Motor Speech Characteristics of Children with Autism

DISSERTATION

Presented in Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy in the Graduate School of The Ohio State University

By
Richa Soumitra Deshmukh
Graduate Program in Speech and Hearing Science

The Ohio State University
2012

Dissertation Committee:
Professor Rebecca McCauley, Advisor
Professor Laura Wagner
Professor Paula Rabidoux
Copyrighted by
Richa Deshmukh
2012
Abstract

A considerable number of children with autism spectrum disorders (ASD) do not acquire spoken communication. Children with ASD exhibit general motor planning impairments and therefore it has been postulated that in addition to socio-pragmatic difficulties, children with ASD may exhibit speech motor impairment that adds to their difficulty in learning to speak. In order to test the hypothesis that children with high functioning autism (HFA) have difficulties with speech motor control, speech motor performance of 13 children with HFA, in the age range of 4-10 yrs was compared to that of age-matched children with motor speech disorders (MSD, n =11), and those developing typically (TD, n = 13). Overall, although the TD group performed best, followed by the HFA group then the MSD group, only differences involving the MSD group reached statistical significance. In addition, no significant correlation was found between the speech motor scores and the expressive vocabulary. However, 15% of the children with HFA did exhibit a speech delay as reflected by their scores on the GFTA-2. These results suggest that children with HFA do not have speech motor deficits, but have an increased risk for speech delay as compared to the population risk reported in the literature.
Acknowledgments

I wish to express my sincere gratitude to my advisor, Dr Rebecca J. McCauley for the innumerable things that I have learnt from her. Her continuous guidance, patience and constant encouragement have been invaluable in my journey as a doctoral student.

I would like to thank my committee members, Dr. Laura Wagner and Dr Paula Rabidoux, for their unwavering support and encouragement throughout my doctoral education.

My thanks are due to all the children and their parents who participated in this project with amazing enthusiasm. Their willingness to go out of their way to contribute to science and make lives better for themselves and for others is truly impressive.

I would also like to thank Andrea Fitzgerald, Rebecca Wenzke and Jill Daher-Twersky for their immense help in data collection. It was a joy to work with all of them. I am also grateful to Bridget Mahler for her help in coding the data.

Special thanks are due to my fellow doctoral students in the department of speech and hearing science, for all their help and encouragement throughout.

Finally, I would like to thank my husband Soumitra, for without him I would not have ventured on this path. Words cannot express the gratitude I feel for all that he has done and continues to do for me. I also feel extremely grateful for the unshakable belief...
that my parents, my mother-in-law and my sister have in me. Last but by no means the least; my thanks are due to my 11 month old son Samyak, for letting me spend a lot of time away from him in order to complete this project.
Vita

June 1999 .............................................Higher Secondary School Certification,
Maharashtra State Board, India

2002 ..............................................B.Sc. Speech Language Pathology and
Audiology, University of Mysore

2004 ..............................................M.Sc. Speech Language Pathology and
Audiology, University of Mysore

2007 to present ...................................Graduate Teaching Associate, Department
of Speech and Hearing Science, The Ohio
State University

Fields of Study

Major Field: Speech and Hearing Science
Table of Contents

DISSERTATION ........................................................................................................... 1

Abstract .................................................................................................................. ii

Acknowledgments ................................................................................................. iii

Vita ........................................................................................................................... v

Fields of Study ...................................................................................................... v

Table of Contents .................................................................................................. vi

List of Tables .......................................................................................................... viii

List of Figures ........................................................................................................ ix

Chapter 1: Introduction ........................................................................................ 1

Chapter 2: Review of Literature .......................................................................... 7

Motor characteristics of children with Autism Spectrum Disorders (ASD) ........... 8

Measures of Speech Motor Skills .......................................................................... 24

Chapter 3: Methods .............................................................................................. 34

Design ..................................................................................................................... 34
Appendix A: Individual scores on Standardized assessments ........................................ 94

List of Tables

Table 1 Summary of general motor impairments in children with ASD .................... 18
Table 2 Participant description measures .................................................................. 40
Table 3 Experimental tasks .......................................................................................... 41
Table 4 Mean age of participants .................................................................................. 51
Table 5 Mean standard scores on standarized assessments ........................................... 53
Table 6 Mean scores on Multisyllbic Word Repetition task ......................................... 67
Table 7 Summary of results showing significant comparisons between groups .......... 70
Table 8 Individual scores on standardized assessments ............................................... 94
List of Figures

Figure 1 Types of stimuli used in speech motor tasks based on the psycholinguistic assessment framework by Stackhouse & Wells (1997). This figure describes the processes involved in repetition of various types of stimuli.................................................. 30

Figure 2. Rate of repetition on DDK tasks. This figure illustrates the mean and standard errors of rate of repetition on the DDK tasks................................................................. 59

Figure 3. Accuracy of repetition on DDK tasks. This figure illustrates the mean and standard errors of accuracy of repetition on DDK tasks.......................................................... 60

Figure 4. Consistency of repetition on DDK tasks. This figure illustrates mean and standard errors of consistency scores on the DDK tasks. ......................................................... 60

Figure 5. Non-word repetition scores. This figure illustrates mean and standard errors on the non-word repetition task .................................................................................. 65

Figure 6. Syllable Repetition Task (SRT). This figure illustrates the mean and standard error on the SRT........................................................................................................ 67
Chapter 1: Introduction

Autism spectrum disorders (ASD) are known to be characterized by impairments in social interaction, communication skills and repetitive and restricted behaviors and interests (DSM IV-TR, American Psychiatric Association, 2000). Significant language delays in almost all the domains of language are observed early in childhood, for example, poor phonological processing skills (Tager-Flusberg, 2006), lower receptive language abilities (Luyster, et al., 2008; Ventola, et al., 2007), and impairments in pragmatic language skills (Philofsky, Fidler & Hepburn, 2007), poor expressive language skills (Ventola, et al., 2007). Nearly 50% of children with ASD may not communicate verbally (Seal & Bonvillian, 1997); although this proportion is decreasing with increase in early identification (Tager-Flusberg, Paul & Lord, 2005). It is important to investigate this inability to acquire spoken communication skills because it will directly impact outcomes for these children and their families. Although their difficulties in learning to speak are typically ascribed almost entirely to socio-communicative and symbolic impairments (e.g., Wetherby, Prizant & Schuler, 2000) the findings in the literature regarding the general motor impairments (reviewed in the following chapter) suggest that such impairments may be compounded by motor speech impairments, in some if not all children with ASD (Prizant, 1996). The anecdotal evidence that Prizant (1996) provided includes the ability to successfully acquire the use of AAC strategies in non-speaking
children with ASD, symptoms of oral motor impairment like drooling, history of feeding problems, low facial tone, etc., and poor intelligibility of speech in those individuals with ASD who do manage to acquire speech. He described the speech characteristics of the children with ASD who learn to speak as being very similar to those with apraxia of speech, for example, limited repertoire of consonants, difficulty in sequencing speech sounds in multisyllabic words, decreasing intelligibility with increase in utterance length and comparative ease in automated speech (like echolalia) as compared to spontaneous speech.

This hypothesis is based on evidence from two separate lines of research—general motor and praxis impairment and that on phonetic/phonological deficits in children with ASD. Among others, Dzuik, et al., (2007) provided a piece of empirical evidence that the motor difficulties experienced by individuals with ASD have a basis in praxis deficit and not just motor delay. They found that children with HFA and Asperger’s syndrome (mean age 10 yrs) show poorer praxis as compared to their typically developing counterparts. The number of praxis errors was significantly correlated with scores on the ADOS-G (Lord, et al., 2000), showing a direct correlation between praxis and social communication development. They attributed this correlation to a possible common neurological basis for both dyspraxia and social interaction impairment. As regards speech performance of children with ASD, several researchers have identified phonological/phonetic deficits, viz., speech delay (e.g., Cleland, et al., 2010; Rapin et al., 2009) and speech errors (e.g., Shriberg, et al., 2001), but have failed to consider the role of speech motor impairment to account for these deficits. Deficits in nonspeech oral
motor skills have been identified in children with ASD in a few studies (Page & Boucher, 1997; Thurm, Lord, Lee & Newschaffer, 2007). In addition, Gernsbacher, Sauer, Geye, Schweigert and Goldsmith (2008) found that oral motor skills differentiate autistic children’s speech fluency (minimal, moderate and high). However, the relationship between nonspeech oral motor abilities, speech motor skills and speech acquisition is not well understood in neuro-typical individuals (McCauley, Strand, Lof, Schooling & Frymark 2009; Wilson, Green, Yunusova & Moore, 2008). Consequently, knowledge about nonspeech oral motor skills or their impairment in persons with autism provides inadequate information about their motor speech skills and possible impairments. Because speech motor skills play a key role in the ultimate expression of language in terms of articulation, fluency and prosody, an understanding of these skills in individuals with autism may explain the huge variability in expressive language skills commonly associated with this group of children.

So far, few studies have investigated motor speech disorders in children with ASD (e.g., Adams, 1998; Velleman, et al., 2010). Adams (1998) reported that children with autism in the age range of 9 yrs to 11 yrs had significant difficulties with oral motor movements and exhibited some speech motor difficulties that are known to be associated with childhood apraxia of speech, for example, complex consonant production synthesis; blend synthesis and polysyllabic synthesis/sequencing as compared to their typically developing peers. However, the number of participants in their study was very small ($n = 4$), and hence the generalizability of those results is questionable. Velleman et al. (2010) reported that children with autism in the age range of 4 yrs to 6 yrs 5 months demonstrate
deficits in focal oromotor skills and sequencing of oromotor gestures. Acoustic analyses revealed both similarities and differences in the performance of children with ASD and those with suspected childhood apraxia of speech (sCAS). Children with ASD differed from the sCAS group and the typically developing group in that they had lower fundamental frequencies, higher vowel formant frequencies, and lower maximum phonation times. However, they performed similar to the sCAS group in that they had less average variation in their speech duration and had greater variability in their lexical stress ratios as compared to the typically developing children (Velleman et al., 2010). However, the participants in the ASD group in this study were younger than the other two groups and demonstrated a wide range of auditory comprehension skills. Thus the interpretation of these results is negatively impacted by these limitations.

Recently, Shriberg, Paul, Black & Santen (2011), analyzed continuous speech samples to test the hypothesis that children with ASD have concomitant CAS which can explain some of the speech, voice and prosody deficits observed in children with ASD. They found that the ASD group differed significantly from the CAS group in terms of their speech voice and prosody characteristics and therefore refuted the hypothesis of CAS in children with ASD. Children with ASD, however, did have a higher prevalence of speech delay and speech errors. They also had higher rates of inappropriate prosody and voice characteristics than children with CAS, those with speech delays and typically developing children. However, the use of continuous speech samples may not have elicited the subtle speech motor deficits in children with HFA that might otherwise become evident in more challenging tasks like rapid repetition of syllables, repetition of
lengthy words, etc. Another major limitation of this study is the inclusion of only those children with ASD who had speech intelligibility above 70%. Thus, those children who had poor intelligibility (possibly due to motor speech impairment) might have performed differently on the measures of speech motor control.

Thus, there is a paucity of literature that documents speech motor characteristics of children with ASD. Those few studies that have attempted to describe these have used widely different methods to study different age groups of children with ASD therefore making it impossible to compare results across studies. Also, limitations in the above studies in terms of inclusion of subjects from the entire autism spectrum, small sample sizes and assessment protocols impact the generalizability of their results. Consequently, there is a significant need to identify and systematically describe the speech motor characteristics of children with autism. This knowledge can lead to a better understanding of underlying deficits and assist in the development of evidence based intervention plans.

To enhance our understanding of speech motor skills in children with ASD the current project describes a comparative study of the speech motor skills of three groups: (a) children with high functioning autism (HFA), (b) children with motor speech disorders (MSD), and (c) those with typical development (TD). Children with HFA, rather than those with other forms of ASD, were selected because of their greater ability to participate in conventional evaluation procedures designed to assess speech motor skills. The current project has two specific hypotheses:
1. Performance on the speech motor tasks will be the best for TD children, followed by children with HFA, followed by children with MSD. This prediction is based on the hypothesis that TD children (by definition) will have no speech motor impairment, those with HFA will show some impairment and those with MSD (by definition) will exhibit speech motor impairment.

   a. $M_{TD} > M_{HFA}$ (where $M$ is the mean score on the speech motor tasks)
   
   b. $M_{HFA} > M_{MSD}$ (where $M$ is the mean score on the speech motor tasks)

   Speech motor performance: $M_{TD} > M_{HFA} > M_{MSD}$ (where $M$ is the mean score on the speech motor tasks)

2. (a) Expressive vocabulary scores and speech motor skills will be positively correlated for children in both the HFA and MSD groups, but that

   (b) A higher correlation will be seen for children with MSD than in HFA (given the co-morbid socio-linguistic difficulties). This prediction is based on the view that children with ASD will experience socio-linguistic as well as motor influences on speech production.

   $r_{EV-SMS\;MSD} > r_{EV-SMS\;HFA} > 0$
Chapter 2: Review of Literature

The focus of this dissertation – an investigation of speech motor skills of children with high functioning autism – draws upon several research themes that have developed along almost entirely independent paths. Despite the high level of research activity surrounding Autism Spectrum Disorders (ASD) since its identification as a constellation of related developmental disabilities in the DSM III-R (American Psychological Association, 1987) and the many reports of widespread challenges associated with it (e.g., Lecavalier, 2006), much of the literature on that topic has assumed essentially normal speech motor function in that population. Consequently, this literature review is structured so as to follow several discrete paths, viz., a short summary of linguistic behaviors of children with ASD; descriptions of general motor behaviors (including praxis skills) and non-speech oral motor behaviors, arriving only towards its end at a fortuitous intersection – the very small number of studies that describe speech motor behaviors of children with ASD and thus provide a direct motivation for the research reported in this dissertation.

This review of literature is divided into two major sections – the first one (titled motor characteristics of children with ASD) providing background information in order to emphasize the need for studying speech motor skills in children with ASD. In
particular, this section will begin with a short overview of language characteristics in children with ASD, followed by the review studies of phonological skills in order to describe the speech behaviors of children with ASD; and general motor behaviors in children in with ASD in order to sum up the nature and severity of general motor and praxis impairments in this population. This will be followed by a review of literature pertaining to non-speech motor skills in children with ASD, and the limited number of studies examining the nature of speech motor characteristics in children with ASD will be reviewed at the end of this section. The second section (titled measures of speech motor skills) will describe the methods that have been used to study motor speech disorders, the rationale behind various stimuli used finally reviewing the studies that have applied these tools.

**Motor characteristics of children with Autism Spectrum Disorders (ASD)**

Autism spectrum disorders (ASD) have been characterized by functional impairments in triad of symptoms (1) limited reciprocal social interactions, (2) disordered verbal and non-verbal communication skills, and (3) restricted, repetitive behaviors and circumscribed interests according to DSM IV-TR (APA, 2000). Significant impairments in the various domains of language are seen in children with ASD. Poor discourse strategies (Tager-Flusberg & Anderson, 1991) and universal impairment in pragmatics (Philofsky, Fidler & Hepburn, 2007; Tager-Flusberg, Paul & Lord, 2005) which is evident early in the childhood has been reported to be persistent in the later years. Pragmatic impairments have even been reported in those children who seem to have
outgrown their ASD diagnoses (Kelley, Paul, Fein, & Naigles, 2006). Children with ASD are also reported to have syntactic difficulties such as tense and number marking (Roberts, Rice and Tager-Flusberg, 2004), use of less complex language than is expected for their developmental level (Eigsti, Bennetto & Dadlani, 2007), and use of fewer function words and simpler syntax in relation to their mean length of utterance (Scarborough, Rescorla, Tager-Flusberg, Fowler, & Sudhalter, 1991; Tager-Flusberg, Calkins, Noin, Baumberger, Anderson & Chadwick-Dennis, 1990). Children with ASD are known to have significant difficulties with certain classes of words like the mental state verbs (Kelley, Paul, Fein, & Naigles, 2006) and semantic processing in children with ASD has been found to be different from that in typically developing children (Kamio, et al., 2007).

Thus, communication skills in children with ASD are greatly impacted by this complex of impairments in various linguistic domains, depending upon the severity of the disorder. Indeed, in some children with ASD impairments in all of the linguistic domains are severe enough to impair their communication in daily functioning (e.g., Kjelgaard & Tager-Flusberg, 2001), whereas, some other children with ASD present with relatively spared structural language skills with impairment evident only in the pragmatic areas (e.g., Kelley, Paul, Fein, & Naigles, 2006). It has been reported that as many as 50% of children with ASD may not be able to develop any verbal communication skills at all (Seal & Bonvillian, 1997), although this number is decreasing with the increase in early intervention (Tager-Flusberg, Paul & Lord, 2005). This inability to acquire spoken language in some children with ASD is largely ascribed to socio-communicative and
symbolic impairments described above (e.g., Wetherby, Prizant & Schuler, 2000) that are a predominant feature of this disorder. However, some researchers have proposed that along with socio-communicative and symbolic impairments, the difficulty in the acquisition of spoken language may also be compounded with apraxia, or oral-motor impairment (Prizant, 1996; Tager-Flusberg, Paul, Lord, et al., 2005). Prizant (1996) provided anecdotal evidence for the basis of this postulation a) children with ASD who cannot speak can still master an alternative method of communication that involves symbols (e.g., pictures, signs, etc.), b) children with ASD display classic symptoms of oral motor impairment viz., drooling, low facial tone, limited independent movement of the articulators, feeding problems, etc., c) and children with ASD who do acquire speech show errors that are similar to those found in childhood apraxia of speech. He described apraxia-like errors in the following manner – primarily vowel-like vocalizations, limited consonant repertoire, difficulty in sequencing phonemes in multisyllabic words, reduction in intelligibility with increase in utterance length, and greater intelligibility of automatic speech (echolalia) as compared to spontaneous speech.

The basis of Prizant’s postulation is evident in the results of two separate lines of research – one describing phonetic/phonological impairments in children with ASD and the other describing general motor impairments and praxis deficits in children with ASD. A review of studies of phonological impairments in children with ASD is presented below, followed by a review of studies investigating the general motor impairments and praxis deficits.
**Phonology in ASD.** Though it is important to keep in mind the entire language profile of children with ASD in order to understand their expressive communicative abilities as a whole, the language domain that is the most pertinent to this research study is phonological skills. There have been mixed reports in the literature about phonological development in children with ASD. Some researchers have reported phonological skills in this population to be within the normal range (Boucher, 1976; McCann et al., 2007; Pierce & Bartolucci, 1977; Kjelgaard & Tager-Flusberg, 2001; Tager-Flusberg 1981). However, a considerable number of studies have found phonological and articulation deficits in children with ASD (for example, Bartak, Rutter & Cox, 1975; Bartolucci & Pierce, 1977).

Children with ASD have been reported to have both speech delays and speech errors, where, according to the Speech Disorders Classification System (SDCS; Shriberg, et al., 2010), speech delay is defined as substitution, omission and distortion errors that significantly affect intelligibility in children between 3-6 yrs of age and speech errors are defined as distortion errors of sibilants, rhotics or both, without impacting intelligibility in children between 6-9 years of age. Cleland, Gibbon, Peppe, O’Hare and Rutherford (2010) have reported a prevalence of speech delay in 12% and speech errors in 41% in their sample of 69 children with ASD who were between 5 and 12 yrs of age. Rapin, Dunn, Allen, Stevens & Fein (2009) reported persistent and severe phonological impairment in 24% of a total of 118 seven and nine years old children that they studied. Schoen, Paul and Chawaraska (2011) found that phonological development in toddlers with ASD was directly related to their language level. That is, their sample had speech
delays as compared to the age matched typical group but were not different from the language matched typical group. Along the same lines, McCleery et al. (2006) reported severe phonological impairment in their sample of 2 to 7 yr old children with ASD who also had severe language impairment. In addition to delayed phonological processes, unusual phonetic repertoires and unusual sound changes such as excessive glottal replacement and atypical cluster reductions have been reported in 2 to 9 yr old children with ASD (Wolk & Edwards, 1993; Wolk & Geisen, 2000). Residual speech distortion errors have been reported in about 33% of adolescents and adults with HFA and Asperger’s syndrome (AD; Shriberg, et al., 2001). In a more recent study Shriberg, et al. (2011) reported that 15% of their sample of 4 to 7 yr old children with ASD had speech delay and approximately 30% of them had speech errors.

Most of the research discussed above classifies the segmental errors found in children with ASD as speech delay and has not carefully distinguished speech disorders from motor speech disorders, thus disregarding the role of speech motor skills in these impairments. However, general motor planning deficits found in this population (described below) and the nature of speech errors (e.g., Wolk & Edwards, 1993; Wolk & Geisen, 2000) reported in those studies that have classified speech errors in these children may indicate an involvement of the speech motor system. Thus, the speech characteristics of children with ASD might be more in alignment with those of motor speech disorders as opposed to speech sound disorders.
**General Motor Impairments in ASD.** Although ASD is primarily defined by social impairments, impairments in motor functioning are not uncommon in this population (Bhat, Landa & Galloway, 2011). Page and Boucher (1998) reported that approximately 80% of their sample of children with ASD had at least some type of motor impairment. They also reported that all of the children who had a motor impairment had concomitant oro-motor impairment (the nature of which was frequently found to be dyspraxic) and that 55% of their sample had additional manual impairments and 18%, gross motor impairments. In addition, they reported that higher levels of motor impairment were associated with lower educational levels and poorer language scores in children with ASD.

Several other researchers have noted deficits in motor skills in children with autism. For example, asymmetry in motor milestones like lying, rolling over, delay in sitting, asymmetrical lack of adequate support in the arms for crawling, and asymmetry and delay in walking (Teitelbaum, Teitelbaum, Nye, Fryman & Maurer, 1998). These findings were derived through a retrospective video analysis of infant videos of 17 children later diagnosed with autism and those of 15 typically developing children. Clumsiness, motor incoordination, disturbances in reach-to-grasp movement (Ghaziuddin & Butler, 1998; Green, Baird, Barnett, Henderson, Huber & Henderson, 2002; Mari, Castiello, Marks, Marraffa & Prior, 2003) and impaired postural control (Kohen-Raz, Volkmar & Cohen, 1992; Minshew, Sung, Jones & Furman, 2004) have also been reported.
Investigations related to sign use in 9 to 21 yr old non-verbal children and adolescents with ASD revealed that sign vocabulary size and accuracy of signing were both highly correlated with the children’s performance on measures of apraxia and fine motor age scores (Seal & Bonvillian, 1997).

Ming, et al. (2007) investigated the prevalence of motor deficits in a sample of 154 children with ASD. They divided this group into 2 cohorts based on their ages. The first cohort was comprised of children between the ages of 2 and 6 years and the second of children between the ages of 6 and 18 yrs. They assessed motor deficits like hypotonia, motor apraxia, toe-walking, delayed gross motor milestones, and reduced ankle mobility. Out of these, some skills were assessed based on the physical examinations conducted by the pediatricians (hypotonia, motor apraxia-oral and limb apraxia and reduced ankle mobility), and other by history (toe walking, motor milestones). They found that all children with reduced ankle mobility had past or present history of toe-walking and that apraxia and hypotonia were more prevalent in younger children than older ones. In the younger group, apraxia (both oral and limb apraxia) was present in 41% of the children whereas it was only found in 27% of the children in the older age group.

Thus, children with ASD show a general delay in the acquisition of motor milestones in addition to disturbances in independent movements, coordination, etc. One of the sources of these deficits might be impairment of imitation skills (Velleman, et al., 2010), which has been widely reported in children with ASD (e.g., Charman, et al., 1997; Smith & Bryson, 1998). In order to determine whether motor deficits in imitation in
children with ASD were specific to imitation or whether they were a part of a generalized
deficit associated with dyspraxia. Motofsky, Dubey, Jerath, Jansiewicz, Goldberg and
Denckla (2006) studied 45 children with ASD in the age range of 8 and 12 years. They
specifically studied the performance of gestures to command, gestures to imitation and
gestures with tool-use in children with ASD in comparison to typically developing
children. The ASD group showed impairments not only in gestural imitation but also in
gestures in response to verbal commands and tool use. Thus the authors concluded that
motor difficulties in autism are associated with a generalized praxis deficit and not
specifically to imitation deficits. Other studies describing general praxis deficits in ASD
are reviewed next.

**General Motor Planning Impairments in ASD.** Some empirical evidence from
recent literature points to the likelihood that the motor difficulties experienced by
individuals with ASD summarized in the above section have a basis in praxis deficit and
are not just an outcome of motor delay. The evidence for motor planning deficits is
provided by an experiment conducted by Glazebrook, Elliot & Szatmari et al. (2008) that
was designed to determine whether adults with ASD used advanced information to plan
their movements in the same way that typical individuals do. This experiment was
conducted at two levels of difficulty in terms of the planning required. In the first part,
they measured reaction time and movement time of all the individuals when provided
with the direction and the extent of the target’s appearance. They found that the ASD
group took longer to react and plan their movement but they used the information
provided in the same manner as the typical individuals. In the second part, participants were asked to perform aiming movements towards a target circle within a specific time. It was found that the ASD group did not optimize their reaction and movement time like the typical group did. Thus, when the information is given directly, the individuals with ASD use it to plan their motor movements in advance, but when they are required to use self-generated strategies to plan their movements; they differ significantly from the typical group.

Another piece of evidence in favor of the planning deficit hypothesis is provided by an experiment by Rinehart, Bellgrove and Tonge, (2006), which investigated movement kinematics in 5-19 yr old children and adolescents with high functioning autism (HFA) and Asperger Disorder (AD). The mean age of participants in the HFA group was 8.1 years and they were compared to typically developing children who were matched on age, sex and IQ. The mean age of the AD group was 12 yrs and they were also compared to typically developing peers matched on age, sex and IQ. In the first level of the experiment the participants were required to move a stylus towards the target as quickly as possible. In the second level, participants were instructed as to which side most targets would appear, so that they would have to inhibit their actions when target came to unexpected side. In the last level, participants were told to move the stylus in direction opposite to that of the target. Children and adolescents with HFA were found to be slower to prepare their movements in all three conditions. Thus, HFA group displayed a clear motor preparation deficit compared to their typically developing peers and those
with AD. The authors concluded that the motor deficits seen in children with HFA are clearly at the planning level rather than at the execution level.

Dziuk and colleagues (2007) assessed children with ASD on a measure of apraxia (predominantly using gestures) and basic motor skills. They reported a significant effect of motor skill on praxis performance after controlling for IQ in their sample of 47 children with a mean age of 10 yrs, who were diagnosed with HFA and Asperger’s syndrome. Additionally, they found that the number of praxis errors significantly predicted reciprocal social interaction, communication and stereotyped behaviors—the defining features of autism measured using the Autism Diagnostic Observation Schedule-G (ADOS-G; Lord, et al., 2000). They also reported that this predictive relationship remained significant after accounting for basic motor skills. Dziuk and colleagues concluded that praxis in children with autism is strongly correlated with social, communicative and behavioral impairments that define autism. In doing so, they can be seen as suggesting that dyspraxia may be a core feature of autism or a marker of underlying neural deficits.

Thus, the review of literature on general motor behavior in children with ASD provides evidence of praxis impairment in this population. Table 1 summarizes the different types of motor speech impairments observed among children with ASD. Next, the literature concerning non-speech oral motor skills in children with ASD will be reviewed.
Table 1

Summary of general motor impairments in children with ASD

<table>
<thead>
<tr>
<th>Type of motor impairment</th>
<th>Specific nature of impairment</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross, fine and oromotor impairments</td>
<td>Gross motor impairments</td>
<td>(Seal &amp; Bonvillian, 1997)</td>
</tr>
<tr>
<td></td>
<td>Fine motor impairments</td>
<td>(Page &amp; Boucher, 1998)</td>
</tr>
<tr>
<td></td>
<td>Oromotor impairments</td>
<td>(Page &amp; Boucher, 1998)</td>
</tr>
<tr>
<td>Motor milestone delays</td>
<td>Alterations in motor milestone development</td>
<td>(Teitelbaum, Teitelbaum, Nye, Fryman and Maurer, 1998)</td>
</tr>
<tr>
<td>Cerebellar deficits</td>
<td>Clumsiness and motor incoordination</td>
<td>(Ghaziuddin &amp; Butler, 1998)</td>
</tr>
<tr>
<td></td>
<td>Disturbances in reach-to-grasp movement</td>
<td>(Mari, Castiello, Marks, Maraffa and Prior, 2003)</td>
</tr>
<tr>
<td>Muscle Tone abnormality</td>
<td>Hypotonia</td>
<td>(Ming, et al., 2007)</td>
</tr>
<tr>
<td>Apraxia</td>
<td>General apraxia</td>
<td>(Seal &amp; Bonvillian, 1997)</td>
</tr>
<tr>
<td></td>
<td>Motor apraxia</td>
<td>(Ming, et al., 2007)</td>
</tr>
<tr>
<td></td>
<td>Motor planning deficits</td>
<td>(Glazebrook, Elliot &amp; Szatmari et al., 2008; Rinehart, Bellgrove &amp; Tonge, 2006)</td>
</tr>
</tbody>
</table>

**Non-Speech Oral Motor Skills in ASD.** Like the general motor deficits, deficits have also been identified in nonspeech oral motor skills in children with autism in a few studies (Page & Boucher, 1997; Thurm, Lord, Lee & Newschaffer, 2007). Gernsbacher, Sauer, Geye, Schweigert and Goldsmith (2008) have examined the role of oral-manual-motor skill in predicting speech development in children with ASD. They conducted a
landmark based interview with parents, analyzed home videos of children with ASD and studied the relationship between current day speech fluency and motor deficits. Oral motor skills were found to differentiate speech fluency (minimal, moderate and high) in children with ASD. However, the relationship between nonspeech oral motor abilities, speech motor skills and speech acquisition is not well understood in neuro-typical individuals (McCauley, Strand, Lof, Schooling & Frymark 2009; Wilson, Green, Yunusova & Moore, 2008). Consequently, knowledge about nonspeech oral motor skills or their impairment in persons with autism provides inadequate information about their motor speech skills and possible impairments. In addition, given the evidence of praxis deficits in general motor functioning in autism, the possibility of apraxia of speech seems plausible. Because speech motor skills play a key role in the ultimate expression of language in terms of articulation, fluency and prosody, an understanding of these skills in individuals with autism may help contribute to an explanation of the huge variability in these children’s spoken language abilities. This understanding can be derived through a detailed assessment of speech motor skills in children with ASD.

**Speech Motor Deficits in ASD.** A study of the speech motor differences that might be present in children with ASD has a significant potential to influence the nature of interventions used for these children, which, in turn could improve the quality of life for them as well as those of their parents and caregivers. Despite the compelling need to understand all of the factors that may contribute to these children’s deficits in speech language communication, speech motor characteristics of children with ASD have not
been studied extensively. Even those researchers who have addressed the role of speech sound production in autism (e.g., Cleland, Gibbon, Peppe, O’Hare & Rutherford, 2010; McCleery, Tully, Sleve & Schreibman, 2006; Wolk & Gieson, 2000) have not carefully distinguished motor speech from other speech sound disorders. In fact, only three (Shriberg, Paul, Black & Santen, 2011; Velleman, et al., 2010; Adams, 1998) have specifically focused on speech motor skills in autism so far. These studies addressing the issue of motor speech disorders in children with autism have used either acoustic methods (Shriberg, Paul, Black & Santen, 2011; Velleman, et al., 2010) or perceptual methods (Adams, 1998).

Using perceptual measures, Adams (1998) compared the nonspeech oral and speech motor abilities of four children with autism in the age group of 9-11 yrs to those of four age-and gender matched typically developing children on an adaptation of the prototype of Kaufman Speech Praxis Test for Children (KSPT; Kaufman, 1995). They sought to answer two primary research questions – whether children with ASD exhibited oro-motor/speech motor difficulties and whether their oromotor/speech motor capabilities different from those of non-affected peers. As a part of the assessment protocol, the accuracy of three tasks – oral motor movements, simple syllable productions, and complex syllable productions was assessed. Findings indicated that children with autism had significantly lower accuracy on the oral motor movement task. They also had lower accuracy on some of the speech motor tasks, for example, complex consonant production synthesis; blend synthesis and polysyllabic synthesis/sequencing. However, the nature of the stimuli in terms of their lexicality for these tasks is not clear. Also, the findings of
this study, however, cannot be generalized because of the small sample size \((n = 4)\). An assessment protocol, a prototype of the Kaufman Speech Praxis test, was the only assessment measure used in the study.

The two studies that employ acoustic methods have both used the measure of rate; one derived from a structured repetition of a phrase (Velleman, et al., 2010) and the other derived from a continuous speech sample (Shriberg, et al., 2011). The details of their findings as regards rate of repetition and other measures follow.

In addition to rate of repetition, Velleman et al. (2010) examined a variety of acoustic parameters in the speech of 10 children with a diagnosis of some type of autism spectrum disorder, in order to explore the nature and extent of motor speech disorders in children with ASD. All of their participants were between the ages of 4 and 6; 5 yrs and had an oral vocabulary of at least 10 words. They found that 7 children demonstrated deficits in focal oromotor skills and 5 children demonstrated deficits with respect to sequencing of oromotor gestures on the Verbal Motor Production Assessment in Children (VMPAC; Hayden & Square, 1999). They found that children with ASD were slower in their production of vowel /i/, in the word “key” that was a part of repetition of phrase “pea tea key”. Other measures that differentiated children with ASD from those with childhood apraxia of speech (CAS; \(n = 8\)) and typically developing children \((n = 8)\) were fundamental frequencies and vowel formant frequencies, maximum phonation times and extreme and variable lexical stress ratios. The significant variability in lexical stress ratios, lower range for speech duration and higher range for pause duration, which is a feature of the speech of children with CAS, was found in their sample of children with
ASD. In addition, although not found in Velleman and her colleagues’ sample of children with CAS, difficulties with lexical stress, such as those seen in their ASD sample, have been associated with CAS (ASHA, 2007; Shriberg, et al., 2003). Overall, however, the sample used in this study was small and included participants from the entire autism spectrum. The participants with ASD were neither developmentally- nor age-matched to the comparison groups (children with ASD were younger). In addition, the group of children with ASD was reported to have a wide range of auditory comprehension skills as measured on the PLS. Thus, the poor performance of the children on the speech and nonspeech oral motor tasks may have been due to receptive language challenges presented by the tasks rather than due to difficulties in speech motor skills, for at least some participants in the group.

Recently, Shriberg, Paul, Black & Santen (2011) analyzed continuous speech samples from 46 children with ASD between the ages of 4 and 7 yrs in comparison with 40 typically developing children, 13 preschool children with speech delay and 15 participants with CAS between the ages of 5 and 49 years. The specific hypothesis that was tested was that the speech, prosody and voice impairments in children with ASD are due to associated CAS in these children. They obtained accuracy measures on speech sound production in real words in continuous speech and nonword repetition in the structured Syllable Repetition task (SRT), in addition to measures of rate, stress, loudness and 10 different indices of motor speech impairment. Based on the accuracy of speech sounds they found that the autism group had significantly more speech delays and speech errors than found in the general population, where speech delays were defined as age-
inappropriate errors of substitution, omission, distortion that severely affect intelligibility in children between 3 and 9 yrs of age and speech errors were defined as errors limited to distortions of sibilants and rhotics that do not affect intelligibility in children between 6 and 9 years of age. The ASD group did not differ from the TD group on the accuracy of SRT. While the rate of speech was found to be age-appropriate, differences were found on the other prosody measures, viz., loudness, stress and pitch. The following indices of motor impairment were used – lengthened vowels, distorted rhotics, increased percentage of phoneme distortions, slower speaking rate, slower articulation rate, increased repetition and revisions, reduced percentage of glides correct, lowered sibilant centroids, increased vowel consonant intensity ratio and less stable whole word errors. The ASD group was found to be significantly different from the CAS group in terms of the number of positive markers. In order to find out if a subgroup of children with ASD have concomitant CAS, they compared only those children with ASD who also had a speech delay with the CAS group. They found the two groups to be significantly different. Thus they attributed the speech, voice and prosody impairments in children with ASD to the impairment in communication intent and social reciprocity that is a hallmark of this disorder and not to motor planning problems as seen in CAS. This study analyzed continuous speech samples for the examination of speech motor skills. Thus, subtler deficits in speech motor skills which appear only during challenging speech tasks like rapid repetition, etc. might not have been elicited. Another major limitation to the study was that children with ASD who had intelligibility scores under 70% were excluded from
participation. This might have led to a biased sampling; such that only those children who had little or no difficulties in speech motor skills participated.

These studies reveal a very preliminary and mixed evidence of motor speech impairment in children with autism. In spite of this, there is a dearth of studies systematically investigating the speech motor characteristics of children with ASD. The studies that have been conducted so far have been limited by the sample size, reliance upon a general and unstudied assessment protocol and the lack of information about the comprehension abilities of the participants as described above. A more detailed description of the motor speech skills and deficits in a group of children with ASD for which confounding impairments are minimized (i.e., those with high functioning autism; HFA) could contribute to a better understanding of their existing speech differences (CAS, dysarthria, mixed, SSD without MSD) and thus to hypothesize about neurobiology and appropriate intervention methods. The current proposal is designed to address these concerns and provide a clearer view of the motor speech characteristics of a larger, relatively homogeneous sample of children with autism (namely those with HFA). This study is designed to identify motor speech impairments in children with HFA and to clarify the nature of the impairment.

The following section summarizes the ways of examining speech motor skills that are used for children as well as adults with motor speech disorders.

**Measures of Speech Motor Skills**
Speech motor limitations in children can be measured using various methods. It has been recommended (Crary, 1995; Strand & McCauley, 1999) that speech motor assessment in children should be carried out using a combination of articulation tests and speech motor tasks. The measures of speech motor skills that have been most frequently used are rate, accuracy and consistency of repetition in the identification of deficits/differences. Two major types of stimuli – real words and non-words – in varying lengths have been used to obtain these measures. A psycholinguistic framework proposed by Stackhouse & Wells (1993) emphasizes the need to distinguish between linguistic and non-linguistic stimuli in the assessment of speech motor skills. This framework is based on a model of speech processing proposed by Stackhouse & Wells (1997), which describes three major processes – auditory speech input processing (perception, discrimination and recognition of speech stimuli), storage of individual words (lexicon) and speech output processing (where phonological information is retrieved from storage and used to articulate the word). According to this model, real words (lexicon) have phonological representations and semantic representations (word meanings) associated with them. Phonological representations are distinct from output phonology in the following manner where phonological representations contain information that is just enough to recognize a word based on the sounds, output phonology or motor plans have more detailed information about the actual execution of the articulatory movements. Speech processing tasks are classified based on the necessity of using stored linguistic knowledge versus involvement of manipulation of sensory motor phenomena alone (Williams & Stackhouse, 2000), for example, real vs.
nonwords. Thus, a task that requires repetition of monosyllables can be considered to be at the lowest level of speech output, involving only the manipulation of sensory motor phenomena. On the other hand, repetition of real lengthy word will involve speech processing at comparatively high level, such that both lexical and phonological representations need to be accessed in addition to the execution of motor plans.

The following section reviews the literature that describes the use of the measures of rate, accuracy and consistency obtained from various stimuli described with reference to the psycholinguistic framework described above.

**Rate.** Measures of rate of speech can be obtained from continuous speech sample and/or from structured elicited imitation tasks. The structured task that is most commonly used to elicit rate of repetition is the diadochokinetic task (DDK). Fletcher (1978; as cited in Williams & Stackhouse, 2000) described diadochokinesia as: “the study of motor control integrity in bodily functions through performance in rapidly alternating movements, e.g. pronation and supination of the hand and side to side motions of the tongue. In speech, the term has been extended to include syllable repetition at a maximum rate of utterance.” The speech DDK rate assesses the rapid alternating movement for production of syllabic sequences such as /pa/, /ta/, /ka/ (Strand & McCauley, 1999) and provides information on motor coordination and control of major articulators (Ruscello, St Louis, Barry & Barr, 1982). The use of syllables in the measurement of rate enables the study of speech motor system at the lowest level, that is, without the involvement of lexical/phonological representations (Stackhouse & Wells, 1993).
Some reference values for DDK rate for different age groups in typically developing children have been reported in the literature (e.g., Prathane, Thanaviratananich, & Pongjanyakul, 2003; Williams & Stackhouse, 1998). For example, Modolo, Berretin-Felix, Genaro & Brasolotto (2011) assessed speech DDK of one hundred and fifty typically developing children between the ages of 8 and 10 years in order to establish reference values. They found that with age, the average DDK rate, the coefficient of variation of period for the syllable /ka/ and the coefficient of variation of peak intensity for /ta/ increased. They also found that girls produced a higher number of utterances per second for /ta/ and 8 year old girls produced the lowest number of trisyllabic utterances as compared to other subgroups.

While rate provides important information about motor coordination, this information alone does not provide a complete picture of one’s speech motor skills. Rate is known to be closely related to accuracy, for example, one might repeat a stimulus at a very rapid rate but compromise the accuracy while another might pay a great deal of attention to the accuracy and consequently repeat the stimulus at a slower speed (Williams & Stackhouse, 2000). Thus it has been recommended that accuracy and consistency of repetition should also be examined in addition to rate (Yaruss, 1997).

Accuracy. Accuracy of speech production can be assessed using a variety of stimuli. While oral repetition of any kind of stimulus requires an involvement of the speech motor system, some stimuli warrant the involvement of phonological and lexical systems as well (Stackhouse & Wells, 1993). The most commonly used stimuli that
provide a measure of accuracy are naming pictures and real word repetition. These are common methods of assessing children’s articulation and are employed by most standardized tests of articulation. These stimuli can be considered to be at the easiest level with regards speech motor skills. In addition to semantic and phonological representations (Stackhouse & Wells, 1997), real words/pictures make use of motor programs that have been pre-stored and probably have been practiced multiple times. Thus repetition of real words can be considered to be the easiest of all the speech motor tasks. However, as the length of the real word increases, the planning/sequencing demands on the speech motor system also increase. Long words or multisyllabic words require an individual to rapidly select phonemes and use them in the correct sequence (Lewis & Freebairn, 1997). Accuracy of multisyllabic word repetition (MWR) thus provides information about the sequential abilities of the speech motor system under high planning demands. Nonwords represent the next level of difficulty in terms of the demands on the speech motor system. They are slightly harder than real words because they have never been produced before and require the creation of a new speech motor program. Nonwords do not have lexical representations associated with them (Lewis & Freebairn, 1997), but might have phonological associations depending on the structure of the nonwords, thus finding an intermediate position between real words and syllables. Accuracy of non-word repetition can be used to tap phonological encoding and phonological memory (Lewis & Freebairn, 1997). Syllables, the stimuli that are used in the DDK tasks, represent the highest level of difficulty in terms of speech motor demands. They have neither lexical nor phonological representations associated with
them and therefore can be used to study speech motor skills in isolation. Because it is thought that DDK tasks do not require access to a stored (long-term) phonological representation, they are often used to assess speech motor function (Preston & Edwards, 2009).

Preston & Edwards, (2009) used the measures of rate and accuracy to assess the speech production of adolescents (10 to 14 yrs of age) who had residual speech sound errors and those who were developing typically. They administered oral DDK task involving the rapid production of /pataka/, and two rapid naming tasks-monosyllabic letter names and multisyllabic picture names. They found no group differences in the rate of DDK production, whether examining only the correct attempts or all attempts. However, they did find that the group who had residual speech errors was significantly less accurate and less consistent than the typical group. The group of adolescents who had residual speech errors was slower and phonologically less accurate in naming multisyllabic pictures as compared to the typical group. The authors concluded that both speed and accuracy may be impaired in adolescents with residual errors.

**Consistency.** Consistency has been found to be useful in differential diagnosis of speech disorders (Dodd, 1995). Inconsistency of errors is one of the important indicators of motor planning deficits that are seen in children with CAS (Davis, Jakielski, & Marquardt, 1998). Like accuracy, consistency of repetition can be obtained through the use of different types of stimuli, for example, syllable repetition in DDK tasks and repetition of real words. Williams and Stackhouse (2000) found that consistency measures were more developmentally sensitive to age than the measures of accuracy and
rate. They had their sample of 3-, 4- and 5-yr old typically developing children repeat syllables, syllable sequences, nonsense words and real words. They found that both rate and accuracy of repetition improved with age however, there was much variability, especially in the younger groups. Besides, they observed trade-offs between rate and accuracy (for example, slower rate, higher accuracy). However, consistency of repetition was found to be high even in the youngest age group and increased progressively with age for which reason the authors suggest that consistency measures have high utility in clinical settings. Typically developing children and those with delayed phonological development might present with inaccurate but consistent speech errors, whereas those with planning/programming issues may present with inaccurate and inconsistent speech errors (Williams & Stackhouse, 2000). Thus, consistency is a useful measure to examine in addition to the more common measures of rate and accuracy.

Figure 1 Types of stimuli used in speech motor tasks based on the psycholinguistic assessment framework by Stackhouse & Wells (1997). This figure describes the processes involved in repetition of various types of stimuli.
Measures of speech motor skills described above have been used in children and adults with motor speech disorders (e.g., Thoonen, et al., 1996; Yorkston, Beukelman, Strand & Hakel, 2010), given the nature of their disability. The next section discusses the utility of these measures in the assessment of speech characteristics of children with motor speech disorders.

**Use of Speech Motor Tasks in Children with Motor Speech Disorders (MSD).**

Childhood Apraxia of Speech (CAS) and dysarthria are among the childhood motor speech disorders for which researchers have already used the measures of speech motor skills mentioned above. These measures have been found to be useful in identification and differentiation of the speech motor profiles found in children with motor speech disorders. For example, Thoonen, Maasen, Wit, Gabreels and Schreuder (1996) administered a set of maximum performance tasks, including maximum phonation and maximum repetition rate (DDK) to children with CAS, spastic dysarthria and typically developing children. They found that monosyllabic repetition rate and vowel prolongation differentiated children with spastic dysarthria from those with CAS and the typically developing children. Fricative prolongation, trisyllabic repetition rate and trisyllabic repetition accuracy differentiated children with CAS from those developing typically.

In a longitudinal study, Lewis, Freebairn, Hansen, Iyengar & Taylor (2004) examined the accuracy of real words (measured on standardized articulation tests),
nonwords, and multisyllabic words, in addition to DDK rate. They found that children with CAS showed improvement in their accuracy of real word repetition from preschool to school-age, but they still had significant difficulties with rate of repetition and accuracy of non-word repetition and syllable sequencing. Thus, accuracy of non-word repetition and syllable sequencing is a measure that is sensitive to underlying speech motor deficits even when accuracy of real words skills seems to be improving.

Recently Aziz, Shohdi, Osman & Habib (2010) assessed groups of children with suspected CAS, multiple phonological disorders (MPD) and typically developing children on measures of language, speech and oral motor skills. Participants who displayed more than 3 phonological error types were assigned to the MPD group, while children with CAS were diagnosed based on the characteristics described by Davis, Jakielski & Marquardt (1998), namely, high frequency of consonant and syllable omissions, vowel errors, prosodic abnormalities, inconsistent errors and reduced ability to imitate non-verbal speech movements. In addition to language tests and non-speech tasks, they used accuracy and consistency of vowels, consonants, syllable number, syllable shape, syllable sequencing and prosody. They found that both the accuracy and consistency of vowel and consonant errors differentiated CAS group from the phonological disorders group. Accuracy of syllable number, shape and sequencing differentiated CAS from both phonological disorders group and the typically developing group.

Thus, a variety of measures of speech motor skills have been shown to be useful in identifying speech motor deficits and differentiating motor speech disorders from
phonological disorders. The present study draws from this literature and proposes the use of a series of tasks to compare the speech motor skills in children with HFA to those in children with MSD and typically developing children. The next chapter describes the details of the methods used.
Chapter 3: Methods

Design

The current study employed a comparative group design to study speech motor characteristics in children with High Functioning Autism (HFA) and those with Typical Development (TD), and Motor Speech Disorders (MSD). Relationships between motor speech and language variables for participants in these three groups were also investigated. Group membership was treated as the independent variable and selected measures of motor speech skill, as dependent variables.

Participants

Three groups of participants were studied: 12 children with high functioning autism (HFA); 11 children with motor speech disorders (MSD); and 11 children characterized as typically developing (TD). Participants ranged in age from 4 to 10 years. They were recruited through announcements in schools, day care and medical centers, the Ohio State University’s Speech Language Hearing Clinic, parent support groups at local hospitals, parents’ group listservs, the Autism Spectrum Disorders clinic at the University’s Nisonger Center, and local speech and language clinics. All participants met the following selection criteria based on parental reports:
(1) absence of hearing impairment or physical disability, (2) no history of head injury; (3) oral expressive vocabulary of at least 20 words, (4) the ability to imitate at least 5 communicative gestures, (5) receptive vocabulary within normal limits, (6) current chronological age (CA) between 4 and 10 yrs, and (7) English was the primary language spoken at home.

Additional selection criteria based on parent report were used to verify group membership. Specifically children in the HFA group were required to have a diagnosis of autism before the age of 3 years. High functioning autism was defined by receptive vocabulary within normal limits as per parent report and as measured on the Peabody Picture Vocabulary Test IV (Dunn & Dunn, 2007). Children in the MSD group were required to have a diagnosis of childhood apraxia of speech (CAS), or dysarthria, or motor speech disorder, from a speech-language pathologist. However, by chance, all of the participants in MSD group had a diagnosis of Childhood Apraxia of Speech as reported by the parents. One participant in this group was reported to have a history of epilepsy. Finally, children in the TD group were required to have no previous diagnosis of any developmental disorder (i.e., no sensory, cognitive, or communication disorder).

Materials

Standardized tests and informal measures of participants’ speech and language status were used for descriptive purposes and to verify inclusion criteria related to ASD status as well as receptive and expressive vocabulary.
Social Communication Questionnaire (SCQ; Rutter, Bailey & Lord, 2003). This questionnaire was administered to the parents of all the participants in order to verify group membership either to the HFA group or otherwise. This questionnaire is reported to have 71% sensitivity in identifying children with ASD (Eaves, Wingert, Ho & Mickelson, 2006).

Peabody Picture Vocabulary Test–IV (PPVT-IV; Dunn & Dunn, 2007). PPVT-IV is a measure commonly used for vocabulary assessment and has excellent test-retest reliability (94%) and validity (Dunn & Dunn, 2007). For the administration of this test, the experimenter orally presented a stimulus word with a set of pictures and the participant was asked to select the picture that best represented the word’s meaning, thus yielding a standardized receptive vocabulary score.

Expressive Vocabulary Test (EVT-2; Williams, 1997). EVT-2 is a commonly used measure for assessment of expressive vocabulary and has good test-retest reliability (95%) and validity (Williams, 1997). For the administration of this test, the experimenter pointed to a picture or a part of the body and asked a question for the labeling items and presented a picture and stimulus word(s) within a carrier phrase for the synonym items. This test provided a standardized expressive vocabulary score for each participant.

Oral Speech Mechanism Screening Examination, third edition (OSMSE-3; St. Louis & Ruscello, 2000). This screening measure is a quick test of participants’ speech and non-speech motor skills and has a test-retest reliability of 96.3%. Participants were asked to imitate oral motor movements (e.g., lip rounding, moving tongue from side to side, etc.) and their oral structure was examined for any organic deficits. In addition they
were also required to perform one trial of each of the 5 DDK tasks-3 monosyllabic repetitions, one bi-syllabic repetition and one trisyllabic repetition task.

**Goldman Fristoe Test of Articulation-2 (GFTA-2; Goldman & Fristoe, 2000).** The Sounds in words subtest was administered to all the participants in which the experimenter pointed to a picture and asked the participant to name it. This test yielded a standardized score for articulation skills of all the participants. This measure is reported to have high test-retest reliability and validity (Goldman & Fristoe, 2000).

**Diagnostic Evaluation of Articulation and Phonology (DEAP; Dodd, Hua, Crosby, Holmes & Ozanne, 2006)-inconsistency subtest.** This subtest of DEAP required participants to name each picture three times. This provided a measure of consistency of articulation error patterns in all the participants. The DEAP has a test-retest reliability of 93%, as reported in the examiner’s manual.

**Conversation:** A three-minute conversation sample was obtained by asking the children to describe their last birthday party and summer vacation in detail in order to obtain connected speech sample. However, because not all the participants in all the groups provided samples of adequate lengths, it was not included in the analysis at this stage.

**Diadochokinetic task:** This task assesses the rapid alternating movement for production of syllabic sequences such as /pa/, /ta/, /ka/ (Strand & McCauley, 1999). The participants were asked to say the monosyllables /pa/, /ta/ and /ka/ and the trisyllabic sequence /pataka/ as fast as they could. All the participants were given 5
trials for each of the monosyllables and the trisyllabic sequence. However, not all the participants in all the groups completed all 5 trials. Consequently, the number of trials for each of the DDK task for the participants varied slightly. This task provided important information about the speed, accuracy and consistency of monosyllabic and trisyllabic repetitions.

**Multisyllabic word repetition**: Children were administered the multisyllabic screening test of the Hodson Assessment of Phonological Patterns (HAPP-3; Hodson, 2004). This is a picture naming task, where the examiner models the multisyllabic words for the child and the child is expected to repeat the words. This task places high demands on sequential motor speech abilities and can thus provide information about any subtle deficits therein.

**Nonsense word repetition**: Two types of non-word repetition tasks were used – Nonword Repetition Task (NRT; Dollaghan & Campbell, 1998) and the Syllable Repetition Task (SRT; Shriberg, Lohmeier, Campbell, Dollaghan, Green & Moore, 2009). For the administration of NRT, the 16 nonsense words were audio recorded and presented through a computer. The speaker for this recording was a native speaker of American English who spent the majority of her childhood in the Midwest. The participants were given the following instructions, “You are now going to hear some made-up words. Say them after the lady exactly the way she says them.”

For the administration of SRT, the 18 stimuli available from the authors (Shriberg & Lohmeier, 2008) were used. The instructions to the participants, as recommended by the authors, were “You are going to say some silly words. Every time you hear the
woman say a word, you try to copy her. Say the word exactly the way she says it.”

Because they use non-words they provide information about an individual’s speech motor performance in the absence of lexical cues, also providing information about phonological encoding and phonological memory. The SRT only uses 4 consonants within two manner features and so is ideal for participants with severe speech impairments and hence was added to the speech motor assessment protocol.

Thus the various tasks used in the study represent a hierarchy of levels of complexity of stimuli in order to tap any breakdowns that might occur in a speech motor system that is dysfunctional. For example, repetition of a trisyllabic sequence or a multisyllabic word is harder than repetition of monosyllables as regards the demands it places on phonemic planning. Lexical stimuli make use of existing motor programs and hence are easier to repeat as compared to non-word stimuli. The non-word stimuli require one to create a new motor program and use it without any prior practice. A speech motor system that is not functioning at its optimum can be expected to break down at the higher levels of difficulty, like the trisyllabic sequence, multisyllabic words, and nonwords.

**Procedure**

Each child was tested individually by the researcher in a quiet room, in the presence of his or her parent/caregiver. A trained research assistant audio and video recorded the session. All the participants were verbally praised in a non-directive manner for staying on task. In addition, they were reinforced with a tangible reinforcer on completion of each task and with a T-shirt at the end of the entire study. All the sessions
were audio and video recorded using a Canon VIXIA HV 30 high definition camcorder, WLX-PRO VHF wireless lapel microphone and Olympus DS-40 digital stereo voice recorder in order to ensure a high quality acoustic signal for analysis.

All participants were administered the tests for nonspeech oral motor examination, the speech motor assessment protocol, as well as standardized articulation and vocabulary tests in the following order: conversation, the speech motor battery (DDK, MWR, NWR, and SRT), OSMSE, DEAP inconsistency subtest, PPVT IV, EVT-2, GFTA-2. This order was followed for all the participants in all the groups to prevent loss of data due to fatigue/boredom. The entire battery is summarized in Tables 2 and 3 and took approximately two hours to complete.
<table>
<thead>
<tr>
<th>Measures</th>
<th>Test</th>
<th>Stimuli</th>
<th>Description</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parental questionnaire</td>
<td>Social Communication</td>
<td>Questions</td>
<td>Questionnaire administered to</td>
<td>Group membership</td>
</tr>
<tr>
<td></td>
<td>Questionnaire</td>
<td></td>
<td>parents</td>
<td>verification</td>
</tr>
<tr>
<td>Vocabulary measures</td>
<td>Peabody Picture</td>
<td>Pictures</td>
<td>Single word receptive vocabulary</td>
<td>Receptive vocabulary</td>
</tr>
<tr>
<td></td>
<td>Vocabulary Test-IV</td>
<td></td>
<td>test</td>
<td>score</td>
</tr>
<tr>
<td></td>
<td>Expressive Vocabulary</td>
<td>Pictures</td>
<td>Single word expressive vocabulary</td>
<td>Expressive vocabulary</td>
</tr>
<tr>
<td></td>
<td>Test – 2</td>
<td></td>
<td>test</td>
<td>score</td>
</tr>
<tr>
<td>Articulation test</td>
<td>Goldman Fristoe</td>
<td>Pictures</td>
<td>Articulation test</td>
<td>Articulation score</td>
</tr>
<tr>
<td></td>
<td>Test of Articulation – 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Sounds in words subtest)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oral motor screening</td>
<td>Oral Speech Mechanism</td>
<td>N/A</td>
<td></td>
<td>Description of speech</td>
</tr>
<tr>
<td></td>
<td>Screening Examination – 3</td>
<td></td>
<td></td>
<td>and non-speech oral</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>motor skills</td>
</tr>
</tbody>
</table>
## Table 3

Experimental tasks

<table>
<thead>
<tr>
<th>Task</th>
<th>Stimuli</th>
<th>Real word</th>
<th>Complexity of stimulus</th>
<th>Basic task</th>
<th>Dependent Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Rate</td>
</tr>
<tr>
<td>Diadochokinetic tasks</td>
<td>(/pa/, /ta/, /ka/)</td>
<td>-</td>
<td>monosyllabic</td>
<td>Rapid repetition</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>/pataka/</td>
<td>-</td>
<td>3 syllables</td>
<td>Rapid repetition</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>Syllable repetition task</td>
<td>18 nonwords in increasing length using only 4 consonants</td>
<td>-</td>
<td>2 to 4 syllables</td>
<td>Repetition</td>
<td>*</td>
</tr>
<tr>
<td>(Shriberg, Lohmeier, Campbell, Dollaghan, Green &amp; Moore, 2009)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-word repetition (Dollaghan &amp; Campbell, 1998)</td>
<td>16 nonwords in increasing length</td>
<td>-</td>
<td>1-4 syllables</td>
<td>Repetition</td>
<td>*</td>
</tr>
<tr>
<td>Multisyllabic word repetition (Hodson, 2004)</td>
<td>12 real multisyllabic words</td>
<td>+</td>
<td>3-5 syllables</td>
<td>Repetition</td>
<td>*</td>
</tr>
</tbody>
</table>
Table 3 continued

| DEAP inconsistency subtest (Dodd, Hua, Crosby, Holmes & Ozanne, 2006) | 10 stimulus words | Real word | 1-4 syllables | Repetition (3x) | *

Note. * = Measures that were obtained for each task
Coding

All the standardized tests were scored according to the instructions provided in the respective test manuals. The important coding procedures related to the speech motor protocol are summarized below:

All the imitative responses for the speech motor protocol were analyzed from the digitally recorded audio files and coded for accuracy and consistency of production. Unless otherwise specified, the accuracy of production or proportion of errors was calculated in accordance with Betz and Stoel-Gammon (2005) as (number of accurate productions/total productions) X 100.

**DDK.** The DDK productions were analyzed for accuracy, consistency and rate of all the monosyllables and the trisyllabic sequence.

*Accuracy.* The accuracy of productions in this case was measured in accordance with the Betz & Stoel-Gammon procedure mentioned above. Speech sound errors during repetition were scored as incorrect. The mean accuracy of all the trials that participants attempted was used in the analysis.

*Consistency.* The consistency of production was measured as compared to the child’s own production. The first imitated response was taken as the baseline (regardless of its accuracy) and the following responses that matched the baseline were scored to be consistent. (Williams & Stackhouse, 2000). Percentage of consistency for each trial was obtained by dividing the number of consistent repetitions by the total number of repetitions and multiplying it by 100. The mean
of consistency scores across all trials attempted by each participant was used in
the analysis.

Rate. Rate of repetition was calculated as the number of correct repetitions in one
second. (Thoonen, et al., 1996). The fastest rate from among the completely
accurate trials was used in the final analysis.

Description of types of speech errors has been useful in classification of speech
sound disorders. For example, children with motor planning issues have been known to
have higher number of sequencing errors as compared to the group of children with
speech sound disorders (ASHA, 2007). Therefore, a qualitative analysis of errors in the
trisyllabic repetition was conducted. The errors were categorized in the following
manner: perseveration (when the sequence was preserved but one of the three syllables
was repeated, e.g. /papatakata/), wrong sequence (e.g., /patakata/), missing consonants
(when there were three syllables in a set but one of the consonants was missing (e.g.,
/papata/), missing syllable (when only a set of two syllables was repeated, e.g., /pata/),
addition (when a fourth sound other than /p/, /t/ or /k/ was added, e.g., /platatakata/), and
vowel errors (e.g. /paitai/kai/).

NWR (accuracy of production). Percentage of correct consonants (PCC) scores
was calculated by dividing the number of correct consonants in the child’s production by
the total number of consonants in the target word. PCC scores were calculated for each
participant for one-, two-, three- and four syllable words and a mean of all of these
yielded an overall NWR score.
SRT (percentage of consonants correct). The productions on the Syllable Repetition Task were scored according to the authors’ instructions (Shriberg, Lohmeier, Campbell, Dollaghan, Green & Moore, 2009) to obtain the percentage of correct consonants. The number of correct consonants was divided by the total number of consonants and multiplied by 100 to yield the PCC scores for words of all lengths - SRT-2, SRT-3, SRT-4. An overall SRT score was obtained by calculating the mean of SRT-2, SRT-3 and SRT-4.

Scores on MWR (accuracy of production). The participants’ responses to the Multisyllabic Word Repetition task from the Hodson Assessment of Phonological Patterns (HAPP-3; Hodson, 2004) were compared to the target words to obtain an accuracy score. Percentage of single consonants correct and percentage of consonant clusters correct was also calculated for each participant.

Scores on the DEAP inconsistency subtest. As instructed in the users’ manual of the DEAP, the number items that were produced differently were calculated. That number was divided by total number of items repeated and then multiplied by 100, thus obtaining a percentage score of inconsistency. It should be noted that this measure is different from the consistency measure used in the DDK task, where a higher score indicates higher consistency. In this task, a higher score indicates less consistency.

Reliability

Approximately 25% of the participants (four) in each group were randomly selected for the reliability study. The data (audio files from the sessions) from these
participants was analyzed for accuracy by a trained research assistant. The mean (and range) of percentages of agreement for judgment of correctness for all the tasks is as follows: NWR-92.7% (87.5-100%), SRT-98.1% (94.4-100%), MWR – 91.67 % (84-100%), DDK accuracy 93.33% (91-95%). In addition, the rate of repetitions for each of the DDK tasks was also measured by a second coder. The mean difference in rate calculated by the two coders was within 0.25 syllables/second for all the DDK tasks.

Statistical Analysis

The primary aim of the study was to examine speech motor characteristics of children with HFA and identify any differences from TD and MSD groups. Group comparisons were made for each of the measures described in section 3.5 above (as dependent variables) in the following manner:

DDK monosyllables (/pa/, /ta/, /ka/). A repeated measures mixed MANOVA was used, where the group was the between subjects factor with three levels consisting 3 participant groups- HFA, MSD, and TD; and type of syllable repeated was the within subjects factor and the rate, accuracy and consistency of repetition were the dependent variables. The results were followed up by individual univariate analyses and Bonferroni corrections to examine specific group differences.

DDK trisyllabic sequence (/pataka/). One way ANOVA analyses were used to determine group differences in terms of accuracy and consistency of repetition of the trisyllables. Because very few participants provided data for the rate of repetition of
/pataka/, a non-parametric test, k means Kruskal Wallis test was used to examine any group differences.

**NWR, MWR, SRT.** A repeated measures mixed ANOVA was used to examine group differences on the dependent measures of PCC on the NWR and SRT tasks. The between subjects factor was the groups and the within subjects factor was the word lengths for each of the tasks. A one way MANOVA was run to examine group differences on the dependent variable of percentage of single consonants correct and percentage of consonant clusters correct on the MWR task. This analysis was followed up by univariate analyses to examine specific DVs and group differences.

**DEAP inconsistency subtest.** A one way ANOVA was used to examine group differences on the percentage of inconsistent repetitions on the DEAP subtest. This analysis was followed up by pair wise comparisons using Bonferroni correction.

The second aim of the study was to determine if the receptive and expressive language abilities of children with autism correlate with their speech motor abilities. In order to address this aim of the study, correlation analysis were run on the vocabulary scores (PPVT scores and EVT scores) and the dependent variables. Spearman’s correlation coefficient was calculated for the PPVT-IV, EVT and SCQ scores and each of the dependent variables mentioned above. It was hypothesized that the EVT scores and speech motor skills will be positively correlated for children in both the HFA and MSD subgroups, but that a higher correlation will be seen for children with MSD than in HFA (given the co-morbid socio-linguistic difficulties). Similarly, the SCQ and EVT scores would show a higher correlation in the HFA group than in the MSD group. This
prediction was based on the view that children with HFA would experience socio-linguistic as well as motor influences on speech production.
Chapter 4: Results

The primary purpose of the study was to determine whether the speech motor skills of children with High Functioning Autism (HFA) were different from those with Motor Speech Disorders (MSD) and typically developing children (TD). To enable this comparison, accuracy, rate and consistency were examined using stimuli and tasks that have frequently been used to examine motor speech status in children and adults. These tasks and stimuli varied speech production demands in terms of number of syllables, word/nonword status, and whether the repetition requested was speeded versus a self-selected typical rate. The second aim of the study was to examine relationship between expressive vocabulary scores and the speech motor variables mentioned above.

The number of participants in each group, their mean age with the standard deviations and age-range can be found in Table 4. A one way ANOVA showed that there was no significant age difference between the groups, $F(2, 34) = 1.053, p = 0.36$. Approximately half of the TD group was females, whereas there was only one female participant in the MSD group and none in the HFA group.
Table 4
Mean age of participants

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Mean (years)</th>
<th>Standard Deviation (years)</th>
<th>Range (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HFA</td>
<td>13</td>
<td>6.49</td>
<td>1.87</td>
<td>4-10.25</td>
</tr>
<tr>
<td>MSD</td>
<td>11</td>
<td>5.35</td>
<td>2.13</td>
<td>4-10.6</td>
</tr>
<tr>
<td>TD</td>
<td>13</td>
<td>6.16</td>
<td>1.85</td>
<td>4.25-9.5</td>
</tr>
</tbody>
</table>

*Note.* MSD=Motor Speech Disorders, HFA=High Functioning Autism, TD=Typically developing

**Standardized Tests**

Group performances on the standardized tests, namely, Social Communication Questionnaire (SCQ), Peabody Picture Vocabulary Test IV (PPVT-IV), Expressive Vocabulary Test-2 (EVT-2), and Goldman Fristoe Test of Articulation-2 (GFTA-2) are reported in Table 5. The SCQ was administered to ascertain group membership, PPVT and EVT were administered to obtain a description of vocabulary and the GFTA-2 was used to describe articulation skills of all the participants. Two participants in the HFA group did not complete the PPVT IV and one did not complete the EVT-2 due to loss of interest and poor attention span.

The OSMSE-3 has three major sections – structural, functional and DDK screening. With the exception of one participant in the MSD group, all the participants passed the structural and functional screening, indicating structurally and functionally normal oral mechanisms. The participant in the MSD group who failed the functional screening scored low on the section assessing tongue movements and therefore did not
meet the cut-off score for his age. In the DDK screening, only 3 participants in the HFA group and 4 participants in the TD group passed the screening while none of the participants in the MSD group passed the DDK screening task. The reason for failure of most of the TD and HFA children on this task might be fatigue. The OSMSE was administered after the administration of the experimental DDK tasks (which required participants to attempt a total of 20 trials), multisyllabic word repetition, non-word repetition, and syllable repetition tasks. Thus by the time the DDK task from the OSMSE-3 was administered the participants might have been too tired to perform at their optimum capacity.

None of the participants in the TD or MSD group met the cut-off scores for autism on the SCQ, thus confirming their group membership in the non-HFA groups. As seen in Table 5, EVT-2 and PPVT IV scores for all the participants fell within normal limits. This suggests that at least in the terms of their single word vocabulary, all of the participants in the study were found to perform typically.

All the participants in the TD group had GFTA-2 standard scores within the average range (85-115). In contrast, 2 participants from the HFA group and 5 from the MSD group had scores that fell more than one standard deviation below the mean for their age on the GFTA-2. Thus, about 45% of the MSD group and 15% of the HFA group could be described as having a speech sound disorder. Although this was predictable for the MSD given recruitment methods, no mention of SSD status (either present or absent) had been included in recruitment materials for the HFA group. In addition, the fact that less than 50% of the participants in the MSD group had GFTA-2
scores within normal range indicated an improvement in their articulation skills since their diagnosis.

Table 5

*Mean standard scores on standardized assessments*

<table>
<thead>
<tr>
<th>Standardized tests</th>
<th>MSD Mean (SD)</th>
<th>HFA Mean (SD)</th>
<th>TD Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCQ</td>
<td>5.8 (4.1)</td>
<td>16.2 (3.2)</td>
<td>2.8 (2.1)</td>
</tr>
<tr>
<td>PPVT IV</td>
<td>99.8 (14.3)</td>
<td>101.1 (17.7)</td>
<td>115.9 (16.3)</td>
</tr>
<tr>
<td>EVT 2</td>
<td>100.4 (14.9)</td>
<td>100.0 (14.8)</td>
<td>116.6 (11.6)</td>
</tr>
<tr>
<td>GFTA 2</td>
<td>85.4 (20.1)</td>
<td>95.1 (26.1)</td>
<td>108.2 (4.0)</td>
</tr>
</tbody>
</table>

*Note.* SCQ=Social Communication Questionnaire, PPVT IV=Peabody Picture Vocabulary Test IV, EVT 2=Expressive Vocabulary Test-2, GFTA 2=Goldman Fristoe Test of Articulation-2

The results from the experimental tasks for each of the two hypotheses are presented next. Multiple dependent variables for some of the experimental tasks were analyzed together for statistical purposes. For example, the accuracy and rate of repetition was analyzed together in a MANOVA design for the DDK task. Therefore, the results of the group comparisons will be discussed in a task by task manner. However, all the results will be summarized in terms of the measures obtained (viz., accuracy, rate and consistency) at the end of this chapter because of the different kinds of information about the process of speech production provided by each of these variables when examined across tasks. The discussion of results in the following chapter will also follow this last pattern.
**Hypothesis 1: Nontypical performance of the HFA group**

The first aim of the study was to compare the speech motor characteristics of children with HFA to those with MSD and TD. The specific hypothesis was that mean scores on all the speech motor task variables (rate, accuracy, consistency) would be the highest for TD group, followed by HFA group, followed by MSD group. That is, the TD group would be the fastest, most accurate and most consistent, followed by the HFA group and the MSD group would be the slowest, least accurate and least consistent on the measures of speech motor skills. Specifically, the following two parts of the null hypothesis were tested:

\[ M_{TD} = M_{HFA} \]
\[ M_{HFA} = M_{MSD} \]

where \( M \) is the mean score on a given dependent variable

**Diadochokinetic (DDK) Tasks.** With regard to the statistical examination of Hypothesis 1 concerning differences between the HFA and other groups, although no significant differences were found between the TD and the HFA group; there were significant differences between the HFA and the MSD group on all the DDK tasks and variables. In addition, there was a trend in the raw data in the direction of poorer performances by the HFA group than the TD group. The details of the analyses follow.

**Trial analysis.** Out of the five required trials on each of the DDK tasks, the mean number of trials attempted by the HFA group was 4.5, while it was 4.9 in the MSD group
and the TD group each for the monosyllables. On the trisyllabic repetition, the mean number of trials attempted was 4, whereas it was 4.6 for the MSD group and 4.7 for the TD group. The mean number of trials attempted for each task was examined for group differences to determine if data loss appeared to be differentially associated with any particular group. No difference in the number of trials attempted by the three groups was found for any of the 4 diadochokinetic stimulus types.

**Monosyllabic repetition in the DDK task.** The rate, accuracy and consistency of children’s speeded productions of three monosyllables (/pɑ/, /tɑ/ and /kɑ/) were obtained for each participant in all the three groups. Means and standard errors of rate, accuracy and consistency scores on various DDK tasks are presented in Figures 2, 3 and 4, respectively.

In order to understand the effect of diagnosis on the dependent variables, a repeated measures mixed MANOVA analysis was conducted with rate, accuracy and consistency as the dependent variables, stimulus type as the within-subjects factor with three levels (/pɑ/, /tɑ/ and /kɑ/), and diagnosis as the between-subjects factor with three levels (HFA, MSD and TD). There was a significant effect of group, Wilk’s $\lambda = 0.542, F(6, 60) = 3.582, p = 0.004$, as well as the type of monosyllables, Wilk’s $\lambda = 0.603, F(6, 27) = 2.959, p = 0.024$. However, the interaction between group and the type of monosyllable was not found to be significant, Wilk’s $\lambda = 0.573, F(12, 54) = 1.442, p = 0.176$. The follow-up analyses are described below.
The omnibus MANOVA was followed up with separate MANOVAs for each of the three monosyllables-/pɑ/, /tɑ/ and /kɑ/. Correlation between accuracy and consistency scores was examined and because the measures of consistency and accuracy were highly correlated, the consistency data were analyzed separately to avoid collinearity.

/pɑ/ rate and accuracy. The three groups differed significantly on these measures, with a medium sized effect on the repetition of the monosyllable /pɑ/, Wilk’s λ = 0.597, $F(4, 66) = 4.856, p = 0.002, \eta_p^2=0.227$. On examining the univariate results, it was found that only the rate of repetition of /pɑ/ was different among the groups, $F(2, 34) = 3.471, p = 0.042, \eta_p^2 = 0.170$, with a small effect. Pairwise comparisons using Bonferroni corrections revealed that the MSD group was significantly different from the TD group ($p = 0.040$) on the measure of rate. The accuracy scores were not significantly different among the groups, $F(2, 34) = 2.334, p = 0.112, \eta_p^2 = 0.121$. These results show that the MSD group was the slowest in repeating /pɑ/, followed by the HFA group and the TD group was the fastest in terms of repeating the monosyllable /pɑ/. The HFA group was slower than the TD group; however, the difference in the performance was not found to be statistically significant (See Figure 2). Thus, the three groups differed on the rate of repetition of /pɑ/ and not on the accuracy of repetition.

/pa/ consistency. One way ANOVA revealed that there was no significant effect of diagnosis on the consistency of repetition of /pɑ/, $F(2, 34) = 1.371, p = 0.268, \eta_p^2 =
0.075. Thus the groups were not found to be significantly different on the consistency of their productions of /pa/.

/ta/ rate and accuracy. There was a small significant effect of diagnosis on the repetition of the monosyllable /ta/, Wilk’s $\lambda = 0.690$, $F(4, 66) = 3.364$, $p = 0.014$, $\eta^2_p = 0.169$. On examining the univariate results, it was found that only the rate of repetition of /ta/ was significantly different among the groups, $F(2, 34) = 4.887$, $p = 0.014$, $\eta^2_p = 0.223$ with a moderate effect. Accuracy of repetition was not found to be significantly different among the groups, $F(2, 34) = 2.236$, $p = 0.122$, $\eta^2_p = 0.116$. Pairwise comparisons using Bonferroni corrections revealed that the MSD group was significantly different from the TD group on rate ($p = 0.013$). These results show that the repetition rate for /ta/ differed among the groups, in a fashion similar to that of rate of /pa/. The MSD group was the slowest, followed by the HFA group and the TD group was found to be the fastest in terms of repetition of monosyllable /ta/. Though the HFA group was slower than the TD group, the difference in their performance did not reach statistical significance (See Figure 1). The groups also differed slightly on the accuracy of repetition of /ta/ with the MSD group being the least accurate, the TD group being the most accurate and the HFA group’s performance falling in between the two (See Figure 3). However, these differences did not reach statistical significance.
/ta/ consistency. There was no significant effect of diagnosis on the consistency of repetition of /ta/, $F(2, 34) = 1.324, p = 0.279, \eta_p^2 = 0.072$. No group differences emerged on the consistency of production of /ta/ (See Figure 4).

/ka/ rate and accuracy. The effect of diagnosis approached significance with a small effect size for the monosyllable /ka/, Wilk’s $\lambda = 0.751, F(4, 62) = 2.388, p = 0.06$, $\eta_p^2 = 0.134$. The univariate tests revealed that the rate of repetition was significantly different for the three groups, $F(2, 32) = 3.771, p = 0.034, \eta_p^2 = 0.191$ with a small effect size, whereas the accuracy of repetition was not significantly different, $F(2, 32) = 1.908, p = 0.165, \eta_p^2 = 0.107$. Pairwise comparisons revealed that the MSD group differed significantly from the TD group ($p = 0.037$) on the rate of repetition. As seen in Figure 1, the rate of repetition for /ka/ followed the same pattern as that of the other two monosyllables. The MSD group was the slowest in repeating /ka/, followed by the HFA group and the TD group. However, only the difference between the MSD group and the TD group was statistically significant. The groups did not differ significantly on the accuracy of repetition of /ka/.

/ka/ consistency. No significant differences were found among the groups in the consistency of repetition of /ka/, $F(2, 32) = 1.181, p = 0.32, \eta_p^2 = 0.069$.

In summary, the MSD group had a significantly slower repetition rate compared to the other two groups for each of the three monosyllables. However, the three groups did not differ on the accuracy and consistency of monosyllabic productions.
Figure 2. Rate of repetition on DDK tasks. This figure illustrates the mean and standard errors of rate of repetition on the DDK tasks.
Figure 3. Accuracy of repetition on DDK tasks. This figure illustrates the mean and standard errors of accuracy of repetition on DDK tasks.

Figure 4. Consistency of repetition on DDK tasks. This figure illustrates mean and standard errors of consistency scores on the DDK tasks.
Trisyllabic repetition in the DDK task.

Rate. Not all the participants in all the groups could complete the trisyllabic repetition task in a completely accurate manner resulting in quite small n’s for each group for the rate analysis. Therefore, group differences on the rate of repetition of the trisyllabic sequence were examined using a non parametric test. Independent samples Kruskal Wallis test revealed that the difference between the groups approached significance (\(p = 0.055\)) on the rate of repetition of /\texttt{pataka}/. As can be seen from the Figure 2 the mean performance of the MSD group was worse than the other two groups, however, this difference was not statistically significant. This could be due to loss of power resulting from the small number of participants in each cell. Alternatively, it could mean that, unlike the monosyllables, all the groups found it equally difficult to repeat the trisyllabic sequence.

Accuracy and consistency. The groups differed significantly on the accuracy of repetition of the trisyllabic sequence, \(F(2, 32) = 4.045, p = 0.027, \eta_p^2 = 0.202\), with a small effect. Pairwise comparisons revealed that only the difference between the MSD and TD groups was statistically significant (\(p = 0.035\)). The difference between the groups on consistency of repetition approached significance, \(F(2, 31) = 3.041, p = 0.062, \eta_p^2 = 0.160\). See Figures 2 and 3.
**Error analysis.** Because type of errors can be indicative of the nature of speech problem (articulation difficulty vs. sequencing difficulty), a qualitative analysis of the errors was carried out. Each error made during the trisyllabic repetition was classified as a perseveration (when the sequence was preserved but one of the three syllables was repeated, e.g., /papataka/), wrong sequence (e.g., /pakata/), missing consonants (when there were three syllables in a set but one of the consonants was missing, e.g., /papata/), missing syllable (when only a set of two syllables was repeated, e.g., /pata/), addition (when a fourth sound other than /p/, /t/ or /k/ was added, e.g., /plataka/), or vowel error (e.g., /pitaikai/). The error categories were mutually exclusive, that is, if a participant missed a syllable, they were not additionally scored off for a missing consonant. It was found that the groups differed only in terms of addition errors, $F (2, 35) = 6.548, p = 0.004, \eta^2_p = 0.284$, with a moderate effect size. The MSD group made significantly more addition errors than either the HFA group ($p = 0.011$) or the TD group ($p = 0.009$). The groups did not differ on any other errors types.

Thus, not only was the MSD group slower than the other two groups, but it was also far less accurate and less consistent when attempting to repeat the trisyllabic sequence /pataka/. Although the HFA group’s performance was similar to the TD group in consistency of repetition, it was found to be more inaccurate than the TD group. Qualitative analysis of the error patterns revealed that the groups made similar types of
errors on the trisyllabic tasks, except for the higher number of addition errors by the MSD group.

**Non-Word Repetition task (NWR).** The overall NWR score is the percentage of consonants correct of 16 nonwords that contained from 1 to 5 syllables. There was no significant difference between the performances of the TD and the HFA group on the overall NWR score. Hence the null hypothesis 1a could not be rejected. In addition, there was no significant difference between the HFA and the MSD group on the overall NWR score; therefore the null hypothesis 1b could also not be rejected. The details of the analyses follow.

The groups were found to be significantly different from each other on the overall NWR scores using a one way ANOVA, $F(2, 34) = 3.962, p = 0.028, \eta^2_p = 0.189$, with a small effect size. Pairwise comparisons using Bonferroni corrections revealed that the MSD group was significantly different from the TD group ($p = 0.027$) but not from the HFA group ($p = 0.192$). Although the HFA group’s score performance was poorer than the TD group, it did not reach statistical significance (See Figure 5).

A mixed ANOVA was used to examine the effects of the between subjects variable diagnosis and the within subjects variables of word length on the various sub-scores of NWR-1, NWR-2, NWR-3 and NWR-4 on the dependent variable percentage consonants correct (PCC). The group differences on the sub-scores of the NWR approached significance, $F(2, 34) = 3.044, p = 0.062, \eta^2_p = 0.152$, with a small effect size. The within subject factor of word length was found to have a moderate significant
effect, $F(3, 102) = 9.606, p < 0.001, \eta^2_p = 0.22$. Specifically, performance on one syllable words was significantly different from that on 4-syllable words ($p = 0.001$), and performance on 2-syllable words was significantly different from that on the 4-syllable words ($p < 0.001$). The interaction between diagnosis and the word length was also found to be significant, $F(6, 102) = 6.722, p < 0.001, \eta^2_p = 0.283$, such that as the word length increased, the performance of the MSD group worsened, as compared to the other two groups. As seen in Figure 4, the TD group was the most accurate in repeating the nonwords, followed by the HFA group and the MSD group (with the exception of NWR-4, where the HFA group performed slightly better than the TD group). However, only the difference between the MSD group and the TD group was found to be statistically significant. For all the groups, the shorter words were easier to say as compared to the longer words. However, the significant interaction shows that the word length was the most important for the MSD group, in terms of accuracy of repetitions. They found the longer words harder to repeat as compared to the other two groups.
Figure 5. Non-word repetition scores. This figure illustrates mean and standard errors on the non-word repetition task

Syllable Repetition Task. The overall SRT score is the percentage of consonants correct on the repetition of 18 nonword stimuli varying from 2-4 syllables in length. There was no significant difference between the performances of the TD and the HFA group on overall SRT accuracy. Hence the null hypothesis 1a could not be rejected. However, there was a significant difference between the HFA and the MSD group on the overall SRT score; therefore the null hypothesis 1b was rejected. The details of the analyses follow.

A one way ANOVA revealed a moderate significant effect of group on the overall SRT scores, $F(2, 35) = 9.726, p < 0.001, \eta_p^2 = 0.371$. Specifically, the MSD group was
significantly different from both the HFA group \((p = 0.01)\) and TD group \((p < 0.001)\), see Figure 6.

A mixed model ANOVA analysis was run to examine the group differences with diagnosis as the between subjects factor and syllable length as the within subjects factor (with three levels) on the various SRT sub-scores. There was a moderate significant difference between the groups on the sub-scores of SRT, \(F(2, 33) = 8.651, p = 0.001, \eta^2_p = 0.344\). Pairwise comparisons revealed that the MSD group performed significantly more poorly than the HFA \((p = 0.013)\) and the TD group \((p = 0.001)\). The performance of the HFA group was poorer than the TD group; however, this difference was not statistically significant.

The within subject factor of word-length also had a moderate significant effect, \(F(2, 66) = 18.397, p < 0.001, \eta^2_p = 0.358\). Specifically, scores on SRT-2 were significantly different from those on SRT-3 \((p = 0.007)\), scores on SRT-3 were different from those on SRT-4 \((p = 0.014)\) and scores on SRT-2 were significantly different from those on SRT-4 \((p < 0.001)\). The interaction of diagnosis and syllable length was not significant. Thus, all the groups found the two syllable sequences easier to repeat as compared to the 4 syllable sequences on the SRT.
Figure 6. Syllable Repetition Task (SRT). This figure illustrates the mean and standard error on the SRT.

Multisyllabic Word Repetition (MWR). There was no significant difference between the performances of the TD and the HFA group on the MWR scores. Hence the null hypothesis 1a could not be rejected. However, there was a significant difference between the HFA and the MSD group on the percentage of correct consonant clusters on the MWR task, therefore the null hypothesis 1b was rejected. The details of the analyses follow.

The percentage of consonants correct and percentage of consonant clusters correct for each of the multisyllabic words was calculated for all the participants. Means and standard deviations of the MWR scores can be found in Table 6. A one way ANOVA revealed a moderate significant effect of groups for percentage of single consonants
correct $F(2, 34) = 8.913, p = 0.001, \eta^2_p = 0.34$. Specifically, the MSD group was found to be significantly different from the TD group ($p = 0.001$). A one way ANOVA using the percentage of correct consonant clusters also showed a moderate significant effect of the diagnosis, $F(2, 34) = 12.534, p < 0.001, \eta^2_p = 0.424$. Pairwise comparisons revealed that the MSD group was significantly different from both the HFA group ($p = 0.031$) and the TD group ($p < 0.001$). However, the HFA group was not significantly different from the TD group on this measure. Thus, the TD group was the most accurate, followed by the HFA group and the MSD group was the least accurate as regards repetition of multisyllabic words.

Table 6

<table>
<thead>
<tr>
<th>Group</th>
<th>Accuracy of single consonants (%)</th>
<th>Accuracy of consonant clusters (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>MSD</td>
<td>55.21 (23.01)</td>
<td>32.12 (30.08)</td>
</tr>
<tr>
<td>HFA</td>
<td>74.01 (32.36)</td>
<td>65.67 (40.56)</td>
</tr>
<tr>
<td>TD</td>
<td>95.30 (06.77)</td>
<td>93.84 (12.90)</td>
</tr>
</tbody>
</table>

**DEAP Inconsistency Subtest.** The inconsistency score on DEAP was the percentage of different responses on three attempts of picture naming. This task involves the naming of 10 pictures depicting words of varying lengths (1-5 syllables). There was no significant difference between the performances of the TD and the HFA group on the
inconsistency subtest of DEAP. Hence the null hypothesis 1a could not be rejected. In addition, there was no significant difference between the HFA and the MSD group on the inconsistency subtest of DEAP, therefore the null hypothesis 1b could also not be rejected. The details of the analyses follow.

The MSD group had the highest percentage of inconsistent errors on the inconsistency subtest of the DEAP \((M = 43.64, SD = 28.73)\). The TD group had no inconsistent errors \((M = 0, SD = 0.0)\) and the HFA group had a mean of 4.55 \% \((SD = 12.14)\) inconsistent errors. Thus, there was a significant difference between the groups with regards the inconsistency of errors as shown by a one way ANOVA, \(F(2, 34) = 21.625, p < 0.001, \eta^2_p = 0.575\), with a large significant effect. Specifically, only the difference between the MSD group and the HFA group \((p < 0.001)\) and that between the MSD group and the TD group \((p < 0.001)\) was significant. The difference between the HFA and TD groups was not found to be significant. Thus, the MSD group had more inconsistent errors as compared to the TD and the HFA groups.

**Hypothesis 2 Relationship between Motor Speech Variables and Expressive Vocabulary**

The second aim of the study was to examine the correlation between speech motor variables and expressive vocabulary. The specific hypothesis studied was that the expressive vocabulary scores on the EVT-2 and scores on the speech motor tasks would be positively correlated. Specifically, the following null hypothesis was tested.

\[
\rho_{EV-SMS\ MSD} > \rho_{EV-SMS\ HFA} > 0
\]
In order to test this hypothesis, correlations between the expressive vocabulary scores (EVT-2), and the speech motor measures (rate, accuracy and consistency of /pa/, /ta/, /ka/, /patakα/, NWR, SRT, MWR, DEAP inconsistency scores) were examined. Because a total of 16 correlations were tested in all, Bonferroni correction was applied and the corrected alpha (0.00325) was used to determine statistical significance.

No significant correlations were found among the speech motor variables and the EVT scores for any of the three groups. Thus the speech motor abilities seemed to be independent of the expressive vocabulary skills.

**Overall Summary of Results.** The hypothesis of Motor Speech Impairment in HFA. A summary of these results is presented in Table 7. Overall, this table indicates that the HFA group was not different from the TD group on any of the measures on the speech motor tasks. MSD group differed from both of the other groups on almost all the tasks that measured accuracy and the task that measured inconsistency of errors. The MSD group differed from the TD group only on the rate of monosyllabic repetition. In addition, MSD group also differed from the HFA group on accuracy of the multisyllabic stimuli (overall NWR, all SRT, and MWR scores). It was found that none of the scores on the measures of speech motor skills were significantly correlated with expressive vocabulary for any of the groups.

The results from this study indicate that children with HFA do not exhibit deficits in speech motor skills as measured by tasks with various levels of difficulty. Their performance on some of the more difficult tasks is significantly better than children with
MSD, thus providing evidence against the hypothesis of speech motor deficit in children with HFA. In addition, none of the groups, including HFA demonstrate a significant relationship between their expressive vocabulary scores and speech motor scores.

Table 7

<table>
<thead>
<tr>
<th>Task</th>
<th>Stimuli</th>
<th>Dependent variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diadochokinetic tasks</td>
<td>/pa/</td>
<td>MSD-TD*</td>
</tr>
<tr>
<td></td>
<td>/ta/</td>
<td>MSD-TD*</td>
</tr>
<tr>
<td></td>
<td>/ka/</td>
<td>MSD-TD*</td>
</tr>
<tr>
<td></td>
<td>/pataka/</td>
<td>MSD-TD*</td>
</tr>
<tr>
<td>Non-word repetition</td>
<td>16 nonwords</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>(1-syllable length to 4-syllable length)</td>
<td>MSD-TD*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>NWR-subscores</td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>SRT-overall</td>
<td>18 nonwords</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>(2-syllable length to 4-syllable length)</td>
<td>MSD-TD*</td>
</tr>
<tr>
<td></td>
<td>(2-syllable length to 4-syllable length)</td>
<td>MSD-HFA*</td>
</tr>
<tr>
<td></td>
<td>4 consonants</td>
<td>N/A</td>
</tr>
<tr>
<td>SRT subscores</td>
<td></td>
<td>MSD-TD*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MSD-HFA*</td>
</tr>
<tr>
<td>Multisyllabic word repetition</td>
<td>Single consonants in 12 real multisyllabic words</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Consonant clusters</td>
<td>MSD-TD**</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MSD-HFA*</td>
</tr>
<tr>
<td>DEAP inconsistency subtest</td>
<td>10 stimulus words</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MSD-TD**</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MSD-HFA**</td>
</tr>
</tbody>
</table>

Note * = p < .05; ** = p < .01.
Chapter 5: Discussion

The objective of the present study was to explore the nature of speech motor characteristics in high functioning children with ASD (HFA). Children within this subgroup of ASD were selected for study because of their greater ability to understand the instructions and participate in the conventional speech motor evaluation procedures. In order to examine the speech motor characteristics of children with HFA, their performances on several speech motor tasks were compared to those of children with motor speech disorders (MSD) and children with typical development (TD). Three dependent measures – rate, accuracy and consistency – were obtained in order to gain information both about the final results of their movements (accuracy) under tasks of differing demands, but also their ability to execute those plans rapidly (rate) and accurately across multiple repetitions (consistency). These measures obtained from speech tasks of varying difficulty have been useful in identifying subtle speech motor deficits in children with MSD as well as those who have speech sound disorders with and without language impairment (Davis, Jakielski, & Marquardt, 1998; Lewis & Freebairn, 1997) and hence were chosen to assess the speech motor skills in children with HFA a majority of whom did not have any symptoms of a speech disorder. A second objective of the present study was to examine relationships between the measures of accuracy, rate
and consistency of the production of various types and lengths of stimuli and expressive vocabulary scores. The study of this relationship was deemed to be helpful in understanding the possible contribution of speech motor skills to the development of spoken language in children with ASD.

The major findings in this study were that although the performances of the children with HFA were almost always intermediate to those of the TD group, (which had the best scores), and those of the MSD group (which had the poorest scores), only differences between the MSD and both other groups were found to be statistically different. When expressive vocabulary scores on the EVT-2 were examined for the HFA group, no statistically significant correlation was found with any of the motor speech tasks. Although these findings failed to support the research hypotheses regarding the children with HFA, they nonetheless supported the hypothesis regarding the MSD group – the MSD group’s performance was poor on all the measures. Thus they make a contribution to the existing literature on motor speech skills in children with HFA as well as those with MSD; albeit in different ways. How these findings relate to the existing literature and their implications in shaping future research is discussed below.

Performance of the HFA group on speech motor tasks

Dependent variables were obtained through the repetition of a variety of stimuli. The results will be discussed in terms of the measures obtained – rate, accuracy and consistency-across these stimuli, so as to facilitate the discussion of the different kinds of
information about speech motor functioning that these measures provide when examined across the stimuli.

**Rate.** Rate of speech (whether in spontaneous speech or structured repetition), provides information on the ability of motor coordination (Ruscello, St Louis, Barry & Barr, 1982) and overall control of articulators, skills which are known to be impaired in children with MSD (Thoonen, Maasen, Wit, Gabreels & Schreuder, 1996), as well as in adults with upper motor neuron disorders, cerebellar disorders and Parkinson’s disease (Yorkston, Beukelman, Strand & Hakel, 2010). The rate of repetition was not found to be affected in the present sample of children with HFA, though their performance was slightly poorer than the typical group. Thus these children with ASD did not show any evidence of speech motor coordination difficulties.

To my knowledge, only two studies have looked at the rate variable in children with ASD and these have reported rather mixed findings. This current finding is contradictory to the one study that has employed the use of DDK tasks to examine rate of repetition in children with ASD. Velleman, et al (2010) has reported a significantly slower rate of repetition for one of the 3 stimuli that they used to assess DDK in children with ASD. They used the Verbal Motor Production Assessment for Children (VMPAC, Hayden & Square, 1999) to assess speech and oral motor skills of 4-6.5 yrs old children with ASD (n = 10) and found that they had a slower rate of repetition of the word “key” in repetition of the phrase “pea tea key”. Though the present study found a trend similar to the one reported by Velleman and colleagues, there was no statistical evidence to support it. This difference in findings could arise from two potential reasons. First is the
nature of the stimuli used the VMPAC uses linguistic stimuli in the DDK task whereas the current study did not. The second is the age difference between the two participant groups. Not only was the mean age of participants in the current study slightly higher, but also the age range was much wider, which might have resulted in higher rates of repetition in the current study.

My finding that rate of repetition is not affected in children with HFA can be said to be consistent with that reported by Shriberg, et al. (2011), who found that rate of continuous speech was not affected in children with ASD. Their sample of children with ASD was 4-7 yr old children who had full scale IQs of more than 70 (and therefore comparable to my sample of children with HFA). Though a direct comparison cannot be made across studies as the current study used a structured task to elicit rate of repetition, as opposed to rate of continuous speech obtained by Shriberg and colleagues, the measure can still be said to reflect the same underlying phenomena of speech motor coordination and articulatory control.

Though general motor coordination difficulties have been noted in children with ASD (Ghaziuddin & Butler, 1998), there does not seem to be any evidence of a parallel speech motor coordination deficit, as shown by the results of the current study and those reported by Shriberg, et al (2011), at least in the subgroup of high functioning children with ASD.

**Accuracy.** While rate is a measure speech motor coordination and control, accuracy measures the selection/planning abilities of the speech motor system. Accuracy of performance on a challenging speech task (like multisyllabic word repetition) can
inform us about the ability of the speech motor system to perform under high sequencing demands. It is also important to examine accuracy in addition to rate because there can be a trade-off between the two. For example, while a child might repeat a stimulus at a very high rate, he/she may not be producing it correctly, compromising accuracy for rate (Williams & Stackhouse, 2000). Thus, it has been recommended that in addition to rate, accuracy and consistency of DDK tasks should also be investigated (Yaruss, 1997).

Accuracy of repetition in the present study was examined through 3 different tasks- monosyllabic and trisyllabic DDK repetition, non-word repetition and multisyllabic real word repetition. Repetition of all kinds of stimuli requires the involvement of the speech motor system. However, different types of stimuli require different degrees of association between the speech motor system and other systems (e.g., phonological system, lexical system, etc.). Real word repetition involves accessing a pre-stored motor program and thus using the lexicon places lesser demands on the speech motor system (Stackhouse & Wells, 1993). Non-word repetition involves creation of a new motor program because the word has never been said before (though sometimes the nature of nonwords might allow the aid of phonological representations), placing slightly higher demands on the speech motor system (Williams & Stackhouse, 2000). However, repetition of syllables (like ones used in the DDK tasks) only requires manipulation of sensorimotor aspects of production, without the help of phonological knowledge or the lexicon (Stackhouse & Wells, 1993).

In the literature, comparisons of production accuracy between children with HFA and TD or MSD are quite limited. The present study found that children with HFA had
no more difficulties in sequencing speech sounds than the typically developing children—either in isolated motor contexts, or in lexical contexts, while children with MSD had significant impairments in this respect, as measured by accuracy of repetition. The fact that these children did not have difficulties in accuracy of isolated repetitions is not surprising, given that a majority of them did not present with any speech sound difficulties. However, because the accuracy of some of the more challenging tasks speaks to the skill of rapidly selecting and sequencing phonemes, it can be concluded that children with HFA do not have deficits in this particular skill set.

My finding regarding the accuracy of productions in a non-word repetition task seems to be in accordance with those previously reported in the literature. For example, Shriberg, et al., 2011, found that their sample of children with ASD between the ages of 4 and 7 years had age-typical scores on the syllable repetition task. Kjelgaard and Tager-Flusberg (1991) found that children with ASD between the ages of 4 and 14 years, who had no concomitant language impairment, had no deficits in non-word repetition skills on the subtest of NEPSY- a developmental neuropsychological assessment.

In contrast, the accuracy of multisyllabic word repetition tasks reported in the present study differs from the one reported by Adams (1998). Adams found that the accuracy of polysyllabic sequencing in children with ASD was significantly poorer than that in typically developing children. This discrepancy in the findings could arise from the difference in stimuli used and/or the size and nature of the sample of children with ASD. The present study had a larger sample (n = 13, as opposed to n = 4 reported in Adams, 1998) and had relatively unimpaired language skills, as reported by the parents
and evidenced by the vocabulary scores. It is possible that the polysyllabic words used by Adams (1998) were harder to repeat, than the words from HAPP-3 used in the present study.

**Consistency.** Consistency of speech production has been reported to be one of the chief characteristics of motor planning deficits as seen in children with childhood apraxia of speech (Davis, Jakielski, & Marquardt, 1998). Two types of consistency scores were examined in the present study - consistency of repetition in the DDK tasks and inconsistency of errors in the inconsistency subtest of the DEAP. Children with HFA were found to be as consistent as the TD children in their speech production but were significantly different from the children with MSD. Thus, no evidence of motor planning deficits was found in the current sample of children with HFA. To my knowledge this study is the first to examine the consistency of speech production in children with HFA and hence there is no literature available for comparison.

**Performance of the MSD group on speech motor tasks**

It is important to note that the performance of children with MSD confirmed a part of the hypothesis. Children with MSD performed significantly poorer than both children with HFA and those typically developing on all of the speech motor tasks. That is, they had significant difficulties in speech motor coordination and sequencing as evidenced by DDK tasks, poor phonological representation and motor program execution as seen on the NWR tasks and had inconsistent speech productions. These results support the validity of the tasks used in tapping speech motor skills of children in the age
range of 4 to 10 years. These findings are also in accordance with many others reported in the literature (e.g., Thoonen, Maassen, Gabreels & Schreuder, 1999). For example, rate of repetition of trisyllabic sequence in 6-10 yr old children with MSD was found to be significantly lesser than that in typically developing children (Thoonen, et al., 1996). Lewis, et al. (2004) also reported a poorer rates of repetition in their sample of school age children with childhood apraxia of speech (CAS) in a study in which they followed children with CAS, children who had isolated speech sound disorder (without language impairment) and children who had combined speech and language impairment from preschool age (4 to 6 years) to school age (8 to 10 yrs). In addition to rate, the accuracy of non-word repetition tasks and multisyllabic word repetition tasks was also found to be significantly poorer in their sample of children with CAS. These findings have been reasserted in a more recent study, where Aziz, et al. (2010) found that accuracy on stimuli of all lengths (monosyllables, disyllables and polysyllables) was significantly poorer in their sample of 4-6 yr old children who were suspected of having CAS as compared to children with multiple phonologic disorders and typically developing children.

It should be noted that although all of the participants in this group had a diagnosis of a motor speech disorder (which happened to be CAS for all of them by chance), only 5 of them had articulation scores that fell below average on the GFTA-2. Presumably, this was an indication of improvement in their articulation skills since the time of their diagnosis. Thus, even though more than half of this group had articulation scores in the average range, they had considerable difficulties in the more demanding tasks mentioned above. This finding is consistent with the one reported by Lewis et al.
In their follow-up study of children with CAS, they found that though children with CAS had learnt to articulate phonemes in single target words, they showed little improvement in sequencing syllables in real and non-words.

In summary, the present study contributes to the literature on motor speech disorders in a valuable way, underscoring speech motor coordination deficits and difficulty with sequencing speech sounds in nonwords and lengthy real words in children with CAS. It also provides evidence that measures of rate, accuracy and consistency obtained from various challenging tasks are sensitive to speech motor deficits, even when the articulation skills seem to be minimally affected.

The presence of the significant findings for the MSD, but not the HFA group can be seen as suggestive of the fact that the children with HFA who participated in this study are unimpaired in their motor speech skills. However, the “trend” that was seen in the accuracy and rate of speech motor performance of the groups demands further consideration. On the one hand, perhaps this slightly poor performance on the speech motor tasks is an indicator of a greater speech motor deficit that might be evident only in those children with ASD who are more impaired in their speech and language skills than the current sample. On the other hand, this minor difference in performance might be an outcome of poor attention span and deficits in social interaction skills that are a hallmark of this disorder. This latter explanation is aligned with the speech attunement framework that has been used by Shriberg and colleagues (2011) to explain persistent speech errors (mild errors of distortion that do not impact intelligibility; Shriberg, 1994) and differences in prosody characteristics of children with HFA. According to this
framework, a child needs to “tune in” to the oral communication characteristics of his community and then “tune up” his/her own phonetic/phonological systems, to be able to acquire speech skills. Shriberg (1994) suggests that because of impairments in social interactions, some children with ASD may have difficulty tuning in to others’ speech sounds and/or tuning up their own speech errors (Shriberg, et al., 2011), thus resulting in distortions of certain speech sounds that persist into later years. However, this theory does not explain the higher risk of more severe intelligibility impairments errors due to sound substitutions and omissions that are observed in children with ASD (two in the present study); this risk has been attributed to environmental and/or genetic factors (Shriberg, et al., 2011). Other than the two participants with severe intelligibility impairment, none of the HFA participants in the present study presented with any speech errors nor did they “sound different” in terms of their prosody. The two participants who had severe speech errors did not differ from their group members on the speech motor performance. Thus the findings of the study indicate some non-motor speech difficulties that warrant further investigation.

**Relationship between speech motor skills and expressive vocabulary**

The second aim of this study was to examine the association between expressive vocabulary and speech motor variables. There was no statistically significant correlation between expressive vocabulary and any of the speech motor variables. Though there have been reports of positive relationships between oral motor skills and expressive language in general and expressive vocabulary in particular (e.g., Alcock, 2006;
Gernsbacher, et al., 2006; Nip, Green & Marx 2011), few studies have examined the relationship between speech motor skills and expressive vocabulary. Based on review of current literature, this study is a first comparison of DDK tasks and multisyllabic word repetition with expressive vocabulary. However, one study did report a positive relationship between nonword repetition and expressive vocabulary in two groups of 4-14 yr old children with ASD, one who had concomitant language impairment and other who did not (Tager-Flusberg, 2006). There are three possible reasons why the present study did not replicate this finding. One, the present study used nonwords created by Dollaghan & Campbell (1998) whereas Tager-Flusberg used a nonword repetition subtest on the Comprehensive Test of Phonological Processing. There could be differences in the nature of the nonwords that might explain the difference in the results of the two studies.

Two, the sample size in the present study was relatively small ($n = 13$), compared to that in the other study ($n = 35$) which might have resulted in poor power to detect significant correlation. One other reason that the current study did not find significant correlations between any of the speech motor variables and expressive vocabulary might be that all of the participants had reached a plateau in their expressive vocabulary which made it difficult to identify any relationships with the speech motor variables. An examination of younger children who are in the stage of vocabulary and speech motor growth spurt might reveal a relationship between the two variables.

Lastly, approximately 15% of the members of the HFA group ($n = 2$) had articulation scores that fell below average on GFTA, as compared to 45% ($n = 5$) in the MSD group and none in the typically developing group. Given the nature of their
disorder, children with motor speech disorders have been reported to perform poorly on standardized articulation tests (e.g., Aziz, et al., 2010; Lewis, et al., 2004). Some studies have reported children with ASD to have no speech problems (e.g., Kjelgaard & Tager-Flusberg, 2001) while others have reported prevalence rate up to 33% (Cleland, et al., 2010; McCann, et al., 2007; Shriberg, 2011, Velleman, et al., 2010; Kjelgaard & Tager-Flusberg, 2001). The current finding is consistent with the ones that have reported speech delays in children with ASD. For example, Cleland et al., (2010) reported 12% of their sample of 5-13 yr old children with ASD (which included both HFA and Asperger’s syndrome) to have scores that fell below average on GFTA-2; Shriberg et al., (2011) reported a mean of 15.2% of their sample of 4-7 year old children with ASD to have speech delay (errors of substitution, deletion and distortions). Thus, children with HFA can be said to show a modestly higher risk for speech delay as compared to population estimate. a finding that has been attributed to environmental and genetic risk factors (Shriberg, et al., 2011).

In summary, the present study holds up the findings reported by other studies that the subset of relatively high functioning children with ASD do not show apraxia-like symptoms, neither do they show any subtle speech motor differences, that might otherwise be evident in children who have a history of speech motor problems. The present study also affirms the speech motor deficits seen in children with motor speech disorders. Although the reasons why a large number of children with ASD do not acquire speech are unknown, the findings of this study show that it is unlikely to be related to speech motor involvement. The speech delays that are seen in some children with ASD
appear to be related to factors other than speech motor skills, however, the study needs to be extended to other subgroups of children with ASD (viz., lower functioning children) to be able to draw any firm conclusions.

**Limitations**

Limitations to the current study relate to participant selection, nature of comparison groups, nature of tasks, and sample size. One of the major limitations of the present study is the choice of participants with HFA. Though the reason for selecting participants with HFA was justified in that they were able to fully participate in all the tasks, this same reason might have contributed to a sort of ceiling effect. Thus, in order to draw any firm conclusions about the speech motor characteristics of children with ASD in general, this study needs to be extended to that subset of children with HFA that presents with speech delays and/or those that are lower functioning than the current sample.

Another limitation of the present study was the inability to recruit participants with speech sound disorders. A comparison to such a group would have allowed me to further describe the speech delay in children with HFA as a concomitant speech sound disorder, or otherwise.

The present study only used the data obtained from structured tasks and this can limit the generalization of the findings of the study. It is possible that the participants’ performance might differ in an unstructured task. In addition, the present study also did not use data from continuous speech samples. Acoustic analysis of continuous speech
samples in an unstructured task might provide more objective and complete information regarding the participants’ speech motor characteristics. Also such a method of data collection might be very helpful while studying lower functioning children with ASD.

Finally, another limitation of the study might have related to the reduced power associated with the small numbers of participants in this study. However, if the difference in speech motor skills in children with HFA is so small that it requires huge sample size to be significant, it might not have any significant clinical relevance.

**Implications for future research.**

It is possible that the higher risk of speech delay and slight difference in speech motor performance in children with ASD is consistent with that seen in children with speech sound disorders that do not involve motor impairment. Thus, performances of children with HFA need to be compared to those with speech sound disorders in addition to the motor speech disorders group to identify similarities in speech characteristics, if any. Though previous such comparisons using continuous speech samples have not found differences in performances (Shriberg, et al., 2011), the use of challenging structured tasks may elicit a difference in performance.

It is also important to note that the ultimate goal of the speech motor investigation in children with ASD is to uncover the role of speech motor deficits, if any, in that subset of children with ASD which fails to acquire spoken language. This can be achieved through comparing performances of lower functioning children with ASD to those with age-matched typically developing children. However, a major challenge to such an
investigation is the complexity of the tasks involved. One way to simplify the testing procedure could be to focus on one measure that is the most sensitive (for example, accuracy of repetition) to speech motor deficits. Lower functioning children with ASD might find a syllable repetition task too abstract and hence the use of meaningful linguistic stimuli instead of syllables might also be considered.

**Conclusion.**

Despite the fact that a considerable number of children with ASD do not acquire speech and that they have general motor planning deficits, speech motor skills in this population have been understudied. The present study attempts to add to the limited literature that documents the characteristics of speech motor skills in children with ASD in comparison to those developing typically and those with motor speech disorders. As a group, children with HFA exhibited a slight difference from their typical peers in terms of their speech motor abilities and also had a higher number of members with speech delay. Though this finding is most likely an indication of a non-motor speech deficit that needs further investigation, it should be interpreted with caution. Children with ASD are a heterogeneous group and the question whether nonverbal children with ASD exhibit speech motor impairment, remains unanswered. Another question that arises is whether that subset of children with ASD who exhibits speech delay shows any signs of speech motor involvement. Future studies that look into the speech motor characteristics in these subgroups of children with ASD are needed to answer these emerging questions.
References


## Appendix A: Individual scores on Standardized assessments

### Table 8

**Individual scores on standardized assessments**

<table>
<thead>
<tr>
<th>Participant ID</th>
<th>Diagnosis</th>
<th>SCQ</th>
<th>PPVT-IV</th>
<th>EVT-2</th>
<th>GFTA-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSS 01</td>
<td>HFA</td>
<td>19</td>
<td>100</td>
<td>108</td>
<td>108</td>
</tr>
<tr>
<td>MSS 02</td>
<td>HFA</td>
<td>11</td>
<td>123</td>
<td>93</td>
<td>96</td>
</tr>
<tr>
<td>MSS 03</td>
<td>HFA</td>
<td>17</td>
<td>87</td>
<td>76</td>
<td>107</td>
</tr>
<tr>
<td>MSS 04</td>
<td>HFA</td>
<td>16</td>
<td>126</td>
<td>125</td>
<td>108</td>
</tr>
<tr>
<td>MSS 05</td>
<td>HFA</td>
<td>16</td>
<td>Did not complete testing</td>
<td>Did not complete testing</td>
<td>Did not complete testing</td>
</tr>
<tr>
<td>MSS 06</td>
<td>HFA</td>
<td>20</td>
<td>Did not complete testing</td>
<td>Did not complete testing</td>
<td>Did not complete testing</td>
</tr>
<tr>
<td>MSS 07</td>
<td>HFA</td>
<td>9</td>
<td>91</td>
<td>93</td>
<td>96</td>
</tr>
<tr>
<td>MSS 08</td>
<td>HFA</td>
<td>18</td>
<td>88</td>
<td>86</td>
<td>116</td>
</tr>
<tr>
<td>MSS 11</td>
<td>HFA</td>
<td>17</td>
<td>99</td>
<td>103</td>
<td>112</td>
</tr>
<tr>
<td>MSS 13</td>
<td>HFA</td>
<td>20</td>
<td>129</td>
<td>118</td>
<td>112</td>
</tr>
<tr>
<td>MSS 14</td>
<td>HFA</td>
<td>18</td>
<td>87</td>
<td>118</td>
<td>107</td>
</tr>
<tr>
<td>MSS 21</td>
<td>HFA</td>
<td>14</td>
<td>103</td>
<td>89</td>
<td>40</td>
</tr>
<tr>
<td>MSS 35</td>
<td>HFA</td>
<td>16</td>
<td>91</td>
<td>99</td>
<td>44</td>
</tr>
<tr>
<td>MSS 09</td>
<td>MSD</td>
<td>2</td>
<td>104</td>
<td>97</td>
<td>70</td>
</tr>
<tr>
<td>MSS 10</td>
<td>MSD</td>
<td>6</td>
<td>127</td>
<td>117</td>
<td>108</td>
</tr>
<tr>
<td>MSS</td>
<td>Type</td>
<td>MSD</td>
<td>Number</td>
<td>T</td>
<td>TD</td>
</tr>
<tr>
<td>------</td>
<td>------</td>
<td>-----</td>
<td>--------</td>
<td>---</td>
<td>----</td>
</tr>
<tr>
<td>15</td>
<td>MSD</td>
<td>6</td>
<td>119</td>
<td>87</td>
<td>108</td>
</tr>
<tr>
<td>16</td>
<td>MSD</td>
<td>4</td>
<td>84</td>
<td>74</td>
<td>80</td>
</tr>
<tr>
<td>17</td>
<td>MSD</td>
<td>6</td>
<td>88</td>
<td>88</td>
<td>93</td>
</tr>
<tr>
<td>19</td>
<td>MSD</td>
<td>1</td>
<td>104</td>
<td>121</td>
<td>86</td>
</tr>
<tr>
<td>22</td>
<td>MSD</td>
<td>4</td>
<td>110</td>
<td>109</td>
<td>87</td>
</tr>
<tr>
<td>28</td>
<td>MSD</td>
<td>10</td>
<td>85</td>
<td>100</td>
<td>59</td>
</tr>
<tr>
<td>29</td>
<td>MSD</td>
<td>8</td>
<td>90</td>
<td>92</td>
<td>78</td>
</tr>
<tr>
<td>30</td>
<td>MSD</td>
<td>15</td>
<td>96</td>
<td>119</td>
<td>116</td>
</tr>
<tr>
<td>31</td>
<td>MSD</td>
<td>2</td>
<td>91</td>
<td>100</td>
<td>54</td>
</tr>
<tr>
<td>12</td>
<td>TD</td>
<td>4</td>
<td>95</td>
<td>113</td>
<td>110</td>
</tr>
<tr>
<td>18</td>
<td>TD</td>
<td>5</td>
<td>137</td>
<td>131</td>
<td>106</td>
</tr>
<tr>
<td>20</td>
<td>TD</td>
<td>2</td>
<td>123</td>
<td>113</td>
<td>109</td>
</tr>
<tr>
<td>23</td>
<td>TD</td>
<td>2</td>
<td>131</td>
<td>134</td>
<td>105</td>
</tr>
<tr>
<td>24</td>
<td>TD</td>
<td>1</td>
<td>120</td>
<td>120</td>
<td>106</td>
</tr>
<tr>
<td>25</td>
<td>TD</td>
<td>0</td>
<td>134</td>
<td>120</td>
<td>105</td>
</tr>
<tr>
<td>26</td>
<td>TD</td>
<td>0</td>
<td>109</td>
<td>120</td>
<td>105</td>
</tr>
<tr>
<td>27</td>
<td>TD</td>
<td>6</td>
<td>103</td>
<td>100</td>
<td>117</td>
</tr>
<tr>
<td>32</td>
<td>TD</td>
<td>2</td>
<td>117</td>
<td>128</td>
<td>109</td>
</tr>
<tr>
<td>33</td>
<td>TD</td>
<td>4</td>
<td>126</td>
<td>121</td>
<td>115</td>
</tr>
<tr>
<td>34</td>
<td>TD</td>
<td>1</td>
<td>129</td>
<td>116</td>
<td>105</td>
</tr>
<tr>
<td>36</td>
<td>TD</td>
<td>5</td>
<td>90</td>
<td>106</td>
<td>110</td>
</tr>
<tr>
<td>37</td>
<td>TD</td>
<td>5</td>
<td>93</td>
<td>94</td>
<td>105</td>
</tr>
</tbody>
</table>