SKILLED MOVEMENTS IN AUTISM: A REVIEW OF CURRENT LITERATURE AND TWO CASE STUDIES

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
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To my family

ACKNOWLEDGMENTS

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LIST OF ABBREVIATIONS

ADOS	Autism Diagnostic Observation Scale
ADI-R	Autism Diagnostic Inventory - Revised
ASD	Autism Spectrum Disorder
BOTMP	Bruininks–Oseretsky Test of Motor Proficiency Short Form
fMRI	Functional magnetic resonance imaging
fcMRI	Functional connectivity magnetic resonance imaging
FFA	Fusiform Face Area
GABA	gamma-Aminobutyric acid
HFA	High Functioning Autism
IFC	Inferior Frontal Cortex
IQ	Intelligence quotient
PDD-NOS	Pervasive Developmental Disorder – Not otherwise specified
RRBI	Repetitive and restricted behaviors and interests

Abstract of Thesis Presented to the Graduate School
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Autism is a developmental disorder that is diagnosed behaviorally from deficits in social interaction, communication and repetitive and restricted patterns of behavior. This thesis documents changes in our understanding of these behaviors: early theory proposed that autism was caused by the lack of a strong attachment between the child and his mother or father, yet today it is accepted that autism is a complex genetic disorder affecting brain development in which environment also plays an important role.

To do so this paper reviews the neurobiological and clinical findings of motor deficits in autism and then presents two case studies. The first case study is a detailed analysis of the first time a child with autism is able to eat with a spoon independently contrasted with a typical child also engaging in eating with a fork for the first time. The second study describes the process of teaching a child with autism a fine motor skill. Specifically, the child is taught how to manipulate clothing fasteners such as a button and snap. The second case study was informed in part by the kinematic analysis of the first case study.

Motor aspects of the third diagnostic component for autism, restricted and repetitive behaviors and interests, have traditionally been described as purposeless

mannerisms such as hand flapping or rocking. However, purposeful movements conducted by children with autism can show similar characteristics of repetitive behaviors such as invariance in timing and pattern. For instance, the first case study describes invariance during a purposeful motor skill (i.e., eating with a spoon). The second study shows that it is highly effective to teach a child with autism to button a button or snap a clothing fastener specifically in the pattern he will use when doing the activity. This child had been working in occupational therapy for the prior two years on this skill, but not directly in the pattern he would use. The child learned how to button and snap effectively using this method. This paper presents evidence in support of expanding the definition of restricted and repetitive behavior in ASD to include purposeful, learned skills.

CHAPTER 1
NEUROBIOLOGICAL FINDINGS IN AUTISM RELEVANT TO MOTOR BEHAVIORS

Chapter 1 begins with a review of current diagnostic criterion for autism followed by a review of the neuroanatomical findings in the cerebellum, the cerebral cortex and the basal ganglia. There is evidence to support that the cerebellum may be involved early on in autism and that neuroanatomical differences observed in the cerebral cortex and the basal ganglia may be due to developmental changes in response to the early cerebellar differences (Bauman and Kemper 2005), so this is the order in which these regions are presented. Three firm findings in the brain of people with autism include: decreased numbers of Purkinje cells in post mortem studies and volumetric differences in vivo (imaging) in the cerebellum; enlargement of the brain in the first few years of life and volumetric differences in the striatum of the basal ganglia. Additionally, these structural and functional differences have also been putatatively correlated with behavioral measures.

What is Autism?

In the American Psychiatric Association *Diagnostic and Statistical Manual of Mental Disorders, fourth edition* (DSM IV, Filipek et al., 1999), autism is but one of several categories that fall under the umbrella disorder of pervasive developmental disorders (PDD). Autism, Asperger's syndrome and PDD- Not Otherwise Specified (PDD-NOS) are classified as autism spectrum disorders (ASD), although PDD also includes Rett's syndrome and childhood disintegrative disorder. Inclusion criteria for ASD are impairments in (1) social and (2) communication abilities (the first two domains), and (3) the presence of repetitive and stereotyped behaviors. Exclusion is by other diagnosis such as Rett’s syndrome. The PDD-NOS diagnosis is used when

autistic symptoms are present, but the individual does not meet the full criterion cutoff for autism. Added criteria for categories of PDD relate to developmental progression: e.g. Asperger's syndrome is differentiated from autism in that language appeared to develop normally up until the age of three. The diagnosis of childhood disintegrative disorder is indicated when a child develops normally up until at least 2 years of age, followed by a rapid regression with autistic symptoms. Numerous attempts have been made to improve reliable diagnosis of ASD (Mayes et al., 2009). Current 'gold standards' for ASD diagnosis are behavioral inventories; the Autism Diagnostic Inventory- Revised and the Autism Diagnostic Observation Schedule (Gotham et al., 2009; Lord et al., 1994).

Given that the three core symptom domains of ASD inclusion criteria are generally derived from clinical judgment, several recent studies have used factor analysis as a means to inform whether ASD is best characterized by the current three domains or whether different domains would be a better fit. For example, Georgiades et al. (2007) found the best fit for three, but different, domains: (1) inflexible language behaviors, (2) impaired social communication, and (3) repetitive sensory and motor behaviors. Alternatively, Snow et al. (2009) concluded that a two domain model of (1) social and communication problems, and (2) repetitive and restrictive behaviors and interests (RRBI) were the best fit. Further still, Happe (2008) suggests that autism defined by DSM-IV domains may be a 'fractionable triad' with differing genes responsible for each domain.

Further research is certainly needed before making any firm conclusions, but the above examples illustrate the uncertain and evolving nature of ASD diagnosis.

Diagnostic uncertainty is a recognized challenge for the field. It has been theorized that people with autism suffer from a lack of "central coherence", the cognitive ability to bind together a jumble of separate features into a single, coherent object or concept (Frith, 1989). Ironically, the field of autism research all too often seems like a fragmented tapestry stitched from different analytical threads and theoretical patterns (Belmonte et al., 2004).

Neurobiological Findings in Autism

Abnormalities have been reported in virtually every part of the autistic brain (Stanfield et al., 2008). The present review will focus on areas with particular import to motor function, namely, cerebellum, cerebral cortex (particularly frontal and parietal lobes), and striatum in the basal ganglia. For these regions findings in autism include: early brain overgrowth followed by slowed or arrested overall brain growth, but particularly frontal lobes (Redcay & Courchesne, 2005); differing connectivity and activation patterns (Muller, Pierce, Ambrose, Allen, & Courchesne, 2001; Just, Cherkassky, Keller, & Minshew, 2004; Kana, Keller, Cherkassky, Minshew, & Just, 2006; Mizuno, Villalobos, Davies, Dahl, & Muller, 2006); micro structural differences (Casanova, Buxhoeveden, Switala, & Roy, 2002; Vargas, Nascimbene, Krishnan, Zimmerman, & Pardo, 2005; Casanova et al., 2006); and volumetric differences of the cerebellum (Pierce & Courchesne 2001) and of the striatum (Hollander et al. 2005).

The Cerebellum

Structural Imaging

Guided by post mortem studies of autism brains evidencing abnormally decreased numbers of Purkinje cells, one of the earliest imaging finding was hypoplasia (decreased size relative to typically developing, normal brains) in ASD of vermal lobules

VI and VII in the cerebellum (Courchesne, Yeung-Courchesne, Press, Hesselink, & Jernigan, 1988). Figure 1-1, below, shows a midsagittal section of the cerebellum with areas VI and VII of the vermis smaller in the participants with ASD (A) as compared to the typical participants (B). Comparisons of these panels can be aided by looking at the pons and brainstem, which appear relatively equal in size. The small triangular regions outlined in black are labeled I-V and VI-VII. Comparing the two panels, areas I-V appear roughly equal in size whereas area VI and VII appear smaller in the autism brain (A), as compared to the typical brain (B).

While Courchesne et al. (1988) had found hypoplasia of vermal lobules VI and VII in their original study, subsequent work by their lab showed one subgroup with *hypo*plasia and a second subgroup with *hyper*plasia of these lobules when compared to controls (Courchesne et al., 1994). In contrast, using volumetric measurement, Hardan, Minshew, Harenski, & Keshavan (2001) reported that in non-mentally retarded adolescents and adults with ASD the cerebellar volumes were greater than controls, but no significant difference for the vermis areas were noted. In fact, when reading through the literature pertaining to cerebellar differences in autism, one can easily get confused. For example in a review article, Belmonte (2004) says, "MRI morphometry reveals hypoplasia of the cerebellar vermis and hemispheres and autopsy studies report reductions in the number of Purkinje Cells." Yet, from a recent meta-analysis, Stanfield et al. (2008) reports of firm findings: increased size of the cerebellum overall and some evidence for decreased size of vermal lobules VI and VII and possibly of areas VIII-X.

The reasons for such confusion may stem from diagnostic uncertainty or from common comorbidities with autism such as low IQ. While Courchesne et al. (1988)

found hypoplasia of vermal lobules VI and VII in their study, in their subsequent study (Courchesne et al., 1994) the majority of participants exhibiting hypo- or hyper-plasia of vermal lobules VI and VII were those with verbal IQs less than 70. In Hardan et al. (2001), where no significant differences were found in the vermis, the ASD participants were of average IQ. Indeed, Piven et al. (1992) hypothesized that volumetric differences in the cerebellum might be secondary to IQ differences between ASD and comparison groups, and found no specific differences in areas of the neocerebellum when controlling for IQ. Again in 1997 Piven, Saliba, Bailey, & Arndt (1997) found larger cerebellar volumes in the autism group, but after controlling for total brain volume and performance IQ; there was no difference from controls.

The question whether IQ should be used as a control variable in such studies has been debated. Courchesne, Townsend, & Saitoh, 1994 argue that low IQ measures are a part of the autistic syndrome, while others maintain that by not controlling for IQ any observed abnormalities will be confounded (Piven et al., 1997) because cerebellar abnormalities are also observed in non-ASD disorders associated with mental retardation. Accordingly, Kaufman et al. (2003) compared cerebellar vermis size in children with Fragile X, Down's syndrome and autism, and additionally within Fragile X and Down's syndrome groups, contrasted participants who did or did not have the co-morbid diagnosis of autism. Findings indicated differences in cerebellar vermis across all groups, but hypoplasia of vermal lobes VI and VII as the sole abnormality was specific to the idiopathic autism group.

Table 1-1 outlines study participants, parameters and findings for structural imaging of the cerebellum. When participants included those with mental retardation,

and the participants were at younger ages, vermal size differences were generally found. When participants were older and when total brain volumes and IQs were controlled, no significant vermal size difference emerged.

Functional imaging and behavioral relationship to cerebellar differences

Further investigations into the cerebellum have included examining the relationship between behavior and size differences in the cerebellum, and neural activity through fMRI.

Belmonte et al. (2004) propose that decreased inhibition from the Purkinje cells of the cerebellum during early development would lead to different activity dependent neural activity, which might explain findings of abnormal individual mapping in and overgrowth of the frontal lobes in ASD. Referencing their fMRI findings of abnormally low cerebellar activation during a selective attention task, and abnormally high cerebellar activation during a simple motor task in persons with ASD, Belmonte et al. (2003) argue:

> Both of these functional abnormalities correlate significantly with reduced size of cerebellar subregions, and it seems likely that this structure–function correspondence extends to the microscopic level and in particular to the reduction in Purkinje cell numbers. Such a reduction would release the deep cerebellar nuclei from inhibition, producing abnormally strong physical connectivity and potentially abnormally weak computational connectivity along the cerebello-thalamocortical circuit. This altered pattern of cortical excitation may produce aberrant activity-dependent patterning and may thus be related to findings of abnormal individual variability in cortical maps for motor function (Muller et al., 2001) and face processing (Pierce et al., 2001) and to abnormal overgrowth in frontal lobes (Carper and Courchesne, 2000)." Belmont et al. (2004), pg. 9229

Putative behavioral consequences of damage to the cerebellum

Whereas science has long viewed function of the cerebellum as largely motor, (Middleton & Strick, 2000) recent imaging, behavioral and neuroanatomical studies

indicate there may be a role for the cerebellum in cognitive functions (Strick, Dunn & Fiez, 2009). People who suffer from a stroke that involves the anterior lobules (I-V) of the cerebellum present with the motor symptoms associated with cerebellar damage - gait ataxia, dysmetria, oculomotor abnormalities and dysarthria (Schmahmann & Pandya, 2008). Alternatively, lesions of the posterior lobe of the cerebellum, which includes areas VI and VII,[1] presents in what is known as Cerebellar Cognitive Affect Syndrome (CCAS):

> The CCAS is characterized by deficits in executive function, visual spatial performance, linguistic processing and affective dysregulation. Executive impairments include deficits in working memory, motor or ideational set shifting, and perseveration. Verbal fluency may be impaired to the point of telegraphic speech or mutism. Visuospatial disintegration impairs attempts to draw or copy a diagram, conceptualization of figures can be disorganized, and some patients display simultanagnosia. Anomia, agrammatic speech and abnormal syntactic structure are observed, with abnormal prosody and occasionally high pitched, hypophonic whining. (p.1052)

Schmahmann & Pandya (2008) further have put forward the dysmetria of thought theory that the cerebellum is involved with automatizing and optimizes cognition as well as motor processes:

> We have proposed that the cerebellum plays an essential role in automatization and optimizing behavior around a homeostatic baseline according to context; that the cerebellum modulates cognition and emotion in the same way that it coordinates motor control; and that disruption of the neural circuitry linking the cerebellum with the association and paralimbic cerebral regions prevents the cerebellar modulation of functions subserved by the affected subsystems, thereby impairing the regulation of movement, cognition and emotion. This loss of the ‘‘cerebellumizing’’[2] of behavior leads not only to gait and appendicular ataxia, dysarthria and oculomotor abnormalities when the motor cerebellum is involved, but also to the various

1 Area VI of the cerebellum demonstrates connections to the premotor cortex.

2 The loss of regulation around a baseline homeostasis.

> aspects of the cerebellar cognitive affective syndrome when the cognitive and limbic cerebellar regions are damaged. (p. 1054)

While much of the above discussion relates to adult lesion studies, it is noteworthy that children having posterior fossa tumor resections, which removed areas VI and VII of the vermis, behavioral delays 'reminiscent' of autism such as mutism and language deficits were observed (Riva & Giorgi, 2000).

Middleton & Strick state that the cerebellum may be as specialized, or topographically organized as the cerebral cortex, and that to categorize a patient as a 'cerebellar patient' may be a bad descriptor as just as patients with cerebral cortex focal damage have specific loss of function, so might patients with damage to specific areas of the cerebellum have a specific loss of function as to the area of the cerebellum damage. For example, specific areas of the dentate nucleus are shown to connect to areas of the prefrontal cortex and these areas of the prefrontal cortex in turn connect to the same area of the cerebellum, forming a closed loop. Damage to an area in the cerebellum that connects to Brodman area 46 would likely present as a cognitive deficit, whereas damage to a different area that connects to the primary motor area in the cerebrum would present as a motor deficit.

Though the above citation seems to link the cerebellum, an area implicated possibly at prenatal to early postnatal times, very clearly with symptoms associated with autism, it should be noted that there continues to be debate as to whether the cerebellum is involved in cognitive processing at all (Glickstein, 2007; Strick et al. 2009), and to what extent the cerebellum is affected in autism (Stanfield et al., 2008).

Guided by previous work observing decreased exploration in children with autism, and noting a study that observed decreased exploratory behavior, as compared to a

control, in a guinea pig strain that had abnormalities of cerebellar lobules Vi and VII (Caston et al. 1998), Pierce and Courchesne (2001) examined the relationship between area of vermal areas VI and VII in the cerebellum and behavioral measures of persons with autism in a visuospatial exploration task. Decreased size of the cerebellum was linked to decreased exploration as well as with increased repetitive behaviors in children with autism (Pierce & Courchesne, 2001). Though no relationship was found between IQ and exploratory behavior, the authors suggest it is certainly possible this would affect the results and the measure used, the non-verbal portion of the Leiter, may not have been comprehensive enough to detect the relationship between IQ and exploratory behavior.

Although hypoplasia of the cerebellar vermis, particularly areas VI and VII, has been correlated to the decreased exploratory behavior seen in people with autism, the exact nature and import of this abnormality is still not clear and much work still needs to be done. (Stanfield et al., 2008) In post mortem cases, the most robust finding has been a decrease in number of Purkinje cells in the cerebellum. Also, the reduced Purkinje cell numbers have been found in autism cases with seizure disorders, with children as well as adults, and with differing medications. In post mortem cases, though, reduced Purkinje cell number has not been confined to the posterior vermis (Bauman & Kemper, 2005). To add to the confusing findings, though some investigators (Bauman & Kemper, 1996) have observed a lack of glial cell hyperplasia and propose that, as glial cell hyperplasia is usually seen in children with Purkinje cell loss at older ages secondary to ischemia and inflammation, this implicates an early developmental timeframe for the decrease in Purkinje cell numbers, others (Bailey et al., 1998), have found modest glial

hyperplasia and suggest that if the cerebellar cortex develops normally, then the difference in Purkinje cell numbers may not occur in the prenatal timeframe suggested by Bauman and Kemper.

Alternatively and interestingly though, a recent study investigating the phenomenon of prism adaptation in individuals with autism indicated that prism adaptation was not affected in individuals with autism (Larson et al., 2008). Lesions that involved areas VI and VII did not affect prism adaptation in the monkeys in this study (Baizer, Kralj-Hans, & Glickstein, 1999). While Larson's (2008) null finding does not confirm abnormalities specific to areas VI and VII in the cerebellum, it would be consistent with negative findings in areas outside of these lobules that affect prism adaptation.

In summary, the cerebellum appears to an area of the brain that is malformed in autism and may affect neural connections through experience and developmental plasticity. Further research is certainly needed before we can draw strong conclusions as to the certainty and consequences of cerebellar malformations.

The Cerebral Cortex

Early post mortem studies did not reveal structural differences in the cerebral cortex in autism, but recent imaging and newer stereologic techniques have revealed developmental brain growth differences in individuals with autism as well as micro structural differences.

Brain growth and macrostructure

Other recent research in autism has focused on the finding that there appears to be an early overgrowth of the brain in the first few years of life (up until about 4 years of age) followed by a period of arrested growth when compared to controls. Though

measurement and age differences differed in studies, two recent meta analysis support a firm finding that there is generalized enlargement of the cerebral hemispheres in the first couple years of life in autism (Redcay & Courchesne, 2005; Stanfield et al., 2008). Figure 1-2, reproduced from Redcay & Courchesne (2005), below, for a visual analysis of brain growth differences found in 15 studies on ASD brain size. Estimates of brain size some based on head circumference and others based on structural MRIs were compared across 15 studies. Figure 1-2 plots as percentage difference between estimated autistic brain size versus normative data for typically developing children of similar age, obtained from the Centers for Disease Control, shown as a function of age. Autistic children apparently have smaller than typical brain size quite early in life, but by age two it appears to be as much as 10% larger and then this difference declines with age until reaching near 0 by roughly late adolescence, early adulthood years.

In an attempt to refine the question of where this overgrowth occurs in the brain, Carper, Moses, Tigue, & Courchesne (2002) used a combination of manual tracing and computer algorithms to estimate volume of brain structures from MR images of 35 autistic children. They found, comparing volumes of gray and white matter volumes in the frontal, temporal, parietal and occipital lobes, that the overgrowth appears to be especially pronounced in the frontal lobes while the occipital lobes appear unaffected, with the degree of white and gray matter volumetric differences being decreasingly affected as one moves posteriorly in the brain. Possible proposed mechanisms behind this abnormal enlargement have included abnormal neurotrophic factors and/or differences in neural activation due to early anatomic differences in areas such as the cerebellum.

In a typically developing child, there is increasing development of numbers and connections of neurons (See Figure 1-3) during this time period. Areas that appear to be more affected in autism such as the frontal cortex and higher order areas are also areas that have prolonged periods of growth and are thus vulnerable for longer periods of time (Courchesne & Pierce 2005). For example, while dendritic arbors of the pyramidal cell in the primary visual area have reached maturity by 2 years of age, in the frontal cortex, pyramidal cell dendritic arbors have only reached 48% of maturity by 2 years of age. The frontal cortex, an area inferred to be involved from behavioral studies, is vulnerable for a longer period.

Microstructure

Though early post mortem observations did not include observed differences in the cerebrum, a recent study using newer stereologic techniques, documented differences in minicolumns in the autistic brain. Specifically, in Brodmann areas 9 in the prefrontal cortex, and areas 21 and 22 in the temporal lobe, increased number, smaller width and decreased horizontal spacing between minicolumns have been observed (Casanova et al., 2002).

The same investigators replicated this finding in an independent sample, examining Brodmann areas 3, 4, 9 and 17 in six individuals and matched controls (Casanova et al., 2006). This study similarly found decreased volume of minicolumns but assumed an increase in number of minicolumns in the autistic group as no difference was found in brain weight compared to controls. When comparing this difference across brain regions, area 9 in the frontal lobe had the largest volumetric difference, with the other areas roughly comparable.

What is the minicolumn?

> The minicolumnar circuit is an evolutionarily and ontogenetically conserved template adapted in the various cortical areas according to their specific developmental and functional requirements. The minicolumnar core comprises radially oriented arrays of pyramidal projection neurons. At the core and periphery of the minicolumn, combinations of GABAergic interneurons provide for a diversity of signaling properties that serve to dynamically modulate pyramidal cell inputs and outputs that perform area and task-specific information processing needs. (Casanova et al., 2006 p. 287)

This cytoarchitecture, and knowledge from animal studies of the visual system, has been the basis for theoretical models of information processing in cognitive psychology (Roelfsema 2006). From studies in monkeys, we know that certain visual stimuli are preferentially dependent on feedback, feed forward or lateral inhibitory neural processing. A recent study by Vandebrouke, Scholte, van England, Lamme & Kemner (2008) examined visual processing in autism based on these models (see further mention below).

How should we interpret this increased number but decreased volume of minicolumns?

One possibility raised in the Casanova et al. (2006) study was that increased minicolumn number might be a general indicator of mental retardation. But, Casonova et al. cite Buxhoeveden et al. (2002), which evidences normal minicolumn width with smaller brain volume in individuals with Down's syndrome, a disorder strongly associated with mental retardation. Further, many clinical investigations typically have participants who are high functioning and two recent studies evidenced information processing differences that would be consistent with observed minicolumn differences (see above). More specifically, lateral inhibition has been hypothesized to be aberrant

due to the decrease in neuropil space between minicolumns, where lateral inhibitory neurons reside, in individuals with ASD.

Bertone, Mottron, Jelenic & Faubert (2005) and Vandenbroucke, Scholte, van England, Lamme & Kemner (2008) concluded that lateral inhibition was aberrant in visual processing whereas feedback or recurrent processes were unaffected or enhanced. Vandenbroucke, Scholte, van England, Lamme & Kemner (2009) used different visual stimuli to assess accuracy at detecting differences in feedback processing (detecting surface from background) as compared to visual stimuli to assess horizontal inhibitory influences (detecting boundaries where two different visual orientations meet). Both controls and participants with autism were comparable in discriminating stimuli reliant on feedback processing, whereas the autistic participants scored lower on visual discrimination tasks relying more on lateral inhibitory neural connections. The authors suggest that visual aberrancy in the participants with autism is "probably caused by impaired interactions through horizontal connections in lower visual areas." And that "malfunctioning of horizontal connections is possibly a more general deficit underlying several symptoms of autism."

Connectivity between brain regions

With the advent of techniques to study connectivity to different brain regions, functional connectivity studies using fMRI, fcMRI, been used to study differing connectivity in neural tracts in people with autism. (Just et al., 2004; Kana et al., 2006; Mizuno et al., 2006) Functional connectivity studies use the temporal correlations of activation patterns from fMRI measures in different areas of the brain. One of the more recent models proposed based on some of these findings is increased local overconnectivity with decreased long distance connectivity, resulting in reduced or

aberrant information transfer. (Belmonte et al., 2004; Courchesne & Pierce, 2005) Belmonte et al. (2004) suggest what one would see in this type of network is amplified neural response to sensory stimuli, whether attended or unattended and decreased synchrony between areas of the brain that integrate sensory information. Belmonte cites (Belmonte & Allen, 2000; Belmonte & Yurgelun-Todd, 2003), two studies (EEG and fMRI) that show a pattern of decreased activation in integrative regions in the brain (medial temporal and prefrontal) with decreased synchrony of these regions with sensory regions.

Table 1-2 summarizes imaging studies investigating connectivity in people with ASD. Generally, there appears to be different connectivity in the autism brain with evidence for relatively decreased connectivity to the frontal lobes, (Villalobos, Mizuno, Dahl, Kemmotsu & Muller, 2005; Lee et al., 2008, Turner, Frost, Linsenbardt, McIlroy, & Muller, 2006) but more intact connectivity as one moves posteriorly in the brain (Kleinhans et al., 2008, Just et al., 2004, Villaboos et al., 2005). One recent study investigated connectivity within known corticostriatal loops (Turner et al., 2006). While the control group demonstrated connectivity between the caudate and associative, orbitofrontal, occulomotor and motor regions of the frontal cortex, the autism group showed decreased effects in these regions with increased activation, mostly in pericentral regions, but also in areas not expected such as the visual cortex.

The Striatum

Recent imaging studies in people with autism have evidenced a relationship between the size of the striatum and the restricted and repetitive behaviors and interests (RRBI) domain of autism. Though the studies appear conflicting in that at times there seems to be a positive correlation to the RRBI domain and other times a

negative correlation, this may be due to the type of assessment and the type of repetitive behavior. Langen et al. (2009) suggests that this may be that higher order 'cognitive' behavior appears to be negatively correlated with caudate size, whereas lower order 'motor' behavior tends to be positively correlated with the striatal size, especially the caudate, but further research is needed to confirm this hypothesis. Table 1-3, below, summarizes findings from structural imaging studies of the striatum.

The striatum, comprised of the putamen and caudate, is the major input nucleus of the basal ganglia, with major inputs from frontal areas of the cerebral cortex. Over the last several years there has been increasing evidence supporting a role for the basal ganglia in sharpening the selection of actions and intentions, while suppressing competing actions or intentions. (Mink, 1996; Middleton & Strick, 2000) Additionally, differences in frontal-striatal- thalamic circuitry have been associated with repetitive and restricted behaviors in animal models (Lewis, Tanimura, Lee, & Bodfish, 2007) and in volumetric studies of the striatum (Sears et al., 1999; Hollander et al., 2005; Langen et al., 2009). Different connectivity has also been found between the frontal cortex and the striatum in an fcMRI study with high functioning adults and adolescents with autism (Turner et al., 2006).

Guided by findings of striatal volumetric differences in persons with obsessive-compulsive disorder (OCD) and Tourette's syndrome, disorders with overlapping repetitive behaviors, Hollander et al. (2005) compared 17 adults with autism with 17 controls for difference in putamen and caudate volumes. The right caudate and putamen were larger in the autism group and repetitive behaviors, particularly higher level repetitive behaviors were positively correlated with increased volumes. As the use

of neuroleptics has been associated with increased volume of basal ganglia structures, Langen, Durston, Staal, Palmen, & van Engeland (2007) compared caudate volume in high-functioning individuals with autism with and without neuroleptics use. The volume difference was significant for individuals with autism as compared to controls in both medication and medication naive groups. The difference also remained significant after correction for total brain volume.

Although the Hollander et al. (2005) study evidenced differences in the striatum, the participants in this study were adults so developmental changes could not be detected. A recent large (n= 99 autism participants and n=88 controls) cross sectional study examined volumetric differences in the striatum. (Langen et al., 2009) Whereas caudate volume decreased as age increased for typically developing children, for the children with autism, caudate volume, greatest in the right caudate head, increased with age. These investigators also found a negative correlation for volume of the caudate and the behavioral diagnostic category of insistence on sameness, and this was more apparent in younger subjects.

A comparison to prior findings though revealed apparently conflicting results. For example, (Hollander et al., 2005) found a positive correlation of the size of the right caudate and higher order repetitive behavior. Sears et al. (1999) found a negative correlation between size of caudate and ritualistic patterns, but a positive correlation with complex mannerisms. Similarly, Rojas et al. found a positive correlation between the caudate and repetitive behaviors. Langen et al., (2009) suggest the findings are not as contradictory as they appear as lower order repetitive behaviors (e.g. complex mannerisms) are associated with increased caudate volume, whereas higher order

ritualistic behaviors are negatively associated with caudate volume (at least in three of four studies), so for example in Rojas 2006, the entire category of repetitive behaviors were positively correlated, rather than analyzing individual categories of repetitive behaviors. Table 1-4 compares correlations in different studies with repetitive behaviors listed in the ADI-R.

To summarize, findings implicate an association between the size of the caudate and the behavioral category of repetitive behavior in people with autism. Though the exact nature of the association is not clear, there is evidence that an increased size of the caudate is related to decrease in ritualistic behaviors, but may be related to an increase in complex mannerisms.

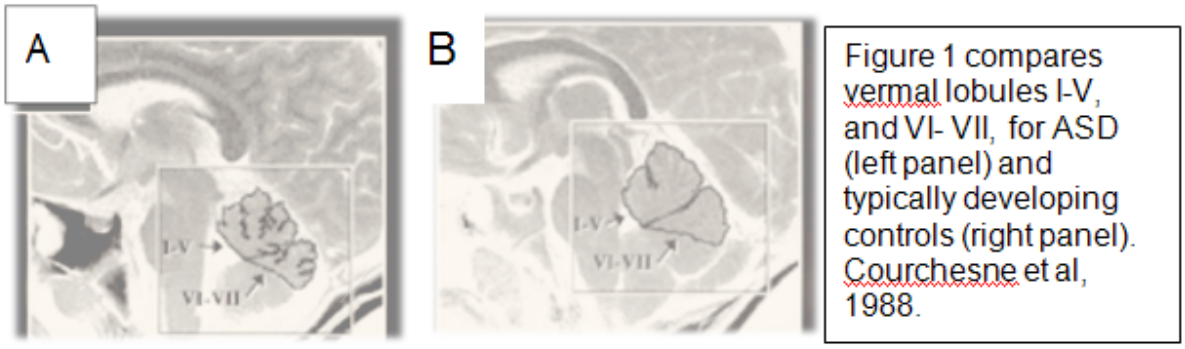

Figure 1-1. Area of cerebellum lobules

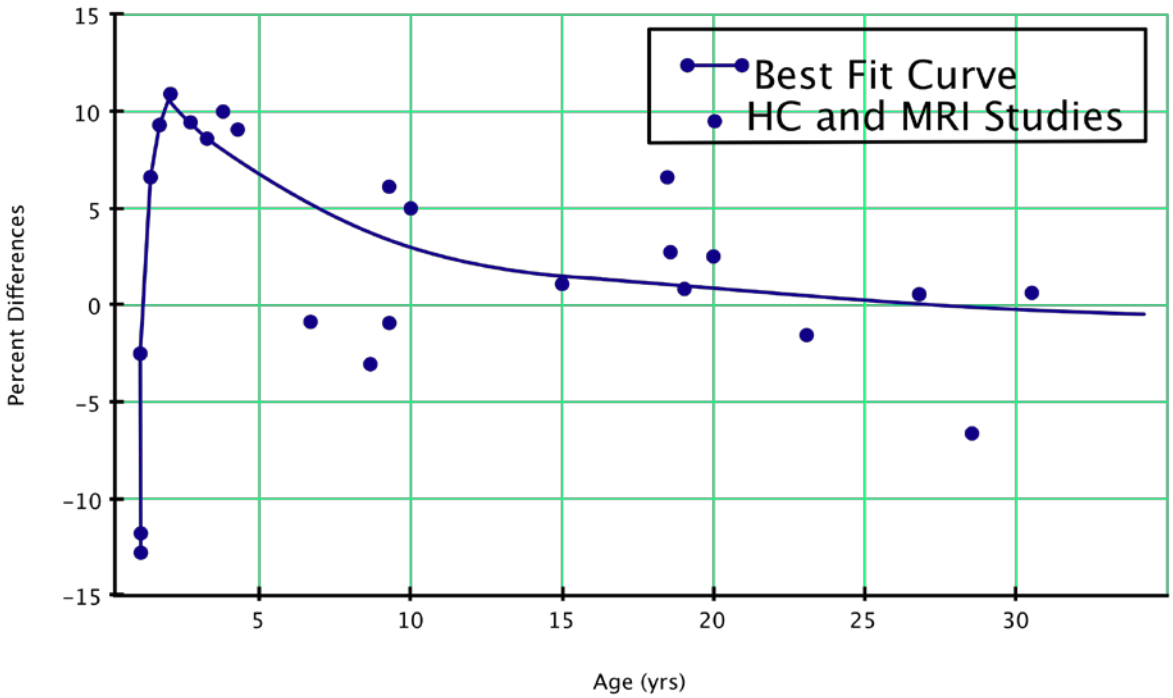

Figure 1-2. Head circumference (HC) and MRI percent differences between autism and controls in studies examining brain size

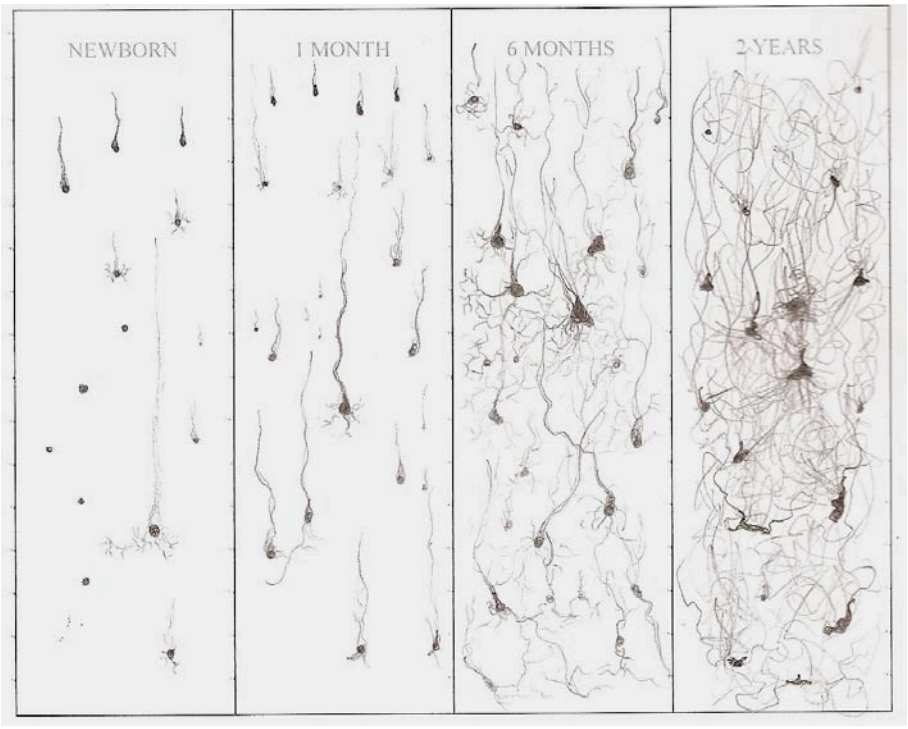

Figure 1-3. Normal development of pyramidal cell in the middle frontal gyrus[3]

[3] Reproduced from Huttenlocher, 2002.

Table 1-1. Imaging studies of the cerebellum

Study	Autism Spectrum Disorder Participants					Comparison Participants				Main Cerebellar Finding
	N (males)	Age range (mean)	Inclusion	Exclusion	IQ* range (mean)	N (males)	Age range (mean)	IQ range (mean)	Matching Criteria	
Courchesne et al. (1988)	18 (16)	6 - 30 (20.9)	DSM-III	other neurol. disorder	70 - 112 (88P, 77V)	12 (9)	9 - 37 (24.9)	not reported	none	VI - VII smaller in ASD
Piven, et al. (1992)	15 (15)	8 - 53 (27.7)	DSM-III, ADI	low functioning	60P - 130P (92.5P)	15 (15)	18 - 56 (30.3)	64P-130P (99.9P)	age, IQ	No significant differences
Piven et al. (1992, cont.)						15 (15)	18 - 36 (28.8)	130P - 130P (130P)	Parental SES	VI - VII smaller in ASD
Courchesne et al. (1994)	50** (41)	2 - 40 (14 for new)	DSM-III	known Fragile X	<50 - 132	53*** (43)	3 - 37 (17 for new)	not reported	none	VI - VII smaller in 86% of ASD
	**18 from 1988					***12 from 1988				VI - VII larger in 14% of ASD
Hashimoto et al. (1995)	102 (76)	0.5 - 20 (6.1)	DSM-III when 3+	chromosome, EEG abnormal	10D - 129D (59.5D)	112 (76)	0.25 - 20 (7.1)	"normal limits"	none	Brain stem, cerebellum smaller in ASD
Manes et al. (1999)	27 (81%)	(14.3 +/- 6.8)	ADI		(4.6 +/- 5.6 MA)	17 (65%)	(11.8 +/- 5.0)	(4.5 +/- 2/7 MA)	Mental Age	No significant differences
Hardan et al. (2001)	16 (16)	12 - 52 (22.4)	ADI-R, ADOS	low functioning	(100.4)	19 (19)	13 - 52 (22.4)	(100.5)	Community SES	ASD larger hemispheres but no difference VI-VII
Kaufmann et al. (2003)	10 (10)	(6.9 +/- 2.4)	DSM-IV, ADI-R, ADOS	co-morbidity	(66,1 +/- 14.4)	22 (22)	(8.3 +/- 1.9)	(120.8 +/- 9.2)	healthy	VI - VII smaller in ASD

Table 1-1. Continued

Study	Autism Spectrum Disorder Participants				Comparison Participants				Main Cerebellar Finding
Kaufmann et al. (2003, cont.)	16 (16)	(7.0 +/- 1.8)	ASD plus Down's	(20.1 +/- 6.9)	11 (11)	(7.2 +/- 2.1)	(41.2 +/- 9.1)	Down's only	VI - VII smaller both groups
Kaufmann et al. (2003, cont.)	13 (13)	(5.7 +/- 2.1)	ASD plus Fragile X	(46.0 +/- 15.0)	9 (9)	(5.3 +/- 1.1)	(56.0 +/- 15.2)	Fragile X only	VI - VII larger co-morbid ASD

***Note: P denotes Performance IQ, V denotes Verbal IQ, D denotes Development IQ, MA denotes Mental Age, else Full-Scale IQ.
* 18 autism participants were from the 1988 study.
** 12 were from the 1988 study
*** ICA = Intracranial area

Table 1-2. Connectivity studies

Study	Participants	Task	Findings
Just et al. (2004)	17 HFA and 17 Controls	Reading an active or passive sentence and then answering as to the agent or recipient of the action	The autism group produced reliably more activation than the control group in Wernicke's (left laterosuperior temporal) area and reliably less activation than the control group in Broca's (left inferior frontal gyrus) area. Furthermore, the functional connectivity between the various participating cortical areas was consistently lower for the autistic than the control participants.
Kashino et al. (2005)	14 HFA and 14 healthy normal controls	N-back working memory task with letters	The control group demonstrated more activation in the left than the right parietal regions, whereas the autism group showed more right lateralized activation in the prefrontal and parietal regions. The autism group also had more activation than the control group in the posterior regions including inferior temporal and occipital regions. The analysis of functional connectivity yielded similar patterns for the two groups with different hemispheric correlations. The temporal profile of the activity in the prefrontal regions was more correlated with the left parietal regions for the control group, whereas it was more correlated with the right parietal regions for the autism group.

Table 1-2. Continued

Study	Participants	Task	Findings
Villaboos et al. (2005)	8 HFA and age and handedness matched controls	A visuomotor button pressing task	Decreased connectivity with area 17 and the inferior frontal cortex in the autism group, but not between area 17 and superior parietal areas.
Kleinhans et al. (2008)	19 HFA and 21 age and IQ matched controls	Activation during identification of previously viewed faces and houses using a one -back paradigm	Significant FFA- amygdala and FFA- superior temporal sulcus functional connectivity was found in both the ASD and control participants. However, the control group had significantly increased connectivity to the left amygdala and the posterior cingulate compared to ASD. Post hoc analyses additionally found increased connectivity to the thalamus in the controls. A significant relationship between abnormal functional connectivity and clinical severity in the ASD group was observed. Specifically, greater social impairment was associated with reduced FFA-amygdala connectivity and increased FFA-right inferior frontal connectivity.
Turner et al. (2006)	8 HFA and 8 sex, handedness and age matched controls	Visuomotor coordination task pressing button with corresponding finger	In the control group, fcMRI effects were found in circuits with known participation of the caudate nuclei (associative, orbitofrontal, occulomotor, motor circuits). Although in the autism group fcMRI effects within these circuits were less pronounced or absent, autistic subjects showed diffusely increased connectivity mostly in pericentral regions, but also in brain areas outside expected anatomical circuits (such as visual cortex).
Kana et al. (2006)	13 HFA and 12 age and IQ matched controls	Participants had to decide whether a low or high imagery sentence was true or false	The autism group activated parietal and occipital brain regions but reduced functional connectivity between parietal and frontal regions.
Lee et al. (2008)	12 HFA and 12 age and IQ matched controls 8-12 yr olds	Go/No Go task	In the ASD group, there was a significant negative correlation between age and 2 right IFC correlation pairs: right IFC--bilateral presupplementary motor area (BA 6) and right IFC--right caudate. Compared with typical controls, children with ASD may not have gross differences in IFC functional connectivity during response inhibition, which contrasts with an adult study of ASD that reported reduced functional connectivity. This discrepancy suggests an atypical developmental trajectory in ASD for right IFC connectivity with other neural regions supporting response inhibition.

Table 1-2. Continued

Study	Participants	Task	Findings
Mostofsky et al. 2009	13 HFA and 13 age, sex and IQ matched peers; 8-12 yrs old	Appositional finger tapping task	The autism group showed significantly less connectivity in motor circuits than typically developing controls.

Table 1-3. Structural imaging studies of the striatum

Study	Participants	Findings
Sears et al., 1999	35 ASD: 12-29 years old; IQ mean = 91 (19.8) and 36 healthy controls: 20.1 (3.8)[4]; IQ mean = 102.1 (12.8)	Size of the caudate was larger in ASD group; Using scores from the ADI-R, increased size was related to increased repetitive behaviors of complex mannerisms, compulsions/rituals and difficulties with minor changes in routine. In an independent sample from a prior study with 15 HFA and 20 controls the authors reproduced the increased caudate size in ASD.
Hollander et al., 2005	17 ASD: 28.39 (11.26) years of age, 97.12 (25.36) IQ; 17 healthy controls: 29.4 (9.08) years of age, 111.5 (14.25) IQ	ASD group had significantly increased size of right caudate. Also, the size of the right caudate and the total putamen volumes were positively correlated with repetitive behaviors; particularly the higher order behaviors.
Rojas et al. 2006	24 ASD: 20.79 (10.58) years of age, 94.75 (20.64) IQ; 22 healthy controls: 21.41 (10.91) years of age, 118.74 (11.18) IQ.	They compared ADI category of RRBI and caudate size was significantly positively correlated. Other brain regions associated with social and communicative deficits and symptom severity were also significantly correlated.
Langen et al., 2007	Two independent samples of medication naïve subjects. Sample 1: 21 HFA and 21 age, IQ, SES, height, weight, gender and handedness controls. Age: 11.2 (2.18) Sample 2: 21 HFA and 21 age, IQ, SES, height, weight, gender and handedness controls. Age: 20.08 (3.01)	The caudate was enlarged in both autism groups. Previous findings of significant correlation with RRBI domain of the ADI-R was not replicated but the authors suggest that this might have been due to low incidence and variability in this domain in this sample.

[4] The mean and standard deviation were only reported in this study for the control group.

Table 1-3. Continued

Study	Participants	Findings
Langen et al., 2009	99 HFA 12.89 (4.4.5) years of age, 107.59 (13.56) IQ and 89 Healthy Controls 12.36 (4.70) years of age, 109.99 (12.81) IQ.	Whereas the caudate decreased in size with development in the control group, the caudate increased in size for the ASD group. A significant negative correlation was noted with the category of insistence of sameness and size of the caudate and this effect tended to decrease with age.

Table 1-4. Brain-repetitive behavior correlations (Reproduced from Langen et al., 2009)

ADI-R Items	Langen *et al.* (2009) n=88	*Sears et al.*(1999*)* n=35	Hollander et al. (2005) n=12	Rojas *et al.* (2006) n=24
Repetitive Use of Objects	Repetitive motor behavior (NS)	n.s.	Low order	Repetitive and stereotyped behavior domain - [a]
Hand and Finger Mannerisms		n.s.	NS	
Other ComplexMannerisms/Stereotyped Body Movements		Lower order +		
Resistance to Trivial Changes in the Environment	Insistence on sameness (-) [a]	n.s.	N/A	
Difficulties with Minor Changes in Routine		High order - [b]	N/A	
Compulsions and Rituals	Circumscribed interests (NS)	High order - [b]	High order +[a]	
Circumscribed Interests		n.s.		
Unusual Preoccupations		n.s.		
Unusual attachments to objects		n.s.	N/A	

[a]Significant correlation with caudate volume (*p* _ .05).
[b]Significant correlation with caudate volume (*p* _ .01)

CHAPTER 2
IMITATION AND PRAXIS IN ASD

Motor Overview

Motor differences investigated in autism have included imitation, gait analysis, postural reflexes and early motor milestones such as crawling, motor planning, procedural learning, and praxis skills (Smith & Bryson, 1994; Vilensky, Damasio & Maurer, 1981; Hughes, 1996; Teitelbaum, Teitelbaum, Fryman & Maurer, 2002; Mostofsky et al. 2000; Mostofsky et al., 2006; Ozonoff et al., 2008). Gait analyses have been interpreted as resembling those with Parkinson's disease (Vilensky et al. 1981) and those with cerebellar damage. As noted from Chapter 1 though, one cannot say that any single brain region can account for the behavioral symptoms of autism. In Chapter 2, based on findings from motor learning studies in ASD, I propose that the kinematics of goal directed motor skills might be more reliant on the fronto-striatal circuitry. This does not mean that autism stems from basal ganglia dysfunction, or that there are no differences in this circuitry for individuals with autism, but rather that learned motor skills in individuals with autism are more reliant on fronto-striatal circuitry.

Historically, motor difficulties of individuals with autism have been a source of controversy, (Teitelbaum et al., 1998). Though it has been noted that there is a clumsiness associated with the diagnosis of autism, two of the core deficit areas are communication and social behavior. How would motor difficulties account for this if there are no overt motor problems, and many children with ASD can become very proficient at certain fine motor skills? For example, in the clinic I have worked with a girl who does not have any expressive language, but can tie and untie things very quickly; yet, she has difficulty with other fine motor skills. This is not inconsistent with relying on

fronto-striatal circuitry for learned motor skills, as fronto-striatal circuitry is thought to be more active for overlearned motor skills (Doyon & Carrier, 2009). Additionally, in an fMRI study, fronto-striatal circuitry has also been noted to be preferentially active in a voluntary eye movement task in people with ASD (Takarae et al., 2007).

One area of motor ability that has been a focus of extensive review in autism has been imitative abilities, as it was thought that this might underlie communication and social difficulties. Chapter 2 will begin by reviewing studies of imitation: major findings and generated hypotheses. Imitation is one aspect of the broader skill of praxis, the ability to learn and perform higher-level motor skills. More recently there has been more focus on praxis deficits in ASD, and findings from these studies will be discussed next, followed by a discussion relating these findings to neuroanatomical findings.

Imitation

Imitation difficulties were noted very early on in autism research:

> A mother described the inability of one 21-month-old child to make pat-a-cake simply from watching her. The only way he could learn the game was to have the mother hold his hands and put them through the appropriate movements. (Ritvo & Provence, 1953)

The idea that deficits in imitation might be part of a more global deficiency in self-other mapping led to studying imitation in autism (Rogers & Pennington, 1991), and a recent review of studies investigating imitation deficits in autism (Williams, Whiten & Singh, 2004) found the following:

imitation tasks that were meaningful were preferentially helpful to participants with autism, with this effect being more apparent with older participants.

reversal errors are common in participants with autism.

imitation of actions with objects produced less group differences in studies than non-meaningful gestures.

Williams et al. (2004) discusses six hypotheses proposed for these deficits, and proposes that existing evidence is inconsistent for the first three:

(1) A deficit in representational or symbolic functioning (Curcio, 1978). Williams et al. (2004) suggest that if this were the case, then meaningful imitation would not be easier for the autism group. Smith and Bryson however argue that evidence is not compelling for the meaningful/non-meaningful distinction from the studies cited (Smith & Bryson 2007). For example Williams cites Rogers et al. (1996) as supporting this hypothesis. But, the control group outperformed the ASD group on 3 out of 4 non-meaningful tasks, but only 1 out of 4 of the meaningful tasks.

(2) Poor engagement in the experimental tasks by the autism group (Trevarthen & Aitken, 2001). If this were the case, then the participants with autism would be equally impaired on imitation tasks and this was not the case.

(3) A long-term deficit in social interaction that leads to less practiced motor skills (Tantum, 1991). Group differences appear to decrease as age increases. If this hypothesis were to be correct, we should expect differences to increase.

(4) A dyspraxic problem (Jones & Prior, 1985). Williams et al. (2004) argue against this hypothesis as Green et al. found that children with Asperger's did worse than the control group of individuals with dyspraxia. And, individuals with autism do better with imitation of meaningful gestures.

(5) A disorder of action representation (Smith & Bryson, 1994). Williams et al. (2004) cites that while Bartak, Rutter & Cox 1975 showed the autism group showed less understanding and expression than a control group with language disorder, Smith and Bryson (1994) found no group difference in the recognition of postures and sequences.

(6) A specific deficit in self-other mapping ability (Rogers, 1998). Williams et al. (2004) suggest that a specific deficit in self-other mapping ability is the most parsimonious explanation of imitation deficits in ASD due to the presence of reversal errors, linked to verbal mental age but not chronological age in individuals with autism. But, further work has been done since Williams' paper, investigating praxis ability beyond imitation and may help shed further light on the nature of this deficit. Specifically, there appears to be general support that children, teens and adults with ASD: 1. Are able to access motor production and/or meaning when an object clue is present, 2. Have praxis deficits beyond imitative deficits, 3. Toddlers with ASD attend more often to motion when there is audio-visual synchrony in biological motion.

Praxis beyond Imitation

Praxis is the ability to learn and perform a motor skill, as when a child first learns how to eat with a spoon. The young toddler watches mom or dad eat and then picks up the spoon and eats. As he grows older he achieves the ability to 'pretend', or gesture, this movement. The imitation of his parents, the ability to use the spoon, and the eventual ability to pretend are all thought to be aspects of praxis, reliant on healthy maturation of specific areas of the nervous system. Heilman & Rothi (1997) define apraxia: a cognitive motor disorder that entails the loss or impairment of the ability to program motor systems to perform purposeful skilled movements. Further, this dysfunction cannot otherwise be attributed to elemental motor dysfunction. For example, an apraxic patient may be able to pat his legs ten times fast but could not pantomime how to use a toothbrush. Apraxia is when the praxis abilities are lost in adults from disorders such as stroke. Developmental dyspraxia is the term used when children have a praxis disorder.

In an adult this disorder is acquired, usually through some identifiable lesion that occurs from a stroke, e.g. While adults with acquired apraxia once were able to perform these skilled movements, children affected with praxis deficits are hindered in progressing through this normal developmental period, which may in turn affect development of typical neural pathways. In children with developmental disabilities, praxis difficulties are more difficult to determine than in adults with acquired praxis difficulties – are there difficulties because the child has attentional or cognitive deficits that prevent initial learning of the motor skill, or is it a failure in the neural networks that are needed for these skills. Tests that measure recognition as compared to production of gestures aim to tease out the nature of praxis difficulties.

Though there is no standardized test available for praxis, typical tests include items such as whether subjects can perform a gesture such as waving goodbye when asked verbally; by visual imitation; from the cue of a picture of the tool e.g. seeing a picture of a hammer and gesturing this motion or by demonstrating how you would use a tool. Trained raters then score whether there are spatial, timing or other type of errors. Additionally, picture cards may be used to assess correct recognition.

Several studies since the Williams article reviewing imitation have provided evidence for a dyspraxic component in children with autism beyond imitative abilities. In 2006, Mostofsky et al. compared praxis in children with autism with an age and IQ matched control group. The participants with autism demonstrated more praxis errors than the control group and this was interpreted as meaning that the praxis deficits in persons with autism are not restricted to deficits in imitation (Mostofsky et al., 2006). In a separate paper (Dziuk et al., 2007) used hierarchical regression and determined that

after controlling for age and IQ while basic motor abilities were predictive of praxis scores, after controlling for basic motor performance, praxis errors were a significant predictor of autism severity. Though it could be reasonably argued that if imitation were the primary deficit, and the skill was never learned correctly that one would expect to see general deficits in praxis.

Dewey et al. (2007) similarly looked at praxis in individuals with autism. Control groups were children with developmental coordination disorder (DCD), children with DCD and Attention Hyperactivity Deficit Disorder (ADHD) and children with just ADHD. While all participants performed poorly on the Bruininks–Oseretsky Test of Motor Proficiency Short Form (BOTMP), a standardized test of motor proficiency, the group with autism had significantly more praxis errors. An ANCOVA with age and IQ included as covariates revealed that the children with autism scored significantly lower than all of the other groups on both gestures to verbal command and imitation. When gender and motor skill measures from the BOTMP was added as a covariate, the difference remained significant.

Praxis gestures can be categorized as either gestures that use tools or social and communicative gestures. Smith & Bryson (2007) evaluated social and communicative praxis gestures and pantomimed object use gestures in children with autism, a language impaired group and a typically developing group, matched on verbal abilities and sex. These investigators used different input modalities (verbal request and pictures) to further investigate neural pathways that might be affected in autism.

These investigators found that children with autism had a significantly more difficult time imitating unconventional use of objects. Though children with autism

demonstrated understanding of the gestures, through the use of pictures, they had a more difficult time with production of gestures through imitation or gesture when verbally requested than the control groups. All of the children with autism passed a control task of performing the gesture with the actual object.

Mentioned in the beginning of this chapter, a relevant recent study (Boria et al., 2009) assessed whether children with autism's could detect information about the goal of an act (e.g. to grasp a cup) and the intention behind the act (e.g. to drink from the cup). Boria et al. compared high functioning children with autism with typically developing controls in a task that asked, based on a picture of an object hand interaction, what an individual was doing and why. The children with autism showed that they could gather the intent of an action through information from the objects represented, but not from the motor action. For example, if the task was to determine why the person was picking up the phone (see figure 2-1 (Boria et al., 2009)) but the information had to be determined by the way the person was grasping the object, the person with autism could not make the determination of why the person was grasping the phone. Alternatively, if the picture had object clues, such as either a container or a paper that had been partially cut, the person with autism could determine the reason for the grasp.

Interestingly, in the Mostofsky et al. study (2006), the persons with autism had an easier time demonstrating pantomimed actions when shown a picture of a tool. These investigators attributed it to a practice effect as this task was presented last. In Smith & Bryson (2007) the participants with autism were able to perform all tasks accurately when given the object.

In Dowell, Mahone, & Mostofsky (2009) the investigators compared persons with autism to typically developing controls on: 1. A basic motor measure 2. A postural knowledge test of gestures with tools, and communicative gestures 3. A praxis test. The autism group performed comparably to the control group on the postural knowledge of gestures that included tools, but the autism group performed significantly worse on postural knowledge of gestures that were communicative. In preliminary results from a study in our lab with children with autism, they performed comparable on tool or communicative gestures if an object was present (e.g. if there was a doll to wave goodbye to). The results of these studies suggest that neural pathways that rely on object identification to access motor representations are intact in ASD, whereas pathways that rely on biological motion alone are impaired in ASD.

Mapping Findings onto fcMRI Studies

While a theory of underconnectivity in autism has been proposed, (Hughes, 2007) two pertinent fcMRI studies indicate that the certain pathways may be intact or even enhanced (Villalobos et al., 2005; Mizuno et al., 2006). Using a visuomotor task to assess thalamocortical function, Mizuno et al. (2006) evidenced increased thalamocortical connections to the left insula, right postcentral and middle frontal regions. Villaboos et al. (2005) examined functional connectivity of the dorsal stream of the visual system, based on mirror neuron dysfunction hypothesis of autism, and found intact connectivity with superior parietal regions but significantly decreased connectivity to inferior frontal area 44.

Possibly applicable to these connectivity differences in autism, (Klin, Lin, Gorrindo, Ramsay, & Jones, 2009) reported on a serendipitous finding that while infants with autism did not show the preference for biological motion associated with typically

developing infants, they did show a preference for viewing motion with audiovisual synchrony. For example, the infant with autism looked for longer periods at a person playing ‘pat a cake’ with clapping sounds and visual point lights coming together but not to a person walking. In the control group, the typical infants did not show such a preference. One possible explanation for this preferential attention to audiovisual synchronies could be reliant on ‘ bottom up’ processing, or thalamocortical activity in children with autism.

To summarize the findings in the imitation and praxis literature in autism:

Children with ASD are preferentially helped in motor production tasks when an object is present

Children with HFA preferentially are able to detect meaning from object clues over biological motion cues, at least for hand grasp

Toddlers with autism show a preference for attending to visual auditory synchrony over biological motion alone

Praxis deficits in ASD are present beyond imitative deficits

Motor Learning and The third core feature of Autism

Though the above studies focus on motor learning as it pertains to social and communicative deficits in autistic persons, other work has focused on the third domain, repetitive and restricted behaviors and interests (RRBI).

As noted in Chapter 1, RRBI has been correlated with volumetric differences in the striatum. Investigations of the role of the basal ganglia, and its connections to the frontal lobes, or fronto-striatal connections, in normal motor learning indicate that this neural pathway is critical for the maintenance and retrieval of over-learned motor skills, whereas cortico-cerebellar circuitry is more active in motor adaptation or in early stages of motor learning. (Doyon et al., 2009) Additionally, there is considered agreement that

the basal ganglia play a role in the sharpening of selection of intentions and actions, while inhibiting competing actions and intentions (Mink, 1996).

Repetitive behaviors have been linked with deficits in executive function (see (Lewis & Kim, 2009) and cortico-striatal-thalamic connectivity. Turner et al. (2006) used a simple visuomotor finger-tapping task to assess connectivity of caudate nuclei. Whereas the control group demonstrated known connectivity of nuclei to orbitofrontal, oculomotor and motor circuits, the autism group showed decreased or absent connectivity to these regions with increased connectivity to pericentral regions and to areas not known to be connected to the caudate, the visual cortex. Repetitive behaviors in animal models have also been linked to alterations in cortico-basal ganglia circuitry (Lewis et al. 2007).

As Lewis & Kim (2009) describe: repetitive behavior describes "a broad class of responses characterized by their repetition, rigidity or inflexibility, and frequent lack of obvious function." In Chapter 3, we will describe an invariant movement pattern in an early praxis skill of a child with autism as compared to a typically developing child. Though repetitive behaviors are typically thought of in terms of lack of purpose, repetitive behaviors are also associated with fronto-striatal circuitry. The movement pattern of the child with autism as compared to the typical child when first eating with a spoon is invariant for timing and pattern of movement, a finding compatible with a pattern more reliant on fronto-striatal circuitry.

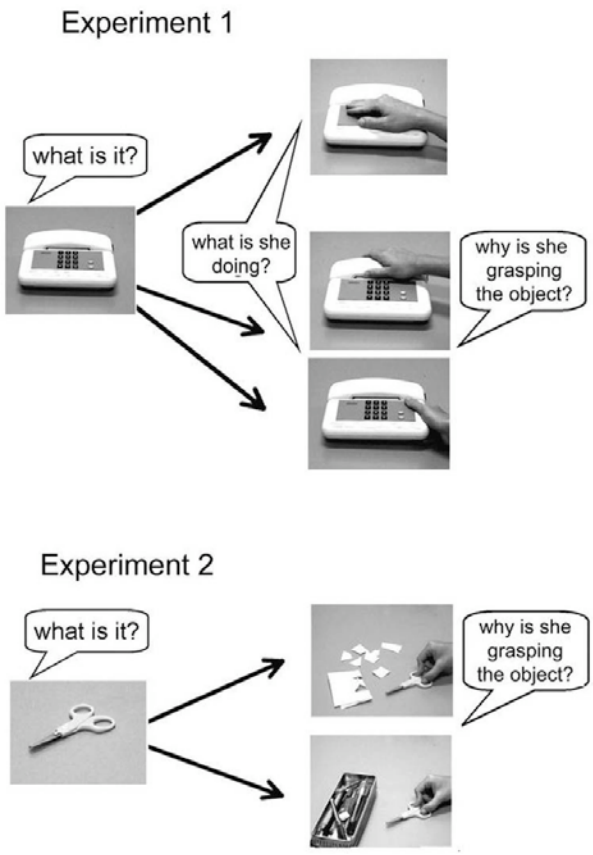

Figure 2-1. What and why of grasping in ASD

CHAPTER 3
CASE STUDY: ANALYSIS OF THE FIRST USE OF AN EARLY PRAXIS SKILL

Chapter 3 presents the kinematic analysis of an early skilled movement in a child with autism as compared to a typically developing child. In a recent retrospective study, (Gernsbacher, Sauer, Geye, Schweigert, & Hillgoldsmith, 2008) demonstrated that early oral motor and manual praxis abilities in children with autism are correlated with verbal skills at a later age. To our knowledge, however, the kinematics of the first use of a skilled movement in a child with autism has not been studied previously. A detailed examination of a praxis skill execution when the child is first performing the skill independently precedes the complication of compensatory mechanisms that come into play later. Eating with a utensil develops in the typical child in the second year of life, thought to be a reflection of cortical maturation and experience (Bundy, Lane & Murray, 2002; Luria 1980). Higher-level skills such as eating with a spoon have been noted to be impaired in autism, although the exact nature of this impairment has not been clearly defined (Mostofsky, et al., 2006; Dewey et al., 2007, Gernsbacher et al., 2008).

The present study compares the movement profiles for two children, one with autism and one typically developing, each child having been captured on home video eating with a utensil for their first time. Qualitative observations concerning movements made by the child with autism included that the movements appeared highly stereotyped; that is, neither the spatial pattern nor timing pattern of the movement varied as much as was the case for the typical child. While the movement appeared highly stereotyped, there were two types of errors that disrupted this patterned movement. Sometimes, the child with autism missed the bowl he was eating from and had to correct the movement trajectory, and at other times, the spoon turned in his hand

so that the handle end was used to scoop the pudding. Such errors were not observed for the typically developing child. Qualitative descriptions of both videos are given in Appendix A.

Methods and Results

ASD Participant

PC is currently ten years old with a diagnosis of autism from the Childhood Autism Rating Scale, with a score of 47, and a score of 38 on the nonverbal portion of the Leiter IQ test. He is essentially nonverbal with comorbid diagnosis of apraxia of speech, but he attempts to read words with spoken approximations. PC underwent praxis testing in a separate study and better-performed gestures that involved use of an object than gestures to command.

Procedure

Approval was obtained through the IRB-2 at the University of Florida to obtain retrospectively home videos of a child who had the diagnosis of autism as well as of a typically developing child. These two videos were screened for motor milestones. Segments of these videos paired for the present analysis were selected on the basis that for both children the videos captured the first time they are eating with a utensil (spoon or fork). The home video of the ASD child had been made about eight years prior to the present study, when the ASD child was 2 years and 4 months old. Home video of the typical child had been made about fourteen years prior, when this typically developing child was 15 months old.

Based on qualitative observations (Appendix A) and on previous findings concerning motor dysfunctions in children with autism, measurements were scored and compared statistically for: (1) direction of motion trajectories, (2) durations of moving

from the bowl to the mouth and from the mouth to the bowl, and (3) errors of missing the bowl or tool use errors of holding the utensil incorrectly.

Movement trajectory directions

Direction of each hand movement was scored using frame-by-frame analysis of 90 seconds duration of video for each child. The 90-second duration was the entire length of time that eating behavior had been captured on the video of the typical child. The video of the ASD child had captured eating behavior for a longer length of time. Accordingly, a starting point was selected by chance and the subsequent 90 seconds were scored for the ASD child.

Two raters, the present author and a psychology undergraduate student, sat side by side in front of a Macbook computer. Angular coordinates had been marked on a clear plastic sheet every 22.5 degrees, to serve as a protractor, allowing trajectory direction to be coded within a range of +/- 11.25 degrees. The center of the back of the wrist was used as the point of reference for hand movement within the coronal plane (when the child lifted his arm in the direction opposing gravity this was coded as 0 degrees, and when the child moved his arm to his left this was coded as 90 degrees). The clear plastic sheet was placed over the computer screen with the middle of the protractor centered over the child's wrist. The 0 degree to 180 degree axis of the protractor was aligned to the apparent gravitational vertical on the video[5]. The video was played on QuickTime, forwarded frame by frame by the present author. Directions were recorded separately for each hand movement by each rater with the raters initially blind to each other's ratings. If either rater needed to see a video segment again for

[5] This only allowed for measuring the movements in two directions.

clarification, the video was replayed.

Directions of the hand movement trajectories were recorded in order of occurrence. The movements lasted for varying lengths of time and covered varying amounts of distance, but those characteristics were not scored. After each reach (a group of roughly 3 to 6 successive hand movement directions) had been scored the ratings were compared. Any disagreement discovered was resolved through review of the video and consensus.

Table 3-1 compares the distributions of hand movement trajectory directions between the typical and the ASD children. Kolmogorov-Smirnov two sample test (Siegel, 1956) was not able to reject the null hypothesis that these direction distributions were drawn from the same population (the largest difference of cumulative proportions, $D = .245$, $\chi^2(2) = 3.277$, $p = .194$).

Table 3-2 compares the distributions of *change in hand trajectory direction* between the typical and the ASD children. Change in trajectory direction is the difference between the directions of two successive hand movement trajectories. In this case Kolmogorov-Smirnov two-sample test *does* reject the null hypothesis that these direction change distributions were drawn from the same population ($D= .400$, $\chi^2 (2) = 8.40$, $p = .015$). In considering the change of hand trajectory directions of the typical child, about half of the time the first trajectory of a pair changed to a smaller angle and the rest of the time changed to a larger angle. For the ASD child, 86% of the changes were to a smaller angle, only 14% to a larger angle.

Figures 3-1 and 3-2 show in polar plots the angular directions of the movements (plotted circumferentially) with sequential order of the movements indicated by radial

distance (earlier movements plotted farther from the center). The plot for the typical child does not have any remarkable pattern, but the plot for the ASD child shows a clear spiral-like pattern. The plot for the ASD child also shows a relatively high density of movement directions along the -45 deg to 135 deg oblique, although the trajectory directions are distributed diversely across most directions.

Variance of movement timing

The duration to move the utensil from the bowl to the mouth and the duration to move the utensil from the mouth to the bowl were measured using frame-by-frame analysis. For these measurements the individual hand movements previously scored were not taken into account. In general, more than one hand movement direction accompanied a particular utensil movement. Utensil movements interrupted by the child being distracted were set aside from analysis. The ratio of utensil movement durations was calculated to account for any differences between children in distances from their bowl to their mouth.

The time to move the utensil from mouth to bowl was initiated at the frame when the utensil came out of the mouth. The end point for this movement was the frame when the utensil stopped going forward into the bowl. For the bowl to mouth utensil movement duration, the time was initiated at the frame when the utensil began an upward movement until the end point frame when the mouth closed around the utensil. Table 3-3 shows the ratios of mouth to bowl: bowl to mouth utensil movement durations. To assess the hypothesis that the timing ratio was less variant for the child with autism, the absolute value of the difference of mouth to bowl/bowl to the mouth – bowl to the mouth/mouth to bowl was calculated. Using a one tailed, group variance comparison test in Stata, version 8, for the absolute value between ratio differences, the null

hypothesis, that there was no variance difference between the groups, was rejected. The ASD child had significantly less variance in these ratios than did the typical child, $F(3, 6) = 24.505$, $p = .0009$. The greater variance for the typical child reflects the varying timing of her movement ratios, in contrast to relatively invariant timing for the ASD child.

Errors

The entire video for each child was recorded for proportion of errors produced for each time the child reached for the bowl.[7] Two types of errors were noted. The bowl was missed or the spoon was held at the wrong end[2]. The typical child had 0 errors out of 6 attempts, and the child with autism had 15 errors out of 32 attempts. Both types of errors were included in these numbers (missing the bowl or holding the utensil incorrectly). The proportion of uninterrupted reaches without error was 17/32 or about 0.53 for the ASD child.

If the typical child in fact had the same likelihood of making errors as did the child with ASD, then the binomial probability of six out of six reaches not containing any errors is 17/32 raised to the sixth power, or approximately $p = .02$. This outcome is instead consistent with rejecting the hypothesis that the ASD child and the typical child had the same likelihood of making these errors. Though this of course needs to be interpreted cautiously as this comparison was only for two individuals.

[7] Operational definitions for different error types were as follows:

Error of tool use: Holding the tool in any position other than that which is intended by its design and attempting to sue it as if in its correct position.

Trajectory error: One direct trajectory which terminates at any point other than the target, followed by a pause, followed by a corrective direct trajectory which terminates at the target.

Discussion

Difficulties with motor planning have been noted in children with autism spectrum disorders. The exact nature of early motor skill acquisition is understudied in this population, unfortunately. The present case study demonstrates highly invariant timing and trajectory directions in the movements of child with autism compared to a typical child, when each first ate using a utensil. Also, trajectory errors that prevented reaching the target, and tool use errors were present for the child with autism, but not for the typically developing child.

The repetitive behavior hallmark for diagnosing individuals with autism has been described as "a broad class of responses characterized by their repetition, rigidity or inflexibility, and *frequent lack of obvious function*" (Lewis & Kim, 2009, p. 114, emphasis added). The present study shows that an inflexible pattern also occurs for a *functional* motor skill in a child with autism. Repetitive behaviors have been associated with fronto-striatal circuitry such as increased size of the caudate associated with complex mannerisms in autism. In animal research, striatal putamen neurons encoding for muscle pattern and direction have been found, but not those encoding for velocity, amplitude, force, position, or acceleration (Mink, 1996). Consistent with a limited capacity to encode variations of movements It is possible that if the child with autism described in this paper had been unusually reliant on fronto-striatal circuitry for first using the praxis skill presently studied, then the relative invariance of his movements would not be surprising. It was somewhat surprising how clearly a pattern of sequential dependencies in movement directions emerged.

A recent study by (Fabbri-Destro et al., 2009) examined the motor kinematics of intentional reaching in typical children compared to children with autism. In typical

individuals, the kinematics of reach changed according to the goal of the movement. For example, when the goal was to place a pencil in a container; for the typical children movement initiation speed was guided by the size of the target container. A typical child will accelerate the initial movement to pick up the pencil for a smaller target container but ASD participants did not change their movement speeds relative to the target. Fabbri-Destro et al. (2009) suggest that individuals with ASD program their movements independent of the target's sensory characteristics. However, an alternative explanation could be that goal oriented movements are less able to be varied in their timing for individuals with autism. Mostofsky et al. (2006) compared children and teens with high functioning autism to a typical control group on a serial reaction time task. The ASD group did not show the characteristic decline in reaction times across blocks typically seen in this paradigm, and seen in their control participants. The reaction times (and therefore the movement times) of ASD participants did not differ between blocks. Mostofsky et al. (2006) attributed this finding to a procedural learning deficit in ASD. Again, however, as with Fabbri-Destro et al. (2009) and as with the present study, the observations were that ASD movements were invariant for timing.

Typical treatment interventions available for occupational and physical therapists to treat praxis difficulties in children with autism include a "bottom up" approach of sensory integration (Schaaf & Miller, 2005), as well as newer techniques such as the interactive metronome and music therapy techniques that use rhythm to assist with the child's sense of internal timing and rhythmicity of a movement (Burpee et al., 2001; Sabado, 2008; Cosper, Lee, Peters, & Bishop, 2009; LaGasse, 2009) Although frequent referrals are made for remediation of fine motor skills (Watling, Deitz, Kanny, &

McLaughlin, 1999), little empirical research addresses the effectiveness of therapeutic interventions (Dawson & Watling, 2000).

If a child with autism has difficulty with motor planning and is highly reliant on movements that are difficult to vary for timing and pattern, then one could infer that interventions capitalizing on repetition of a pattern and rhythmic timing could be particularly helpful in teaching a new motor skill. This conjecture is tested in Chapter 4.

Limitations, Conclusion and Future Research directions

The major limitations of the present study are that it (1) only examined one child with ASD and one typical child, (2) only examined one praxis skill, and (3) the home videos analyzed were of short durations, and were created under uncontrolled conditions analyzed retrospectively. It could nevertheless be demonstrated that first use of the praxis skill of eating with a utensil is highly regular for timing and pattern in the child with ASD as compared to a typical child.

Table 3-1. Distribution of trajectory directions (degrees)

Trajectory (deg)	Typical child Cumulative		ASD child Cumulative		Cumulative Proportion
Bin	Count	Proportion	Count	Proportion	Difference
0	1	0.028	6	0.273	0.245
45	3	0.083	7	0.318	0.235
90	12	0.333	8	0.364	0.030
135	17	0.472	13	0.591	0.119
180	20	0.556	14	0.636	0.081
225	21	0.583	14	0.636	0.053
270	25	0.694	17	0.773	0.078
315	33	0.917	22	1.000	0.083
360	36	1.000	22	1.000	0.000

Table 3-2. Distribution of change in trajectory directions (degrees)

Trajectory Change Bin	Typical child Cumulative Count	Proportion	ASD child Cumulative Count	Proportion	Cumulative Proportion Difference
-180	5	0.143	3	0.143	0.000
-135	11	0.314	8	0.381	0.067
-90	15	0.429	9	0.429	0.000
-45	16	0.457	18	0.857	0.400
45	20	0.571	18	0.857	0.286
90	22	0.629	19	0.905	0.276
135	28	0.800	20	0.952	0.152
180	35	1.000	21	1.000	0.000

Table 3-3. Timing ratios. Ratio of mouth to bowl/bowl to the mouth: movement durations[6]:

Typical	Autism
3.909091	.9527778
1.020734	.8222812
1.975309	1.126374
1.830189	1.098093
	1.074906
	1.588
	1.069697

[6] The number of trials for the typical child was different for timing ratio trials and error trials as timing ratios were only used for movements where the typical child did not pause when taking the spoon out of her mouth. At times she paused and looked at the camera or smiled at Dad off screen. Such discontinuous movements were not included for calculating the movement timing ratios.

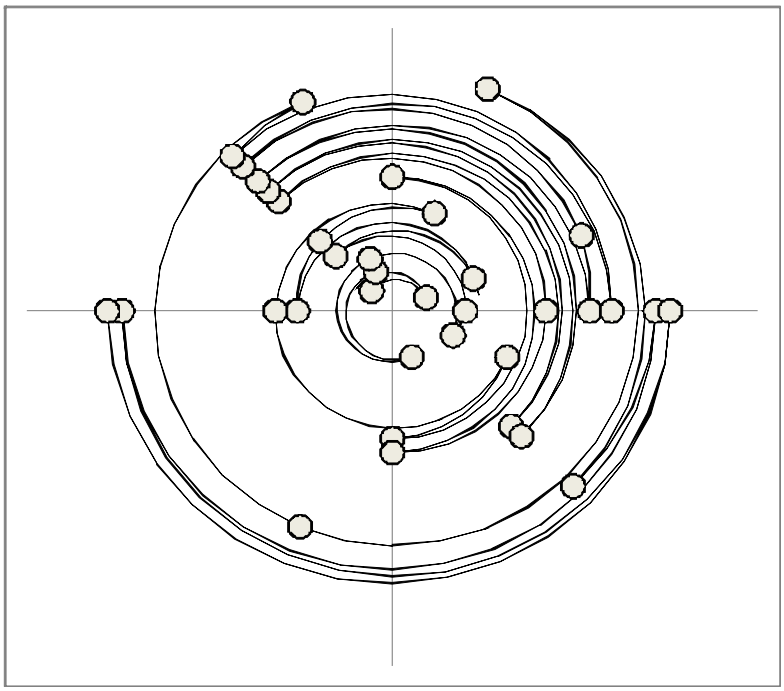

Figure 3-1. Typical child movement trajectory directions.

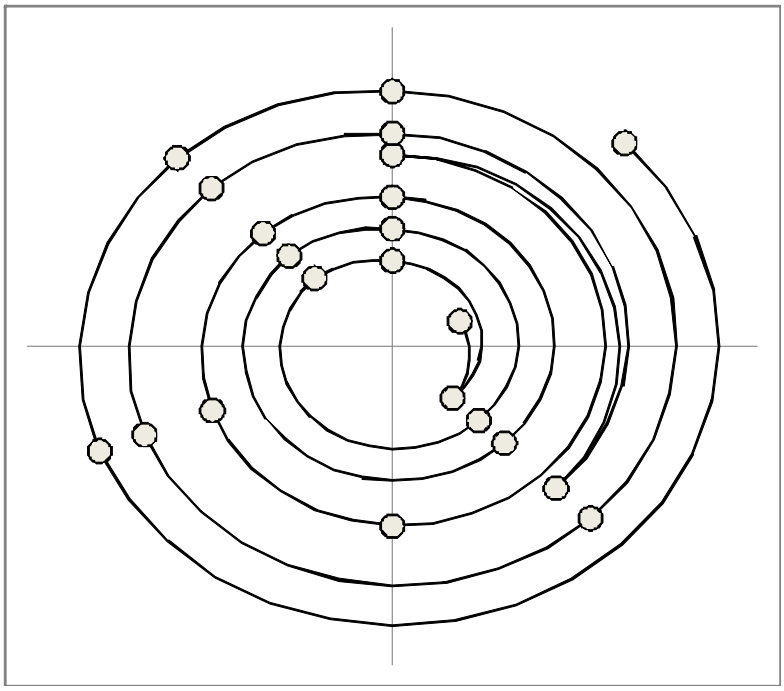

Figure 3-2. ASD child movement trajectory directions.

CHAPTER 4
CASE STUDY: TEACHING THE FINE MOTOR SKILLS OF BUTTONING AND SNAPPING

The author of this paper is a licensed physical therapist. After finishing the study described in Chapter 3, a former client was referred to work on the fine motor skills of buttoning and snapping clothing fasteners. According to the mother, this child had been unsuccessful at reaching independence with these skills from previous therapies carried out for the preceding year or more.

A functional training program was designed to teach buttoning and snapping that focused on motor patterns and movement timing patterns specific to these skills. Additional parameters of the program included intensive training; positive behavioral and visual supports; sensory-motor activities for attention and arousal support; and traditional strengthening exercises. Baseline data were obtained for a two-week period prior to beginning the training program.

Methods

Participant

This child, LC, is a seven-year-old boy with a history of cytomegalovirus infection in utero with subsequent brain damage and diagnosis of autism on the Autism Diagnostic Observation Scale (ADOS) at age 5. LC is verbal. Though his language is marked by frequent repetition of dialogue from favorite videos, he is able to answer questions appropriately with yes or no statements. In school and in therapy, visual and positive behavioral supports had reportedly worked well for LC.

At the time of this study, LC had been working on the goal of buttoning and snapping in school based and private occupational therapy for 30-45 minute sessions two times per week for more than one year. LC had been sporadically successful in

buttoning and snapping on a doll or on apparatus that he accessed on a tabletop, however he lacked independence with snaps and buttons for dressing himself.

Procedure

Rehabilitation studies have demonstrated that there is increased benefit from intensive therapy following a stroke (Kwakkel et al., 2004; Kwakkel, 2006). Additionally, there is evidence that intensive intervention on a daily basis can improve abilities in individuals with autism (Lovaas, 1987). We set up a program using 70-minute daily treatment periods for 5 days per week over 4 weeks.

Before beginning the session, the tasks were written down on a visual schedule (Dettmer, Simpson, Myles, & Ganz, 2000) so that LC could anticipate what came next in the session. Verbal praise and encouragement were used liberally throughout the session to promote LC's engagement (Horner, 2000). Verbal encouragement was guided by a technique, the rapid prompting method, used with children with autism (Mukhopadhyay, 2003). Activity breaks further promoted LC's engagement. Brief periods of swinging have been proposed to increase resting muscle tone temporarily and to increase baseline arousal (Burpee et al., 2001). While there are few studies examining these effects in children with autism (Baranek, 2002; Gardner, 2005), many children with autism love to swing, and LC enjoyed swinging. Choices for an activity break included swinging or running. Aerobic exercise may increase attentional focus in children with autism (Baranek, 2002) and may increase expression of brain derived neurotrophic factor (Cotman & Engesser-Cesar, 2002). Intermittent 5 minute breaks of fast swinging or running (every 20 minutes) took place between strengthening exercise and functional fine motor training. LC chose the activity for each break.

Hand strength exercises consisted of 10-15 repetitions per set for 3 sets of whole hand squeezes, and of individual finger flexions and extensions. These exercises were followed by deep tissue massage to fingers and hands because massage has been shown to improve time on task in children with autism (Xerri, Coq, Merzenich, & Jenkins, 1996). Alternately touching each finger to thumb was then done 5 times per hand.

Practice of buttoning and snapping was done on pants LC wore, for buttoning Lee cotton shorts that had a round wooden button 3/4-inch diameter and for snapping, Lee brand blue jeans that had a ½ inch diameter metal snap. These same pants were used for all assessments for buttoning and snapping. At the beginning of treatment physical assistance was given as needed. To promote modest generalization of the skill (Haring et al., 1987), training was also conducted on clothing of a doll, which had 1-inch diameter round buttons and ½ inch diameter snaps. Skills were trained using two sizes of buttons and two kinds of snaps. Repetitions were for 3 sets of 10 repetitions, alternating on doll and on self. During the practice sessions verbal encouragement and physical assist was given.

Whole hand grasp and pincer grasp strengths were measured using a hand dynamometer. To assess whole hand strength, LC was instructed to squeeze the hand dynamometer as hard as he could and hold this for a count of five. In order to assess pincer grasp, the therapist stabilized the four non-index fingers and LC was instructed to pinch the ball between his thumb and index finger for a count of five. Also, the number of times LC could snap or button his pants during a 30 sec testing epoch were recorded. Four observations of each of these pre-treatment measures were obtained, on the

Wednesday and Saturday for two weeks prior to beginning treatment on the Saturday of the fourth pre-treatment measures. Three measures were then obtained after two, three and four weeks of treatment, all obtained on the last day of that treatment week. Three post-treatment measures were obtained at one month, two months, and fifteen months following the end of treatment. No therapy was given at these follow-up visits, although verbal encouragement was given to engage LC in the measurement tasks.

Results

Pre-treatment LC was unable to button or snap pants he wore during any of the four test epochs, but during treatment and out to 15 months follow-up he could. Figure 4-1 shows the average number of successful button or snap executions made during test epochs, to compare pre-treatment baselines to combined treatment and measures taken after treatment concluded.

Neither skill could be executed at baseline, but both skills could be executed at least once during every test epoch from week 3 of treatment through post treatment measures. Student's t tests for the differences between means at baseline versus at treatment and follow-up combined revealed significant differences (button, $t(8) = -8.3152$, $p = 0.0000$ snap, $t(8) = -4.8913$, $p = .0006$).

LC also improved on test epochs made using the doll. During pre-treatment baseline test epochs, zero buttons and zero snaps were successfully fastened. Combined across treatment and follow-up observations, mean number of buttons fastened on the doll per 30 sec test epoch increased to 1.77 (standard deviation 0.97) and mean number of snaps fastened on the doll increased to 4.8 (standard deviation 0.44), Student's t tests for the differences between means at baseline versus at

treatment and follow up combined revealed significant differences (button, t(8) = -5.488, p = .0003; snap, t(8) = -34.9937, p = .0000

Both left hand pincer grasp and both whole hand grasp strengths showed modestly increased pressure on a hand dynamometer, comparing baseline to the course of treatment and follow-ups. Figure 4-2 shows the average pressures of pincer or whole hand grasps of each hand made during test epochs, to compare pre-treatment baselines to combined treatment and follow-up observations. Student's t tests for the differences between means at baseline versus at treatment and follow up revealed significant differences (left pincer grasp t(7.75) = -2.455, p = .02; left whole hand grasp t(10.95) = -2.347, p = .02; right whole hand grasp t(11) = -3.8651, p = .0013)[7] There was a non-significant trend for improvement of right pincer grasp strength (t(3.8) =-1.9692 p = .06).

Discussion and Conclusion

Many occupational and physical therapists receive referrals for remediation of fine motor skills with children with autism, but there is little empirical work addressing optimum treatment efficacy. The child participating in this study had previously been treated twice weekly for a year leading to limited success on tabletop activities of buttoning and snapping but no success in dressing himself. During the present treatment and up to 15 months follow-up, this child can now button and snap clothing fasteners to dress himself. The present training focus was on few skills trained in an intensive manner for a shorter period rather than at a lower frequency for a longer

[7] Satterthwaite's degrees of freedom are estimated to account for unequal variances between groups.

period. It may be especially effective with children with autism to train the specific motor pattern and motor timing that the skill will need to be performed.

The present study is limited as a case study of a single participant. More frequent observations of the research data would have supported more robust statistical analyses, for example, to rule out spontaneous recovery of hand function. Further research is needed with more participants and more detailed observations before, during, and as follow-ups to treatment to reveal optimal treatment parameters.

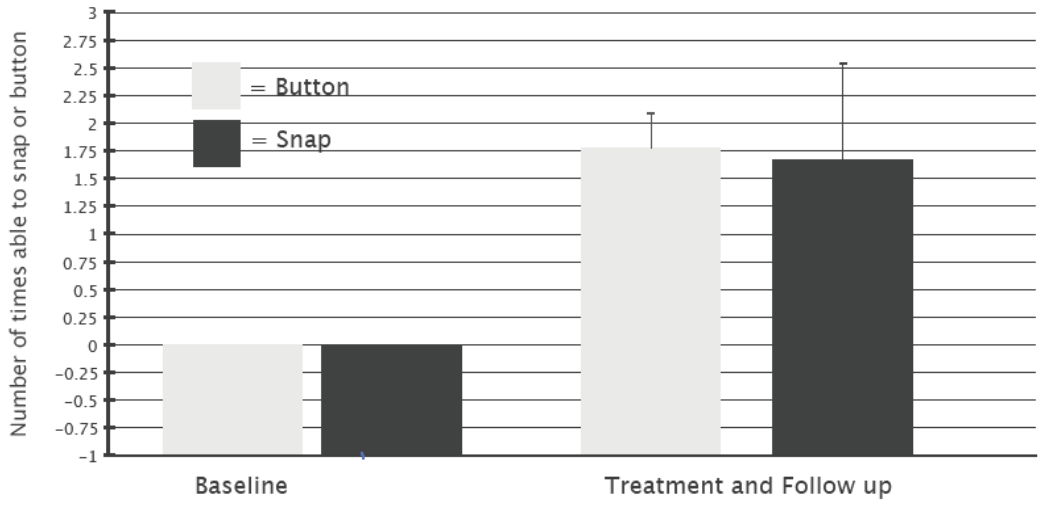

Figure 4-1. Snapping and buttoning ability while dressing self

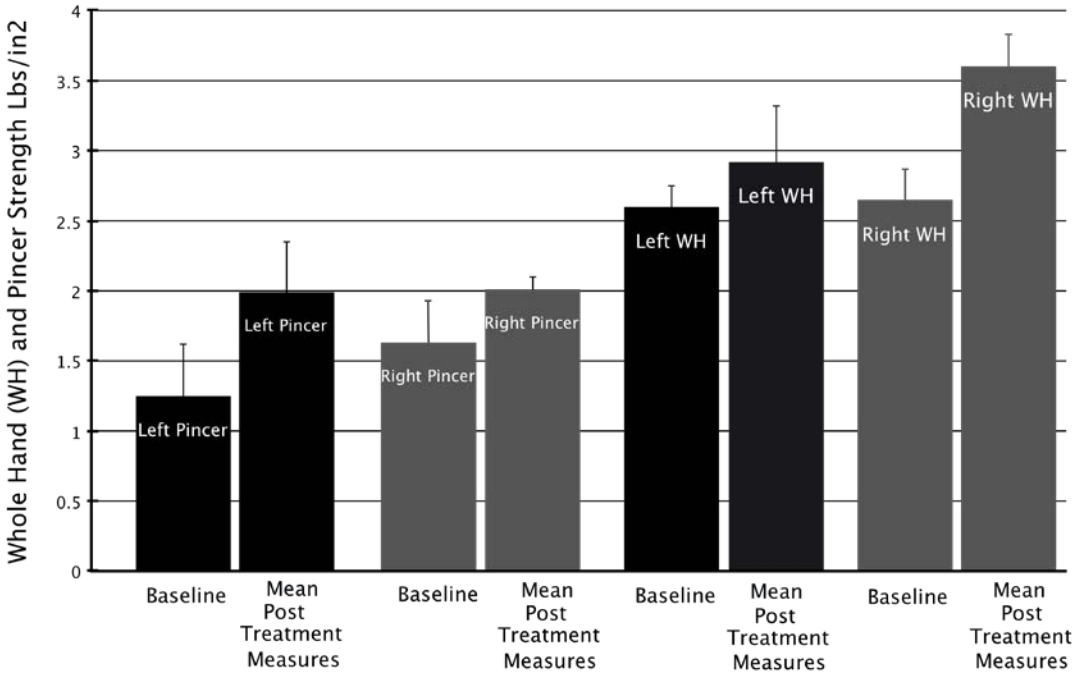

Figure 4-2. Whole hand and pincer grasp

APPENDIX A
QUALITATIVE DESCRIPTION OF VIDEOS FROM CHAPTER 3

Analyses began with observations on the kinematics of motion at the wrist, elbow shoulder and trunk to note joint motions used to complete the task. Based on this qualitative analysis, a strategy to further analyze the segments quantitatively was devised which included scoring the footage (segments) for timing and errors.

Qualitative analysis:

Qualitative analyses were done by the principal investigator, a licensed physical therapist, as well as an investigator trained in the Eschol Wachman Movement Notation System (EWMN). (Teitelbaum et al., 1998) The EWMN system is a system that relies on geometric coordinates, angles and planes to describe a given movement or position. It allows the user to objectively describe the movement and in so doing, qualitatively as well as quantitatively analyze the movement.

Retrospective Footage

General:

Both children sat in a child booster seat at a table. It was the first time self-feeding with a utensil for both children. The child with autism was 2 yr 4 months. The typical child was 15 months.

Child with ASD:

His head rotates back and forth in a repetitive pattern. He does not shift or rotate his trunk. His left arm is positioned next to his body tucked under the table throughout the 3 minutes he is feeding himself with his right hand. There is no active rotation of the forearm, i.e. pronation or supination of the forearm, causing clumsiness to the

movement. Instead, the child uses flexion and extension of the wrist to scoop the pudding. (See Figure A-1).

At times when the child is not looking directly at the bowl, he aims the spoon towards the bowl but misses and has to correct the trajectory. He never misses when he is looking at the bowl. At other times, the spoon shifts in his hand when he scoops the pudding off the spoon and, 'stuck' in the movement pattern, he aims the handle end of the spoon into the bowl. Mom, sitting next to him, switches the spoon to the correct way. See Figure A-2.

The Typical Child

This child uses rotation of the forearm, synergistic with flexion and extension of the wrist, to scoop her food. When she moves her arm, the trunk shifts and rotates to support her movement. The rotational movements of the wrist allow for flexibility in the manipulation of the spoon when scooping the food or bringing it towards her mouth. Though she does have repetitive movements such as shaking the fork (see Figure A-3), as is typical in normal development (Thelen, 1979), her movement when she is eating is not repetitive but manipulated in order to reach her desired target.

Follow-up Footage

As the typically developing child is a relative of the investigator, and the child with autism attends a therapy camp directed by the investigator, recent footage was obtained of the participants eating with a spoon. The length and quality of this for the child with autism was not sufficient for quantitative analysis so a qualitative description was done.

The typical child is presently 17 and the child with autism 10. In a five-minute segment of eating, the child with autism does not make errors with the spoon, but

continues to lack the rotational movements of the forearm. Instead he compensates by rotating the spoon in his mouth. The pattern is less apparent as the child takes his spoon out of his lunch bag, eats with it, then puts it away, then later takes it out again. The typical child does not use the repetitive movements seen at her first time of eating. Her movements continue to be synergistic with rotational movements of the forearm the primary range used to manipulate the bringing the spoon to her mouth.

Figure A-1. Wrist flexion and extension

Figure A-2. Tool use error

Figure A-3. Repetitive movements in a typical child.

APPENDIX B
RAW DATA FROM CHAPTER 4

Table B-1. Snapping and buttoning raw data

Day	#Buttons in 30sec on doll	#Snaps in 30sec on doll	R whole hand strength	L Whole hand strength	R pincer strength	L pincer strength	Snaps pants on self	Buttons pants on self
Pre-test 1	0	0	3.1	2.4	1.7	1.1	0	0
Pre-Test 2	0	0	3	2.4	1.3	1.1	0	0
Pre-Test 3	0	0	2.9	2.7	1.45	1.8	0	0
Pre-test 4	0	0	3.4	2.7	2	1	0	0
After 2 weeks treatment -1	1	5	3.4	2.4	1.8	2.1	1	1
After 2 weeks - 2	1	5	3.6	2.7	1.8	1.9	1	1
After 3 weeks -1	1	5	3.4	2.4	2	2.6	1	1
After 3 weeks - 2	1	4	3.7	2.8	1.6	2.6	2	1
After 4 weeks - 1	3	5	4	3.4	2.1	1.4	1	2
After 4 weeks - 2	2	5	3.6	3.2	2	1.5	3	1
4 Week Post treatment follow up	3	5	4	3.4	2.1	1.4	1	2
2 month follow up	3	5	3.6	3.2	2	1.8	2	1
1 year, 3 months	1	4	3.4	2.8	2	1.4	2	1

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BIOGRAPHICAL SKETCH

Kathleen A. Berger, graduated with her BS in physical therapy in 1984 from Northwestern University. Ms. Berger is the director and founder of Kris' Camp/Therapy Intensive Programs, Inc, a therapy intensive, respite program for children with autism and their families. In the fall of 2006 Kathleen entered the psychology doctoral program at the University of Florida, with her primary research interest in movement differences in autism.