower on the GP compared to TD men (mean age: 24.20 years) in a later study by the same researchers (J M Rumsey & Hamburger, 1990). Although men with HFA were matched on age, gender, and handedness with TD men, the former had a significantly lower IQ than the latter.

Several studies assessed motor integrities and/or impairments of high-functioning children with autism (HFCA; Ghaziuddin, Butler, Tsai, & Ghaziuddin, 1994; Jansiewicz et al., 2006; Mandelbaum et al., 2006; Manjiviona & Prior, 1995; Smith & Bryson, 1998; Williams, Goldstein, & Minshew, 2006a). Although these studies differed in the age ranges of the children included, the groups used for comparison, and the motor skills measured, all studies, except Mandelbaum et al. (2006), found that HFCA displayed fine and gross motor impairments, regardless of the measure used.

2.2.1 Motor Skills in Children, by Age

Regarding age, the only study that examined motor impairments in HFCA younger than 10 years old was Mandelbaum et al. (2006), who compared 7 – 9 year-old HFCA (mean age = 8.7 years, 33 males and 9 females) to children with low IQ (mean age = 8.8 years, 22 males and 15 females), children with autism and low nonverbal IQ (mean age = 9.0 years, 60 males and 14 females), and children with developmental language disorder (DLD; mean age = 8.2 years, 63 males and 26 females). The results indicated that children with a low IQ and children with autism and low nonverbal IQ scored significantly lower on all motor measures (Gross motor skills: Stressed gaits, Station, Balance, and Impersistence; Fine-motor skills: Subtests of the

Physical and Neurological Examination of Soft Signs (PANESS), Purdue Pegboard, and Visuo/Graphmotor), except motor impersistence, compared to HFCA and children with DLD. As this study did not include a typically-developing child control group and did not match groups on chronological age, it is hard to draw a conclusion regarding the motor skills of this age group of HFCA.

2.2.2 Motor Skills in Children, by Comparison Groups

Regarding comparison groups, the studies by Williams et al. (2006) and Jansiewicz et al. (2006) were the only ones that included a sample of TD children, however, the groups were not matched on Full Scale IQ in the latter study. Williams et al. (2006) compared 56 HFCA (mean age = 11.36 years, 46 males and 10 females) to 56 TD children (mean age = 11.82 years, 39 males and 17 females) on four motor measures: Finger Tapping (dominant hand), GP (dominant hand), Coding Scaled subtest of the Wechsler Intelligence Scale for Children-III (WISC-III), and grip strength (dominant hand). There were no significant differences between the groups on chronological age or IQ level. Grip strength and the WISC-III coding subtest discriminated HFCA from TD children, with the former performing at a lower level than the latter. Comparison groups in the other studies included children with Asperger's disorder (Ghaziuddin et al., 1994; Jansiewicz et al., 2006; Manjiviona & Prior, 1995), language impairment (Mandelbaum et al., 2006; Smith & Bryson, 1998), and low IQ (Mandelbaum et al., 2006). HFCA did not significantly differ from children with Asperger's disorder on motor skills in any of the studies. Similarly gross and fine motor skills did not differ between HFCA and children with language impairments (Mandelbaum et al., 2006), however, they performed significantly worse on the GP when compared to children with language impairment (Smith & Bryson, 1998). HFCA displayed superior performance on motor tests when compared to children with low IQ (Mandelbaum et al., 2006).

2.2.3 Motor Skills in Children, by Gross and Fine

Regarding motor skills, gross and fine motor skills were measured in all studies except for that conducted by Smith and Bryson (1998), where only fine motor skills were measured. HFCA exhibited motor impairment on the GP (Smith & Bryson, 1998); the Bruininks-Oseretsky test (Ghaziuddin, et al., 1994), the Test of Motor Impairment-Henderson Revision (TOMI-H; Manjiviona & Prior,1995), the Physical and Neurological Exam of Subtle Signs (PANESS; Jansiewicz et al., 2006), grip strength and the Coding Scaled subtest of the WISC-III (Williams et al., 2006). Although the GP test failed to discriminate between HFCA and TD children (Williams et al., 2006), it did differentiate HFCA from children with language impairment (Smith & Bryson, 1998).

2.2.4 Motor Skills in Children, by IQ

IQ was found to be related to motor impairment in two studies which used different measures. The first study (Manjiviona & Prior, 1995) compared 9 HFCA (mean age: 12.33 years) to 12 children with Asperger's disorder (mean age: 10.92) on the TOMI-H. The second study (Mandelbaum et al., 2006) compared HFCA to children with low IQ, children with autism and low verbal IQ, and children with DLD on fine and gross motor tests. In both studies higher IQ was related to higher motor functioning.

2.3 SENSORY-PERCEOTUAL SKILLS

For the purposes of this dissertation, we delimited our review to one aspect of sensory-perceptual skill; namely, tactile stimulation. Research in sensory and motor development has revealed that the tactile system plays a major role during infancy and childhood. Impairments in the tactile system can negatively affect a child's experiences with objects and materials (Parham & Mailloux, 2005). This in turn may affect functional performance in multiple activity and participation domains; such as play, self-care, and school-related activities. Precise tactile feedback is crucial for motor learning and motor planning. It is speculated that fine motor activities are endangered when tactile feedback is inadequate. Activities such as writing, using scissors, and using eating utensils highly depend on accurate tactile feedback (Case-Smith & Rogers, 2005; Parham & Mailloux, 2005). The role of tactile stimulation carries beyond childhood as tactile information from the hand is crucial for everyday manipulation and grasp. In general, sensory-perceptual functions are under-researched in populations with autism and specifically in adults. We will review the available literature on adults with HFA and then on HFCA.

Minshew et al. (1997) used the Luria-Nebraska (LN) tactile scale (Simple Touch errors, Stereognosis errors, Sharp-Dull Discrimination errors, Position Sense Errors, and Finger position Errors) as well as Fingertip Number Writing to examine tactile differences between IHFA (mean age: 20.91 years) and TDI (mean age: 21.21 years) with 29 males and 4 females in each group. The aforementioned tests failed to discriminate between the two groups (Kappa: .29), although IHFA made significantly more errors on the Fingertip Number Writing compared to TDI.

In addition to examining motor functions, Rumsey and Hamburger (1988) also examined sensory-perceptual functions in a sample of men with HFA (mean age: 26.40 years).

Performance on tactile suppressions, Finger Agnosia, and Fingertip Number Writing was not significantly different between men with HFA and TD men (mean age: 28.40). The same researchers in a later study (Rumsey and Hamburger, 1990) compared the performance on the Fingertip Number Writing of men with HFA (mean age: 26.40 years) to TD men (mean age: 24.20 years) and to men with dyslexia (mean age: 22.00 years). Men with HFA made significantly more errors compared to the TD men but they did not differ significantly from men with dyslexia.

Sensory-perceptual problems are common in children with autism, with up to 88% of children with autism displaying impaired sensory responses (Kientz & Dunn, 1997; Le Couteur et al., 1989; Ornitz, Guthrie, & Farley, 1977). These sensory responses, which vary from child to child, can be fluctuating and coexisting (Keintz & Dunn, 1997). Sensory-perceptual functions in children with autism are under researched, compared to functions such as, language, cognition, and social (Parham & Mailloux, 2005). In addition, the available research is based primarily on parental reports, which can be biased (Baranek, 2002), rather than direct testing with standardized instruments (Parham & Mailoux, 2005).

Williams et al. (2006) compared HFCA (n = 56; mean age = 11.36 years, 46 males and 10 females) to TD children (n = 56, mean age = 11.82 years, 39 males and 17 females) on the Luria-Nebraska (L-N) subtests of Simple Touch, Stereognosis, Sharp-Dull Discrimination, and Position Sense, the Reitan-Klove (R-K) Finger Agnosia subtest, and Halstead-Reitan (H-R) Finger Number Writing subtest. Four of the six measures discriminated between HFCA and TD children; Simple Touch, Stereognosis, the R-K Finger Agnosia, and the H-R Finger Number Writing.

Studies using the Sensory Profile (Kientz & Dunn, 1997) and the Sensory Sensitivity Questionnaire-Revised (SSQ-R; Talay-Ongan & Wood, 2000), both parental questionnaires, found significant differences on touch between children with autism and TD children. Children with autism displayed significant impairment, such as picky eating and aversive responses to standing close to or being touched by people and getting wet or wearing wet clothes. In addition, Talay-Ongan and Wood (2000) reported that sensory sensitivities appeared to increase over ages 4 to 14 years, but reasoned that this may be due to the fact that older children may be better able to express tactile abnormalities. Neither study measured IQ, provided detailed demographic information, or diagnosed autism with a standardized instrument. Furthermore, only age ranges were provided – the ages of children with autism in the Kientz and Dunn (1997) study ranged from 3 to 13 years old (n = 32) and those in the Talay-Ongan and Wood (2000) study from 4 to 14 years old (n = 27).

Davis, Bockbrader, Murphy, Hetrick, and O'Donnell, (2006) administered a self-report questionnaire, the Structured Interview for Assessing Perceptual Anomalies- Child Version (SIAPA-CV), to explore sensory impairments in 9 male, HFCA (mean age: 12.3 years). The HFCA displayed significant impairments when compared to age-matched TD children (mean age: 11.9 years, 6 males and 3 females) who were also matched on verbal-abilities. Over 60% of those with autism reported hypersensitivity to tactile stimulation and the same percentage reported "sensory flooding" in the tactile modality, meaning that they felt "flooded or overwhelmed" by tactile stimulation.

2.4 EXECUTIVE FUNCTIONING

There is a lack of consensus regarding the concept (executive functioning vs. reasoning vs. problem-solving) that a certain neuropsychological test (i.e. the Wisconsin Card Sorting Test [WCST]) measures. The aforementioned concepts have been referred to the same test in different studies. For the following literature review the assignment of a specific test to a certain concept (executive functioning, reasoning, problem-solving) was kept as it was used by each study. As in previous sections, studies with adults with HFA will be discussed first followed by studies of HFCA.

Minshew et al. (1997) found IHFA to be impaired on measures of reasoning in a study of 33 matched pairs of IHFA (mean age: 20.91 years) and TDI (mean age: 21.21 years). The two groups were matched on age, educational level, and full-scale, verbal, and performance IQ and consisted of 29 males and 4 females in each group. Although the groups did not differ on full IQ, verbal, and performance scales, the IHFA group did significantly worse on Stanford-Binet Picture Absurdities, and the 20 Questions test compared to the TDI group. While the study failed to find differences between the groups on the WCST preservative score, the researchers found that the 20 Questions test, Picture Absurdities test, and the TMT-Part B discriminated between the two groups.

Rumsey (1985) found that IHFA were significantly impaired on conceptual problem solving tests. The WSCT was used to compare 9 men with HFA (age range: 18 to 39 years) to 10 TD men matched for age, sex, education, and IQ. Men with HFA displayed impairments in formulating rules as well as preservative tendencies.

Several measures of verbal and non-verbal problem solving were used by Rumsey and Hamburger (1988), to compare 10 men with HFA (mean age: 26.4 years) to 10 matched TD men (mean age: 28.4 years). The two groups were matched on age, gender, IQ, level of education, and handedness and were compared on the TMT, WCST, and Stanford-Binet subtest of Verbal Absurdities, Stanford Binet Picture Absurdities, Problem Situation, and Plan of Search. There was a significant difference between the men with HFA and TD men on all measures of problem solving, with the IHFA group performing worse. Furthermore, the authors conducted a stepwise discriminant analysis on all the neuropsychological measures and found the Stanford-Binet Problem Situation subset to be the best variable to discriminate between the groups. The authors concluded that impairments in problem-solving tests were not due to deficits in visuoperceptual abilities or comprehension, but rather to impairments in integration of information and the ability to make inferences. In a later study, Rumsey and Hamburger (1990) also used all the aforementioned tests, with the exception of the TMT, to measure reasoning and problem solving of 10 men with HFA (mean age: 26.4 years), 15 severely dyslexic men (mean age: 22.0 years), and 25 TD men (mean age: 24.2 years) matched on age, educational level, and handedness, but not on IQ (men with HFA had a significant lower FS-IQ compared to TD men). Men with HFA performed significantly worse than the other two groups on the WCST, and Problem Situation, Picture Absurdities, and Verbal Absurdities subtests of the Stanford-Binet.

The studies of HFCA reached similar conclusions, to those for IHFA, concerning EF abilities. Hoffman and Prior (1982) compared 3 groups of boys; 10 HFCA (mean age: 11.25 years), 10 TD children matched to HFCA on chronological age (CA), and 10 TD children matched on mental age (MA), on TMT-Part B, Colour Form Sorting Test (CFST), and Category Test. The CFST is assumed to be related to frontal lobe functions of the brain (Hoffman and Prior, 1982). HFCA performed significantly worse than the two control groups on all measures. The authors attributed poor performance to the inability to benefit from feedback, shift categories, formalize concepts, and develop problem solving strategies as well as inflexibility and perseveration in responses. However, it should be noted that the IQ level of the HFCA was significantly lower than that of both control groups (Hoffmann & Prior, 1982). In a comparable study with slightly older age groups of children and different problem-solving measures (WCST; Milner Maze), the researchers obtained comparable results (Prior & Hoffmann, 1990). Twelve HFCA were compared to 12 TD children matched on CA (mean age: 13.75 years), and 12 TD children matched on MA (mean age: 11.33 years). Each group was comprised of 9 boys and 3 girls. HFCA performed worse than the two control groups on both measures, except on the nonpreservative errors score of the WSCT. The researchers suggested that low performance may provide evidence of frontal lobe dysfunction.

Ozonoff and McEvoy (1994) investigated whether executive functioning skills, as measured by the WCST and the Tower of Hanoi (TOH), indicated a primary deficit in autism and that persisted through development, or indicated a delay in development. Twenty-three HFCA (mean age: 12.1 years, 21 males and 2 females) were compared to 20 children with learning-disabilities (mean age: 12.4 years, 18 males and 2 females) on the aforementioned two measures. The two groups were followed over 3 years: 17 children in each group completed the study. The two groups were matched on IQ, SES, gender, and age at both time 1 and time 2. Results showed that HFCA performed significantly worse than children with learning disabilities on both measures at time 1 and time 2. Further analysis showed that the scores of the HFCA on both tests did not change significantly over time, however, the children with learning disabilities performed significantly better on the WCST at time 2, and they showed improvement with time on the TOH, however, it was nonsignificant,($p = .13$). There was a significant negative correlation between preservative errors on the WCST and FS- IQ and V-IQ for HFCA. This pattern was not observed in children with learning disabilities.

Williams et al. (2006) found that the Stanford-Binet (S-B) tests of Picture Absurdities, Problem Situation, Plan of Search and the 20 Questions tests failed to discriminate between HFCA (n = 56; mean age: 11.36 years) and TD children (n = 56; mean age: 11.82 years), matched on age, IQ, and years of education. The researchers reported that these tests of reasoning approached the discriminatory level, but did not reach it (Kappa = .35; % of correct classification= 67.3). In an earlier study, adults (mean age: 20.91) with IHFA performed significantly worse on the 20 Questions test and the S-B test of Picture Absurdities compared to their age peers matched on IQ and years of education (Minshew et al., 1997). These tests, along with an additional test of reasoning (TMT – Part B), were able to discriminate between adults with HFA and their matched controls (% of correct classification= 75.8). Williams et al. (2006a) argued that the failure to reach significance in the younger sample might be due to the extensive variability in the children's scores. Another explanation was that different tests were used with the adult population and thus comparison between the two age groups may not be valid. Finally, the authors argued that reasoning deficiency may not be apparent at this age.

3.0 MOTOR AND SENSORY-PERCEPTUAL SKILLS DIFFRENCES BETWEEN INDIVIDUALS WITH HIGH-FUNCTIONING AUTISM AND TYPICALLY DEVELOPING INDIVIDUALS, ACROSS DIFFERENT AGES

The Diagnostic and Statistical Manual of Mental disorders - Text Revision (DSM-IV-TR) does not state any motor features as either core to autism or as clinical or behavioral symptoms of the disorder, however, it states that “odd responses to sensory stimuli (i.e., a high threshold of pain, oversensitivity to sounds or being touched, exaggerated reactions to light or odors, fascination with certain stimuli)” are one of the behavioral symptoms associated with autism (American Psychological Association [APA], 2000. P. 72). Even though motor and sensory impairments are not core to the autism disorder, they play a significant role in differential diagnosis as well as an integral part of intervention planning. However, the assessment of these skills is usually overlooked by clinical practitioners compared to the core features of the disorder (i.e., social interaction, communication, and stereotypical repetitive mannerisms) (Baranek, Parham, & Bodfish, 2005).

3.1 MOTOR INTEGRETIES/IMPAIRMENTS

As previously discussed in Chapter 2, several studies aimed to assess motor integrities and/or impairments in individuals with high-functioning autism (IHFA) across different ages

(Ghaziuddin, Butler, Tsai, & Ghaziuddin, 1994; Jansiewicz et al., 2006; Mandelbaum et al., 2006; Manjiviona & Prior; 1995, Minshew, Goldstein, & Siegel, 1997; Smith & Bryson, 1998; Rumsey & Hamburger, 1988, Williams, Goldstein, & Minshew, 2006). For the purposes of our study, we chose to focus on simple and complex fine-motor skills. Simple fine-motor skills include those functions that do not require higher cognitive abilities for successful performance; such as muscle strength (as measured by grip strength) and speed of tapping (as measured by the Finger Tapping Test [FTT]). Complex fine-motor skills are those that involve higher cognitive skills and require complex coordination (such as those skills measured by the Grooved Pegboard [GP]) Test (Lezak, Howieson & Loring, 2004; Minshew & Goldstein, 1998). Two studies examined grip strength in IHFA (Hardan, Kilpatrick, Keshavan, & Minshew, 2003, adults; Williams et al., 2006, children). Both of these studies found reduced grip strength in IHFA. The results of motor speed as measured by FTT were mixed, with one study reporting impaired FTT performance of IHFA compared to typically developing individuals (TDI; Takarae, Minshew, Luna, Krisky, & Sweeney, 2004) and 3 other studies failing to find any significant differences between the two groups (Hardan et al., 2003; Minshew & Goldstein, 1998; Williams et al., 2006). Similarly, findings of impaired GP performance in IHFA compared to TDI were found across different age groups (Hardan, Kilpatrick, Keshavan, & Minshew, 2003; Minshew, et al., 1997, Rumsey & Hamburger, 1990; Takarae, Minshew, Luna, Krisky, & Sweenry, 2004), however, one study comparing children with HFA and TD children failed to find group differences on the GP (Williams et al., 2006). None of the studies reviewed examined motor integrities/impairments in children with a mean age less than 10 years. In addition, these studies included either a child sample or an adult sample. Thus, comparison of the age-differences for these skills in samples of both children and adults will add to the body of knowledge.

3.2 SENSORY-PERCEPTUAL INTEGRETIES/IMPAIRMENTS

Sensory-perceptual abnormalities in individuals with autism have been documented since the disorder was first described (Kanner, 1943). What we have learned about sensory-perceptual deficits for individuals with autism came from four sources; firsthand accounts by individuals with autism, parental/caregiver's reports, clinical observations, and sensory-perceptual studies conducted on individuals with autism.

Firsthand accounts by individuals with autism provide a substantive understanding of the disorder's nature and the lived experience of autism (Cesaroni & Garber, 1991). IHFA have reported oversensitivities to sound and touch (Grandin, 2005) and being overwhelmed and confused when touched by people (Cesaroni & Garber, 1991). While the value of firsthand accounts cannot be overlooked, they should be viewed with caution, as they tend to be hard to interpret and extremely subjective. Jim, an individual with HFA, reported that sensory processing is "difficult to describe …in a language developed by and for people whose sensory and perceptual processing are different" (Cesaroni & Garber, 1991, p. 305).

Parental reports have provided an understanding of the nature of sensory-perceptual abnormalities at an early age, preceding official diagnosis of autism. Different assessment tools have been developed to assess parental/caregiver insight of sensory-perceptual peculiarities, including the Sensory Profile (Dunn, 1999) and the Sensory Sensitivity Questionnaire-Revised (Talay-Ongan & Wood, 2000). Although they are very informative, parental/caregiver reports can be biased (Baranak, 2002) and can be limited by inference of the observer (Minshew & Hobson, 2008). This limitation also affects the validity of clinical observations by professionals working with individuals with autism.

Clinical observations were the first to bring the attention to sensory abnormalities in individuals with autism (Kanner, 1943) and they provided the impetus for research in this area. However, clinical research studies are needed to provide impartial evidence regarding specific sensory-perceptual phenomenon in individuals with autism. Sensory-perceptual studies provide unbiased and performance-based evidence of sensory-perceptual impairments in the autism population. Even though they are invaluable to the understanding of the nature of sensory-perceptual features of autism, there is a dearth of sensory-perceptual studies with individuals with autism and research in this area is still in its infancy.

For this study, and as previously stated in Chapter 2, we delimited our focus of sensory-perceptual skills to tactile stimulation. Minshew et al. (1997) and Williams et al. (2006) assessed sensory-perceptual integrities in adults with HFA and children with HFA, respectively, utilizing the Luria-Nebraska (LN) Tactile Scales, the Reitan-Klove (RK) Fingertip Number Writing (in both studies) and RK- Finger Agnosia (in the child study only). Although adults with HFA demonstrated significantly more errors on the RK-Fingertip Number Writing, the sensory-perceptual domain as a whole did not discriminate between adults with HFA and TDI. In the Williams et al. (2006) study with children, the sensory-perceptual domain discriminated between children with HFA and TD children, indicating that sensory-perceptual impairment may be more evident in IHFA, however, at a younger age.

Utilizing the Sensory Profile with 104 individuals with autism (ages 3-56 years) and age- and gender matched TDI, Kern et al. (2006) found a decrease in abnormal touch processing with age for individuals with autism while touch processing integrity was stable over time for TDI. This pattern was also observed in high-threshold touch processing (i.e., greater intensity of stimuli to trigger touch perception) but not in low-threshold touch processing (i.e., low intensity of stimuli to trigger touch perception). These findings indicate that TDI were stable over time for touch sensory processing in general, and high and low threshold touch sensory processing, in particular, whereas for individuals with autism there seems to be improvement in touch processing over time. According to Kern et al. (2006) individuals with autism showed significant impairment in touch sensory processing, low threshold touch processing, and high threshold touch processing compared to age- and gender matched TDI. In another study with a mixed sample of 34 children (ages 7 to 14 years) with developmental disabilities, including autism, developmental age was negatively correlated with tactile defensiveness ($r = -.31$, $p < .05$) as measured by the Tactile Defensiveness and Discrimination Test (TDDT; Baranek & Berkson, 1994). These studies, although dependent on parental report, along with the findings of Minshew et al. (1997) and Williams et al. (2006) suggest greater impairments in touch perception for younger rather than older individuals with HFA.

The purpose of this study was to examine differences in motor and sensory-perceptual integrities and impairments in a rigorously diagnosed IHFA and an age-matched TDI sample across different age groups. A cross-sectional design was used. Based on the literature, it was hypothesized that for motor variables, although IHFA would demonstrate significantly lower levels of motor skills, the age differences would be the same for the two groups (IHFA vs. TDI)– in other words, the difference between younger and older IHFA would parallel the difference between younger and older TDI. For sensory-perceptual variables it was hypothesized that the IHFA group would demonstrate lower levels of sensory-perceptual skills, and that there would be a greater difference between IHFA and TDI in the younger age group than in the older age group.

3.3 METHODS

3.3.1 Study Design

The study was conducted through secondary analyses of motor and sensory-perceptual data from three separate grants (MH40858, NS33355, and U19HD35469) and by combining data from these studies we were able to study a broader age range. For the purposes of this study, we utilized data collected for IHFA and TDI with an age range of 5-21 years old for motor (Grip Strength, Finger Tapping Test, and Grooved Pegboard) and sensory-perceptual (Luria-Nebraska tactile scaled score of Simple Touch, Sharp-Dull Discrimination, Position Sense, and Stereognosis, and Reitan-Kolve scales of Finger Agnosia and Fingertip Number Writing) measures. Analysis of Variance (ANOVA), Chi-square tests, and logistic regression were used to explore the changes of motor and sensory-perceptual integrities/impairments in IHFA compared to TDI over time.

3.3.2 Participants

IHFA who participated in this study had to meet the criteria for autism on both the Autism Diagnostic Observation Schedule (ADOS) and the Autism Diagnostic Interview- Revised (ADI-R). In addition, all IHFA had to have a Full-Scale IQ (FS-IQ), Verbal IQ (V-IQ), and Performance IQ (P-IQ) of 80 or higher. Exclusion criteria for IHFA included the presence of neurologic, genetic, metabolic, or infectious disorder. IHFA were excluded if there was a history of seizures, head trauma, or birth injury.

TDI consisted of community healthy volunteers who were recruited through advertisements in neighborhoods with socioeconomic status resembling those of the IHFA families' origin. TDI were excluded if they had a history of learning disability, neurological disorder, any psychological disorder, and if they had a family history of autism.

3.3.3 Measures

3.3.3.1 Motor measures

Grip strength, test of Finger Tapping, and the Grooved Pegboard were used for the analyses in this study. For a description of these measures please refer to Appendix A

3.3.3.2 Sensory-perceptual measures

Reitan-Klove measures of Finger Recognition and Fingertip Number Writing, as well as Luria-Nebraska scales of Simple Touch, Sharp/Dull Discrimination, Position Sense, and Stereognosis were used for the analyses in this study. These aforementioned measures assess several aspects of tactile stimulation. For a description of these measures please refer to Appendix A.

3.3.4 Procedures

For our study, the continuous variable of age was dichotomized into two groups; Young (5.00 to 11.99 years) and Old (12.00 to 21.00 years). The Young age group was further dichotomized into two groups; Young-Young (5.00 to 7.99 years) and Older-Young (8.00 to 11.99 years).

For the Luria-Nebraska (LN) sensory-perceptual measures (Simple Touch, Sharp-Dull Discrimination, Position Sense, and Stereognosis) the raw scores were converted into scaled scores with 0 = unimpaired, 1 = impaired, and 2 = severely impaired. In addition, the two impaired categories were collapsed into one category for statistical analysis, because otherwise cell frequencies would be too small to meet the assumptions for statistical tests. Furthermore, to examine the effects of group (IHFA vs. TDI) and age group (Young vs. Old) simultaneously, the two variables were combined into one variable (Group_Age) with four categories (IHFA-Young, IHFA-Old, TDI-Young, TDI-Old).

3.3.5 Data Analysis

A 2 X 2 (Group [IHFA, TDI] X Age [Young, Old]) between-subjects analysis of variance (ANOVA) was conducted on the motor and sensory continuous variables (Grip Strength, Finger Tapping, and Grooved Pegboard, Reitan-Klove Finger Recognition, and Reitan-Klove Fingertip Number Writing) to compare the level of integrity of these skills between IHFA and TDI for the two age groups (Young vs. Old). Whenever the assumptions of ANOVA were violated, transformation of data was conducted to better fit ANOVA assumptions. Post-hoc analyses comparing the two groups (IHFA vs. TDI) by age group were done using one-tailed, independent samples *t*-tests, with a Bonferroni adjustment.

In cases where a difference between IHFA and TDI was found for younger participants, the younger group was subdivided, into Young-Young and Older-Young to obtain more detailed information about differences between groups at a younger age. Thus, a 2 X 2 (Group [IHFA, TDI] X Age [Young-Young, Older-Young]) between-subjects ANOVA was conducted to reveal if between group differences were still evident in the younger age groups. The assumptions were rechecked for this second ANOVA and transformation of data was conducted if the assumptions were violated. Post-hoc analyses comparing the two groups (IHFA vs. TDI) for each of younger age groups were completed using one tailed, independent samples *t*-tests, with a Bonferroni adjustment.

When differences emerged for the Old age groups, no further analyses were conducted, because the skills assessed tend to reach maturation by age 12. However, effect size calculations were conducted for all independent sample t-tests to assess objectively the magnitude of the observed difference (Field, 2005, p. 32, Rosenthal & Rosnow, 1991, p. 42)

Even after transformation, data for the Retain-Klove Finger Recognition (RK-FR) was extremely skewed due to the high frequency of 0 scores. Therefore this variable was dichotomized with 0 indicating no errors and 1 indicating one or more errors. Chi-square, a non parametric test, was conducted for this variable followed by stepwise logistic regression with group (IHFA, TDI), age (Young, Old), and the interaction between group and age as potential predictors.

Chi-square tests were conducted to explore any significant differences between the four groups (IHFA-Young, TDI-Young, IHFA-Old, TDI-Old) in the Luria-Nebraska (LN) scaled scores. When the chi-square test was significant, it was followed by a stepwise logistic regression procedure with group (IHFA, TDI), age (Young, Old), and the interaction between group and age as potential predictors.

The p-value for all statistical analyses was set at $p < .05$. Effect sizes (*r*) followed the criteria established by Cohen (1992) which denoted an *r* of .10 as a small effect size, an *r* of .30 as a medium effect size, and an *r* of .50 as a large effect size.

3.4 RESULTS

3.4.1 Participants

One hundred forty eight participants met the inclusion and exclusion criteria, 73 in the Young age group and 75 in the Old age group. The IHFA sample (n = 73) was predominantly males (94.5%). The mean educational level was 5.74 years. The Full Scale IQ (FS-IQ), Verbal IQ (V-IQ) scale, and Performance IQ (P-IQ) scale for the IHFA participants were 101.96, 104.25, and 99.18, respectively. The TDI sample (n = 75) was also predominately males (88.0%) with a mean educational level of 6.04 years. FS-IQ was 103.48, V-IQ was 104.04, and P-IQ was 102.48. Sample characteristics, by group (IHFA, TDI) and by Age (Young, Old), are outlined in Table 3-1. The IHFA and TDI for the Young age group and the Old age group did not differ significantly (p = .008 required with the Bonferroni correction) on demographic characteristics and intelligence scales (see Table 3-1).

Table 3-1. *IHFA and TDI Characteristics for the Young and Old Groups*

	IHFA	TDI	Significance*
Young Age Group	n = 35	n = 38	
Male (*%*)	94.30	86.60	.28
Age, years (*M*, *SD*)	8.82 (1.94)	9.25 (2.04)	.36
SES (*M*, *SD*)	3.06 (1.49)	3.57 (1.30)	.13
Educational Level, years completed	2.71 (1.93)	3.41 (2.15)	.16
FS-IQ (*M*, *SD*)	102.74 (11.75)	106.05 (9.27)	.18
V-IQ (*M*, *SD*)	104.74 (13.86)	106.34 (9.24)	.56
P-IQ (*M*, *SD*)	100.26 (11.23)	105.18 (9.15)	.04
Old Age Group	n = 38	n = 37	
Male (*%*)	94.70	89.20	.38
Age, years (*M*, *SD*)	14.92 (2.06)	15.04 (1.67)	.78
SES (*M*, *SD*)	3.28 (1.43)	3.28 (1.11)	.99
Educational Level, years completed	8.77 (2.11)	9.09 (2.01)	.53
FS-IQ (*M*, *SD*)	101.24 (14.01)	100.84 (10.44)	.89
V-IQ (*M*, *SD*)	103.79 (16.50)	101.62 (11.23)	.51
P-IQ (*M*, *SD*)	98.18 (12.24)	99.70 (9.51)	.55

Note. IHFA = Individuals with high-functioning autism. TDI = Typically-developing individuals. SES = Socioeconomic status measured on a scale from 1 to 7 where 1 is the highest and 7 is the lowest. FS-IQ = Full-Scale IQ. V-IQ = Verbal IQ. P-IQ = Performance IQ. *Without Bonferroni correction

Table 3-2 includes demographic characteristics for the two younger groups (Young-Young, Older-Young). Within the two age groups, subjects were predominantly males, with 94.3% and 86.8% male participants in IHFA and TDI groups, respectively. The mean educational level was 3.06 years for the IHFA group and 3.57 years for the TDI group. FS-IQ, P-IQ, and V-IQ were 102.74, 104.74, and 100.25, respectively for the IHFA group and 106.05, 106.34, and 105.18, respectively for the TDI group. The IHFA and TDI for the Young-Young age group and the Older-Young age group did not differ significantly (p = .008 required with a Bonferroni correction) on demographic characteristics and intelligence scales (see Table 3-2).

Table 3-2. *IHFA and TDI Characteristics for the Young-Young and Older-Young Groups*

	IHFA	TDI	Significance*
Young-Young Age Group	n = 12	n = 12	
Male (*%*)	91.7	91.7	1.00
Age, years (*M, SD*)	6.69 (.65)	6.74 (.64)	.85
SES (*M, SD*)	3.42 (1.31)	3.83 (2.04)	.56
Educational Level, years completed	.75 (.75)	.83 (.94)	.81
FS-IQ (*M, SD*)	99.17 (9.82)	100.08 (7.01)	.80
V-IQ (*M, SD*)	99.58 (12.76)	99.25 (7.4)	.94
P-IQ (*M, SD*)	98.75 (8.88)	102.00 (7.70)	.35
Older-Young Age Group	n = 23	n = 26	
Male (*%*)	95.7	84.6	.35
Age, years (*M, SD*)	9.92 (1.36)	10.41 (1.26)	.20
SES (*M, SD*)	2.87 (1.58)	3.44 (.77)	.11
Educational Level, years completed	3.74 (1.51)	4.64 (1.29)	.03
FS-IQ (*M, SD*)	104.61 (12.43)	108.81 (8.98)	.18
V-IQ (*M, SD*)	107.43 (13.90)	109.62 (8.18)	.51
P-IQ (*M, SD*)	101.04 (12.39)	106.65 (9.53)	.08

Note. IHFA = Individuals with high-functioning autism. TDI = Typically developing individuals. SES = Socioeconomic status measured on a scale from 1 to 7 where 1 is the highest and 7 is the lowest. FS-IQ = Full-Scale IQ. V-IQ = Verbal IQ. P-IQ = Performance IQ. *Without Bonferroni correction

3.4.2 Motor Measures

3.4.2.1 Grip Strength

A 2 X 2 (Group X Age) between-subjects ANOVA (see Table 3-3) revealed a significant main effect for group, $F(1, 144) = 39.78$, $p < .001$, and age, $F(1, 144) = 179.02$, $p < .001$. The group X age interaction was not significant, $F(1, 144) = 2.51$, $p = .115$ (see Figure 3-1). One tailed independent sample *t*-tests (with Bonferroni corrections; $p < .025$) revealed significant differences between the two groups (IHFA vs. TDI) for grip strength both for the Young age group, $t(71) = -5.02$, $p < .001$, and the Old age group, $t(73) = -4.52$, $p < .001$, with large and medium effect sizes, respectively (Table 3-4).

Table 3-3. *Analysis of Variance for Grip Strength Differences by Group and Age for IHFA and TDI Groups*

Analysis/Source	*df*	*SS*	*MS*	*F*
Group	1	2349.66	2349.66	39.78*
Age (Old, Young)	1	10575.10	10575.10	179.02*
Group X Age	1	148.52	148.52	2.51
Error (within)	144	8506.60	59.07	

Note. IHFA = Individuals with high-functioning autism. TDI = Typically-developing individuals. *p < .001

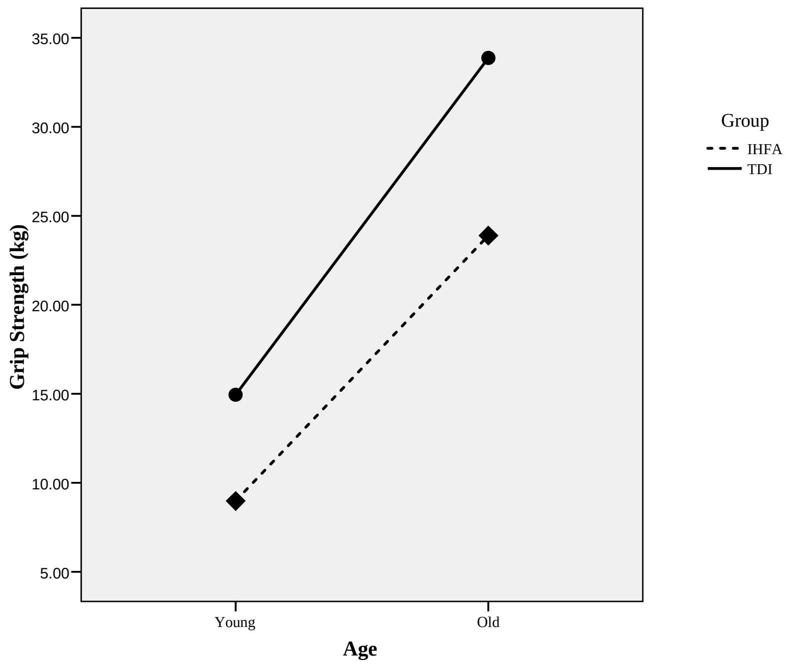

Figure 3-1. Grip Strength differences between Individuals with High- Functioning Autism (IHFA) and Typically Developing Individuals (TDI) Groups

Table 3-4: *Descriptive and t-test Comparisons for Grip Strength for the IHFA and TDI Groups*

	IHFA	TDI	*t*-test	Effect size (*r*)
Young Age Group	n = 35	n = 38		
Grip Strength, kg (*M*, *SD*)	8.98 (4.72)	14.95 (5.39)	-5.02*	.51
Old Age Group	n = 38	n = 37		
Grip Strength, kg (*M*, *SD*)	23.89 (8.76)	33.87 (10.32)	-4.52*	.47

Note. IHFA = Individuals with high-functioning autism. TDI = Typically-developing individuals. *p < .001

Because a significant difference between IHFA and TDI for the Young age was found, a 2 X 2 between-subjects ANOVA was conducted for the Young-Young and Older-Young groups.

This ANOVA (see Table 3-5) revealed a significant main effect for group, F (1, 69) = 25.88, $p < .001$, and age, F (1, 69) = 35.37, $p < .001$. The group X age interaction was not significant, F (1, 69) = 2.58, $p = .113$ (see Figure 3-2). One tailed independent sample *t*-tests (with Bonferroni corrections; $p < .025$) revealed significant differences between the two groups (IHFA vs. TDI) for grip strength for both the Young-Young age group, $t(22) = -3.05$, $p = .006$, and the Older-Young age group, $t(47) = -5.24$, $p <.001$, and the magnitude of the differences yielded large effect sizes (see Table 3-6).

Table 3-5. *Analysis of Variance for Grip Strength Differences by Group and Age for IHFA and TDI Groups*

Analysis/Source	*df*	*SS*	*MS*	*F*
Group	1	441.47	441.47	25.88*
Age (Young-Young, Older- Young)	1	603.42	603.42	35.37*
Group X Age	1	44.06	44.06	2.58
Error (within)	69	1177.11	17.06	

Note. IHFA = Individuals with high-functioning autism. TDI = Typically-developing individuals. *$p < .001$

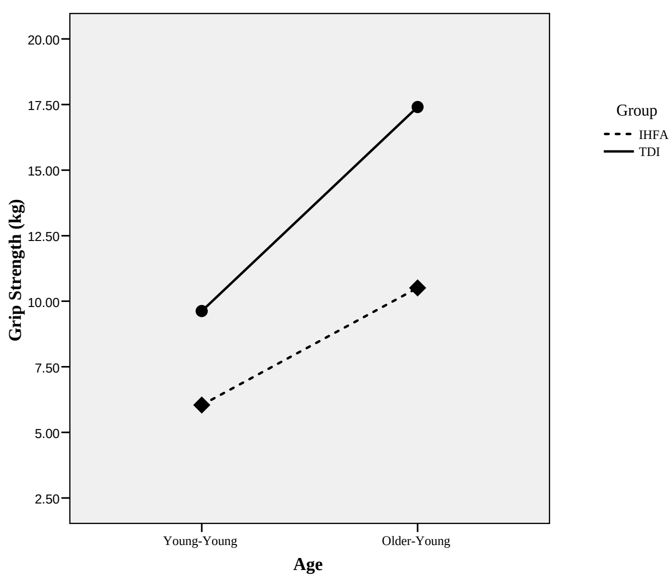

Figure 3-2. Grip Strength differences between Individuals with High- Functioning Autism (IHFA) and Typically Developing Individuals (TDI) Groups

Table 3-6. *Descriptive and t-test Comparisons for Grip Strength for the IHFA and TDI Groups*

	IHFA	TDI	*t*-test	Effect size (*r*)
Young- Young Age Group	n = 12	n = 12		
Grip Strength, kg (*M*, *SD*)	6.04 (2.77)	9.62 (2.99)	-3.04*	.54
Older-Young Age Group	n = 23	n = 26		
Grip Strength, kg (*M*, *SD*)	10.51 (4.84)	17.40 (4.37)	-5.24**	.61

Note. IHFA = Individuals with high-functioning autism. TDI = Typically-developing individuals. *p = .006. ** p < .001.

3.4.2.2 Finger Tapping

A 2 X 2 (Group X Age) between-subjects ANOVA (see Table 3-7) revealed a significant main effect for group, F (1, 137) = 7.868, p = .006, and age, F (1, 137) = 32.54, p < .001. The group X age interaction was not significant, F (1, 137) = .838, p = .362 (see Figure 3-3). One tailed independent sample *t*-tests (with Bonferroni corrections; p < .025) revealed significant differences for Finger Tapping between IHFA and TDI for the Old age group, $t(70) = -2.97$, p = .002, but not for the Young age group, $t(67) = -1.21$, p = .116, with medium and small effect sizes, respectively (see Table 3-8).

Table 3-7. *Analysis of Variance for Finger Tapping Differences by Group and Age for IHFA and TDI Groups*

Analysis/Source	*df*	*SS*	*MS*	*F*
Group	1	396.60	369.60	7.87*
Age (Young, Old)	1	1640.38	1640.38	32.54**
Group X Age	1	42.22	42.22	.84
Error (within)	137	6905.77	50.41	

Note. IHFA = Individuals with high-functioning autism. TDI= Typically-developing individual. *p = .006. **p < .001

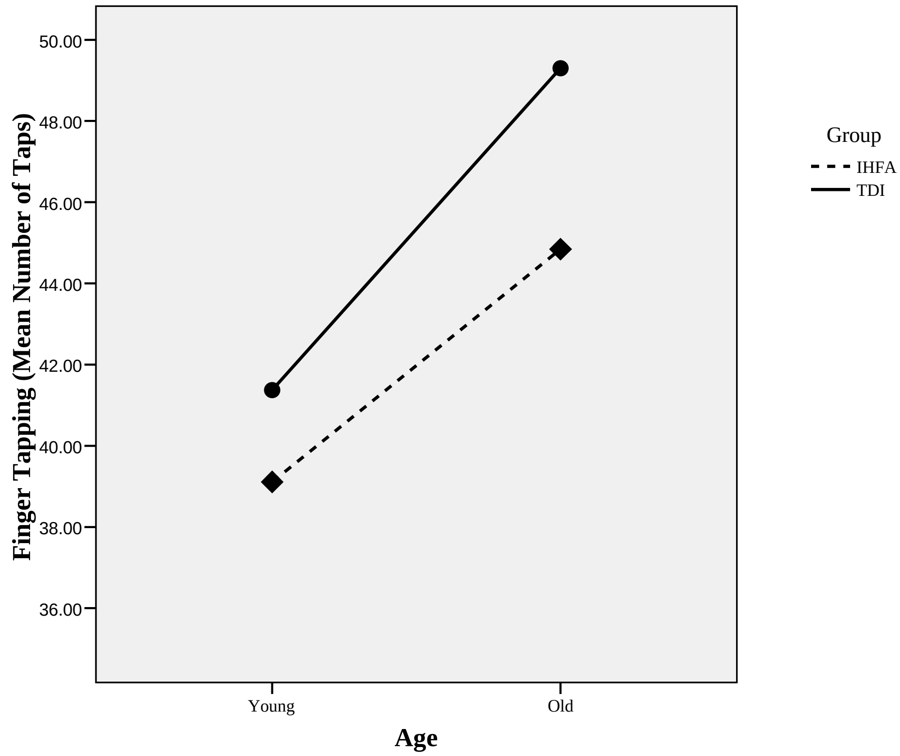

Figure 3-3. Finger Tapping differences between Individuals with High- Functioning Autism (IHFA) and Typically Developing Individuals (TDI) Groups

Table 3-8. *Descriptive and t-test Comparisons for the Finger Tapping for IHFA and TDI Groups*

	IHFA	TDI	*t*-test	*Effect size (r)*
Young Age Group	n = 33	n = 38		
Finger Tapping (*M*, *SD*)	39.11 (8.90)	41.37 (6.62)	-1.21	.15
Old Age Group	n = 38	n = 34		
Finger Tapping (*M*, *SD*)	44.84 (6.93)	49.30 (5.67)	-2.97*	.33

Note. IHFA = Individuals with high-functioning autism. TDI = Typically-developing individuals. *$p = .002$.

3.4.2.3 Grooved Pegboard

The ANOVA for the Grooved Pegboard (GP) was run on transformed data because the original data did not meet the assumptions of the ANOVA. Reciprocal transformation was used. A 2 X 2 (Group X Age) between-subjects ANOVA (see Table 3-9) revealed a significant main effect for group, F (1, 144) = 22.49, $p < .001$, and age, F (1, 144) = 32.23, $p < .001$. The group X age interaction was not significant, F (1, 144) = 2.67, $p = .104$ (see Figure 3-4). One tailed independent sample *t*-tests (with Bonferroni corrections; $p < .025$) revealed significant differences between the two groups (IHFA vs. TDI) on the GP for both the Young age group, $t(71) = -4.00$, $p < .001$, and the Old age group, $t(73) = -2.55$, $p = .007$, with medium and small-medium effect sizes, respectively (Table 3-10). Descriptive statistics of the original data (i.e., before transformation) are provided in Table 3-11.

Table 3-9. *Analysis of Variance for Grooved Pegboard (Transformed) Differences by Group and Age for IHFA and TDI Groups*

Analysis/Source	*df*	*SS*	*MS*	*F*
Group	1	0.00	0.00	22.49*
Age (Young, Old)	1	0.00	0.00	32.26*
Group X Age	1	0.00	0.00	2.67
Error (within)	144	0.00	0.00	

Note. IHFA = Individuals with high-functioning autism. TDI = Typically-developing individuals. *$p < .001$

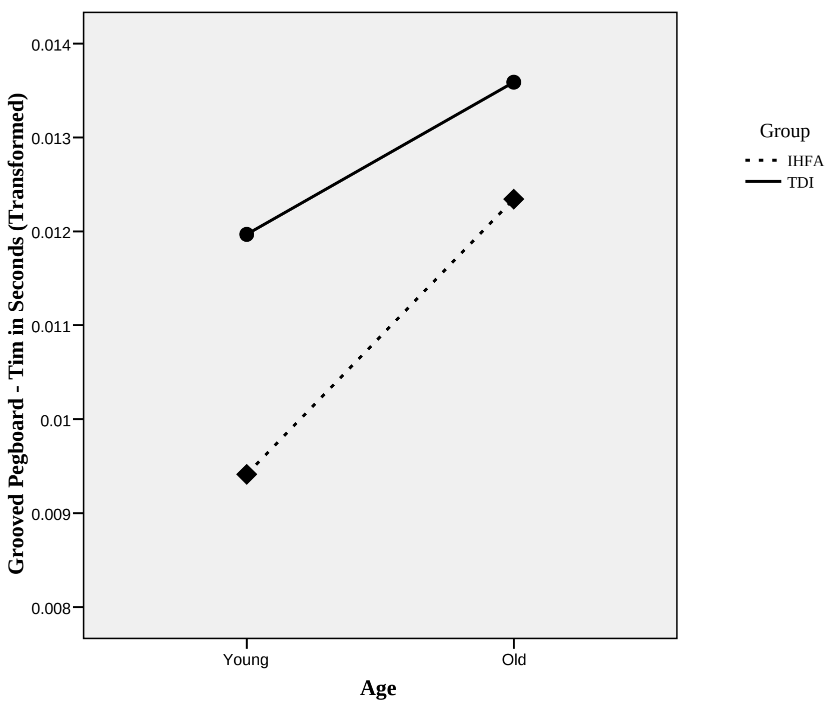

Figure 3-4. Grooved Pegboard (Transformed) differences between Individuals with High- Functioning Autism (IHFA) and Typically Developing Individuals (TDI) Groups

Table 3-10. *Descriptive and t-test Comparisons for the Grooved Pegboard (Transformed) for IHFA and TDI Groups*

	IHFA	TDI	*t*-test	*Effect size (r)*
Young Age Group	n = 35	n = 38		
GP- Transformed (*M*, *SD*)	0.009 (.003)	0.012 (.003)	-4.00**	.43
Old Age Group	n = 38	n = 37		
GP- Transformed (*M*, *SD*)	0.012 (.003)	0.14 (.002)	-2.57*	.29

Note. IHFA = Individuals with high-functioning autism. TDI = Typically-developing individuals. GP = Grooved Pegboard. *p = .007. **p < .001

Table 3-11. *Descriptive Statistics for the Grooved Pegboard (Untransformed) for the IHFA and TDI Groups*

	IHFA	TDI
Young Age Group	n = 35	n = 38
Grooved Pegboard, Time in Seconds (*M*, *SD*)	114.31 (31.68)	89.32(26.23)
Old Age Group	n = 38	n = 37
Grooved Pegboard, Time in Seconds (*M*, *SD*)	84.26 (16.84)	74.70 (9.76)

Note. IHFA = Individuals with high-functioning autism. TDI = Typically-developing individuals

Because there were significant differences between IHFA and TDI at the Young age, a 2 X 2 between-subjects ANOVA was conducted for the Young-Young and Older-Young groups. This ANOVA (see Table 3-12) revealed a significant main effect for group, $F(1, 69) = 19.40$, $p < .001$, and age, $F(1, 69) = 55.65$, $p < .001$. The group X age interaction was not significant, $F(1, 69) = 1.40$, $p = .240$ (see Figure 3-5). One tailed independent sample *t*-tests (with Bonferroni corrections; $p < .025$) revealed significant differences between the two groups (IHFA vs. TDI) for the Young-Young group, $t(22) = -2.23$, $p = .018$, and for the Older-Young group, $t(47) = -4.63$, $p < .001$, with medium and large effect sizes, respectively (see Table 3-13). Descriptive statistics of the original data (i.e., before transformation) are provided in Table 3-14.

Table 3-12. *Analysis of Variance for Grooved Pegboard (Transformed) Differences by Group and Age for IHFA and TDI Groups*

Analysis/Source	*df*	*SS*	*MS*	*F*
Group	1	0.00	0.00	19.40*
Age (Young-Young, Older-Young)	1	0.00	0.00	55.65*
Group X Age	1	0.00	0.00	1.40
Error (within)	69	0.00	0.00	

Note. IHFA = Individuals with high-functioning autism. TDI = Typically-developing individuals. *$p < .001$

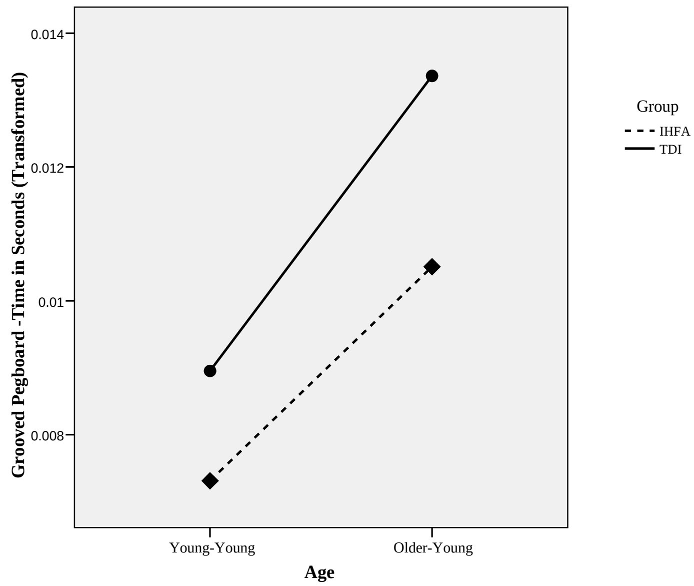

Figure 3-5. Grooved Pegboard (Transformed) differences between Individuals with High-Functioning Autism (IHFA) and Typically Developing Individuals (TDI) Groups

Table 3-13. *Descriptive and t-test Comparisons for the Grooved Pegboard (Transformed) for IHFA and TDI Groups*

	IHFA	TDI	*t*-test	*Effect size (r)*
Young- Young Age Group	n = 12	n = 12		
GP - Transformed, kg (*M*, *SD*)	.007 (.001)	.009 (.002)	-2.23*	.43
Older-Young Age Group	n = 23	n = 26		
GP - Transformed, kg (*M*, *SD*)	.012 (.002)	.013 (.002)	-4.63**	.56

Note. IHFA = Individuals with high-functioning autism. TDI = Typically-developing individuals. GP = Grooved Pegboard *$p = .018$ ** $p < .001$.

Table 3-14. *Descriptive Statistics for the Grooved Pegboard (Untransformed) for the IHFA and TDI Groups*

	IHFA	TDI
Young-Young Age Group	n = 12	n = 12
Grooved Pegboard, Time in Seconds (*M*, *SD*)	141.83 (28.67)	117.50 (27.63)
Older-Young Age Group	n = 38	n = 37
Grooved Pegboard, Time in Seconds (*M*, *SD*)	99.96 (22.61)	76.31 (11.17)

Note. IHFA = Individuals with high-functioning autism. TDI = Typically-developing individuals.

3.4.3 Sensory-Perceptual Measures

3.4.3.1 Reitan-Klove Finger Recognition (Errors)

The chi-square test (See Table 3-15) was significant, $x^2(3, N = 114) = 8.08$, $p = .04$, indicating that at least one of the four groups (IHFA-Young, IHFA-Old, TDI-Young, TDI-Old) was significantly different from the others on the Reitan-Klove Finger Recognition (RK-FR).

Table 3-15. *Frequencies of Reitan-Klove Finger Recognition by Group and Age*

Group	Age	Count/ %	RK-FR		Total	Fisher's Exact
			0	1		
IHFA	Young	Count	12	20	32	
		% within Group_Age	37.5%	62.5%		
IHFA	Old	Count	30	7	37	
		% within Group_Age	81.1%	18.9%		
TDI	Young	Count	16	19	35	
		% within Group_Age	45.7%	54.3%		
TDI	Old	Count	26	8	34	
		% within Group_Age	76.5%	23.5%		
Total			84	54	138	20.52*

Note. RK-FR = Reitan-Klove Finger Recognition. 0 = No errors. 1 = 1 or more errors. IHFA = Individuals with high-functioning autism. TDI = Typically-developing individuals. *$p < .001$.

Because of the significant chi-square test, a stepwise logistic regression (see Table 3-16) procedure was run for the RK-FR. The only predictor selected was age, indicating that neither group (IHFA, TDI) nor the interaction between group (IHFA, TDI) and age (Young, Old) significantly improved prediction after age was in the model. From looking at the frequencies in

Table 3-15 we can see that older participants performed significantly better than younger participants within both IHFA and TDI groups (Figure 3-6). The model with age as the only predictor was significantly better than a model with no predictors (chi-square=20.45, *p* < .001). However, examining the frequencies, we can see a larger difference between age groups (Young vs. Old) with respect to percentage of errors among IHFA than among TDI, 43.6 and 30.8, respectively. Furthermore, the results of the logistic regression showed that interaction (Group X Age) alone was a significant predictor even though it did not enter the model after age was entered.

Table 3-16. *Logistic Regression for the Reitan-Klove Finger Recognition*

	Variables in the Equation	Variables not in the Equation	Chi-square
Step 0	Constant	Group (IHFA, TDI) Age*** (Young, Old) Group X Age**	6.42*
Step 1	Age (Young, Old)	Group (IHFA, TDI) Group X Age	20.45***

Note. IHFA = Individuals with high-functioning autism. TDI = Typically-developing individuals. * p < .02 **p = .003***p <.001

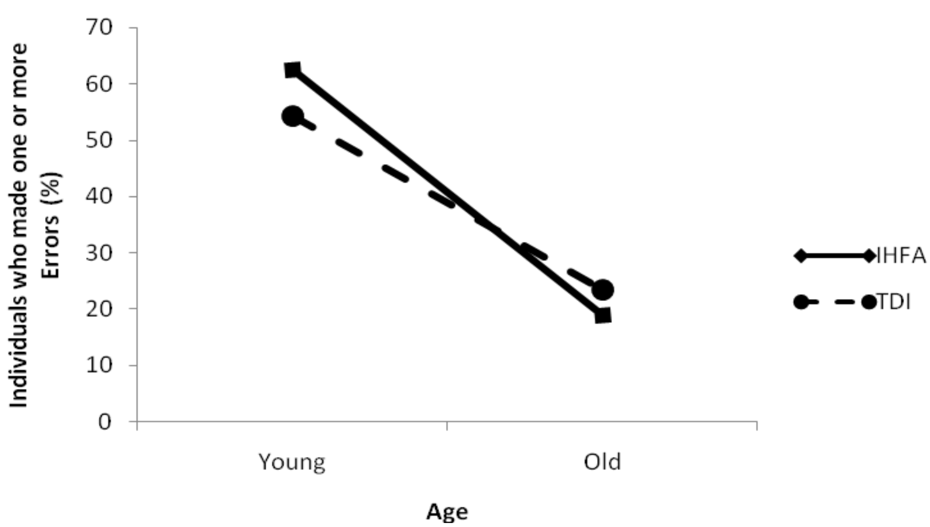

Figure 3-6. Frequencies of Individuals with High-Functioning Autism (IHFA) and Typically-Developing Individuals (TDI) who made one or more Errors on the Reitan-Klove Fingertip Number Writing

3.4.3.2 Reitan-Klove Fingertip Number Writing (Errors)

The ANOVA for the Reitan-Klove Fingertip Number Writing (RK-FTNW) was run on transformed data as the original data did not meet the assumptions of the ANOVA. Square root transformation was used. A 2 X 2 (Group X Age) between-subjects ANOVA (see Table 3-17) revealed a significant main effect for group, F (1, 133) = 6.47, *p* = .012. The main effect for age was not significant, F (1, 133) = .714, *p* = .40, nor was the group X age interaction, F (1, 133) = .087, *p* = .768 (see Figure 3-6). Although the main effect of group was significant, one tailed independent sample *t*-tests (with Bonferroni corrections; *p* < .025) revealed non significant differences between the two groups (IHFA vs. TDI) on the RK-FTNW for both the age groups; Young age group, *t*(64) = 1.78, *p* = .04, and for the Old age group, t(69) = 1.83, *p* = .036 (see Table 3-18). Descriptive statistics of the original data (i.e., before transformation) are provided in Table 3-19.

Table 3-17. *Analysis of Variance for Reitan-Klove Fingertip Number Writing Differences by Group and Age for IHFA and TDI Groups*

Analysis/Source	*df*	*SS*	*MS*	*F*
Group	1	13.28	13.28	6.47*
Age (Young, Old)	1	1.47	1.47	.71
Group X Age	1	.18	.18	.09
Error (within)	133	273.10	2.05	

Note. IHFA = Individuals with high-functioning autism. TDI = Typically-developing individuals. **p* < .001.

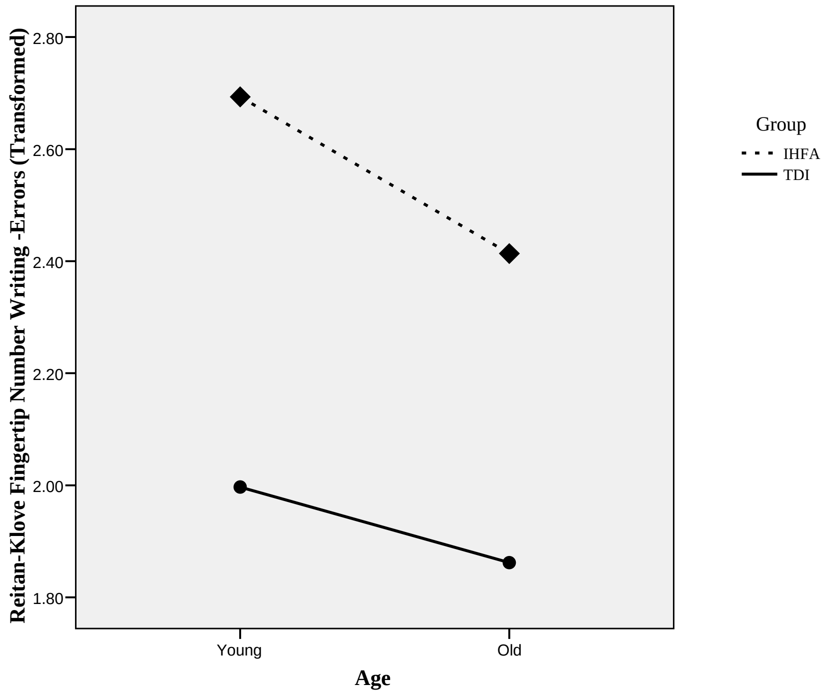

Figure 3-7. Reitan-Klove Fingertip Number Writing differences between Individuals with High- Functioning Autism (IHFA) and Typically Developing Individuals (TDI) Groups

Table 3-18. *Descriptive and t-test Comparisons for the Reitan-Klove Fingertip Number Writing (Transformed) for IHFA and TDI Groups*

	IHFA	TDI	*t*-test	*Effect Size (r)*
Young Age Group	n = 31	n = 35		
RK-FTNW - Transformed (*M*, *SD*)	2.69 (1.71)	2.00 (1.47)	1.77	.22
Old Age Group	n = 37	n = 34		
RK-FTNW - Transformed (*M*, *SD*)	2.41 (1.35)	1.86 (1.82)	1.84	.21

Note. IHFA = Individuals with high-functioning autism. TDI = Typically-developing individuals. RK-FTNR = Reitan-Klove Fingertip Number Writing.

Table 3-19. *Descriptive Statistics for the Reitan-Klove Fingertip Number Writing- Errors (Untransformed) for IHFA and TDI Groups*

	IHFA	TDI
Young-Young Age Group	n = 31	n = 35
RK- Fingertip Number Writing, Errors (*M*, *SD*)	10.10 (9.52)	6.09 (6.30)
Older-Young Age Group	n = 37	n = 34
RK- Fingertip Number Writing, Errors (*M*, *SD*)	7.59 (7.31)	4.82 (4.81)

Note. IHFA = Individuals with high-functioning autism. TDI = Typically-developing individuals.

3.4.3.3 Luria-Nebraska Simple Touch (Scaled)

The chi-square test was not significant, $x^2(3, N = 114) = 3.84, p = .27$. Thus no significant differences were found between the IHFA and TDI groups at the Young and Old age levels (Table 3-20).

Table 3-20. *Frequencies of Luria-Nebraska Simple Touch by Group and Age*

Group	Age	Count/ %	LN-Simple Touch		Total	Fisher's Exact
			0	1		
IHFA	Young	Count	18	7	25	
		% within Group_Age	72.0%	28.0%	100.0%	
IHFA	Old	Count	25	5	30	
		% within Group_Age	83.3%	16.7%	100.0%	
TDI	Young	Count	27	3	30	
		% within Group_Age	90.0%	10.0%	100.0%	
TDI	Old	Count	26	3	29	
		% within Group_Age	89.7%	10.3%	100.0%	
Total		Count	96	18	114	
		% within Group_Age	84.2%	15.8%	100.0%	3.84

Note. LN = Luria-Nebraska. 0 = No errors. 1 = 1 or more errors. IHFA = Individuals with high-functioning autism. TDI = Typically-developing individuals.

3.4.3.4 Luria-Nebraska Sharp-Dull Discrimination (Scaled)

The chi-square test was not significant, $x^2(3, N = 114) = 2.94, p = .41$. Thus no significant differences were found between the IHFA and TDI groups at the Young and Old age levels (Table 3-21).

Table 3-21. *Frequencies of Luria-Nebraska Sharp-Dull Discrimination by Group and Age*

Group	Age	Count/ %	LN-Sharp/Dull		Total	Fisher's Exact
			0	1		
IHFA	Young	Count	9	16	25	
		% within Group_Age	36.0%	64.0%	100.0%	
IHFA	Old	Count	15	15	30	
		% within Group_Age	50.0%	50.0%	100.0%	
TDI	Young	Count	14	16	30	
		% within Group_Age	53.3%	46.7%	100.0%	
TDI	Old	Count	17	12	29	
		% within Group_Age	58.6%	41.4%	100.0%	
Total		Count	57	57	114	
		% within Group_Age	50.0%	50.0%	100.0%	2.94

Note. LN = Luria-Nebraska. 0 = No errors. 1 = 1 or more errors. IHFA = Individuals with high-functioning autism. TDI = Typically-developing individuals.

3.4.3.5 Luria-Nebraska Position Sense (Scaled)

Due to lack of variability in the data for this measure, it was not possible to run any statistical analyses. (Please see Table 3-22 for frequencies)

Table 3-22. *Frequencies of Luria-Nebraska Position Sense by Group and Age*

Group	Age	Count/ %	LN-Position Sense		Total
			0	1	
IHFA	Young	Count	22	3	25
		% within Group_Age	88.0%	12.0%	100.0%
IHFA	Old	Count	30	0	30
		% within Group_Age	100.0%	0.0%	100.0%
TDI	Young	Count	30	0	30
		% within Group_Age	100.0%	0.0%	100.0%
TDI	Old	Count	29	0	29
		% within Group_Age	100.0%	0.0%	100.0%
Total		Count	111	3	114
		% within Group_Age	97.4%	2.6%	100.0%

Note. LN = Luria-Nebraska. 0 = No errors. 1 = 1 or more errors. IHFA = Individuals with high-functioning autism. TDI = Typically-developing individuals.

3.4.3.6 Luria-Nebraska Stereognosis (Scaled)

The chi-square test was significant, $x^2(3, N = 114) = 8.08$, $p = .04$, indicating that at least one of four groups (IHFA-Young, IHFA-Old, TDI-Young, TDI-Old) was significantly different from the others (Table 3-23).

Table 3-23. *Frequencies of Luria-Nebraska Stereognosis by Group and Age*

Group	Age	Count/ %	LN-Sharp/Dull		Total	Fisher's Exact
			0	1		
IHFA	Young	Count	19	6	25	
		% within Group_Age	76.0%	24.0%	100.0%	
IHFA	Old	Count	24	6	30	
		% within Group_Age	80.0%	20.0%	100.0%	
TDI	Young	Count	21	9	30	
		% within Group_Age	70.0%	30.0%	100.0%	
TDI	Old	Count	28	1	29	
		% within Group_Age	96.6%	3.4%	100.0%	
Total		Count	92	22	114	
		% within Group_Age	80.7%	19.3%	100.0%	8.08*

Note. LN = Luria-Nebraska. 0 = No errors. 1 = 1 or more errors. IHFA = Individuals with high-functioning autism. TDI = Typically-developing individuals. **p* = .04

For the stereognosis test, the stepwise logistic regression procedure selected the interaction between group (IHFA, TDI) and age (Young, Old) as the only predictor (Table 3-24). Figure 3-8 is a graph of the percentage of individuals who made at least one error. As shown in this graph, although it was significant, the interaction did not take the predicted form. It was hypothesized that there would be smaller differences between IHFA and TDI at the older age level than at the younger age level. Instead, the observed results showed greater differences at the older age level. In other words, among TDI a noticeable improvement occurs with age, but this does not happen among IHFA.

Table 3-24. *Logistic Regression for Luria-Nebraska Stereognosis*

	Variables in the Equation	Variables not in the Equation	Chi-square
Step 0	Constant	Group (IHFA, TDI) Age* (Young, Old) Group X Age**	36.34***
Step 1	Group X Age	Group (IHFA, TDI) Group X Age	8.91*

Note. IHFA = Individuals with high-functioning autism. TDI = Typically-developing individuals. * *p* < .04 ***p* < .03****p* <.001

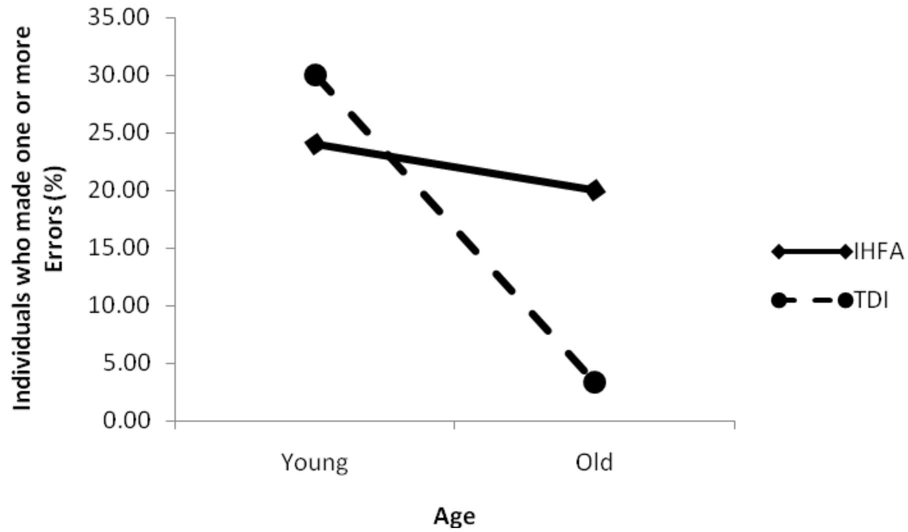

Figure 3-8. Frequencies of Individuals with High-Functioning Autism (IHFA) and Typically-Developing Individuals (TDI) who made one or more Errors on the Luria-Nebraska Stereognosis

3.5 DISCUSSION

This study compared the differences in motor and sensory-perceptual skills of IHFA and TDI across different age groups. Several studies have assessed these skills with different age groups, however, to our knowledge, no study had a combined group of children, adolescents, and young adults rigorously diagnosed with HFA and an age-matched TDI sample. Our hypothesis for motor skills, that IHFA would demonstrate lower levels of motor skills (simple and complex), but that they would parallel their TDI age peers was supported, with the exception of the simple fine motor skills (FTT) which demonstrated no significant difference between IHFA and TDI for children from 5.00 - 11.99 years of age. As for sensory-perceptual skills, our hypothesis that the IHFA group would have lower levels of sensory-perceptual skills and that the differences between groups would be greater for younger children than older children was not supported for simple and complex sensory-perceptual skills. The abilities to localize touch stimulation, differentiate sharp from dull surfaces, and recognize a number written on the fingertip while blindfolded were similar in IHFA compared to age-matched TDI. The ability to recognize which finger is touched (as measured by RK-FR test) showed significant improvement over time for both the IHFA and the TDI, however, differences between both groups were not detected at any age level. Our hypothesis was also not supported for the more complex skill of stereognosis (LN- Stereognosis test) as improvements in stereognosis with age were seen only for TDI group, but not the IHFA group.

Our findings regarding grip strength are consistent with previous literature (Hardan et al., 2003; Williams et al., 2006) and extend the body of knowledge to a younger age. Our findings indicate that weaknesses in grip strength seems to be apparent from a young age for children with HFA and persist through adolescence. Although considered a simple motor skill, the importance of adequate grip strength cannot be overlooked. In general, grip strength is considered an objective measure of the upper extremity functional integrity (Balogun, Akomolafe, & Amusa, 1991). Fair grip strength is essential for independence in early childhood functional tasks such as eating and playing (Hager-Ross & Rosblad, 2002). In addition, development of small muscles and the ability to hold writing utensils are considered primary for handwriting readiness (Amundson, 2005). In children with handwriting difficulties, occupational therapists use activities that encourage total and isolated hand muscle strengthening in preparation for functional use of the hand. Muscle strength was also found to correlate with functional status in a population of community dwelling older adults (Hyatt, Whitelaw, Bhat, Scott, & Maxwell, 1990). Weaknesses in grip strength in IHFA might be explained by the presence of hypotonia that is evident in some children with autism (Ming, Brimacombe, &

Wagner, 2007, Rapin, 1996), which usually modulates with age, and thus this explanation would not apply to adults with autism.

Our findings regarding complex fine motor and manual dexterity skills are consistent with previous research, and add to the body of knowledge. Williams et al. (2006) found non significant differences between children with HFA and TD children on simple motor skills (as measured by FTT), while Takarae et al (2004) found adults with HFA and TD adults to be significantly different on the same skill. Our findings indicated that IHFA adolescents performed significantly worse than TD adolescents on the FTT. Likewise, our findings that impairments in complex manual dexterity and psychomotor skills in IHFA, as measured by the GP, were consistent with previous research. However, we also extended knowledge about the impairments of such skills to a younger age. For younger children with HFA, these findings conform to the complex information processing disorder model (Minshew & Goldstein, 1998) in which simple functions are preserved in IHFA (such as those measured by the FTT) while impairments appear at a higher more complex level of functioning (GP). However, for older IHFA our findings were in contrast to this model, because the adolescents/young adults demonstrated impairment on the simple functions measured by the FTT.

Finally, the results of the sensory-perceptual measures were conflicting, and yielded rather unexpected results. While impairment on simple sensory-perceptual measures were expected to be apparent in our younger group and become less evident with age, no group differences were found for simple touch, sharp/dull discrimination, or RK-FR. Only RK-FR showed a significant age effect for both IHFA and TDI. For the complex sensory-perceptual skills the results were more conflicting with the RK-FTNW showing no group differences for either the younger or the older groups. This finding is inconsistent with previous research

(Minshew et al., 1997; Rumsey & Hamburger, 1988, Williams et al., 2006) and does not conform to the model of complex information processing. Stereognosis skills also showed a surprising pattern with no significant differences between the two younger groups (IHFA, TDI), but significant differences were found in the older groups (TDI > IHFA). Stereognosis is considered one of the higher sensory-perceptual skills, as it relies on higher cognitive functions in addition to intact tactile sensation. Stereognosis, along with other sensory-perceptual skills, was found to successfully discriminate between children with HFA and TD children (kappa = .44; Williams et al. 2006), however, it did not pass the tolerance test for discriminant analysis for adults with HFA. Our findings are in contrast to these, suggesting that some element of stereognosis impairment may also be evident for older IHFA.

In conclusion, based on our study and previous research, impairment in simple and complex motor skills is apparent in IHFA across childhood, and persists through adolescence, and early adulthood and should be of concern to clinical professionals working with this population. Although sensory-perceptual impairments were not as apparent, our findings were not always consistent with previous research, suggesting that with age, these skills may be consistent with those of their older age-matched peers, except for stereognosis.

3.5.1 Clinical Implications

One of the key findings of this study was confirmation of the presence of motor impairments in very young IHFA. This finding has an important implication for practitioners working with IHFA in that assessment and remediation of such skills should begin as early as these impairments can be detected. Grip strength, in specific, holds a great promise for change in young children with HFA, as improvement of grip strength may lead to greater independence in functional activities. Occupational therapists are trained to address impairments in fine-motor functioning and the factors underlying these impairments. For example, in school settings, occupational therapy provides children exhibiting poor grip strength with an array of preparatory activities that aim to enhance muscle strength and ultimately enable functional tasks in the classroom such as handwriting and use of scissors.

Findings of sensory-perceptual skill impairments also indicate the importance of the assessment of such skills, especially for the higher and more complex sensory processing skills. When complex tactile discrimination is deficient, this reduces the integration of sensory input into the system, thus reducing the capacity for adaptation. The integration of inappropriate and distorted sensory-perceptual skills have been correlated with behavioral rigidities in individuals with autism (Baranak, Foster, & Berkson, 2005). Occupational therapists have knowledge of a wide array of sensory-perceptual distortions (e.g., body image, letter reversals, spatial relationships for arithmetic) as well as remedies of such impairments. It is important that early detection and continuous reassessment of such skills occurs throughout elementary and middle schools years, since our findings indicated that some of these skills may persist through early adulthood.

3.5.2 Limitation and Future Research Recommendation

One of the major limitations of this study is its cross-sectional design which lends itself to limited generalizability regarding causal inferences, because the trajectory and exposure to interventions are unknown. Ideally, longitudinal studies offer the best methodology to study developmental trajectories as they control for individual variation with different age groups. Another limitation is sample size, particularly after dividing our two groups into further distinct age groups, yielding small sample sizes that might not be powerful enough to detect differences. Also, with small sample sizes we were not able to analyze some data, as was the case for the LN-Position Sense, since we had low frequencies in some cells which prevented any statistical analyses. As with any secondary analysis, we were limited by the variables in the original datasets.

4.0 FACTORS ASSOCIATED WITH THE INTEGRITY OF FINE MOTOR SKILLS

Motor abnormalities in individuals with high-functioning autism (IHFA) have been well documented in the literature (Ghaziuddin, Butler, Tsai, & Ghazuiddin, 1994; Jansiewicz et al., 2006; Mandelbaum et al., 2006; Manjiviona & Prior; 1995; Minshew, Goldstein, Munez, Payton, 1992; Minshew, Goldstein, & Seigel, 1997; Rumsey & Hamburger, 1988; Smith & Bryason, 1998; Williams, Goldstein, & Minshew, 2006). However, most studies of motor functioning have focused on children and young adolescents with HFA, whereas very few studies examined adults with HFA. Nonetheless, tests of motor integrities have ascertained abnormalities in motor skills across the age span for IHFA.

Integrity of fine-motor skills is fundamental for participation in school activities. Fine-motor activities consume 45% -55% of the school day for first and second grade children and 30 – 60% for fourth grade children (McHale & Cermak, 1992). Paper and pencil tasks account for most fine-motor activities for these grades. Although the use of fine-motor skills changes for older children in middle school, these children still rely on fine-motor skills for science projects, art classes, vocational courses, etc. In addition, older children are expected to execute tasks at a faster pace, which makes mastering fine-motor skills a necessity (Exner, 2005; McHale & Cermak, 1992).

In adults, the effect of fine-motor skills integrity expands beyond school to job placements. Although fine-motor skills requirements are variable among different occupations, an acceptable proficiency of these skills is important for successful work placement. Thus, the specific application of fine-motor skills may change, the general effect of impairment of these skills can be severely limiting across the entire lifespan of an individual.

Several studies suggested the presence of fine-motor impairments in IHFA, however, there is a lack of evidence regarding the factors and processes that contribute to these impairments (Baranek, Parham, & Bodfish, 2005). An understanding of such factors and processes will enhance assessment and intervention planning and implementation. Whether in school or in work, occupational therapists (OT) have an important role in assessing motor skills and planning interventions to remediate motor abnormalities. With in-depth knowledge of both motor development and the effects of motor processes on function, OT are trained to address motor impairments to improve everyday functioning.

In this chapter we will examine the factors that contribute to good and poor performance on a valid and reliable measure of complex fine-motor skills, the Grooved Pegboard (GP). Performance on the GP will be analyzed in relation to several neuropsychological measures of motor skills, sensory-perceptual skills, simple and complex language, simple and complex memory, and executive functioning (EF)/ problem-solving skills, as well as demographic variables, in IHFA and in typically developing individuals (TDI). The results from both groups will be described and compared to each other. In lieu of an a priori hypothesis of what factors will be more strongly associated with the performance of the GP for each group, an exploratory approach was implemented to allow all possible factors to emerge in the analyses.

4.1 METHODS

4.1.1 Study Design

The aim of this study was explored through secondary analyses of the neuropsychological data collected as part of a larger study supported by the National Institute of Mental Health (MH40858). Neuropsychological data from both IHFA and TDI were examined in this study to explore the association between fine-motor skills (target variable) and motor skills, sensory skills, simple and complex language, simple and complex memory, and EF/problem-solving skills (predictor variables) utilizing Exhaustive Chi-Square Automatic Interaction Detection (CHAID). The associations were displayed in two separate models; one for IHFA and one for TDI, and the models were then compared.

4.1.2 Participants

The study involved community dwelling IHFA and TDI. Recruitment of IHFA was initiated by printed advertisements, website postings, and educational seminars geared toward parents and professionals working with IHFA. Inclusion criteria for IHFA were: (a) met the cutoff score for autism on the Autism Diagnostic Observation Schedule (ADOS), (b) met the cutoff score for autism on the Autism Diagnostic Interview-Revised (ADI-R), and (c) had a full IQ, verbal IQ, and performance IQ of over 80. IHFA were excluded if they exhibited any genetic, neurologic, metabolic, or infectious condition or had a history of seizures, birth injury, or head trauma.

The TDI were community volunteers recruited through general advertisements. Inclusion criteria for TDI were: (a) good physical health, (b) no regular medication use, and (c) good relationship with peers as reported by parents and observed by staff during eligibility testing. TDI were excluded if they exhibited any birth or developmental disabilities, a history of, or current psychiatric or neurological disorders, or had a first-, second-, or third- degree relative with autism.

4.1.3 Instrumentation

4.1.3.1 CHAID Target Variable: The Grooved Pegboard (GP)

The GP is used widely to assess psychomotor speed, praxis, eye-hand coordination, and manipulative dexterity (Baron, 2004; Conoley, Imapara, & Murphy, 1995). The test consists of a small board of 25 holes (5 x 5 set). The holes are angled in various directions,the pegs have a keyhole shape and rotation of pegs is necessary for full insertion. When administering the test, the pegboard is positioned in mid-line with the examinee, with the peg tray immediately above the board (Lafayette Instrument Company). The examinee is asked to fully insert the pegs into the holes finishing row by row as quickly as possible. For children under the age of 9 years, only the first two rows are expected to be filled (10 pegs). Only one hand is used in a single trial. The examinee picks up more than one peg at a time. The dominant hand is always tested first.

Normative data were established on 2,000 subjects in three different categories; adult (age 15 years and above), adolescent (age 9 - 14 years), and kiddie (age 5 years to 8 years and 12 months) (For a full review of normative data please see Mitrushina, Boone, Razani, & D'Elia, 2005). The test yields three scores: (1) time to completion (seconds), (2) number of drops, and (3) the number of pegs correctly placed. Completion time is the widely used score in neuropsychological studies.

Validity

Two studies (no reference given) cited in the 12th mental measurements yearbook (Conoley, Impara, & Murphy, 1995)p. 430) explored the utility of the GP in discriminating TD children from children with “suspected neurological dysfunction”, “minimal cerebral dysfunction”, and head injury. Both studies found that the GP adequately differentiated TD children from the other groups. Children with severe head injury were also differentiated from children with mild and moderate head injury with the GP (Knights et al., 1991).

Studies with adults found performance on the GP being significantly slower in patients with multiple sclerosis compared to patients with other neurological disorders (Matthews, Cleeland, & Hopper, 1970). Another study found individuals with unilateral hemispheric stroke or tumor to be impaired on the GP compared to controls who had no neurological impairments (Haaland & Delaney, 1981).

Reliability

Test-retest reliabilities were explored in different studies. Knights and Moule (1968) tested 40 children and adolescents with suspected neurological dysfunction (age range 8 to 15 years), however, they used data from before and after a 6-week trial of Ritalin. Completion time reliability coefficients for the preferred and non-preferred hands were r = .80 and .81, respectively. Test-retest reliabilities, for an interval of 5.4 months, of 121 TDI (mean age: 43.6 years) were r = .86 for both hands (Dikmen, Heaton, Grant, & Temkin, 1999).

4.1.3.2 CHAID Predictor Variables

The predictor variables of fine-motor skills included several neuropsychological measures from motor, sensory-perceptual, language, memory, problem solving/executive functioning, and visual spatial domains, demographic variables of age, socioeconomic status (SES), gender, handedness, and education level, as well as the Wechsler Intelligence Scale for Children – R (WISC-R) and the Wechsler Adult Intelligence Scale – R (WAIS-R) (Table 4-1). A brief description of the neuropsychological measures is provided in Appendix A.

Neuropsychological test assignment to different domains was based on recognized classification systems (Baron, 2004; Lezak, Howieson, & Loring, 2004), followed previously published categorization, and communication with local experts (Minshew, et al., 1992; Minshew, et al., 1997; Williams, et al., 2006).

Table 4-1. *Predictor Variables of Fine Motor Skills*

Domain and Variables
Demographics
Age (Years)
Socioeconomic Status
Gender
Handedness
Education Level (Number of years completed in school)
WISC-R/WAIS-R Intelligence Scales
IQ – Full Scale (FS- IQ)
IQ – Verbal Scale (V-IQ)
IQ – Performance Scale (P-IQ)
Attention Domain
WISC-R/WAIS-R Digit Span subtest
Continuous Performance Test (mean reaction time correct responses)
Number Cancellation – Page 1 (omissions)
Number Cancellation – Page 1 (Time in Seconds)
Sensory Domain
Luria-Nebraska Simple Touch (raw score)
Luria-Nebraska Stereognosis (raw score)
Luria-Nebraska Sharp-Dull Discrimination (raw score)
Luria-Nebraska Position Sense (raw score)
Reitan-Klove Finger Recognition (raw errors)
Reitan-Klove: Fingertip Number Writing (errors)
Motor domain
Finger Tapping – Dominant Hand (Time in seconds)
Finger Tapping – Nondominat hand (Time in seconds)
Grip Strength – Dominant Hand (Kilograms)
Grip Strength – Nondominant Hand (Kilograms)
Grooved Pegboard – Nondominant hand (Time in seconds)
Developmental Test of Visual Motor Integration (Total points)
WISC-R/WAIS-R Coding Subtest

Trail Making Test A (Time in seconds)

Simple Language Domain

- WISC-R/WAIS-R Vocabulary subtest
- Kaufman Test of Educational Achievement – Reading Decoding
- Kaufman Test of Educational Achievement – Spelling
- Verbal Fluency Test – FAS (number of words)
- Woodwock Reading Mastery – Word Attack (standard score)

Complex Language Domain

- Test of Language Competence - Figurative Language (scaled score)
- Test of Language Competence – Making Inferences (scaled score)
- Test of Language Competence – Metaphoric Expression (scaled score)
- Woodwock Reading Mastery – Passage Comprehension (standard score)
- Kaufman Test of Educational Achievement – Reading Comprehension
- Stanford- Binet- IV Verbal Absurdities (raw score)*
- Detroit Test of Learning Aptitude -2: Oral Directions
- Token Test (number correct)

Simple Memory Domain

- Maze Learning Trial 1 (errors)
- Maze Recall (correct/incorrect)
- Paired-Associate Learning (number correct)
- CVLT A List – Trial 1 (number correct)
- WRAML Verbal Index (scaled score)
- WRAML Learning Index (scaled score)

Complex Memory Domain

- Paired-Associate – Delayed Recall
- CVLT A List – Long Delay
- Nonverbal Selective Reminding – Consistent Long Term Retrieval
- WRAML Visual Index (scaled score)
- Rey – Osterrieth Figure – Delayed Recall (number of elements)

Executive Functioning/ Problem-Solving Domain

- Trail Making Test – B (time in seconds)
- Wisconsin Card Sorting Test (preservative errors)
- Stanford – Binet IV Picture Absurdities (raw score)
- Stanford – Binet IV Problem Situation 1 & 2
- Stanford – Binet IV Plan of Search (correct/incorrect)
- Contingency Naming Trial 1 (Time in seconds)
- Contingency Naming Trial 1 (Self-corrections)
- Contingency Naming Trial 1 (Errors)
- Contingency Naming Trial 2 (Time in seconds)
- Contingency Naming Trial 2 (Self-corrections)
- Contingency Naming Trial 2 (Errors)
- Contingency Naming Trial 3 (Time in seconds)
- Contingency Naming Trial 3 (Self-corrections)
- Contingency Naming Trial 3 (Errors)
- Contingency Naming Trial 4 (Time in seconds)
- Contingency Naming Trial 4 (Self-corrections)
- Contingency Naming Trial 4 (Errors)
- 20 Questions (% constraint seeking)

Visual-Spatial Domain

WISC-R/WAIS-R Picture Completion
WISC-R/WAIS-R Object Assembly
WISC-R/WAIS-R Block Design
Rey- Osterrieth Copy

Note. WISC-R = Wechsler Intelligence Scale For Children – Revised. WAIS-R = Wechsler Adult Intelligence Scale – Revised. CVLT = California Verbal Learning Test. WRAML = Wide Range Assessment of Memory and Learning. * Also considered a test of concept formation

4.2 DATA ANALYSES

Exhaustive Chi-Square Automatic Interaction Detection (CHAID) was used to identify factors associated with good and poor performance (i.e., more favorable outcomes; less favorable outcomes) on the GP, using SPSS AsnwerTree 3.1 (SPSS Inc., 2001). CHAID examines the relations between multiple independent predictor variables (categorical or continuous) and a single target outcome measure. The end result is a model delineating these relationships, and identification and categorization of predictor variables that are significantly associated with the target outcome measure (SPSS Inc. 2001). Two models were generated: one for IHFA, and one for the TDI.

Exhaustive CHAID was used because it is exploratory, and uses iterative processes, thus enhancing the possibility of finding more variables that predict, or are associated with more and less favorable outcomes of the target outcome. CHAID automatically applies Benferroni adjustments to account for the multiple iterative testing processes that it performs. However, with small sample sizes it is recommended to turn that feature off in order to increase the power of the analysis, which we did. In this study, the target outcome was the GP time (seconds) for the dominant hand.

Validation of the models generated by Exhaustive CHAID analyses was conducted through the *n*-fold cross-validation procedure. Validation assesses the generalizability of the models from the used sample to a larger sample (SPSS Inc., 2001). The *n*-fold cross validation procedure involves randomly dividing the sample into smaller subsamples over which the model is regenerated. The number of subsamples is defined by the researcher and each model that is generated excludes the data from each subsample in turn (SPSS Inc., 2001). The output of the cross-validation procedure is a table displaying the Risk Estimate and the Standard Deviation (SD) of the Risk Estimate for the Risk Statistics and Cross-validation. The closer the values of the Risk Estimate for the Risk Statistics and Cross-validation, the stronger the predictive value of the model is (SPSS Inc., 2001).

4.3 RESULTS

4.3.1 Participants

One hundred ten participants met the inclusion and exclusion criteria. The sample characteristics, by group, are outlined in Table 4-2. The IHFA group was predominantly males (92.70%) with a mean age of 15.80 years. The mean educational level for IHFA was 7.38 years. The Full Scale IQ (FS-IQ) was 100.96, Verbal IQ (V-IQ) scale was 103.02, and the Performance IQ (P-IQ) scale was 98.56. Males were predominant in the TDI group as well (89.10 %) with a mean age of 16.26 years. The mean educational level was 7.84 years. The values for the FS-IQ, V-IQ, P-IQ were 102.12, 102.71, and 100.96, respectively. The two groups did not differ significantly on demographic characteristics or intelligence scales (see Table 4-2)

Table 4-2. *IHFA and TDI Characteristics*

	IHFA n = 55	TDI n = 55	Significance
Male (%)	92.70	89.10	.51
Age, years (*M*, *SD*)	15.80 (9.67)	16.26 (10.16)	.81
SES (*M*, *SD*)	3.42 (1.50)	3.40 (1.44)	.95
Educational Level, years completed	7.38 (5.06)	7.84 (5.22)	.64
FS-IQ (*M*, *SD*)	100.96 (12.95)	102.12 (12.80)	.94
V-IQ (*M*, *SD*)	103.02 (15.58)	102.71 (13.22)	.91
P-IQ (*M*, *SD*)	98.56 (11.35)	100.96 (11.48)	.27

Note. IHFA = Individuals with high-functioning autism. TDI = Typically developing individuals. SES = Socioeconomic status measured on a scale from 1 to 7 where 1 is the highest and 7 is the lowest. FS-IQ = full-Scale IQ. V-IQ = verbal IQ. P-IQ = performance IQ.

4.3.2 Fine Motor Skills: CHAID Analysis for Individuals with High Functioning Autism

In the IHFA model (see Figure 4-1), the factor most strongly associated with performance on the GP --dominant hand (GP-D; time in seconds) was education level, measured by number of years of school completed, $F(2,52) = 40.06$, $p < .001$. Education level divided our sample into three subsamples; less than one year of schooling (GPA I, n = 10), 2 to 11 years of schooling (GPA II, n = 32), and more than 11 years of schooling (GPA III, n = 13). Time needed to perform the GP-D decreased as education level increased; GPA I = 148.00 seconds, GPA II = 95.84 seconds, GPA III = 77.69 seconds.

Among those IHFA in GPA I (mean age: 6.52 years, mean education level: 0.5 year), the number of errors made on the Maze Learning (ML) test was the next strongest factor associated with performance on the GP-D, $F(1,8) = 8.40$, $p = .02$, dividing GPA I into two subsamples. Children with HFA who made more than 6 errors on the ML (GPA Ia; n = 5, mean age: 6.20 years, mean education level = 0.40 years, mean ML = 14.60) were slower on the GP-D (166.60 seconds) compared to children with HFA who made 6 or fewer errors on the same test (GPA Ib;

n = 4, mean age: 6.98 years, mean education level = 0.50 years, mean ML = 3.75) (128.00 seconds).

The WISC-R/WAIS-R Object Assembly Subtest (WW-OAS) further differentiated the 32 IHFA (mean age: 13.06 years, mean education level: 6.94 years) in the GPA II into three subsamples, F (2,29) = 9.16, p < .001. IHFA who scored 9 or less on the WW-OAS (GPA IIa; n = 13, mean age: 14.85 years, mean education level = 8.54, mean WW-OAS score = 6.31) were faster on the GP-D (91.62 seconds) compared to IHFA who scored 10 or 11 on the same subtest (GPA IIb; n = 11, mean age: 11.28 years, mean education level = 5.09 years, mean WW-OAS score = 10.45) (110.36 seconds). However, IHFA who scored 12 or greater on the WW-OAS (GPA IIc; n= 8, mean age: 12.61, mean education level: 6.88, mean WW-OAS score = 14) were the fastest (82.75 seconds).

Of those who scored 9 or less on the WW-OAS (GPA IIa), the Number Cancellation Test – Page 1 Total omissions (NCT-TO) was the next strongest predictor of performance on the GP-D, F (1,11) = 9.01, p = .01. IHFA who made 3 or 4 omissions (GPA IIa1; n = 5, mean age: 15.10 years, mean education level: 8.80 years, NCT-TO = 3.6) were slower on the GP-D (105.00 seconds) compared to IHFA who made 2 omissions or less (GPA IIa2; n= 7, mean age: 15.59 years, mean education level = 9.14, mean NCT-TO = 1.0) (82.71 seconds).

Preservative Errors (PE) on the Wisconsin Card Sorting Test (WCST) further differentiated our IHFA in the GPA III (mean age: 29.65 years, mean education level: 13.77) into two subsamples, F (1,11) = 5.83, p = .03. IHFA who had more PE on the WCST (GPA IIIa; mean age: 27.83, mean education level: 12.80, mean PE-WCST: 20.20) were faster on the GP-D (67.20 seconds) compared to IHFA who had 10 or less PE on the WCST (GPA IIIb; mean age: 30.79, mean education level: 14.38, mean PE-WCST: 7.50) (84.25 seconds).

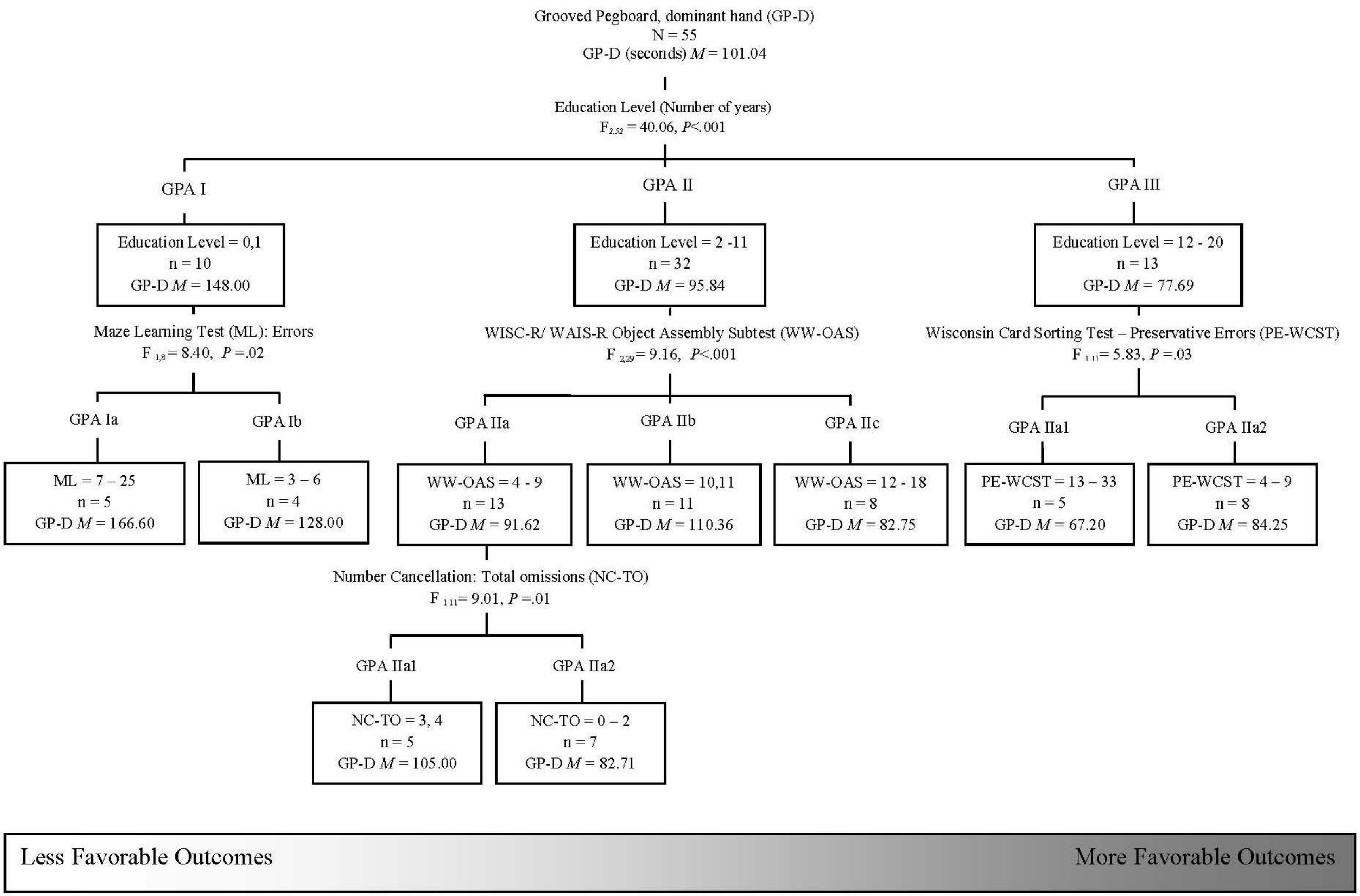

Figure 4-1. Factors Associated with Fine-Motor Skills for Individuals with High-Functioning Autism

4.3.3 Fine-Motor Skills: CHAID Analysis for Typically Developing Individuals

Factors associated with more or less favorable outcomes on the GP-D (time in seconds) for TDI (see Figure 4-2) were quite different from those in the IHFA model. Age (years) was the factor most strongly associated with performance on the GP-D, dividing our sample into two subsamples, $F(1,53) = 122.97$, $p < .001$. TDI 7.42 years and younger (GPC I) were significantly slower on the GP-D (123.09 seconds) compared to TDI older than 7.42 years (GPC II, 74.45 seconds).

Among those participants in GPC I (mean age: 6.50 years), the Contingency Naming Test (CNT; Trial 1, time in seconds) was the next strongest factor associated with performance on the GP-D, $F(1,9) = 7.78$, $p = .02$, dividing GPC I into two subsamples. There was an inverse relationship between the GP-D and the CNT where TDI who performed slower on the CNT (GPC Ia; $n = 5$, mean age: 6.60, mean CNT = 42.80) were faster on the GP-D (106.60 seconds), and TDI who were faster on the CNT (GPC Ib; $n = 5$, mean age: 6.38 years, mean CNT = 26.40) were slower on the GP-D (139.60 seconds).

Performance on the GP by the non-dominant hand (GP-ND; time in seconds) differentiated the 44 TDI (mean age: 18.70 years) in the GPC II into three subsamples; GPC IIa ($n = 5$), GPC IIb ($n = 28$), and GPC IIc ($n = 11$), $F(2,41) = 16.39$, $p < .001$. There was a direct relationship between the GP-D and the GP-ND, as TDI who were slowest on the GP-ND (GPC IIa; mean age: 11.77 years, mean GP-ND = 115.60 seconds) were also the slowest on the GP-D (87.40). TDI in the GPC IIb subsample (mean age: 18.04 years, mean GP-ND = 81.36 seconds) were faster than the GPC IIa subsample and slower than the GPC IIc subsample (75.36 seconds).

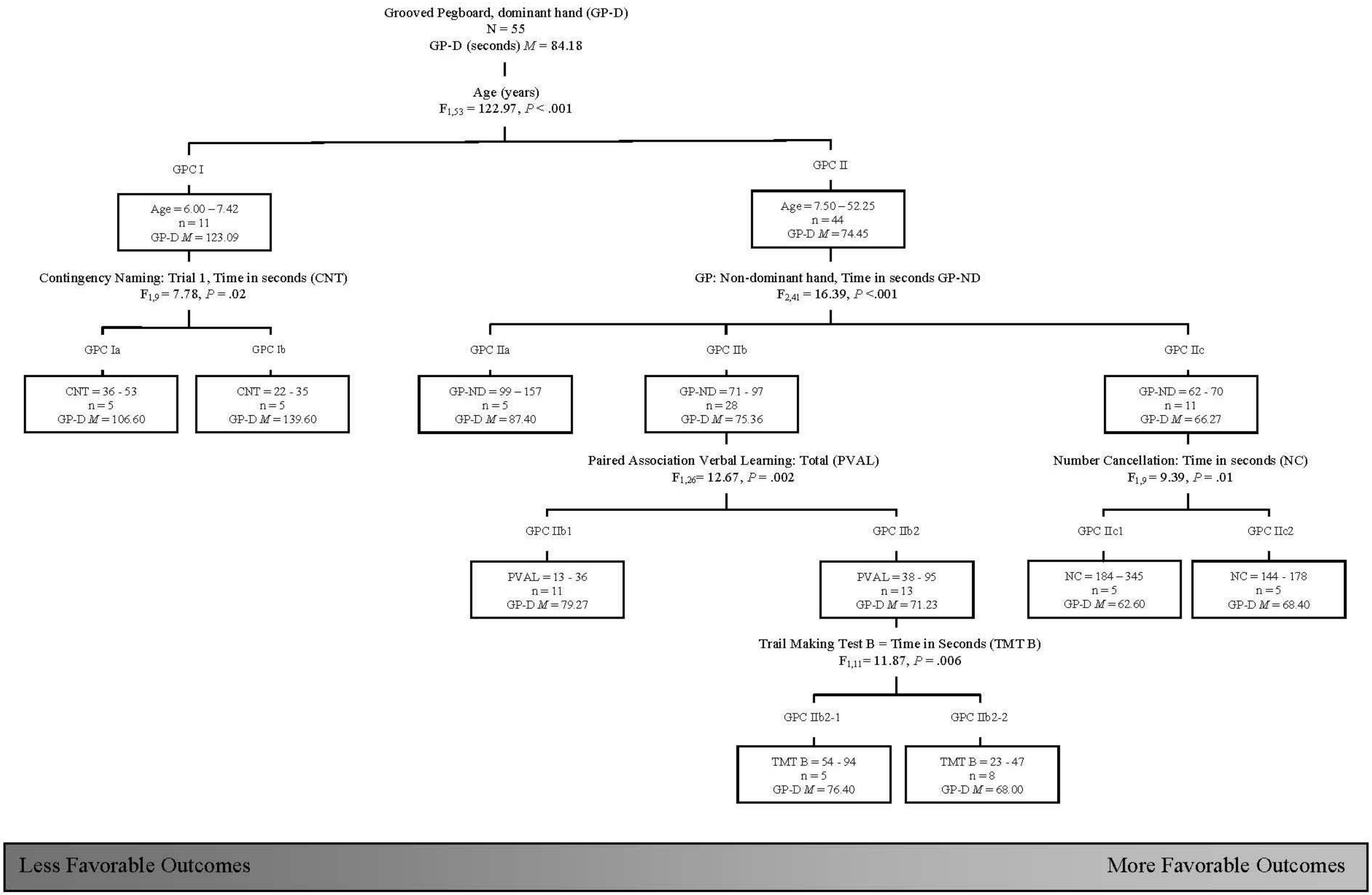

Figure 4-2. Factors Associated with Fine-Motor Skills for Typically Developing Individuals

The GPC IIc subsample (mean age: 23.52 years, mean GP-ND = 66.82 seconds) was also the fastest on GP bilaterally (GP-D dominant = 66.27 seconds).

Paired Associate Verbal Learning (PVAL; total correct) further divided TDI in GPC IIb into two subsamples; GPC IIb1 (n = 11) and GPC IIb2 (n = 13). TDI who recalled fewer words on the PVAL (GPC IIb1; mean age: 17.33 years, mean PG-ND = 85.00 seconds, mean PVAL = 26.27) were slower on the GP-D (79.27 seconds) compared to TDI who recalled more words on the PVAL (GPC IIb2; mean age: 21.76, mean PVAL = 61.53, mean GP-ND = 79.07) (71.23 seconds).

Trial Making Test B (TMT B; total time in seconds) further differentiated TDI in the GPC IIb2 into two subsamples; GPC IIb2-1 (n = 5) and GPC IIb2-2 (n = 8). There was a direct relationship between the GP-D and the TMT B where TDI who were slower on the TMT B (GPC IIb2-1; mean age: 30.11 years, mean GP-ND = 81.80, mean PVAL = 70.40, mean TMT B = 67.80 seconds) were also slower on the GP-D (76.40 seconds) and TDI who were faster on the TMT B (GPC IIb2-2; mean age: 15.57 years, mean GP-ND = 77.38, mean PVAL = 56.00, mean TMT B = 36.25) were also faster on the GP-D (68.00 seconds).

TDI who were the fastest on the GP (GPC IIc) were further differentiated into two subsamples by their speed on the Number Cancellation (NC) test. There was an inverse relationship between the NC and the GP-D where TDI who were slower on the NC (GPC IIc1; mean age: 22.25 years, mean GP-ND= 67.00 seconds, mean NC = 244.80 seconds) were faster on the GP-D (62.60 seconds) and TDI who were faster on the NC (GPC IIc2; mean age: 26.18 years, mean GP-ND = 66.20, mean NC = 162.00) were slower on the GP (68.40 seconds).

4.3.4 Validation of the Models

Tables 4-3 and 4-4 outline the results obtained from the *n*-fold cross-validation procedure for the IHFA model and the TDI model, respectively. The number of folds was set at 10 for each model. As displayed in the tables the values of the Risk Estimates for the Risk Statistics and Cross-validation were fairly close indicating stronger validity of the models.

Table 4-3. *Cross-Validation Results for the IHFA Model*

	Risk Statistics	Cross-Validation
Risk Estimate	177.10	169.12
Standard deviation of Risk Estimate	30.57	49.68

Note. IHFA = Individuals with high-functioning autism.

Table 4-4. *Cross-Validation Results for the TDI Model*

	Risk Statistics	Cross-Validation
Risk Estimate	71.79	78.92
Standard deviation of Risk Estimate	29.34	34.16

Note. TDI = Typically-developing individuals.

4.4 DISCUSSION

The purpose of this study was to identify predictors associated with a fine-motor praxis outcome in samples of IHFA and TDI from a wide age range. To our knowledge, factors that affect fine-motor skills, as measured by the GP-D, have not been studied in IHFA, nor compared to factors that affect the same skills in TDI. Our study demonstrated that differential GP-D performance could be predicted for IHFA and TDI by age, education, attention, memory, visual-spatial, problem-solving, and executive functioning skills. Furthermore, a pattern of parallel development of many factors emerged in the TDI model, but not in the IHFA model. These results indicate that factors associated with more or less favorable fine-motor skill development differ between IHFA and TDI.

The strongest predictors in the two models juxtaposed age with education. We found that education (a structured experience) had the strongest predictive value in IHFA, whereas age in years (a variable independent of structure) held stronger predictive value in TDI. This finding suggests that structured educational experiences contributed more to the fine-motor development of IHFA than did chronological age, as in TDI

By the eighth birthday, sensorimotor functions are considered to be consolidated in TDI (Parham & Mailloux, 2005, p. 364). Consistent with this, we found our TDI were split into two subsamples, with TD children 7.42 years and younger being significantly slower on the GP-D compared to those older than 7.42 years. Moreover, although the children in the lower educational level group of the IHFA model matched the ages of the younger children in the TDI model, the IHFA group was slower. Similarly, the older TDI were faster on the GP-D than the two upper educational levels of IHFA. These two findings are consistent with previous research which found IHFA performing slower on the GP-D compared to TDI (Minshew, et al., 1997; Williams et al., 2006).

The disparity between IHFA and TDI in age versus education suggests that IHFA derive certain fine motor skill developmental influences from a structured environment (i.e., years of education), whereas TDI obtain them with developmental maturation and are less dependent on structured learning for them to emerge. The maturation and acquisition of motor skills in TDI depends on the interaction with novel environments and objects. For children on the autism spectrum this may be challenged due to the stereotypical and repetitive behaviors that they exhibit which delimits their repertoire of fine-motor experiences (Pierce & Courchesne, 2001).

Thus, for these fine-motor skills to develop, individuals on the autism spectrum may need structured fine motor experiences (such as those offered in school) for fine motor skills to develop. This finding also builds on several MRI and fMRI studies which have suggested brain structure, functional alterations and underconnectivity of brain structures in IHFA (Just, Cherkassky, Keller, Kana, & Minshew, 2007; Just, Cherkassky, Keller, & Minshew, 2004; Minshew, Johnson, & Luna, 2001; Muller, Pierce, Ambrose, Allen, & Courchesne, 2001). Based on established research with animals and humans, which suggested that functional changes in the cerebral cortex is mediated by synaptic strength, horizontal connections, and increases in number of synapses by neurons (Kolb & Whishaw, 1998; Nudo, Plautz, & Shawn, 2001), our findings would suggest that brain alterations and underconncetivity in IHFA may be due to their limited engagement with novel environments and objects that promote fine motor skills.

Our second strongest predictor associated with a more favorable outcome for our older TDI, GP-ND, was consistent with previous literature that suggested that between-hand performance on the GP does not differ significantly. In other words, it was expected that performance on the GP by the non-dominant hand would be parallel to that of the dominant hand (Conoley & Impara, 1995), reflecting that developmental control of fine-motor skills appears symmetrical in nature. Importantly, this pattern was not observed in IHFA, indicating that developmental symmetry in fine-motor skills may be one of the processes impaired in IHFA. Attention was our third strongest predictor associated with more favorable outcome in the TDI model for TDI who showed the highest level of fine-motor skills bilaterally. The inverse association between attention and fine-motor skills is unclear. The fact that higher abilities in one are related to lower abilities in the other is not directly explainable and was not found in previous research of typical development.

In our IHFA model, an executive functioning measure was the second strongest predictor associated with a favorable outcome for our IHFA with the highest level of education. However, a parallel relationship between better fine-motor skills and better executive functioning was not observed. In other words, participants who performed better on one measure performed worse on the other. This may suggest that parallel maturation across domains, may not be evident in IHFA. In addition, this emphasizes the notion that professionals working with IHFA should not assume that level of performance of one skill in a particular domain is indicative of skill level in another domain. Therefore, assessment of IHFA should be comprehensive, namely, it should encompass several domains and skills.

In our TDI model, measures of memory and problem-solving were most strongly associated with moderate fine-motor praxis skills. Performance on memory and problem-solving measures paralleled performance on the fine-motor skills measure, meaning that as performance on fine motor skills improved, so did performance on memory and problem-solving. This reflects an expected and typical maturation of skills across different domains in TDI. However, again the pattern observed in our IHFA model was quite different.

In our IHFA model, visual spatial skill sequencing was most strongly associated with moderate fine-motor skills. The effect of schooling for IHFA seems to, at least to some extent, influence the predictive value of visual-spatial skills. Unexpectedly, the predictive value of visual-spatial skills did not have a clear linear pattern of association with fine-motor skills in IHFA. Upon close examination of educational level among IHFA within each subsample differentiated by visual-spatial skills, we found that those who showed lowest level of fine-motor skills also had the lowest educational level despite the fact that these individuals were moderate in their visual-spatial skills. Thus, fine-motor skill predictability, by visual-spatial skills or other skills, may be secondarily influenced by education. Attention was also associated with moderate fine-motor skills in the IHFA model and its association with fine-motor skills was parallel. It is important to note that regardless of its level of association with fine-motor skills, attention had a different predictive pattern in the IHFA model versus the TDI model suggesting that some element of attention that influences fine-motor skills cannot be correlated between IHFA and TDI. This finding further underscores that the processes associated with the development of fine-motor skills in IHFA may be reliant on separate processes than those of TDI. Nonetheless, the contribution of attention to such skills can not be ignored

In our TDI model executive functioning emerged and it was strongly associated with less favorable fine-motor skills. An inverse association between fine-motor skills and executive functioning was evident at this level of fine-motor skills. The same relationship was observed in the IHFA model, however, in the IHFA model executive functioning was associated with more favorable fine-motor skills. It is important to note that the TD children differentiated by the executive functioning measure were too young (less than 7 years) and thus the results of the executive functioning test may be very variable at this age which makes it hard to draw a conclusion about the association between fine-motor skills and executive functioning skills at this level.

Finally, in our IHFA model, memory was our second strongest predictor associated with less favorable fine-motor skills. Memory emerged in our TDI model as well, however, it was associated with relatively moderate fine-motor skills of TDI. Nonetheless, in both models better fine-motor skills were related to better memory functions.

Not only did we find that individual variables held different predictive value in TDI versus IHFA, but we also found the interrelationship (patterns) between predicated variables were divergent between groups. Although the same variables were used in both analyses, distinctive predictive patterns of these variables emerged for each group. The differences in the predictor variables that are associated with fine-motor performance between IHFA and TDI illustrate the importance of this CHAID analysis in the creation of models that illustrate the interrelated nature of a variety of contributing processing leading to fine-motor skill performance. While assessment of individual predictive skills may be important to define the specific traits associated with fine-motor skills, understanding the complex and multiple levels of predictive patterns may be key to developing successful assessment and intervention plans.

4.4.1 Clinical Implications

The most prominent finding from our two models of CHAID sheds light on the importance of intervention for IHFA. Practicing dexterity and motor manipulation skills are of great importance for IHFA to attain a comparable skill level with their peers. School provides a wide array for practicing such skills including writing, crafts, and leisure activities. However, if these skills are targeted and practiced at a younger age, IHFA may be in a more advantageous position to develop advanced motor skills that require dexterity and motor speed.

Another relevant clinical finding is that the model indicated that memory, attention, and executive functioning were all significantly associated with fine-motor skills in IHFA. This suggests that these skills should also be assessed and targeted for intervention in IHFA whose fine motor skills are impaired.

4.4.2 Limitations and Future Research Recommendation

One of the major limitations of this study was sample size. Larger sample size is needed to increase the power and validity of such analysis. Although, one of the strengths of this study was the heterogeneity of our sample in relation to age, additional studies with more homogeneous samples will better enhance the understanding of performance predictors for different age groups. Our choice of variables was limited due to the nature of secondary analysis that lends itself to missing data, and thus only variables that had little or no missing data were included. Exploration of fine-motor skills with other target variables will enhance the understanding of such skills in populations with HFA. It is also important to note that the generalizabily of these results is limited to IHFA only. Examining fine-motor skills in other individuals with autism along the spectrum is necessary.

5.0 FACTORS ASSOCIATED WITH EXECUTIVE FUNCTIONING SKILLS

Executive Functioning (EF) skills involve the ability to identify appropriate goals, develop possible paths toward the goals, assess potential consequences of actions, and reach sound judgments, all of which are crucial for everyday problem solving and functioning in the community (Shallice & Burgess, 1991). In community-dwelling older individuals, EF skills were found to be more accurate predictors of instrumental activities of daily living (IADL) than other measures such as memory, language, visual-spatial skills, and psychomotor speed. In addition, when compared to general characteristics such as age, general health status, and educational level, they accounted for more variance in IADL performance (Cahn-Weiner, Malloy, Boyle, Marran, & Salloway, 2000). EF skills, when intact, were also found to increase the level of functional independence for neurologically intact older adults (Grigbsy, Kaye, Baxter, Shetterly, & Hamman, 1998; Grigbsy, Kaye, & Robbins, 1995).

As discussed in Chapter 2, individuals with high-functioning autism (IHFA) face difficulties with a wide range of EF skills. Other than the significant role they play in everyday functioning in the general population, EF skills were also found to be strong predictors of social outcomes and long-term outcomes for individuals on the autism spectrum (Gilotty, Kenworthy, Sirian, Black, & Wagner, 2002; Szatmari, Bartolucci, Bremmer, Bond, & Rich, 1989)

Although several studies reported that IHFA exhibit impairments in tests of EF, there is a dearth of research evidence examining factors associated with such impairments. Researchers have argued that performance on tests of EF, such as the Wisconsin Card Sorting Test (WCST), assess not only EF, but also categorization, working memory, inhibition, selective attention, and encoding of verbal feedback (Bond & Buchtel, 1984; Dehaene & Changeux, 1991; Perrine, 1993). While some authors have chosen to examine each of these factors separately (Ozonoff, South, & Provencal, 2005), we chose an exploratory approach, using Chi-Square Automatic Interaction Detection (CHAID), to identify factors and patterns that are most strongly associated with EF in IHFA and typically developing individuals (TDI). Utilizing a large database that included IQ, motor, sensory, language, memory, EF, problem-solving, and visual-spatial measures, we explored which of these concepts were most strongly associated with favorable and unfavorable outcomes on the WCST for IHFA and TDI. Differences in CHAID predictor variables and patterns of predictor variables hold the potential to enhance our understanding of how and why EF outcomes differ in IHFA compared to TDI. This understanding, in turn, could directly impact intervention planning and implementation.

Considering the exploratory approach of such analysis, we did not have a priori hypotheses. The results are discussed in terms of differences in the two models and in light of previous research conducted in this area.

5.1 METHODS

5.1.1 Study Design

Analyses were completed utilizing the neuropsychological data collected as part of a larger study that aimed to evaluate different theories of autism neuropathology. This research was supported by the National Institute of Mental Health (MH40858). In this study, we utilized completed data collected for two independent groups of IHFA and TDI taken at one time point for each participant (no repeated measures factor) Using CHAID, we generated two models, one for IHFA and one for TDI, delineating the associations between EF skills (target variable) and motor, sensory-perceptual, language, memory, EF/problem-solving, and visual-spatial skills (predictor variables). The models were visually presented and differences and similarities between the two were discussed.

5.1.2 Participants

Participants with HFA included in this study had to meet the criteria for autism in the two structured diagnostic instruments; the Autism Diagnostic Observation Scale (ADOS) and the Autism Diagnostic Interview (ADI). In addition, participants with HFA had to have a full-scale IQ, verbal IQ, and performance IQ of 80 or higher. Potential participants with HFA were excluded if they were found to have an associated genetic, infectious, neurologic, or metabolic disorder.

The TD participants were healthy, neuropsychiatrically normal community volunteers. They were recruited to match participants with HFA on age, sex, education level, and IQ. Potential TD participants were excluded if they had a family history of autism, birth or developmental disabilities, or any past or current psychiatric or neurological disorders.

5.1.3 Instrumentation

5.1.3.1 CHAID Target Variable: The Wisconsin Card Sorting Test

The WCST is a test of abstraction and shift of cognitive set. It has been also considered as a measure of EF due to its sensitivity to frontal lobe lesions (Heaton, 1981). The test includes 2 identical decks each containing 64 cards, with one of four symbols on each one – triangle, star, cross, or circle. The number of symbols on each card varies from one to four and they are printed in blue, red, yellow, or green. Four stimulus cards are presented in front of the examinee; one red triangle, two green stars, three yellow crosses, and four blue circles. A deck of cards is given to the examinee who is asked to match the cards one by one under one of the stimulus cards, according to a rule that is not shared. The examinee has to comprehend the rule from the examiner's responses to his/her placement of the cards. For example, the first principle is color. The examinee should place a card that is printed in red, regardless of the symbol or the number of symbols printed on that card, under the red stimulus card, and so forth. If the examinee places a yellow card with triangles on it (i.e. matching the symbol on the stimulus card), the examiner acknowledges that as a "wrong" response and asks the examinee to try again. After 10 consecutive correct placements (i.e. 10 matching on colors), the examiner shifts the rule, without any comments, to symbol. The examinee has to comprehend this shift by the "wrong" responses communicated by the examiner. The test continues until six successful trials have been completed, or until both decks of cards have been used.

Several scores can be derived from the WCST; the total number of errors, the total number of correct responses, the number of categories completed, perseverative errors (PE), and non-perseverative errors. The PE score is regarded as the "most useful diagnostic measure that is derived from the test" (Heaton, 1981, p. 22). PE occur when the examinee continues sorting according to a previous successful rule. PE was selected to be the EF target variable in our study.

Validity

Validity of the WCST has been established in several studies. In a group of 58 college students, PE loaded on a "Piagetian measure of formal operational reasoning" (Shute & Huertas, 1990). In several studies, performance on the WCST was found to be impaired in patients with predominantly frontal lobe lesions (Anderson, Damasio, Jones, & Tranel, 1991; Heaton, 1981; Robinson, Heaton, Lehman, & Stilson, 1980). Individuals with other neurodegenerative diseases, Parkinson's disease (Alevriadou, Katsarou, Bostantjopoulou, Kiosseoglou, & Mentenopoulos, 1999; Tomer, Fisher, Giladi, & Aharon-Peretz, 2002), Alzheimer's disease (Binetti et al., 1996), frontotemporal dementia (Razani, Boone, Miller, Lee, & Sherman, 2001), and Huntington's disease (Paulsen et al., 1995) also showed impaired EF on the WCST.

It is important to note the WCST was found to be a potential predictor for job placements of 28 severely head-injured adults 1 year or more post-injury (Kibby, Schmitter-Edgecombe, & Long, 1998). In addition, better performance on the WCST is significantly correlated with greater independence on the Living Status Scale in a sample of 202 individuals with Traumatic Brain Injury (Little, Templer, Persel, & Ashley, 1996).

Reliability

Test-retest reliabilities, over 1 year, were found to be moderate to low (r = .12 - .65) in 87 normal elderly individuals (Paolo, Axelrod, & Troster, 1996). However, moderate test-retest reliability (r = .64) for PE over 1 year was found in 229 community-dwelling adults on a modified version of the WCST. Ingram, Greve, Ingram, and Soukup (1999) found strong test-retest reliability (r = .83) for PE for 29 individuals with sleep apnea over 1-71 days. Ozonoff (1995) found high test-retest reliability (generalizability coefficients > .90) for a group of individuals with autism (n = 9), individuals with Pervasive Developmental Disorder Not Otherwise Specified (n = 8), and individuals with Learning Disability (n = 17) over 2.5 years. Also, strong intra-rater (r = .94) and inter- rater (r = .92) reliabilities were found by Axelrod, Goldman, and Woodard (1992) for PE on the WSCT in a sample of 30 normal adults.

5.1.3.2 CHAID Predictor Variables

The predictor variables included in this study were identical to the ones used in our previous study with the Grooved Pegboard (see Chapter 4, Table 4-1, and Appendix A) with the exception of the Visual Motor Integration test (VMI), which had to be removed from this analysis due to large amounts of missing data.

5.2 DATA ANALYSES

Factors that are associated with the performance on the WCST were indentified using Exhaustive Chi-Square Automatic Interaction Detection (CHAID). Through an iterative process, CHAID automatically identifies several predictor variables that are significantly associated with a specified target outcome variable. CHAID then differentiates the sample into subsamples based on significant differences in their performance on the predictor variable. For each subsample, the process is repeated, and predictor variables significantly associated with each subsample are identified, and new subsamples are formed, based on significant differences in their performance on the new predictor variable. The strength of CHAID analysis is based on the reduction of researcher bias in indentifying the final predictor variables and the arbitrary cutoff scores of the predictor variables (SPSS, Inc., 2001). The results of CHAID analysis are presented in a model delineating the interaction of different predictor variables in relation to the target variable. Two distinct models were examined: a model for IHFA, and a model for TDI (for a further description of CHAID, please see Chapter 4). In this study, the target outcome variable was PE on the WCST (PE-WCST).

The *n*-fold cross-validation procedure was also conducted for the IHFA and TDI models to examine the strength of the predictive validity of the models. Please see Chapter 4, p. 56 for a further description of the *n*-fold cross-validation procedure.

5.3 RESULTS

5.3.1 Participants

The numbers of participants who met the inclusion and exclusion criteria were 49 and 50 in the IHFA and TDI groups, respectively. The sample characteristics are outlined in Table 5-1. The IHFA group was predominantly males (91.8%) with a mean age of 16.54 years. The mean educational level for the HFA participants was 7.48 years. The Full Scale IQ (FS-IQ) was 101.96, Verbal IQ (V-IQ) scale was 103.57, and the Performance IQ (P-IQ) scale was 99.80. Males were predominant in the TDI group as well (88.00 %) with a mean age of 17.07 years. The mean educational level was 8.46 years. The values for the FS-IQ, V-IQ, P-IQ were 102.98, 103.84, and 101.28 respectively. The two groups did not differ significantly on any demographic characteristics (see Table 5-1).

Table 5-1. *IHFA and TDI Characteristics*

	IHFA n = 49	TDI n = 50	Significance
Male (%)	91.80	88.00	.52
Age, years (*M, SD*)	16.54 (9.95)	17.07 (10.25)	.80
SES (*M, SD*)	3.43 (1.44)	3.26 (1.28)	.54
Educational Level, years completed	7.48 (5.11)	8.46 (5.00)	.54
FS-IQ (*M, SD*)	101.95 (12.85)	102.98 (13.01)	.67
V-IQ (*M, SD*)	103.57 (15.93)	103.84 (13.12)	.93
P-IQ (*M, SD*)	99.80 (11.00)	101.28 (11.98)	.52

Note. IHFA = Individuals with high-functioning autism. TDI = Typically developing individuals. SES = Socioeconomic status measured on a scale from 1 to 7 where 1 is the highest and 7 is the lowest. FS-IQ = Full-Scale IQ. V-IQ = Verbal IQ. P-IQ = Performance IQ.

5.3.2 Executive Functioning Skills: CHAID Analysis for Individuals with High-Functioning Autism

For IHFA (see Figure 5-1), the factor most strongly associated with PE-WCST was the Verbal Absurdities Test (VA), $F(2,46) = 13.82$, $p < .001$, which divided our sample into three subsamples; WCST- A I (n = 9), WCST-A II (n = 19), and WCST- A III (n = 20). As PE-WSCT decreased, the VA scores increased. IHFA in WCST-A I subsample (mean age: 9.08 years, mean FS-IQ = 93.67) scored the lowest on the VA (mean: .56) and made the most PE on the WCST (mean: 37.22). The WCST-A II (mean age: 13.11 years, mean FS-IQ = 102.53) fell between the two subsamples (WCST-A I and WCST-A III) in both measures (mean PE-WCST = 23.63, mean VA = 6.21). IHFA in the WCST-III (mean age: 23.72, mean FS-IQ = 104.90) scored the highest on the VA (mean: 12.30) and made the least PE on the WCST (mean: 9.95).

IHFA in the WCST-A II were further subdivided into two subsamples, WCST-A IIa (n = 7) and WCST-A IIb (n = 6), by the Visual Memory Index of the Wide Range Assessment of Memory and Learning (VM-WRAML), $F(2,16) = 13.23$, $p < .001$. There was an

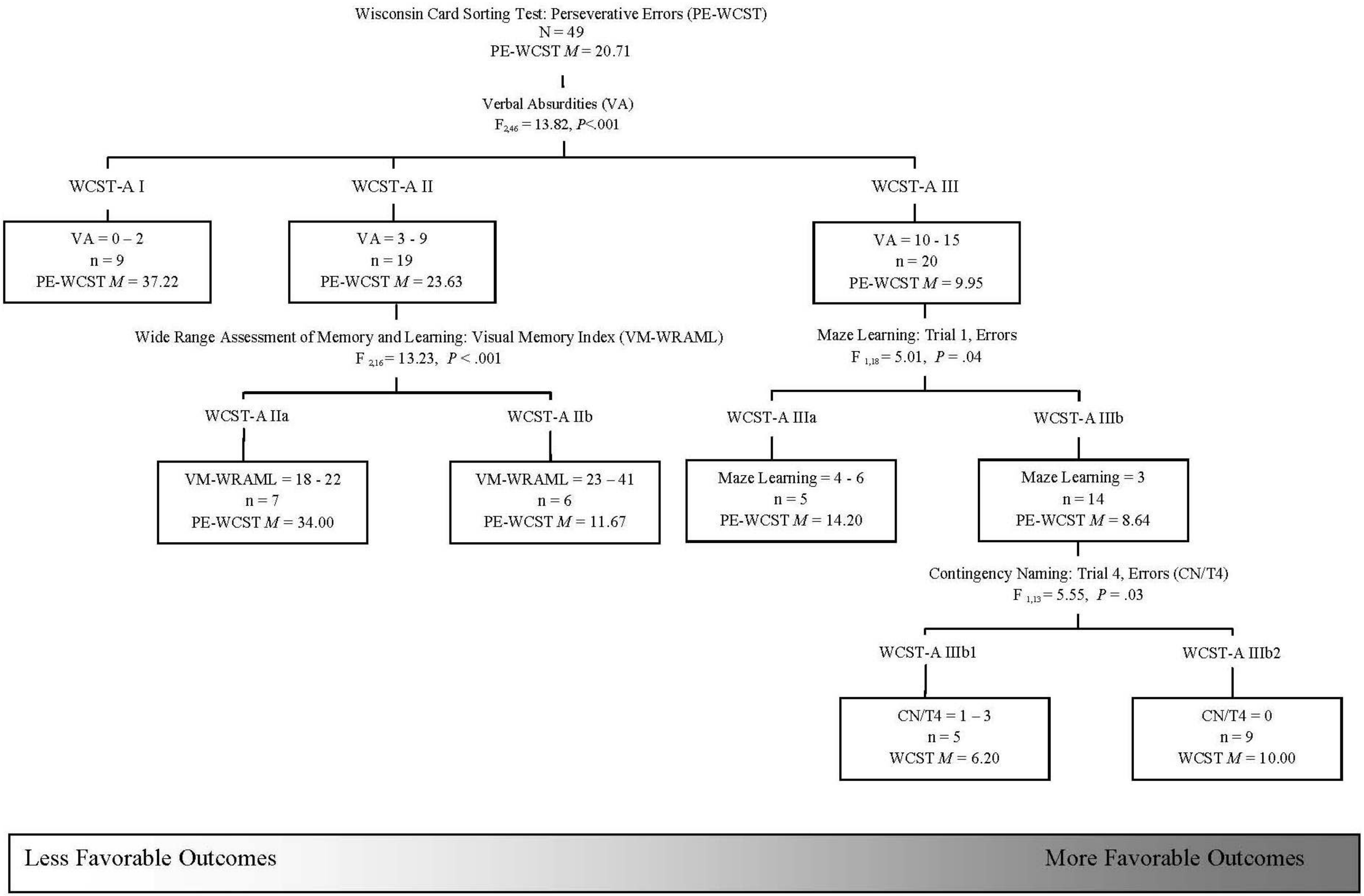

Figure 5-1. Factors Associated with Executive Functioning Skills for Individuals with High-Functioning Autism

inverse relationship between the PE-WCST and VM-WRAML. IHFA who scored 22 and less on the VM-WRAML (mean age: 12.66, mean FS-IQ = 99.86, mean VA = 7, mean VM-WRAML = 19.86) made more PE on the WCST (mean: 34.00) compared to IHFA who scored higher than 22 (mean age: 9.32, mean FS-IQ = 111.16, mean VA = 4.83, mean VM-WRAML = 30.83) (mean: 11.67)

Among those IHFA in WCST-A III, the Maze Learning Test (ML; Trial 1, number of errors) was the next strongest factor associated with PE-WCST, F (1,18) = 5.01, p = .04, dividing WCST-A III into two subsamples. IHFA who made 4 to 6 errors on the ML (WCST-A IIIa; n = 5, mean age: 25.07, mean FS-IQ = 98.40, mean VA = 12.28, mean ML = 4.60) made more PE on the WCST (mean: 4.20) compared to IHFA who made 3 errors on the ML (WCST-A IIIb; n = 14, mean age: 24.14 years, mean FS-IQ = 107.14, mean VA = 12.60) who made fewer PE on the WCST (mean: 8.64).

Errors made on the 4th trial of the Contingency Naming Test (CNT/T4) further differentiated the 14 IHFA in the WCST-A IIIb into two subsamples, F (1,13) = 5.55, p = .03. IHFA who made 1 to 3 errors on the CNT/T4 (WCST-A IIIb1; n = 5, mean age: 28.23 years, mean FS-IQ = 109.60, mean VA = 12.00, mean ML = 3, mean CNT/T4 = 1.60) made fewer PE on the WCST (mean: 6.20) compared to IHFA who made no errors on the CNT/T4 (WCST-A IIIb2, n = 9, mean age: 21.87 years, mean FS- IQ = 105.78, mean VA = 12.44, mean ML = 3) but made more PE on the WCST (mean = 10).

5.3.3 Executive Functioning Skills: CHAID Analysis for Typically Developing Individuals

In the TDI model (see figure 5-2), the total score on the Paired Association Verbal Learning (PAVL) was the factor most strongly associated with PE on the WCST, dividing our sample into

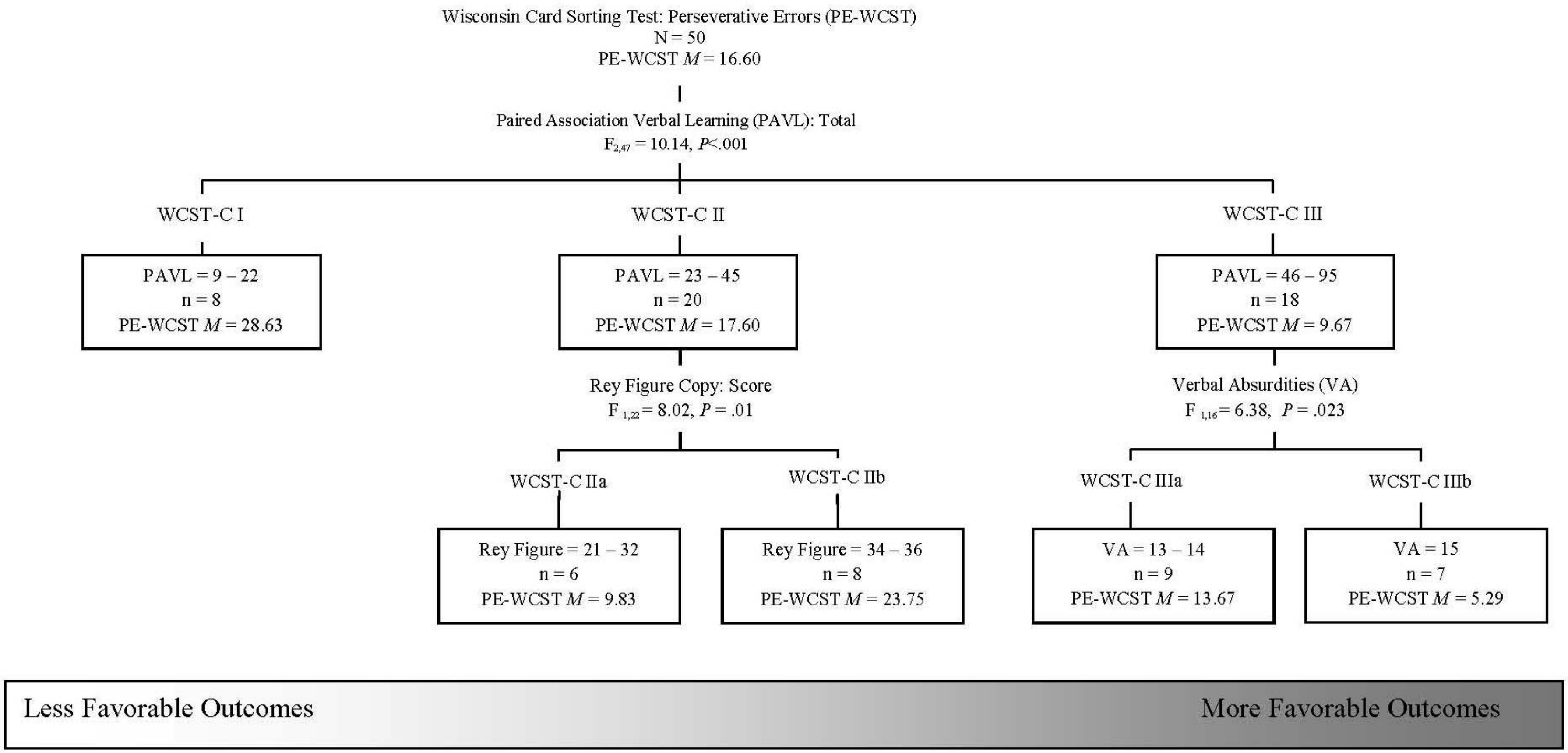

Figure 5-2. Factors Associated with Executive Functioning Skills for Typically Developing Individuals

three subsamples, F (2,47) = 10.14, p < .001. TDI who scored the lowest on the PAVL (WCST-C I, n = 8, mean age: 13.65, mean FS-IQ = 99.13, mean PAVL = 15.88) made the most PE on the WCST (mean: 28.63) compared to the other two subsamples. TDI who scored between 22 and 45 on the PAVL (WCST-C II; n = 20, mean age: 15.68, mean FS-IQ = 100.05, mean PVAL = 32.95) made fewer PE on the WCST (mean: 17.60) compared to the WCST-C I but more than the WCST-C III. The WCST-C III (n = 18, mean age: 21.70, mean FS-IQ = 105.61, mean PAVL = 67.56) made the fewest PE on the WCST (mean: 9.67) compared to the other two subsamples.

For those TDI in WCST-C II subsample, the copy score on the Rey Figure test was the next strongest factor associated with performance on the WCST, F (1,22) = 8.02, p = .01, dividing WCST-C II into two subsamples. TDI who scored 32 and less on the Rey Figure test (WCST-C IIa; n = 6, mean age: 13.50, mean FS-IQ = 94.83, mean PVAL = 34.67, mean Rey Figure = 27.83) made fewer PE on the WCST (mean : 9.83) compared to TDI who scored more than 32 on the Rey Figure test (WCST-C IIb, n = 8, mean age: 23.47, FS-IQ = 92.88, mean PVAL = 35.00, mean Rey Figure = 35.13) who made more PE on the WCST (mean : 23.75).

Performance on the Verbal Absurdities (VA) Test further differentiated the 18 TDI in the WCST-C III into two subsamples; WCST-C IIIa (n = 9) and WCST-C IIIb (n = 7), F (1,16) = 6.38, p = .023. There was an inverse relationship between the PE-WCST and the VA test, with TDI who performed worse on the VA (WCST-C IIIa; mean age: 22.01, mean FS-IQ = 101.11, mean PVAL = 64.11, mean VA = 13.79) making more PE on the WCST (mean : 13.67) compared to TDI who performed better on the VA (mean age: 23.19 , mean FS-IQ = 112.57, mean PVAL = 71.71, mean VA = 15.00), and who made fewer PE on the WCST (mean : 5.29).

5.3.4 Validation of the models

The results of the *n*-fold cross-validation procedure for the IHFA model and the TDI model are outlined in Tables 5-2 and 5-3, respectively. The number of folds was set at 10 for each model. The differences between the Risk Estimates for the Risk Statistics and Cross-validation were fairly small for both models suggesting stronger validity of the models.

Table 5-2. *Cross-validation Results for the IHFA Model*

	Risk Statistics	Cross-Validation
Risk Estimate	86.94	88.19
Standard deviation of Risk Estimate	25.76	31.97

Note. IHFA = Individuals with High-functioning autism

Table 5-3. *Cross-Validation Results for the TDI Model*

	Risk Statistics	Cross-Validation
Risk Estimate	64.83	70.95
Standard deviation of Risk Estimate	20.12	19.88

Note. TDI = Typically-developing individuals.

5.4 DISCUSSION

The purpose of this exploratory approach was to (1) identify models of measures and concepts that are associated with EF skills for IHFA and TDI and (2) compare and contrast the predictors and patterns that emerged in each model. The differences between the models for the two groups are of importance, as they enhance the understanding of EF skills of IHFA and how they differ from those of TDI. Understanding these differences can be used to identify priorities for assessment and it advances the planning and implementation processes of intervention. To our knowledge, this is the first study that examined and compared such associations between IHFA and TDI.

Complex language skills were the strongest predictor associated with EF outcomes in the IHFA model. This is consistent with previous research that examined EF in IHFA, which indicated that PE-WCST as an EF measure, was found to be highly correlated with verbal IQ and that differences in PE-WCST between a group of IHFA and a group of individuals with developmental language delay became non-significant when the "Verbal IQ was partialled out" (Liss et al., 2001). Related research found similar results when performance on the WCST using examiner administration was compared with administration using a computerized version of the WCST (Kaland, Smith, & Mortensen, 2007; Ozonoff, 1995). These studies found that individuals with autism performed better on the computerized version of the WCST compared to the examiner administration. This finding was crucial, because the authors hypothesized that EF deficits of IHFA on the WCST may be overestimated due to their incapacity to comprehend the examiners' feedback during testing, rather than reflecting true impairment levels in EF. In other words, IHFA performance on the WCST was enhanced when the element of individual-to-individual interaction was eliminated.

The Verbal Absurdities test (VA) is also considered to measure concept formation skills. Previous research, utilizing Principal Component Analysis (PCA), found concept formation (as measured by the VA) and concept identification (as measured by PE on the WCST) to load on a separate factors for IHFA, however, they loaded on same factor for TDI (Minshew, Meyer, & Goldstein, 2002). The authors concluded that a dissociation between concept formation and concept identification exists in the IHFA group that was not evident in the TDI group. In general, concept formation seems to be a harder task for IHFA compared to concept identification (as measured by PE-WCST).

In our TDI model, simple memory was the strongest predictor variable associated with EF skills, and more favorable EF outcomes were associated with better simple memory functions. Although previous research has ascertained the role of “working memory” (i.e. immediate memory during a task) in EF skills (Lehto, 1996; Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001), we did not find any documentation in the literature regarding the association between simple memory functions and EF, thus this information is new to the body of knowledge. Chronological age also paralleled EF and simple memory in the TDI model, showing a developmental influence -- as the TDI sample aged, EF and simple memory improved.

Simple memory also emerged in our IHFA model as our second strongest predictor associated with high EF skills. For those with more favorable EF outcomes, as EF skills improved so did simple memory functions, a pattern also seen in the TDI model. This finding builds on previous research, which found that simple memory functions were intact in IHFA (Minshew, et al., 1997; Minshew & Goldstein, 2001) .Also, for those with more favorable EF outcomes, the IHFA model delineated that after complex language/concept formation skills, simple memory and then another measure of EF (the CNT) led to more favorable EF outcomes in IHFA. It seems as when the complex language/concept formation skills of IHFA improve, simple memory becomes the factor that contributes to better EF outcomes. In addition to simple memory, another measure of EF (the CNT) was also associated with more favorable EF outcomes in the IHFA sample. However, for those in the WCST-A III subsample (best EF skills), EF (as measured by the CNT) was inversely related to EF skills (as measured by the WCST). This may reflect that for this subsample, they relied more on memory for EF than those EF skills assessed by CNT. As with the TDI model, the association between EF and simple memory skills was not found in any previous literature. Whereas complex language/concept formation (as measured by VA) skills were most strongly associated with EF, followed by simple memory in the IHFA model, the reverse is true for the TDI model. Complex language/concept formation emerged in our TDI model as the second strongest predictor associated with more favorable EF outcomes. This finding is consistent with previous research that found the correlation between VA and PE-WCST to be slightly higher for IHFA (r = .51) compared to the TDI (r = .40) (Minshew et al., 2002). This finding provides an explanation why VA appeared to have a stronger association in the IHFA model compared to the TDI model. This also indicates that complex language/concept formation skills are necessary for better EF outcomes and that they may increase the capacity of EF. Nonetheless, it is important to note that their influence is secondary to simple memory functions for TDI.

For the IHFA subsample with more moderately favorable EF outcomes, complex memory was most strongly associated with moderate EF outcomes. Previous research has found that IHFA were impaired on complex memory functions (Minshew & Goldstein, 2001; Williams, Goldstein, & Minshew, 2006). The IHFA model again illustrates that as complex memory functions improve, so does EF. Consistent with our findings, Minshew and Goldstein (2001, p. 1100) suggested that complex memory deficits in IHFA are “intrinsic to the memory system rather than secondary to EF.” The IHFA model shows that complex memory functions are a necessary prerequisite of complex language functions, which in turn support more favorable EF outcomes.

For the TDI subsample with more moderately favorable EF outcomes, visual-spatial skills were most strongly associated EF outcomes and unexpectedly the relationship was inverse, not parallel as were the relationships in the TDI subsample with the most favorable EF outcomes. Instead, it is similar to the IHFA subsample with the most favorable EF outcomes which had an inverse relationship between EF skills (as measured by WCST) and another measure of EF (the CNT). A possible explanation of for these two unexpected findings may be found in the association between EF and full-scale IQ (FS-IQ). FS-IQ has been found to be negatively correlated with PE on the WCST (Ardila, Pineda, & Rosselli, 2000; Heaton, 1981; Merriam, Thase, Haas, Keshavan, & Sweeney, 1999). Although FS-IQ did not appear as one of our predictor variables in either the IHFA or the TDI models, it is important to note that for the TDI visual-spatial subsample and the IHFA EF (CNT) subsample, higher FS-IQ was associated with higher EF outcomes (i.e. fewer PE on the WCST).

Finally, in both the IHFA model and the TDI model, the number of participants in the least favorable EF outcomes category was too small for CHAID to branch. Therefore, no predictors could be generated in either model.

In conclusion, we have found that similar measures had different levels of association to EF outcomes in the IHFA model versus the TDI model. While a measure of complex language/concept formation emerged to be the strongest predictor variable in the IHFA model, it appeared to have a secondary association with more favorable EF performance in the TDI model. Similarly, simple memory was the strongest predictor of EF outcomes in TDI model, however, it emerged as a secondary predictor of more favorable EF performance in the IHFA model. This discrepancy between the level of association of certain skills to EF outcomes is clinically relevant to practitioners for establishing assessment and intervention priorities for IHFA. While other studies have compared IHFA to TDI, and found that they were significantly different in EF skills (Ozonoff et al., 2005; Pennington & Ozonoff, 1996) as well as complex memory (Minshew et al., 1997; Minshew & Goldstein, 2001; Williams, 2006) and complex language/concept formation skills (Minshew et al., 1997; Williams et al., 2006), the relationships among these concepts to EF skills has not been delineated. Our IHFA model can help to guide practitioners, because it not only identifies the factor mostly strongly associated with EF skills, but also the subskills that contribute to complex language/concept formation skills, and are also important for further assessment and intervention.

5.4.1 Clinical Implications

The potential relationship between EF and complex language/concept formation has a significant clinical implication. Other studies have found that IHFA, across the age, are impaired on complex language functions (text comprehension, verbal problem solving, comprehension of complex grammatical construction) compared to simple language functions (simple vocabulary, verbal fluency, reading) (Minshew et al. 1997, Williams et al., 2006). It is fair to assume that to enhance the performance of IHFA on EF tasks, the language context of such tasks should be simplified. Occupational therapists are known for their skills in activity analysis and in breaking down complex functions into simpler ones. This is a potential area for intervention, and for collaboration with speech therapists, because occupational therapists can aid IHFA by breaking down complex language to a more comprehensible format. Moreover, occupational therapists can focus on concept formation with the use of everyday objects such as hammers, screwdrivers and pliers (tools), or Cheerios, Wheaties, and Captain Crunch (cereal) to work on concept formation. Additionally, our findings support focusing on simple and complex memory skills, which can also be broken down into smaller and more meaningful units of learning for IHFA. It is also important to communicate such finding to teachers, aides, employers, and family members of IHFA, as this might enhance the communication between these individuals and IHFA.

5.4.2 Limitations and Future Research Recommendations

Although one of strength of this study was the heterogeneity of the sample in relation to age, further studies of more homogeneous samples are needed to increase the validity and generelizability of the results across specific age ranges. In addition, sample size was one of the major limitations of this study. With larger sample sizes more predictor variables can be used and the validity of the results can be further established. As the case of any secondary data analysis, missing values limited our choice of the target variable, and predictor variables were limited to those included in the original study. Further studies with other EF tasks, as well as other defined groups in the autism spectrum disorder are needed to enhance our understanding of the factors that contribute to EF impairments in individuals with autism across the total spectrum.

6.0 CONCLUSION

The purpose of this dissertation was to explore motor, sensory-perceptual, and executive functioning (EF) skills of individuals with high-functioning autism (IHFA) compared to age, gender, and IQ-matched typically-developing individuals (TDI). The general aims of this dissertation were to:

1) compare simple and complex motor skills and simple and complex sensory-perceptual skills between IHFA and TDI for different age groups, extending from children to adolescents, to young adults;
2) explore factors that are associated with good and poor complex motor skills, as measured by the Grooved Pegboard (GP), and
3) explore factors that are associated with good and poor EF skills, as measured by the Wisconsin Card Sorting Test (WCST).

The first investigation examined simple-motor skills (as measured by grip strength and the Finger Tapping Test [FTT]) and complex motor skills (as measured by the GP) in a group of IHFA and a group of TDI ranging from 5 to 21 years of age. Simple sensory-perceptual skills (as measured by the Luria-Nebraska Scales of Simple Touch, Sharp/Dull, Position Sense, and the Reitan-Klove Finger Recognition) and complex sensory-perceptual skills (as measured by Luria-Nebraska Stereognosis Scale and the Reitan-Klove Fingertip Number Writing) were also examined for the same IHFA and TDI groups. The two groups were age-and gender-matched and there were no differences between them on IQ or educational measures. IHFA were found to be significantly impaired compared to TDI on all motor measures across the age continuum with one exception; speed of tapping as measured by the FTT which revealed no differences between IHFA and TDI at a young age (8.82 and 9.25 years for the IHFA and TDI groups, respectively) but revealed impairments for IHFA compared to TDI at an older age (14.92 and 15.04 years for the IHFA and TDI groups, respectively). Additionally, we were able to extend the body of knowledge regarding impaired grip strength and complex motor skills in IHFA to a younger age (from 8 to 5 years).

None of the simple sensory-perceptual skills revealed any differences between the two groups at any age. The ability to localize touch-perception (as measured by the Reitan-Klove Finger Recognition) was the only simple sensory-perceptual measure that showed significant improvement over time for both groups. As for the complex sensory-perceptual measures, the only skill that revealed significant differences between the two groups was stereognosis, with older IHFA (mean age: 14.92 years) exhibiting significant impairment compared to older TDI (mean age: 15.04 years). No significant differences were found between the two groups for stereognosis at the younger age (8.82 and 9.25 years for the IHFA and TDI groups, respectively).

The second investigation examined factors associated with good and poor complex fine-motor skill of psychomotor speed, eye-hand coordination, and manipulative dexterity as measured by the GP. Two models, one for IHFA and one for TDI, were generated utilizing Exhaustive Chi-Square Automatic Interaction Detection (CHAID). Different factors held significant associations in the IHFA model (educational level, memory skills, attention skills, visual-spatial skills, EF skills) versus the TDI model (age, fine-motor skills of the non-dominant hand, memory skills, attention skills, EF skills, and problem-solving skills). In addition, the patterns of association were divergent between the two groups. The most prominent finding of this study was the strong association between complex fine-motor skills and educational level in the IHFA model versus the strong association between complex fine-motor skills and age in the TDI model. Our findings suggested that IHFA rely on structured experiences (such as those provided in schools) to acquire complex fine-motor skills which are acquired with age (a variable independent from structure) in TDI. This finding has a significant clinical implication reflecting on the importance of early intervention for IHFA, because the development of complex fine-motor skills for IHFA appears to necessitate structured experiences that utilize such skills in order for them to fully mature. In addition, the models generated by CHAID illustrate which factors are associated with complex fine-motor skills, and how they are related to each other. The model has the potential to provide guidance on factors that need to be assessed in IHFA, as well as for the development of intervention planning.

The third investigation also explored two models, one for IHFA and one for TDI, of the factors associated with good and poor EF skills, as measured by Perseverative Errors (PE) made on the Wisconsin Card Sorting Test (WCST). The models were also generated with CHAID analyses. In general, we found similar factors; complex language/concept formation and memory were important factors in both models. However, complex language/concept formation skills had the strongest association with EF in the IHFA model, and memory had the strongest association with EF in the TDI model. In addition, memory also emerged in our IHFA model, however, it followed complex language/concept formation skills, while complex language/concept formation followed memory in the TDI model. These findings are of significant clinical importance for guiding assessment and intervention planning for IHFA. While memory skills appear to enhance the capacity of EF skills, their influence for IHFA seems to be secondary to complex language/concept formation skills that are usually challenging for IHFA. Examining the similarities and differences in the IHFA and TDI models enables practitioners to set priorities for both assessment and intervention for IHFA.

In summary, findings from these studies suggest the importance of the assessment and intervention for simple and complex motor skills as well as sensory-perceptual skills across the continuum of age. In addition, the analytical models generated from CHAID analyses have great potential for guiding comprehensive assessment and intervention for IHFA.

APPENDIX A

PREDICTOR VARIABLES FOR FINE-MOTOR AND EXECUTIVE FUNCTIONING SKILLS

A brief description of the Exhaustive Chi-Square Automatic Interaction Detection (CHAID) predictor variables for fine-motor skills and executive functioning (EF) is provided. Unless otherwise specified, the description of these tests were based on the illustrations by an expert neuropsychologist or illustrations provided in the Neuropsychological Assessment (2004) by Lezak, Howieson, and Loring. The predictors are organized in the order they appeared in Table 4-1.

Attention Domain

- **WISC-R/WAIS-R Digit Span subtest**: On this test, the subject is asked to repeat a series of strings of digits (either backward or forward) that are read by the examiner. This test mainly relies on the subject's attention capacity while the examiner reads the digit.
- **Continuous Performance Test:** This test is considered a test of vigilance (the ability to sustain and focus attention). In this test, alphabetical letters appear briefly on the center of a screen in a random order. There are two conditions of the test; a simple condition in which the subjects are asked to respond to every X they see, and complex condition in which subjects are asked to respond to every X they see only if it follows an A.

- **Number Cancellation test**: On this test, the subject is asked to cross out every "6" that it is to be found on two sheets of paper with rows of different numbers. The ability of the subject to attend to the specified number and inhibit the rest of numbers is evaluated.

Sensory Domain

- **Luria-Nebraska Simple Touch**: On this test, the subject is asked to localize touch stimulation given by the examiner with the eraser end of a pencil on either hand or arms.
- **Luria-Nebraska Sharp/Dull Discrimination**: As its name implies, this test measures a subject's ability to discriminate between sharp and dull stimulation.
- **Luria-Nebraska Position Sense**: On this test, the subject is asked to place his/her arm in the same position the other arm is placed by the examiner.
- **Luria Nebraska Stereognosis**: On this test, the subject is asked to identify a three-dimensional object placed in the hand without any visual feedback.
- **Reitan-Klove Finger Recognition**: On this test, the subject is asked to identify which finger is being touch while vision is occluded.
- **Reitan-Klove Fingertip Number Writing**: On this test, the subject is asked to identify a number written on the finger tip with an empty ballpoint pen while vision is occluded.

Motor Domain

- **Finger Tapping**: this test consists of a tapping key, with a device recording number of taps, made over five 10-seconds trials. This test is considered a measure of dexterity.
- **Grip Strength**: assesses grip strength in kilograms.
- **Grooved Pegboard**: a detailed description of this test is provided in Chapter 4, p. 49.
- **Developmental Test of Visual Motor Integration**: this test consists of a developmental sequence of geometric shapes to be copied with paper and pencil. As its name implies, this test assesses the integrity of visual-motor integration skills.

- **WISC-R/ WAIS-R Coding Subtest**: in this test the subject is asked to mark rows of shapes with different lines based on a code as fast as possible for subjects under the age of 8 years or to transcribe a digit-symbol code as fast as possible, for subjects 8 years and older.
- **Trail Making Test A**: this test was developed as a measure of scanning, visumotor tracking, and cognitive flexibility. The subject is asked to draw lines to connect consecutive numbers.

Simple Language Domain

- **WISC-R/WAIS-R Vocabulary subtest**: on this test, the subject is asked to define a set of words with increasing difficulty.
- **Kaufman Test of Educational Achievement – Reading Decoding**: this test involves "identifying letters and words that appear individually on a graded list" (Minshew, Goldstein, Taylor, & Siegel, 1994)
- **Kaufman Test of Educational Achievement – Spelling**: as its name implies, the test measures the subject's spelling abilities.
- **Verbal Fluency Test (FAS)**: on this test, the subject is asked to write as many words as possible starting with a specific alphabet letter over a specified period of time.
- **Woodwock Reading Mastery – Word Attack**: this test measures the "subject's ability to apply phonic and structural analysis skills to pronouncing words that are not recognizable by sight. The test items consists of nonsense words (letter combinations that are not actual words) and words used very infrequently in English" (Woodcook, 1987, Word Attack Section)

Complex Language Domain

- **Test of Language Competence – Figurative Language**: this subtest measures the subject's ability to associate different meanings to the same words/expressions (Minshew, Goldstein, & Siegel, 1995).
- **Test of Language Competence – Making Inferences**: this subtest measures the subject's ability to consider other's mental states (Minshew et al., 1995).

- **Test of Language Competence – Metaphoric Expression**: this subtest measures the subject's ability to comprehend metaphorical expressions that have both concrete and abstract associations.
- **Detroit Test of Learning Aptitude -2 (Oral Directions)**: on this test, a set of pictures of common objects are presented to the subject who is asked to connect these pictures by drawing lines following the examiner's instructions. Directions can be complicated and successful completion of the test requires abilities that are beyond word comprehension only (Minshew et al., 1995).
- **Woodwock Reading Mastery – Passage Comprehension**: the test measures "the subject's ability to comprehend a short reading passage and identify a key word missing from it" (Woodwock, 1987, Passage Comprehension Section)
- **Stanford Binet Verbal Absurdities**: in this test the subject is asked to identify the logical impossibilities in a set of several short stories. This test assesses the ability to comprehend the story text as well as concept formation skills.
- **Token Test**: in this test a set of tokens that vary in shape and color are presented to the subject. The subject is asked to touch several tokens according to the examiner's instructions. The examiner's instructions vary in difficulty. Success on the test highly depends on the subject's comprehension of the examiner's simple and complex instructions.

Simple Memory Domain

- **Maze Learning – Trial 1:** in this test the subject is to regenerate a path, through a maze, that has been previously demonstrated by the examiner. Trial one is the simplest, (i.e., shorter path). This test is dependent on the subject's memory of the demonstrated path.
- **Paired- Associate Learning**: on the test, the subject is asked to repeat pairs of words read by the examiner.
- **California Verbal Learning Test – Trial 1:** on this test, the subject is asked to recall a shopping list, "Monday List," of names of fruits, herbs, article of clothing, and tools.

- Wide Range Assessment of Memory and Learning – Verbal Index: this index consists of a number/letter sequence memory task, sentence memory task, and a story recall task. (Williams, Goldstein, & Minshew, 2006b)
- **Wide Range Assessment of Memory and Learning – Learning Index**: this index consists of a "word list recall task, a sound symbol association task, and a design location task" (Williams, et al., 2006b, p. 24)

Complex Memory Domain

- **Paired Associate Learning- Delayed Recall:** on this test, a delay period is given between reading pairs of words to the subject and then asking him/her to recall these pairs.
- **California Verbal Learning Test (CVLT) – Consistent Long Term Retrieval**: this score reflects the number of words recalled from any specific trial of the CVLT that was recalled on previous trials.
- **Wide Range Assessment of Memory and Learning – Visual Index**: this index assesses "recall of geometric designs, picture scenes, and sequences" (Williams et al., 2006, p. 24)
- **Rey – Osterrieth Figure – Delayed Recall**: In this test the subject is asked to copy a complex figure, which has been copied before by the subject, from memory. This test assesses complex visual memory.

Executive Functioning/Problem-Solving Domain:

- **Trail Making Test – B:** this test was developed as a measure of scanning, visumotor tracking, and cognitive flexibility. The subject is asked to draw lines to connect consecutive numbers and consecutive letter alternating between the two sequences. The subject is asked to draw the lines as fast as possible without lifting the pencil from the paper.
- **Wisconsin Card Sorting Test:** a detailed description of this test is provided in Chapter 5, p. 71.

- **Stanford-Binet IV Picture Absurdities**: This test is considered a measure of reasoning and abstraction. It consists of a set of pictures that depict an illogical or impractical situation which the subject should identify.
- **Stanford-Binet IV Problem Situation**: This test is considered a measure of abstraction and reasoning. Short situations are read to the subject, who is asked to point out a logical explanation of the incident described.
- **Stanford-Binet IV Plan of search**: On this test, the subject is asked to draw by pencil a searching path for a purse missing in a diamond field. This test measures the ability of the subject to efficiently generate successful search strategies.
- **Contingency Naming Test (CNT):** CNT is considered a measure of inhibition and mental set-shift. It consists of a set of colored shapes with a smaller shape within each shape. The inside shape can be similar or different from the outside shape. The test has four different trials with increasing difficulty. In the first trial, the subject is asked to name only colors (regardless of the shape). In the second trial the subject is asked to name only the outside shape. In the third trial, the subject is asked to name the color when the inside and outside shapes are similar, and to name the outside shape if the two shapes are different. Finally in the fourth trial, the subject is asked to apply the same rules as in trial 3, but when a backward arrow appears over the stimulus the subject is asked to reverse the rule, name the color but not the shape.
- **20 Questions:** 20 questions is a measure of conceptual problem solving. On this test a card with different pictures of a variety of objects is presented to the subject who is asked to identify the object that is on the examiner's mind by asking yes/no questions. Three types of questions can be generated through the process of identifying an object; constraint-seeking questions are those questions that would help eliminate two or more objects (i.e., is it something we can eat?), psuedoconstraint questions which refers to a specific object as if it were constraint seeking however the alternatives are not reduced (i.e., does it swim in the sea?), and hypothesis testing questions which refer to a specific object (i.e., is it a fish?). Constraint seeking questions are considered a measure of abstraction and concept formation.

Visual-Spatial Domain

- **WISC-R/WAIS-R Picture Completion**: On this test the subject is shown incomplete pictures of human features, familiar objects, or scenes. The items are arranged with increasing difficulty and the subject is asked to name the most important missing part of the picture.
- **WISC-R/WAIS-R Object Assembly**: The test consists of cut-up cardboard figures of familiar objects with increasing difficulty. The subject is asked to assemble the pieces as fast as possible.
- **WISC-R/WAIS-R Block Design**: On this construction test, the subject is asked to replicate constructions made by the examiner or from printed designs using a set of blocks that has two white sides, two red sides, and two half-red half-white sides.
- **Rey-Osterrieth Figure – Copy**: On this test a complex figure is presented to the subject who is asked to copy the figure. The test measures perceptual organization.

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