DIADOCHOKINESIS IN INDIVIDUALS WITH REMITTING-RELAPSING MULTIPLE SCLEROSIS

Ameena Subhakani S.

Registration No: 16SLP002

Dissertation submitted in partial fulfillment for the Degree of

Master of Science (Speech-Language Pathology)

University of Mysore, Mysuru.

ALL INDIA INSTITUTE OF SPEECH AND HEARING

MANASAGANGOTHRI,

MYSURU – 570 006.

April 2018

CERTIFICATE

This is to certify that this dissertation entitled ***"Diadochokinesis In Individuals With Remitting-Relapsing Multiple Sclerosis"*** is a bonafide work in part fulfillment for the degree of Master of Sciences (Speech –Language Pathology) of the student (Registration No. 16SLP002). This has been carried out under my guidance and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru
April 2018

Prof. S.R. Savithri
Director
All India Institute of Speech and Hearing
Manasagangothri, Mysuru-570006

CERTIFICATE

This is to certify that this dissertation entitled ***"Diadochokinesis In Individuals With Remitting-Relapsing Multiple Sclerosis"*** is a bonafide work in part fulfillment for the degree of Master of Sciences (Speech –Language Pathology) of the student (Registration No. 16SLP002). This has been carried out under my guidance and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru
April 2018

Guide
Dr. Swapna N.
Reader in Speech Pathology
Department of Speech-Language Pathology
All India Institute of Speech and Hearing
Manasagangothri, Mysuru-570 006.

DECLARATION

This is to certify that this dissertation entitled ***"Diadochokinesis In Individuals With Remitting-Relapsing Multiple Sclerosis"*** is the result of my own study under the guidance of Dr. Swapna N., Reader in Speech Pathology, Department of Speech-Language Pathology, All India Institute of Speech and Hearing, Mysuru and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru
April 2018

Registration No.: 16SLP002

Dedicated to Amma

& Daddy

ACKNOWLEDGEMENT

Thanks to the Almighty for the blessing me with this beautiful life filled will all beautiful things around me. I know you were always with me and will continue to be my support throughout........ I thank all my teachers and staffs without whom am not who I am at present. I thank them for their support, guidance and love towards me, which has brought me up to this part of my life.

I extend my immense and heartfelt gratitude towards my guide **Dr. Swapna N. Mam**, for helping me complete my dissertation. Without her, I wouldn't have come this far with my work. Thank you so much Mam, for being my support throughout……

Dear **Amma & Daddy**, thank you so much for all the things you have done to make us all happy. Words are enough to thank you… I always look up to you both for my inspiration and the way you handle everything ma & daddy. I am always blessed to have you both as my support system. Just hearing your voices can take all the worries and stress away from me… Luv you both so much…… My dear **Thambi boy and Bena**, luv u so much. You both make me happy always with the cute pranks and smiles. No one can replace the way we are now. Thanks to **Allah**, for bringing all of us together as a family.

My heartfelt thanks to **Dr. R. Ranjith Sir**, just because you took me in as your student, I have learnt so much. Thank you so much for the experience you have given to all of us. The always encouraging and motivating speech, the smile even when visiting him after a day hard word and the always welcome gestures. You have given me lots to remember Sir.

My seniors from MERF-ISH and AIISH… Thank you Sunanda akka, you have taught me and helped me during my difficult times… I look up to you as my own sister. Next to Rashmi akka and Shubha akka for being my support in AIISH, then to Sumanth anna for supporting me… Thanks to all my senior batches of MERF-ISH from whom I have learnt a lot. Have never seen a batch as them anywhere. Thanks and luv you akkas' and anna's……

Here comes the special thanks to my best buddies, with whom I have made the wonderful and joyful memories that are to be cherished for lifetime……

My buddies of AIISH, Angel, Vanthanaa, Sabee, Disha, Tanvi and Rose, who made me forget the worries and were with me in my happy and sad times… Luv you guys equal to my BBzzz……

I specially thank Vanthanaa for being my constant support during my dissertation work, she was my savior, joke and foodie partner; Angel dear for being my soulmate; Disha my foodie partner; Tanvi my kutthu partner; Sabee dear my soulmate, we share the same wavelength; and Rose my sports and shopping partner…… No matter what, we all can go about walking and walking and walking just for food, creating loads and loads of memories on the way. All of u have made my life here in AIISH a wonderful time to remember and cherish… Luv you guys the most forever ppl………

Secondly to my loveable buddies of **Blitzkrieg Bandits** my second family, from whom I learnt that friends are for life… I luv you guys now and forever and ever to come. Especially Siva, Sai anna, Yasin anna, Rashmi and Indu, though we have fought a lot, finally you are the ones who hold my back wherever possible... My Suji akka, our second mother, luvs to be with us and make us enjoy as her own... Luv u tons and tons akka...

I extend my deepest gratitude to Siva, Sai anna and Yasin anna, for being with me till now and being my strong shoulder to cry on and my pillar of support both physically and mentally, no matter what. You ppl have made a huge part of my college diaries. I can never part with you ppl... Luv you guys to the deepest and wish to be with you as long as possible......

Next, to my lovely juniors of MERF-ISH... Kiddos, who take all advices seriously. Thanks to my dear bros' and sissys' who made me happy and feel at home each and every time I visit them. Special thanks to Sonia, Sam, Raja, Vicky, Muthu, Giri, Veronica, Anamika, Suji .... and the list extends..................... till the current batch Monisha, Keerthana......

Coming to AIISH, I thank all my staffs who motivated and encouraged me with their constant support when I came new to this place.

I thank each and every one who were a part of this work and made this come to a success.

Thank You all for all the support......!!!!!!!!!!!!!!!!!!!!!!!!!

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Speech is the most familiar feature of daily life that we rarely pause to define it. It seems as natural to humans as walking. However, speech production is a complex process which involves planning, programming, and execution of movements. Speech is the act of expressing or describing thoughts, feelings, or perceptions by the articulation of words through a series of movements (motor acts) produced by precisely coordinated muscle actions. The motor acts include the movements of the peripheral process of respiration, phonation, articulation, and resonance in coordination. The movement of these structures in swift, precise gestures helps the production of speech. However, the central nervous system is essential to plan, program and trigger the movement of these structures. Thus speech is a unique, dynamic and complex motor activity.

Speech motor control (SMC) refers to the systems and strategies that regulate the production of speech, including the planning, programming of movements and the execution of movement plans to result in muscle contractions and structural displacements (Kent, 2000). The process of SMC intervenes between the peripheral somatic sensory information and the central motor representations. The SMC undergoes gradual changes from birth till puberty. The achievement of adult speech motor control is dependent on the maturation of the individual's nervous system. During the process of speech development the child becomes familiar with the speech mechanism and in later years, refinement of speech production takes place (Kent, 1976).

SMC is the most complex task when compared to other human motor tasks. One way of measuring this complex motor activity is by using the traditional task of diadochokinesis (Cohen & Waters, 1999). West and Ansberry (1968) stated that "The individuals who negotiate rapid shifts of muscle contraction inhibition, possess a high speed of oral diadochokinesis and make rapid articulatory movements" (p. 189). This proves that there exists a relationship between diadochokinetic movements and speech production. Though there are numerous ways to investigate the speech motor skills, such as imaging techniques, movement transduction, and point tracking methods; these instruments may not be easily accessible to all professionals. Hence diadochokinetic (DDK) rates are continued to be used in the investigation of speech motor skills (Yaruss & Logan, 2002).

Diadochokinesis is the measure of how swiftly a person is able to repeat a series of rapid, alternating phonetic sounds and it has been used largely in the assessment and treatment of motor functions of the oral articulators by Speech-Language Pathologists (Darley, Aronson, & Brown, 1975). The DDK rates can be calculated by using two types of repetition tasks: The Alternating Motion Rate (AMR) and the Sequential Motion Rate (SMR). AMR requires the rapid repetition of a single phonetic unit, such as /pa/ or /ta/ or /ka/, whereas SMR requires the rapid repetition of the sequence of the phonetic units: /pa-ta-ka/.

Measurement of DDK can be manual or automated. In the manual method, the DDK rate is calculated in terms of either counting the number of iterations per second or the time required to produce a specific number of iterations of a mono-, bi-, or a trisyllabic token. The rate will be calculated and compared to the published norms. For example, in the data published by Fletcher (1972), the norm for 20 repetitions of the syllable /pa/ for a child at age 10 was 3.7 seconds. This method is named as the Fletcher Time-by-Count Test of Diadochokinetic Syllable Rate.

In the later years, a simple modification of the procedure was made. The use of stop-watch or oscillograms was introduced (Fletcher, 1972). If the number of syllables rather than the time interval was pre-established, the overlapping attentional requirements would be eliminated and the stop-watch could be started when the speaker began to repeat the syllables. The examiner's full attention could be then directed to the syllable count until the required number of repetitions was uttered. The watch could be then turned off and the elapsed time could be noted. The DDK rate is calculated by dividing the total number of iterations by the duration of the trial or by determining the time it took the client to make a set of the number of iterations. Literature describes some studies using hand measurement for counting the number of sequence produced by an individual during a pre-determined period of time (Modolo, 2007; Wang, Kent, Duffy, & Thomas, 2009), to count the time that the individual takes to perform a number of repetitions (Wang et al., 2009) and some to do both measures (Prathanee, Thanaviratananich, & Pongjanyakul, 2003).

On the other-hand, DDK can be measured automatically using an automatic DDK analyzer which provides greater efficiency on the results since in addition to quantifying the number of sequences produced, the software is also able to make many different analyses. The Motor Speech Profile (MSP) model 5141 manufactured by KayPENTAX accompanied with Computerized Speech Lab (CSL) introduced a new arena for obtaining information regarding various DDK parameters objectively. The Motor Speech Profile is a computer-based program that extracts and analyzes speech performance of patients with motor speech disorders. The MSP measures various aspects of speech including voice, tremor, diadochokinesis, second formant transition, intonation, and syllabic rate. It contains built-in protocols for eliciting specific speech samples, extracting desired parameters, and displaying results in numeric and graphical formats. MSP is a widely used program among speech-language pathologists because of the built-in protocols, time management, easy to use structure, available options for the integration of other programs, non-invasive method, and the easy interpretation of the results with the help of numerical, graphical, and bar representations.

A number of available reports have acknowledged that individuals with motor speech disorders exhibit sluggish, inaccurate and inconsistent oral diadochokinesis due to the presence of an underlying neurological insult. Researchers have performed numerous widespread examinations in dysarthria subsequent to strokes (Ziegler & Von-Cramon, 1986; Kent, Duffy, Kent, Vorperian, & Thomas, 1999), in adult dysarthrics secondary to cerebral palsy (Platt, Andrews, Young, & Neilson, 1978; Schliesser, 1982**)**, in amyotrophic lateral sclerosis (Langmore & Lehman, 1994), in individuals with ataxic dysarthria (Tatsumi, Sasanumo, Hirose, & Kiritani, 1979; Portnoy & Aronson, 1982; Gentil, 1990; Ziegler & Wessel, 1996) and in basal ganglia disorders (Kreul, 1972; Ludlow, Connor & Bassich, 1987; Hefter, Arendt, Stremmel, & Freund, 1993; Ackermann, Hertrich, & Hehr, 1995). Majority of the above-quoted reports highlighted the sensitivity of DDK task as a key indicator of motor speech impairment. Multiple Sclerosis is one such neurological variety where the speech motor control has been reported to be affected (Tjaden & Watling, 2003).

Multiple Sclerosis (MS) involves an immune-mediated process in which an abnormal response of the body's immune system is directed against the Central Nervous System (CNS), specifically the myelin sheath, the fatty substance that surrounds and insulates the nerve fibers. The demyelination of the myelin sheath in the CNS causes plaques giving a scar-like appearance on the nervous tissues and hence the name MS. Sclerosis (gliosis) is seen in the brain as irregular gray islands in the white matter and are more prominent in the periventricular (lateral and the third ventricle) areas. Similar plaques are also found in the white matter of the spinal cord and cerebellum, optic nerves, and optic chiasma or optic tracts. They appear scattered throughout the white matter, while the gray matter is relatively unaffected. The meticulous target that the immune cells are briefed to attack remains unknown and that is why MS is considered to be “immune-mediated” rather than “autoimmune”.

The World Health Organization (WHO) and the Multiple Sclerosis International Federation (MSF) took a major collaborative measure and established the global epidemiology of MS between 2005 and 2007. In the various regions of India, based on hospital data, it has been suggested that the prevalence of MS is about 0.17 to 1.33 per 100,000 of the population (Singhal, 1985). When compared to West, the “remitting-relapsing type” is reported to be more prevalent in India (Singhal & Adyani, 2015). The age of onset of MS is usually in the fourth decade of life which is between 30 and 40 years of life; 5% of cases have been reported with childhood onset and it is rarely diagnosed after 70 years of age. Across ethnicity, the female to male ratio of MS is 3:1 (Scolding & Wilkins, 2012).

The primary symptoms of MS include weakness, stiffness, sensory disturbance of the limbs, problems with coordination, balance, vision, and extensive fatigue (Ryberg, 1989). In a study of World War II veterans, Kurtze, Beebie, Nagler, Kurland, and Auth (1968) stated that 20 years after the onset of the illness, 17% had mild or no impairment, 65% had a moderate disability and 18% were severely disabled. In a majority of patients, these symptoms characteristically come and go spontaneously.

MS is usually classified into four types, namely, (a) clinically isolated syndrome, (b) remitting-relapsing, (c) secondary progressive, and (d) primary progressive (Hooper, 2011). The first manifestation of the symptoms is usually diagnosed as clinically isolated MS where inflammatory demyelination is present, but does not fulfill the diagnostic criteria of MS. If clinically isolated syndrome of MS remains active and meets the criteria for diagnosing MS based on MRI and other clinical test findings, then these subjects are diagnosed with remitting-relapsing MS. The remitting relapsing type of MS would show either complete recovery after a period of relapse or incomplete recovery with residual deficits. If the remitting-relapsing type of disease begins to progress into worse neurological accumulation processes after a period of relapse and remissions, then it is diagnosed as secondary progressive type. The imaging, clinical or pathological data which defines the transition from relapsing condition to progressive is not yet well defined (Lublin, Reingold, Cutter, Sorensen, Thompson, & Bebo, 2014). Annual imaging studies would further enhance the differentiation as a progressive disease would remain relatively stable over a period of time. Factors such as the severity of signs and symptoms, frequency of relapses, the rate of worsening, residual disability, and impairment are being used to differentiate remitting relapsing from progressive disease course. If the disease begins with progressive neurological lesions without any remissions in the initial stages, then they would be diagnosed as primary progressive type MS. The clinical course of the disease is variable.

Approximately 40% of all individuals with MS present some degree of speech impairment. A study by Murdoch and Theodoros (2000) concluded that the prevalence of mild to severe dysarthria in individuals with MS was 51% and this compromised all components of speech production: respiration, phonation, oral motor performance, articulation, prosody, and intelligibility. Dysarthria has an estimated prevalence of 40-50% in multiple sclerosis and is least described (Merson & Rolnick, 1998; Hartelius, Runmarker, & Andersen, 2000). Dysarthria associated with MS has been characterized as spastic or ataxic. This classification was primarily based on the combination of auditory-perceptual characteristics and the site of lesion (Darley, Aronson, & Brown, 1969; Darley et al., 1975). Most individuals with MS show a progressive decline in speech intelligibility as the disease progresses (Farmakides & Boone, 1960).

A few studies have been carried out in the past to assess the DDK rates in individuals with MS. Jensen (1960) studied the motor speech of 50 patients with MS (cerebellar, diffuse and spinal type). The perceptual assessment of the recorded speech sample revealed that 38% made errors on articulation test and 35% made articulation errors on a contextual speech task. The speech of 78% was rated by the listeners as defective. The DDK samples were recorded and analyzed using photographed oscillographic display of the speech signal. The majority of the subjects had slower than normal oral DDK (58% on repetition of /pa/, 64% on /ta/, and 70% on /ka/). Oral diadochokinetic rate measures decreased as the degree of severity of defectiveness of the articulation increased. The authors also reported that the severity of speech involvement was not significantly related to the duration of illness and duration of the permanent symptoms of the disease.

Rosen, Goozee, and Murdoch (2008) stated that DDK rates and F_2 transition are a fruitful way of detecting the speech deviations in MS since dysarthric component affects the extremely rapid changes. In this study, 14 participants with MS and 14 healthy controls were included. One of the 12 individuals with MS was diagnosed with remitting-relapsing type, 8 with progressive (primary, secondary, chronic or slow progressive) and 3 with an undetermined clinical course by the neurologist. The participants were selected based on their performances on Multiple Word Intelligibility Test and of the connected speech with the Assessment of Intelligibility of Dysarthric Speech. DDK rates and F_2 transition were analyzed acoustically. The results revealed that dysarthric component disproportionately affected the production of extremely rapid changes in speech.

Konstantopoulos, Charalambous, and Verhoeven (2011) investigated 27 MS patients with spastic or ataxic dysarthria and 27 age- and gender-matched control group for the DDK rates. The individuals participated in the study were ruled out for cognitive impairment using the Mini-Mental State Examination. The temporal analysis of the sequential motion rate was carried out in PRAAT. The articulation rate, stop-gap duration, vowel duration, the release of burst, and the duration of each segment was measured and compared with the healthy control group. Their findings indicated that the articulation rate (syllables/second), especially the sequential motion rate was significantly lower than the control group. The authors concluded that sequential motion rate is relevant for the description of MS patients with speech motor impairment. They attributed the slow rates to the longer stop-gap duration and vowel duration.

Nishio and Niimi (2006) reported a significant correlation between DDK rate, speaking rate, and articulation rate, and indicated that DDK rate was more sensitive to the detection of abnormal articulation rate and speaking rate. The rate of DDK probably is related to dimensions of overall speech performance in the motor speech disorders, but the relationship reported between both is not consistent across the literature.

Ziegler and Wessel (1996) indicated a high relationship between DDK rate and the intelligibility and the severity of the dysarthria, however, Kent, Duffy, Thomas, Weismer, and Stuntebeck (2000) did not find a significant relationship between DDK rate and overall severity of dysarthria. Wang, Kent, Duffy, Thomas, and Weismer (2004) reported significant relationships between DDK rate and overall severity, overall intelligibility, word intelligibility, and overall prosody of dysarthria in Traumatic Brain Injury (TBI), however, Ozwa, Shiromoto, Ishizaki, and Watamori (2001) reported that DDK rate was not correlated with the overall intelligibility and dysarthria.

Hartelius et al. (2000) reported a positive correlation between the deviations present in the speech production to the overall severity of the neurological involvement, type of disease course, and the duration of the disease in Multiple Sclerosis. In a study of 77 individuals with MS, Hartelius and Lillvik (2003) confirmed that DDK rate was positively related to articulatory imprecision and moderately related to the disease progression, while other authors like Famakides and Boone (1960), Schliesser (1982), Kent et al. (1999) have proposed that the duration of the disease had no relation with the DDK rates.

Darley, Brown, and Goldstein (2016) stated that speech impairment was positively correlated to the severity of the neurological involvement, however, it was not related to the age of the patient or the duration of illness. The authors had studied a series of 168 individuals (65 males and 103 females) with MS at the Mayo Clinic over a period of 38 months. Eighty-three percent of the group had symptoms of the disease for at least 2 years and 31% had them for 10 years or more. For each individual, a tape recorded sample of a standard passage (My Grandfather), counting, describing a picture, AMR, SMR and prolongation of /a/ was obtained. The results indicated no significant relationship between the speech measures and age, duration of the illness or the duration of the permanent symptoms, whereas, a strong significant correlation was found between the severity of the overall neurological impairment and the severity of the speech involvement.

Need for the study

Comprehensive studies related to the aspects of speech motor characteristics are crucial in understanding the normal and disordered population. The DDK tasks have been widely recommended for the investigation of speech motor characteristics of individuals with neurologic impairments. Previous research related to neurogenic motor speech disorders clearly suggested the sensitivity of the oral diadochokinesis in capturing the abnormal speech production, since the production of a sustained syllable in DDK, requires integrity of several speech musculatures that need to work in coordination. A study done by Deepa and Jayashree (2012) concluded that oral diadochokinesis is indicative of structural and physiological changes. The results of that study projected that DDK was sensitive enough to reflect the speech motor control disruptions observed with aging.

Though several studies have been done to analyze DDK in several neurological impairments, the studies investigating DDK in individuals with MS are scanty. The previously established studies in individuals with MS, unequivocally suggested that the DDK was affected.

Further, investigating DDK using instrumental methods has its own advantages. DDK measured using an automatic DDK analyzer provides greater efficiency on the results, since in addition to quantifying the number of sequences produced, the software is also able to make many different analyses. MSP is one of the recent software which assists in the analysis of DDK and its related parameters. The availability of various built-in protocols and numerous parameters analyzed in each protocol makes MSP more advantageous over other objective measures such as PRAAT, oscillographic measures, etc. However, studies analyzing DDK in MS using MSP are limited. According to Duffy (1995), the objective measures of speech and non-speech orofacial motor control, in general, are sparse. The application of objective acoustic measurements in clinical description and evaluation of individuals with neurogenic speech motor disorders, especially in MS, will open windows towards establishing guidelines needed to reliably rate the dysarthric speech and differential diagnosis.

Further, several studies have been carried out in order to document the DDK in western typical and atypical population. However, in the Indian context, such studies are limited. It is essential to conduct such studies in different contexts, since numerous studies have shown that speech differs as a function of different major sociological categories, like ethnicity, gender, age, and social class (Labov, 1966; Trudgill, 1974; Harrington, Cox, & Evans, 1997). In a study by Icht, and Ben-David (2014), who investigated the oral diadochokinesis rates across languages (English and Hebrew) stated that age, culture and cross-language differences had an impact on oral DDK rates. Byrd (1994) demonstrated differences in speech rate across eight broadly defined dialects of US. E'Jacewicz, O'Neil, and Salmons (2009) reported increased articulation rate for northern USA English speakers than for the southern speakers. The evidence provided above indicates that oral DDK scores might vary across languages.

Further, the literature on the relationship between DDK and speech intelligibility is equivocal. Some studies report a strong relationship between DDK rate and speech intelligibility, however other authors did not find such a relationship. Such studies investigating this relationship, particularly in individuals with MS are limited.

Also, it would be interesting to study the influence of the duration of the disease with the DDK and speech intelligibility. Hartelius and Lillvik (2003) confirmed that DDK rate was positively related to articulatory imprecision and moderately related to the disease progression, while other authors like Famakides and Boone (1960), Schliesser (1982), Kent et al. (1999) reported that the duration of the disease had no relation with the DDK rates. MS is one of the most common neurological diseases, and it is frequently associated with the disturbances in speech and voice. Yet, MS has rarely been the object of any perceptual or instrumental studies. Keeping this in view, the present study was planned with the aim of investigating the DDK of Tamil speaking individuals with MS.

Aim of the study

The aim of the present study was to investigate the speech production using diadochokinetic tasks in 18 - 50-year-old Tamil speaking individuals with the remitting-relapsing type of MS. The specific objectives of the study were:

- To compare the parameters of DDK obtained using Motor Speech Profile (MSP-model 5141 manufactured by KayPENTAX) between individuals with remitting-relapsing multiple sclerosis and neurotypical healthy individuals.
- To assess the speech intelligibility of individuals with remitting-relapsing multiple sclerosis.
- To assess the relationship between diadochokinetic rate parameters and speech intelligibility.
- To assess the influence of duration of the disease on the diadochokinetic rate parameters.

CHAPTER II

REVIEW OF LITERATURE

Speech is one among the most powerful tools possessed by the human species and contributes enormously to the character and quality of life. Speech production is arguably the most complicated motor acts executed by human beings. It requires more motor fibers than any other human mechanical activity (Fink, 1986).

Speech production requires the integrity and integration of numerous neurocognitive, neuromuscular, and musculoskeletal activities. When thoughts, feelings, and emotions generate an intent to communicate, they must be organized and converted to verbal symbols in a manner that abides by the rules of language. These activities are referred to as *cognitive-linguistic processes*. The intended verbal message must be organized for neuromuscular execution. This activity includes the selection and sequencing of sensorimotor "programs" that activate the speech muscles at appropriate coarticulated times, durations, and intensities. These activities are referred to as *motor speech planning and programming*. The central and peripheral nervous system activity must then combine to regulate and execute speech motor programs by innervating the respiratory, phonatory, resonatory, and articulatory muscles, in a manner that generates an acoustic signal that faithfully reflects the goals of the programs. The neuromuscular transmission and subsequent muscle contractions and movements of speech structures are referred to as *neuromuscular execution*. The combined processes of speech motor planning, programming, and neuromuscular execution are referred to as motor speech processes. All these systems and strategies that regulate the production of speech, including planning, programming of movements and the execution of movement plans result in muscle contractions and structural displacements that are referred to as speech motor control (SMC) (Kent, 1976).

When one or any combination of the motor speech processes is affected, the result will be a motor speech disorder. Motor speech disorders are a group of developmental or acquired speech impairments co-existing with dysphagia, cognitive dysfunction, or language impairment that affects all speech processes: respiration, phonation, voice, resonance, prosody, fluency, and articulation. Speech motor control inconsistencies and inaccuracies have been reported in individuals with motor speech disorders (Duffy, 1995). Researchers have performed numerous widespread examination of dysarthria subsequent to various neurological causes such as strokes (Ziegler & Von-Cramon, 1986; Kent et al., 1999), in adult dysarthrics secondary to cerebral palsy (Platt et al., 1978; Schliesser, 1982**)**, in amyotrophic lateral sclerosis (Langmore & Lehman, 1994), in individuals with ataxic dysarthria **(**Tatsumi et al., 1979; Portnoy & Aronson, 1982; Gentil, 1990; Ziegler & Wessel, 1996) and in basal ganglia disorders (Kreul, 1972; Ludlow et al., 1987; Hefter et al., 1993; Ackermann et al., 1995). One such neurological variety where the speech motor control has been reported to be affected is Multiple sclerosis (Tjaden & Watling, 2003).

Multiple Sclerosis (MS)

Multiple sclerosis (MS) is the most common acquired demyelinating disorder of the central nervous system (CNS) causing progressive disability in young and middle-aged adults through axonal loss and dysfunction of several functional systems (Weinshenker, 1995). It is a chronic, degenerative, demyelinating, inflammatory disease of the central nervous system, which predominantly affects the white matter of the brain. The areas of inflammation and swelling are called plaques which are formed by demyelinated axons and the dead oligodendrocytes. The demyelination usually involves the periventricular areas, white matter tracts of the brainstem, optic nerves, spinal cord and less commonly the myelinated fibers of gray matter.

Causes of Multiple Sclerosis

The cause of MS is not yet well defined, though factors such as immune system response, environmental, and hereditary have been attributed. MS is not directly inherited from parent to child and there is no single gene that causes it. Though over 110 genes that are linked to MS have been discovered, not everyone with these genes develops MS. It is the interaction between these genes, the environmental factors, lifestyle, and Vitamin D level that makes an individual prone to this disorder. The genes such as "HLA-DRB1" (human leucocyte antigen) and "IL7R" (interleukin 7) receptor alpha chain have been involved in MS. The "HLA-DRB1" gene has been observed in 70% of the individuals with MS and "IL7R" gene has been observed in the inflammatory responses and the immune system, which in turn leads to the development of MS (deDios-Pérez, 2016).

The only infectious cause that can be related to MS is the Epstein–Barr virus (EBV) which causes MS as result of body's immune system response. The virus increases the risk of acquiring MS, only if the virus attacks in adulthood, whereas if it is in childhood, it increases the immunity of the person. The effect of the virus is varied by environmental factors such as toxins, nutrition, or infections, which includes Vitamin D (Ascherio & Munger, 2007). MS is less common in tropical countries near the equator that get lots of sunshine, which helps in the synthesis of Vitamin D in our body. More people have MS in places farther away from the equator like Britain.

Incidence and prevalence of MS

The World Health Organization (WHO) and the Multiple Sclerosis International Federation (MSF) took a major collaborative measure and established the global epidemiology of MS between 2005 and 2007. The prevalence of MS was found to be 30 per 100,000 individuals. Regionally Europe had the highest prevalence (80 per 100,000), followed by the Eastern Mediterranean (14.9), the Americans (8.3), the Western Pacific (5), South-East Asia (2.8), and Africa (0.3), (Atlas, 2008). In the various regions of India, based on hospital data, it has been suggested that the prevalence of MS is about 0.17 to 1.33 per 100,000 of the population. When compared to West, the "remitting-relapsing type" is reported to be more prevalent in India (Singhal & Adyani, 2015). The age of onset of MS is usually in the fourth decade of life which is between 30 and 40 years of life; 5% of cases have been reported with childhood onset and it is rarely diagnosed after 70 years of age. Across ethnicity, the female to male ratio of MS is 3:1 (Scolding & Wilkins, 2012).

Clinical course of Multiple Sclerosis

Two stages of MS have been reported which include, a period of inflammation of cells which occur early in the disease course, and a second stage, which includes a period of degeneration/cell death leading to long-term deterioration of functions (Rog, Burgess, Mottershead, Talbot, & Robertson, 2010). The course is unpredictable, in about $2/3^{rd}$ of the patients with MS, the symptoms come and go spontaneously, with relapse (period of inflammation caused due to demyelination) and remissions (recovering from inflammation due to remyelination). The period between relapse depends on the body's repair system. In the remaining $1/3^{rd}$, the course is progressive (Charcot, 1877).

MS is usually classified into four types, namely, (a) clinically isolated syndrome, (b) remitting-relapsing, (c) secondary progressive, and (d) primary progressive (Hooper, 2011). The first manifestation of the symptoms is usually diagnosed as clinically isolated MS where inflammatory demyelination is present, but does not fulfill the diagnostic criteria of MS. If clinically isolated syndrome of MS remains active and meets the criteria for diagnosing MS, based on MRI and other clinical test findings, then these subjects are diagnosed with remitting-relapsing MS. The remitting relapsing type of MS would show either complete recovery after a period of relapse or incomplete recovery with residual deficits. If the remitting-relapsing type of disease begins to progress into worse neurological accumulatory processes after a period of relapse and remissions, then it is diagnosed as secondary progressive type. However, the imaging, clinical or pathological data which defines the transition from relapsing condition to progressive is not yet well defined (Lublin et al., 2014). Factors such as the severity of signs and symptoms, frequency of relapses, the rate of worsening, residual disability, and impairment are being used to differentiate remitting-relapsing from progressive disease course. Annual imaging studies would further enhance the differentiation as the progressive diseases would remain relatively stable over a period of time. If the disease begins with progressive neurological lesions without any remissions in the initial stages, then they would be diagnosed as primary progressive type MS.

Clinical features of Multiple Sclerosis

Charcot first described MS in 1877 with the triad symptoms: nystagmus, scanning speech, and intention tremor. The more frequent symptoms are monocular visual loss (retro bulbar neuritis), diplopia, gait difficulty (ataxia or spasticity), paresis or incoordination of an upper extremity, and urinary difficulties. Less frequent symptoms include vertigo, hemiparesis, Lhermitte's symptom (paresthesia down the spinal column or into the extremities on flexion of the cervical spinal column), facial palsy, fecal incontinence, dysphagia, and dysarthria. Brain and Walton (1969) also reported motor weakness, incoordination in the upper limbs usually intentional tremor, acute unilateral retro-bulbar neuritis, nystagmus, cerebrospinal fluid abnormalities, dysarthria and a few cases with aphasia.

Optic neuritis is one of the earliest and the most obvious symptom because it is a more concrete symptom as opposed to vaguer neurological symptoms such as numbness or tingling sensation. Other symptoms include dizziness, poor bladder and bowel control, fatigue, poor memory and thinking, poor mental health, speech impairments, spasms and stiffness, tremor and swallowing difficulties.

Dysphagia is also present in around 30% of individuals with MS (Hartelius & Svensson, 1994; Poorjavad, Derakhshandeh, & Etemadifar, 2010) and can increase to over 60% in people who have advanced MS (De-Pauw, Dejaeger, & D'hooghe, 2002). It is particularly prevalent in individuals whose MS includes the involvement of the brainstem. Swallowing difficulties can affect all four stages of swallowing (oral preparatory, oral, pharyngeal, and esophageal) and can include difficulty in chewing, pocketing food in the cheeks, fluids escaping from between the lips, residue in the pharynx after the pharyngeal swallowing, and episodes of coughing/choking when eating or drinking. These difficulties can be caused by weakness, impaired coordination, and spasticity, or some combination of each. The severity of dysphagia may vary from one individual to another.

A study by Danesh-Sani, Rahimdoost, Soltani, Ghiyasi, Haghdoost, and Sabzali-Zanjankhah (2013) focused on the orofacial manifestations in individuals with Multiple sclerosis. The authors examined 500 individuals with MS between 11 to 69 years old. All individuals underwent a standard neurological evaluation. They collected information regarding demographic information and clinical variables such as disease duration and family history, to assess the factors associated with orofacial symptoms in individuals with MS. The results revealed that 88.6% of the individuals had orofacial manifestations. Among them visual complications (80.4%), temporomandibular disorders (58.2%), and dysarthria (42.1%) were more commonly observed.

Typically, language is not directly affected in MS, however, Yorkston, Klasner, and Swanson (2001) found that cognitive changes could impact language in terms of word-finding and verbal organization. Foong, Chew, and Kumar (1998) found cognitive changes to be especially likely as the disease is entering the progressive phase (cited by Yorkston et al., 2001). Reischies and Lidenberger (1999) found a reduction in social activities and increased psychopathology in those with cognitive impairment, meaning difficulties could impact an individual’s social and emotional wellbeing (cited by Yorkston et al., 2001).

MS usually encounters a diverse spectrum of clinical manifestations, due to diversity in plaque location, which can be highly disabling. People with the same lesion site also may not necessarily experience the same symptoms in the same way. The disability progresses so rapidly that 40% of the patients affected by MS become wheelchair bound within 10 years following the disease onset (Scolding & Wilkins, 2012).

Speech impairments in Multiple Sclerosis

Charcot (1877) described speech impairment as the cardinal symptom of MS. Speech impairment is one of the vital features of MS, referred to as "scanning speech" (Darley et al., 1972). Darley et al. (1972) studied 168 individuals with MS and reported that 41% displayed deviant speech performance, whereas 59% had near normal speech production. Beukelman, Kraft, and

Freal (1985) proposed that 23% of 656 individuals reported of speech and other communication deficits as a symptom of MS. According to the National Multiple Sclerosis Society (2000) almost 25-40% of the people with MS exhibit speech deficits. A study by Murdoch and Theodoros (2000) concluded that the prevalence of mild to severe dysarthria in individuals with MS was 51% and this compromised all components of speech production including respiration, phonation, oral motor performance, articulation, prosody, and intelligibility. Dysarthria has an estimated prevalence of 40-50% in multiple sclerosis and is least described (Merson & Rolnick, 1998; Hartelius et al., 2000).

Speech impairment in MS have been correlated with the demyelination in the cortical and sub-cortical areas that leads to the reduction in the expression of neuronal proteins which are responsible for the axonal transport, synaptic plasticity, glutamate homeostasis, memory/ learning, and neuronal survival. This can affect the way speech is produced and can cause problems that may come and go including slurred speech, low volume or a weak voice.

Normal speech depends on a very complex system of nerve signaling in the brain, and hence, the specific type of speech problem a person suffers from, will depend on where the CNS damage or demyelination occurs. For instance, damage in the cerebellum, which is the primary cause of speech problems in MS, often results in a slowing of speech with diminished fluency. If brain areas that control the tongue, lips, soft palate, cheeks, or breathing muscles are affected, speech patterns can become slurred. Problems with speech in MS may come and go, appear with exacerbations during which symptoms often worsen then gradually improve. Whether problems progressively worsen depends on the course of the disease for a particular patient.

Dysarthria associated with MS has been characterized as spastic or ataxic. This classification is primarily based on the combination of auditory-perceptual characteristics and the site of lesion (Darley et al., 1969; Darley et al., 1975). Darley et al. (1975) described syllable repetitions of 7 different types of dysarthria with respect to the rate of repetition and the regularity of rhythm of repetition. From among the seven types, it was proved that ataxic and spastic dysarthric components were predominantly seen in individuals with MS.

Respiratory musculature may be affected in individuals with neuromuscular disorders (Hixon & Hoit, 2005; Brown, DiMarco, Hoit, & Garshick, 2006) and respiratory dysfunction can also result in speech problems. Respiratory impairment is most common during the relapses or in advanced MS, when there are large lesions in several areas, or when areas in the medulla that are responsible for respiratory control are affected (Smeltzer, Utell, Rudick, & Herndon, 1988; Nogues, Roncornoni, & Benarroch, 2003). Weaknesses in the respiratory muscles and decreased expiratory flows have also been reported in mild MS (Altintas, Demir, Ikitimur, & Yildirim, 2007).

Murdoch, Chenery, Stokes, and Hardcastle (1991) found normal values for the total lung capacity in the participants with moderate to severe cerebellar MS, which is similar to that reported by Altintas et al. (2007) in individuals with mild MS. However, the participants in the study by Murdoch and colleagues had vital capacity below normal limits (<80% of the expected) in 7 of the 9 participants, and the respiratory kinematics showed restricted and abnormal movements of the rib cage and abdomen during speech tasks (reading, narration, alternating motion rate [AMR], sequential motion rate [SMR], and sustained vowels). The reduced vital capacity was thought to be reflected by the finding that the participants initiated both reading and conversation utterances below the levels reported as normals, and had slightly lower lung volume excursions compared with a group of healthy controls. The participants also showed irregular (bizarre) movements during inspiration and expiration which were thought to be related to the breakdown in coordination between the rib cage compartment and the abdomen.

Darley et al. (1975) found that 25% of patients with MS exhibited hypernasality. Murdoch and Theodoros (2000) concluded that hypernasality may be a result of the associated ataxic condition causing a reduction in the speed and coordination of velopharyngeal closure.

Various aspects of phonatory dysfunction, such as pitch breaks and harsh voice quality, as well as vocal fatigue, have been reported in 18-70% of individuals with mild-moderate MS (Feijo, Parente, Behlau, Haussen, de-Veccino, & Martignago, 2004; Dogan, Midi, Yazici, Kocak, Gunal, & Sehitoglu, 2007), and in up to 90% of individuals with severe MS (Fitzgerald & Chenery, 1987).

Phonatory instability is also common in MS, with studies reporting a higher presence of jitter and shimmer in individuals with MS than in healthy control individuals (Farmikides & Boone, 1960; Darley et al., 1972; Feijo et al., 2004; Dogan et al., 2007). Perceptually a predominant voice characteristic in MS is harshness (Darley et al., 1972; Fitzgerald & Chenery, 1987).

The most apparent difficulty is the imprecise articulation (the consonant place is most affected with fewer vowel distortions) which significantly impacts the intelligibility, however, the communication is comprehensible when contextual cues are accounted (Dykstra, Hakel, & Adams, 2007). This is in line with the diagnosis of ataxia or cerebellar lesions that can cause reduced coordination and muscle tone, thus affecting the articulatory speed and precision (Duffy, 2005). Spasticity causing reduction in skilled, voluntary movement may also reduce articulatory precision (Duffy, 2005).

Farmakides and Boone (1960) reported on the speech examination done on 82 MS patients based on a medical referral. The authors had reviewed the case histories of these 82 individuals who reported to the Physical Medicine and Rehabilitation Department, Cleveland, Ohio, in the past 5 years and concluded that the following five speech characteristics were predominantly observed and contributed to the poor communicative abilities: nasal voice quality (excessive nasopharyngeal resonance due to weakness or lack of coordination in the velopharynx), weak phonation of voice (often secondary to a general disturbance in respiration), changes in pitch (inability to control the phonation with the instantaneous initiation and cessation of voice), slow rate (movements of the articulators become slow, sluggish and weak that articulation becomes slurred and indistinct) and intellectual deterioration and emotional liability (occurs with the progression of the disease resulting in observable personality changes). They also reported that slow rate of speech is the chief contributing factor to identify the dysarthric condition in MS. The authors also reported that a decrease in the intelligibility of the MS individuals who are emotionally liable due to the presence of explosive, abrupt, uncontrollable laughing or crying for no apparent reason.

Speech intelligibility in MS

Intelligibility is a common effect of dysarthria in multiple sclerosis. Intelligibility refers to the degree or the accuracy with which a listener recovers the acoustic signal or message produced by a speaker (Duffy, 2013). Intelligibility has also been described or defined as how effective one is in his or her communication (Cannito, Suiter, Beveryly, Chorna, Wolf, & Pfeiffer, 2012), the ease with which the acoustic speech signal is understood (Kim & Kuo, 2012), or the extent to which the acoustic signal is understood (Tjaden, Sussman, & Wilding, 2014).

Intelligibility is a matter of major concern in patients with neuromuscular disorders because it is the correlate of a general communicative impairment (Weismer & Martin, 1992). Intelligibility and naturalness of speech can be affected by diminished strength, speed, and range of the articulatory muscles. Sometimes intelligibility is confused with articulation and phonology (Kent, Miolo, & Bloedel, 1994). In fact, it is the product of a series of interactive processes as phonation, articulation, resonance, and prosody. Hence if any one system is altered in its function, it results in poor intelligibility. The degree of the intelligibility may vary depending on the extent, site, and severity of the damage to the subsystems mentioned above.

Since speech is the result of a complex process, intelligibility measures preferably include aspects of all speech dimensions. Theodoros, Murdoch, and Chenery (1994) found that in a group of neuromuscular impaired individuals with overall intelligibility problems, patients also showed more than 90% of occurrence of the dimensions related to nasality and mixed nasality, resonance, articulation (consonant precision), prosody and voice (pitch variations) (Chenery, 1998).

Kent et al. (1999) showed that most disrupted phonetic features of speech in patients with dysarthria secondary to MS involved phonatory function and velopharyngeal valving next to lingual movements for the production of vowels and consonants. Their finding was based on a word intelligibility test. However, the findings did not suggest to what extent each of these dimensions affected the overall intelligibility of connected speech.

A study was done by Mackenzie and Green (2009) which aimed to investigate the presence of and nature of cognitive-linguistic deficits, the association between levels of cognitive-linguistic ability and speech intelligibility, and both of these with functional disability and time since onset of multiple sclerosis symptoms. The Arizona Battery for Communication Disorders of Dementia

(ABCD) (Bayles & Tomoeda, 1993), The Assessment of Intelligibility of Dysarthric Speech (AIDS) Sentence Intelligibility Task (Yorkston & Beukelman, 1984), and the Modified Barthel Activities of Daily Living Index (MBADLI) (Shah, 1998) were administered to 24 chronic progressive multiple sclerosis participants with dysarthria. A total of 24 non-neurologically impaired participants, matched for gender, age and education, formed a control group. A strong correlation was found between AIDS and MBADLI; AIDS and time since onset; AIDS and ABCD. The results revealed a strong association between dysarthria, as measured by connected speech intelligibility testing, and cognitive-linguistic deficit, in people with chronic progressive-type of MS.

Stipancic, Tjaden, and Wilding (2015) compared the objective intelligibility metric of orthographic transcription with the subjective intelligibility metric of Visual Analog Scale (VAS) between individuals with Parkinson's disease (PD) – 8 men and 8 women, Multiple Sclerosis (MS) – 10 men and 20 women, and healthy controls - 10 men and 22 women. Single-word intelligibility from Word intelligibility (Kent, Weismer, Kent, & Rosenbeck, 1989) and sentence intelligibility for SIT (Yorkston, Beukelman, & Tice, 1996) was used as stimuli. The subjects were asked to read the stimuli in a habitual, clear, loud, and slow condition. Fifty individuals were asked to orthographically transcribe the recorded sample of the subjects. The results revealed that both the MS and the PD groups performed poorer than the healthy controls in both sentence and word intelligibility tasks, in which sentence intelligibility scores were poorer than the word intelligibility score. They also concluded that both VAS and the orthographic transcription measures correlated well with each other.

Tjaden and Martel-Sauvageau (2017) studied the impact of clear speech or an increased vocal intensity on consonant spectra for speakers with mild dysarthria secondary to MS or mild dysarthria secondary to PD and healthy controls. Sentences were read in habitual, clear, and loud conditions. The results revealed that the loud and clear conditions were more intelligible than the habitual speaking condition of the individuals. The findings reported that the loud and especially clear condition yielded fairly subtle changes in consonant spectra which suggested that global techniques may minimally enhance the consonant segment production and thereby improve the intelligibility.

Thus speech motor control is affected in persons with MS. There have been many studies in the past by various researchers (Bruner, 1973; Smith & Goffman, 1998; Kim & Kuo, 2012) which uses motor approach to study the speech motor control. According to them, even the minute changes in speech motor control can be captured through various speech acts. Few commonly used speech motor measures are the Diadochokinetic rate (DDK), F_2 transition, Voice and tremor parameters, syllabic rate and intonation stimulability (Cohen & Waters, 1999). Majority of the above-quoted reports highlighted the sensitivity of DDK task as a key indicator of motor speech impairment (Deepa & Jayashree, 2012). DDK rate that requires alternating articulatory movements can be used to provide an objective measure of the impairment of the lips, the anterior and posterior tongue and the mandible to screen neurological disorders.

Diadochokinetic Rate in MS

Diadochokinesis is the ability to make antagonistic movements in quick succession (Tjaden & Watling, 2003). The maximum rate of syllable production in DDK tasks is widely used in both research and clinical contexts as a means of gaining insight into an individual's speech motor ability. DDK assesses the rate, accuracy and consistency of the speech motor skills during the rapid production of alternating syllables /pa-ta-ka/ or /pa/ (Fletcher, 1972). These phonetic sounds, called tokens, are premeditated to evaluate different parts of the oral cavity, such as the lips, tongue, soft palate and the pharyngeal regions.

Duffy (2005) speculated that both Alternating Motion Rate (AMR) and Sequential Motion Rate (SMR) are considered as sensitive indices of speech motor impairments due to the involvement of maximum articulatory performances. AMR requires the talker to produce repetitions of the same syllable (e.g.: /pa-pa-pa/), while SMR requires the talker to produce repetitions of a sequence of syllables (e.g.: /pa-ta-ka/).

Computation of DDK

The oral DDK reflects the neuromotor maturation and integration of the orofacial structures involved in speech (Manson, Helmick, Unger, Gattozzi, & Murphy, 1977; Baken & Orlikoff, 2000; Wang et al., 2004). The presence of inconsistent or an abnormal oral DDK performance might indicate disorders of the central nervous system or peripheral sensory-motor functions. The DDK tasks have been widely recommended for the investigation of speech inconsistencies in individuals with neurologic impairments. Earlier research related to neurogenic motor speech disorders clearly suggested the sensitivity of the oral diadochokinesis in capturing the abnormal speech production, since the production of a sustained syllable in DDK, requires integrity of several speech musculatures that need to work in coordination.

The calculation of DDK (AMR and SMR) can be manual or automated. In the manual method, the DDK rate is calculated in terms of either counting the number of iterations per second or the time required to produce a specific number of iterations of a mono-, bi-, or a trisyllabic token. The rate will be calculated and compared to the published norms. For example, in the data published by Fletcher (1972), the norm for 20 repetitions of the syllable /pa/ for a child at age 10 was 3.7 seconds. This method is named as the Fletcher Time-by-Count Test of Diadochokinetic Syllable Rate. In the later ages, a simple modification of the procedure was made. The use of stop-watch or oscillograms was introduced (Fletcher, 1972). If the number of syllables rather than the time interval was pre-established, the overlapping attentional requirements would be eliminated and the stop-watch could be started when the speaker began to repeat the syllables. The examiner's full attention could be then directed to the syllable count until the required number of repetitions were uttered. The watch could be then turned off and the elapsed time could be noted. The DDK rate is calculated by dividing the total number of iterations by the duration of the trial or by determining the time it took the client to make a set of the number of iterations. Some clients, especially preschool age children, may have difficulty complying with the instructions or completing the DDK tasks. In such cases, real words such as "buttercup" or "patty cake" may be used to test the DDK rate.

Fletcher (1972) used the time-by-count measurement of DDK rate on 6-13-year-old typically developing children with 24 boys and 24 girls in each group. The subjects were asked to repeat the syllables in different combinations (mono-, bi- and tri-syllables). Fletcher used both oscillographic measurement and stopwatch method to analyze the recorded samples. The result revealed a highly consistent trend of change by age, with the least marked difference in the 6-7-year olds. There was only small difference found between boys and girls in the DDK performance, where girls performed slightly faster than boys. Based on Fletcher's Time-by-count method, DDK rate worksheets have been provided with norms, which are used as a reference during the assessment and treatment.

Comprehensive studies related to the aspects of speech motor characteristics are crucial in understanding the normal and disordered population. Vital information regarding temporo-spatial characteristics of speech is obtained from the analysis of speech rate of the individual. Recent advances in technology have paved way for studies related to the speech motor profiling in typical and atypical individuals.

There is specialized recording equipment and computer software program available to record and analyze the DDK rate. The use of software to calculate DDK rate provides quick and automatic results. The iterations are recorded and fed into the software program which analyzes the recorded sample and provides the result with a click of a button. DDK fits for automatic analysis also because of its intrinsic cyclic and relative simplicity. The task of DDK permits the application of programs for the calculation of average and variation of DDK period, rate, and peak intensity to oral motor control and speech intelligibility. One such promising program that provides automatic instrumental quantitative analysis of DDK is the Diadochokinetic Rate Analysis (DRA), part of the Motor Speech Profile (MSP) Model 5141 and a software option for the KayPENTAX Computerized Speech Lab (CSL) Model 4500.

The MSP is a software used for the objective analysis of diadochokinesis and provides a reproducible and non-invasive method for assessing speech motor characteristics in subjects. Specifically, the DDK analysis using MSP will provide information on others aspects such as temporal and amplitude variations. The Diadochokinetic Rate Analysis (DRA) protocol of MSP measures the rate and regularity of consonant-vowel (CV) syllables repeated in a task involving maximum-rate repetition on one breath. Several factors can complicate the accuracy of DRA results. For example, the impaired oral motor function could result in articulatory undershoot (a weak articulatory force that is insufficient to achieve or maintain articulatory closure) and affect the accuracy of the DRA outputs.

Wertzner, Pagan-Neves, Alves, and Barrozo (2013) verified the performance of children with and without speech sound disorder (SSD) in oral motor skills measured by oral DDK according to age and gender and compared the results by manual and automatic methods of analysis. Results revealed that gender did not statistically influence the number of sequences produced per second and correlation between age and the number of sequences produced was observed. Results presented a moderate to strong agreement between the values of oral DDK measured manually and by motor speech profile (MSP).

Gadesmann and Miller (2009) studied the reliability of speech diadochokinetic test measurement and compared between objective and perceptual methods. Ten speech-language therapists and ten untrained controls were asked to rate 12 DDK speech samples, including 2 pairs of identical samples, of individuals with different neurological speech disorders. Counts by time were compared with the objective outcomes from sound spectrogram. The results revealed that inter and intra-rater reliability was lower for counts by time method when compared with the objective outcomes. The authors also concluded that counting the syllables within the first 5 seconds was most accurate and correlated well with the objective outcomes.

Performance on DDK tasks in healthy individuals

The performance and the accuracy of DDK tasks improve with age until about the age of 18 years (Fletcher, 1972; Weismer & Liss, 1991; Linville, 1996; Wohlert & Smith, 1998; William & Stackhouse, 2000) in typically developing children. Jung, Cho, Cho, Park, Kim, Chung, Won, and Rubinstein (2002) carried out a research to provide norms for the diadochokinetic rate in the Korean population. One hundred and twenty-three normal people with ages ranging from 2 to 73 years were studied and were divided into 7 groups according to their ages for the purpose of the study. The authors recorded 7 diadochokinetic rate movements /pa/, /ta/, /ka/, /pa-ta/, /pa-ka/, /ta-ka/, and /pa-ta-ka/. The subjects were instructed to produce the sounds as rapidly as possible at comfortable pitch and loudness for 7 seconds. Three trials were elicited. The results revealed that the DDK rates increased as people aged and then started to decrease after the age of 40 years. The difference in DDK rates between male and female subjects was not significant. Young females tend to perform better than males. However, elderly males tend to perform better than females. DDK rates decreased from high to low in the following order: /ta/, /pa/, /ka/, /pa-ta/, and /pa-ka/. The performance of one syllable, two syllables, and three syllables showed the rate ratio 3:2:1.

Normative data on DDK rates in English speaking children are available for a variety of monosyllabic, bisyllabic, and polysyllabic sequences (Fletcher, 1972; Canning, & Rose, 1974; Robbins, & Klee, 1987). The normative data for adults has been published in English fairly with a range of 5 and 7 syllables per second by Deliyski and Gress (1997), 6.15 syllables per second by Icht, Maltz, and Korecky (2013), 6.3 syllables per second by Lass and Sandusky (1971), 6.05 syllables per second by Ptacek, Sander, Maloney, and Jackson (1966), 6.25 syllables per second by Robb, Hughes, and Frese (1985), and 6.55 syllables per second by Topbas (2010). The DDK rate norms have been established for adults in other languages also like Portuguese – 6.54 syllables per second (Meurer, Wender, Corleta, & Capp, 2004; Padovani, Gielow, & Behlau, 2009; Louzada, Beraldinelle, Berretin-Felix, & Brasolotto, 2011), Greek – 6.97 syllables per second (Konstantopoulos et al., 2011), Hebrew – 5.6-7.2 syllables per second (Icht & Ben-David, 2014) and Farsi – 7.12 syllables per second (Seifpanahi, Dadkhah, Dehqan, Bakhtiar, & Salmalian, 2008).

Several studies have been carried out on DDK in healthy individuals using MSP. Some of the studies have been described below. The normative for DDK has been established using MSP by Wong, Allegro, Tirado, Chadha, and Campisi (2011) in English speaking children aged 4-18 years. One hundred and twelve subjects (54 females and 58 males) were included in the study. The subjects were asked to repeat the syllables /pa/ and /pa-ta-ka/ as rapidly and regularly as possible. The DDK rates for 4-8 years: /pa/-4.54sy/s and /pa-ta-ka/-3.85sy/s; for 9-13 years: /pa/-5.39sy/s and /pa-ta-ka/-4.97sy/s; and for 14-18 years: /pa/-5.62sy/s and /pa-ta-ka/-5.54sy/s. The authors reported that the DDK rate increased with age and there was no significant difference between males and females.

Deyliski and Gress (1997) have established norms for English speaking adults aged 18-60 years using MSP. Thirty individuals were included in the study. The subjects were instructed to repeat the syllables /pa/, /ta/, /ka/, and /pa-ta-ka/ accurately and rapidly and the samples were recorded. The results revealed that the DDK rates decreased as the age increased and certain DDK parameters showed significant difference between the genders.

In the Indian context, the same has been developed in Kannada for children aged 4-10 years, by Deepthy (2015). The study included 90 typically developing Kannada speaking children. The participants were instructed to say /pa/, /ta/, /ka/ and /pa-ta-ka/ as clearly as possible and the samples were audio recorded. The DDK rates were analyzed using MSP. The DDK rates were as follows for 4-6 years: /pa/-4.22sy/s, /ta/-3.87sy/s, /ka/-3.90sy/s and /pa-ta-ka/-4.22sy/s; for 6-8 years: pa/-4.73sy/s, /ta/-4.68sy/s, /ka/-4.80sy/s and /pa-ta-ka/-5.15sy/s and for 8-10 years: pa/-5.29sy/s, /ta/-5.22sy/s, /ka/-5.08sy/s and /pa-ta-ka/-5.44sy/s.

John, Ganapathy, John, and Rajasekhar (2014) established norms for Kannada speaking adults aged 20-60 years. Three hundred subjects were included in the study. The subjects were instructed to say /pa/ as rapidly and clearly as possible. The DDK parameters were analyzed using MSP. The DDK rate for 20-40 years: /pa/-6.33sy/s; for 41-50 years: /pa/-4.34sy/s; and for 51-60 years: /pa-2.72sy/s. The authors reported a decreasing trend in the DDK rate and attributed it to the age related changes. They also reported a significant difference between the male and the female speakers.

Norms have also been established for Telugu speaking adults aged 20-60 years, by Patil and Manjula (2013) using MSP. Four hundred healthy adults were included in the study. The participants were instructed to repeat the syllables /pa, /ta/, /ka/, and /pa-ta-ka/ clearly and rapidly. The DDK rates were analyzed using MSP. The DDK rates for 20-30 years: males-4.68sy/s and females-5.23; for 30-40 years: males- 5.05sy/s and females-4.98sy/s; for 40-50 years: males-5.38sy/s and females-5.00sy/s; and for 50-60 years: males-5.28sy/s and females-4.67sy/s. They indicated that the DDK rate was higher in males when compared with females.

Padovani et al. (2009) analyzed the DDK rate in healthy subjects of two groups using MSP software. Group one consisted of 14 females and 9 males, aged between 30 and 46 years and group two included 14 females and 9 males, aged between 47 and 94 years. The individuals were instructed to produce repetitively the syllables /pa/, /ta/, /ka/, the vowel /a/, and the sequence /pa-ta-ka/, in the same order, as fast as they managed with the comfortable pitch and loudness. Samples were recorded and analyzed using MSP module. Five parameters from the available eleven were selected for the analysis. The results revealed that rate changed according to syllable produced and it reduced as the articulatory point went backward. The rate did not significantly vary with age; however, the intensity peak had great variation in all tasks for the elderly adults. The elderly adult group presented with great variability, which reflects difficulty with controlling intensity, probably due to the deviation inherent to the aging process such as spindled shape glottal chink and the intrinsic laryngeal muscles atrophy that results in a less biomechanical efficiency of the whole system.

Performance on DDK tasks in individuals with multiple sclerosis

Jensen (1960) studied the motor speech of 50 patients with MS. The perceptual assessment of the recorded speech sample revealed that 38% made errors on articulation test and 35% made articulation errors on a contextual speech task. The speech of 78% was rated by the listeners as defective. The DDK samples were recorded and analyzed using photographed oscillographic display of the speech signal. The majority of the subjects had slower than normal oral DDK (58% on repetition of /pa/, 64% on /ta/, and 70% on /ka/). Oral DDK rate measures decreased as the degree of severity of defectiveness of the articulation increased. Jensen also reported that the severity of speech involvement was not significantly related to the duration of illness and duration of the permanent symptoms of the disease. Patients diagnosed as "diffuse type" performed poorly when compared with the other types, and the "spinal group" performed better when compared with the other types.

Portnoy and Aronson (1982) studied the rate and regularity of diadochokinetic syllable repetitions of /pa/, /ta/, and /ka/ in 30 normal, 30 subjects with spastic dysarthria, and 30 subjects with ataxic dysarthria using an oscilloscope and a computer. Each subject was instructed to repeat, on one uninterrupted breath, as rapidly, regularly, and as long as possible, the syllable /pa/ and successively the syllables /ta/ and /ka/. The 90 tape-recorded samples were dubbed onto a master tape and computer measurements of syllable duration were made. The results revealed that the normal subjects had DDK rates of 6.4s, 6.1s, and 5.7s, while the spastic dysarthric subjects had 4.6s, 4.2s, and 3.5s and the ataxic dysarthric subjects had 3.8s, 3.9s, and 3.4s for /pa/, /ta/, and /ka/ respectively. The authors concluded that the spastic and ataxic individuals were significantly slower and more variable than the normal subjects and the ataxic subjects were more variable than the spastic subjects. Darley et al. (1972) also stated that the spastic and ataxic dysarthria yielded relatively clear perceptions of abnormally slow rate of repetition and abnormal rhythm of repetition, respectively.

Rosen et al. (2008) stated that DDK rates and F_2 transition are a fruitful way of detecting the speech deviations in MS since dysarthric component affects the extremely rapid changes. In this study, 14 participants with MS and 14 healthy controls were included. One of the 12 individuals with MS was diagnosed with remitting-relapsing type, 8 with progressive (primary, secondary, chronic or slow progressive) and 3 with an undetermined clinical course by the neurologist. The participants were selected based on their performances on Multiple Word Intelligibility Test and of the connected speech with the Assessment of Intelligibility of Dysarthric Speech to identify speaker with potential dysarthria that affected the intelligibility. DDK rates and F_2 transition were analyzed acoustically using the standard MSP stimuli. The results revealed that dysarthric component disproportionately affected the production of extremely rapid changes in speech.

Konstantopoulos et al. (2011) explored the sequential motion rates in individuals with multiple sclerosis and compared it with age and gender-matched healthy controls. Twenty-seven individuals with MS (with dysarthria) with a mean age of 35.2 years and 27 age and gender-matched controls with a mean age of 35 years were included in the study. The subjects were instructed to repeat the syllable sequence /pa-ta-ka/ as rapidly and accurately as possible on a single exhalation. The productions were recorded and the temporal analysis of the SMR was carried out using PRAAT and each segment was annotated. The result revealed that the articulation rate of the MS group (6.17syll/s) was significantly lower than the control group (6.97syll/s). The articulation rate was 11.4% lower than in the control group, which was justified by a slight incoordination of the oropharyngeal muscles and fatigue. The MS individuals produced fewer /pa-ta-ka/ tokens because they failed to achieve the rapid antagonistic muscle contractions. Hence the authors concluded that SMR is relevant for the description and determination of the speech impairment in individuals with MS.

Rusz, Benova, Ruzickova, Novotny, Tykalova, Hlavnicka, …Horakova (2017) tried to characterize the motor speech disorders and to identify the relationship between the severity of speech disorder and neurological involvement. A total of 141 individuals (101 women & 40 men) with a mean age of 44 years and with a neurologically-confirmed diagnosis of MS according to the revised McDonald Criteria (Polman, Reingold, Banwell, Clanet, Cohen, & Fillippi, 2011) were included. One hundred and seven individuals were diagnosed with relapsing-remitting MS 18 with secondary progressive MS, 6 with clinically isolated syndrome and 10 with primary-progressive MS. All individuals included were relapse-free for at least 30 days prior to the testing. The speech samples (phonation, AMR, SMR, & reading) were recorded during a single session by the SLP. Quantitative analyses were done based on 10 speech dimensions related to phonatory, diadochokinetic, articulatory, and prosodic abnormalities using acoustic analysis. Twenty-six individuals (18%) exhibited spastic-ataxic, 9 individuals (6%) showed spastic, 4 individuals (3%) ataxic, and 1 individual (1%) showed non-specific components of dysarthria and the severity was generally found to be mild. The strongest relationship was observed between the irregular SMR and the neurological involvement. The authors concluded that the severity of several speech patterns such as irregular pitch fluctuations, signal perturbations, slow oral diadochokinesis, imprecise consonants, slow rate, and excess loudness variations correlated with the severity of neurological involvement in MS.

Certain studies have tried to delineate the relationship of the DDK with speech intelligibility, duration of disease, degree of neurological involvement, etc. Such studies have been carried out in individuals with dysarthria secondary to several neurological conditions and have been described below.

Farmakides and Boone (1960) had reviewed the case histories of 82 individuals with MS who reported to the Physical Medicine and Rehabilitation Department, Cleveland, Ohio, in the past five years and concluded that the following five speech characteristics were predominantly observed: nasal voice quality, weak phonation of voice, poor respiration cycle, changes in pitch, and slow rate accompanied with poor intelligibility, intellectual deterioration and emotional liability. They also reported that slow rate of speech was the chief contributing factor to identify the dysarthric condition in MS. The authors suggested that speech problems were common in individuals with MS. They reported that the symptoms began to progress and exaggerate as the underpinning neurological impairment progresses and in no way had correlation with the duration of the disease. According to Darley et al. (1972), dysarthria severity was more pronounced in individuals with MS where the disease process involved a greater number of neurological systems and not the duration of disease.

Schliesser (1982) studied 15 adults with cerebral palsy (CP) and dysarthria. AMR for the syllables /ma/, /da/, /ga/; and connected speech samples served as the stimuli and were recorded. Two SLPs analyzed and judged the mean rating for each sample. The severity of dysarthria in the individuals were directly correlated with the degree of neurological insult and not related to the duration of the illness. The results of the study suggested that in CP adults, the AMR predicted the severity of the dysarthria.

Ziegler and Wessel (1996) studied the syllabic timing in individuals with ataxic dysarthria (cerebellar atrophy – 10, Friedreich's ataxia – 6) in natural sentence production and in DDK task.

The recorded samples were analyzed using PRAAT for the syllable durations and the average syllabic rate. The authors also calculated the within trial variation of syllable duration and the various articulatory maneuvers used by the subjects. The results indicated that slowed syllable repetition was in specific the powerful predictor of the severity of dysarthria. They indicated a high relationship between DDK rate and the intelligibility and the severity of the dysarthria. The authors also observed that different patterns of between articulator variations (intelligibility issues), irregular pacing of syllable repetitions in all individuals except for one subject. This disproportionate slowing and articulatory impairments in the dysarthric individuals can be owed to the difficulty in the adaptation to the motor tasks that is impaired and the severity of the impairment.

Hartelius et al. (2000) attempted to find the prevalence and characteristics of dysarthria in MS population (relapsing-remitting – 23; primary progressive – 9; secondary progressive – 45) and the correlation between severity of dysarthria and the disease progression. Seventy-seven individuals with definite and probable MS were included in the study. The clinical dysarthria test procedure was administered which included subtests on respiration, phonation, oral motor performance, articulation, prosody, and intelligibility. All the speech samples (reading, conversational speech, and oral diadochokinesis) were recorded and analyzed by two SLPs. The samples were transcribed using broad IPA transcription and analyzed. The results indicated that the prevalence of dysarthria in MS population was about 45% and the most common deviation were defective consonant articulation, prolonged speech intervals, and deviations in speech rate. The predominant type was mixed dysarthria (spastic and flaccid types). The authors also inferred that even when a predominant type of dysarthria did exist, it was not generally associated with a characteristic profile of neurological deficits. Rather, severity of speech deviation was positively correlated to overall severity of neurological involvement, type of course, and the number of years in progression.

Kent et al. (2000) obtained perceptual and acoustic data (several speaking tasks, including sustained vowel phonation, syllable repetition - AMR, sentence recitation, and conversation) from 14 individuals with dysarthria (7 men and 7 women). Multi-dimensional Voice Protocol (MDVP) was for the acoustical analysis. Syllable alternating motion rate was slower and irregular in typical. Conversation samples and the sentence recitation samples presented with varied degree of intelligibility. Qualitative analyses of the collected data indicated that the unintelligible episodes had defined syllable pattern and rate, but the degree of the acoustic contrast between the vowels and consonants were not maintained. The authors concluded that DDK rates had poor correlation with the degree of intelligibility.

A study by Ozawa et al. (2001) indicated that the DDK rates had no correlation with the speech impairments presented in the dysarthric individuals. Acoustic analyses was conducted on 6 individuals with spastic and 6 individuals with ataxic dysarthria. Monosyllables /pa/ and /ta/ were used as the stimuli and the alternating motion rates were recorded. The samples were analyzed using the CSL (Kay Elemetrics, 4300B). Quantitative analyses of syllable duration, gap duration, voice onset time, and formant frequencies of vowels were obtained. Sound spectrographic measures were applied to examine the oral articulatory motions and laryngeal motions individually. The authors observed prolonged syllable and gap durations and irregular articulatory functions. The results indicated that the syllable duration and the gap components did not directly correlate with the articulatory functions indicating that each of the component has a separate function and contributes individually to the decreased AMRs.

Nishio and Niimi (2006) made a comparison of the speaking rate, articulation rate and alternating motion rate in dysarthric speakers. A total of 96 subjects (62 dysarthric speakers and 34 control speakers) were included in the study. The dysarthric group included 46 men and 16 women diagnosed as having dysarthria due a variety of neurological conditions (CVA, ALS, PD, Olivopontocerebellar atrophy, TBI, Cerebritis, Radioneuritis, Shy-Drager syndrome, Dystonia, and MG). The control group included 17 men and 17 women. The speech samples including speaking rate during reading of Japanese standard passage (The North Wind and the Sun), AMR (repeat monosyllables /pa/, /ka/, and /ta/), and a measure of speech intelligibility (conversation sample) were collected and audio recorded. The conversation samples were transcribed using broad IPA transcription. The results indicated that based on the degree of intelligibility measures, the dysarthria group had mild to moderate severity. A significant correlation was observed between the intelligibility score, AMR, and speaking rate in the moderate and severe dysarthric groups, however, low to moderate correlations was observed between intelligibility scores, AMR and speaking rate in the mild dysarthric group. Hence the authors concluded that there was a significant correlation that exists between the articulation rate, speaking rate, AMR and the intelligibility for all syllables in the dysarthric group. In all the groups, the AMR was significantly reduced, and this in particular was more pronounced for the moderate and the severe dysarthric groups.

In par with the previous study, a study of 77 individuals with MS by Hartelius and Lillvik (2003) confirmed that DDK rate was positively related to articulatory imprecision and moderately related to the disease progression, while other authors like Famakides and Boone (1960), Schliesser (1982), Kent et al. (1999) proposed that the duration of the disease had no relation with the DDK rates.

A systematic review of the literature revealed that, MS is one among the motor speech disorders where there is mild to severe impairments in different subsystems depending on the type, site and extent of demyelination, leading to a wide variety and degree of signs and symptoms. As a result of these, speech which is an overlaid function becomes affected in individuals with MS. Measures of oral diadochokinesis is widely used in the assessment of motor speech disorders and they play a role in detecting the abnormality, and monitoring speech performance changes. Since DDK is the measure of rapid speech movements, it is a significant clinical tool in the assessment of MSD. However, the usage of DDK using both manual and objective methods, in the assessment of MS is sparse. Although in clinical practice DDK is generally measured perceptually, without support from instrumental methods that display the acoustic waveform, and no standard measurement procedures are employed, the review clearly has stated that there is a strong correlation between the subjective and objective methods and the latter has a good stand because of the advantages. The objective measures provide quantification, along with the analysis of different other parameters. Even though the use of objective method has been justified, it has not been used widely in the assessment of individuals with MS in specific. MSP which is one such computer-based program has been used in the current study.

All the studies have been carried out in a variety of contexts, but only a handful is available in the Indian contexts. Literature reveals that contextual, language and dialectal variations can affect the performance of DDK. Further, the findings are equivocal with respect to the relationship of DDK with speech intelligibility ad duration of the disease. Hence, there is a need to understand the speech motor patterns of individuals with MS with respect to the duration of the disease and the speech intelligibility in the Indian scenario. The studies in MS have been done on progressive, cerebellar, diffuse, or spinal types of MS, with only a few studies considering remitting-relapsing type of MS. Keeping this in view, the present study was planned with the aim of investigating the DDK of Tamil speaking individuals with remitting-relapsing type of Multiple Sclerosis using the Motor Speech Profile and also to correlate the duration of the disease and speech intelligibility with the DDK rate.

CHAPTER III

METHOD

The present study focused on the speech motor coordination in Tamil speaking individuals with remitting-relapsing Multiple Sclerosis (MS) using diadochokinetic tasks. The main objective of the study was to compare the DDK performance of individuals with remitting-relapsing MS, with a group of healthy controls. The second objective was to investigate the effects of the duration of the disease and speech intelligibility on DDK performance in these individuals.

Participants

A total of 10 native Tamil speaking individuals diagnosed with definite MS in the age range of 18 - 50 years were selected for the present study. The group consisted of 4 males (mean age 35.5±8.54 years) and 6 females (mean age 37.1±8.37 years). They constituted the clinical group. The participants with specifically, the remitting-relapsing type of MS, diagnosed by an experienced neurologist were selected for the study from Multiple Sclerosis Society of India-Chennai chapter and Local hospitals located in Chennai. The participants within 3 months of the last relapse of the condition were selected. Psychological issues such as depression and apathy was also ruled out through an informal assessment. Amongst the ten participants, two of them had spastic dysarthria, one had ataxic dysarthria and the rest of them did not have any dysarthria.

Ten age and gender matched neurotypical healthy individuals were included and considered as the control group. They were screened for neurological, psychological, and motor deficits.

Visual or auditory deficits in both the groups were ruled out through an informal assessment. The clinical and the control groups were matched for the socio-economic status using the NIMH socioeconomic status scale developed by Venkatesan (2011), age, and gender. The NIMH Socio-Economic Status Scale (SES) was developed to address the socio-economic status of individuals in the Indian context. This scale has sections such as occupation and education of the parents, annual family income, property, and per capita income to assess the socioeconomic status. The individuals are scored by encircling the appropriate number on a 5-point rating scale, with 1-being the lowest and 5-being the highest. The raw scores of each category are then summed to give the 'Grand Total'. The interpretative norms are also provided for the overall SES: 0-4 is SES I, 5-8 is SES II, 9-12 is SES III, 13-16 is SES IV, and 17-20 is SES V. Two participants (2 females) belonged to the SES category V, 7 participants (3 females and 4 males) belonged to SES category IV, and 1 participant (1 female) belonged to SES category III in both the clinical and the control group.

The Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) was administered for the clinical and the control group. MMSE is a 30 point questionnaire that is extensively used in clinical and research setting to measure cognitive impairment. It examines functions including registration, attention and calculation, recall, language, ability to follow simple commands and orientation. Any score greater than or equal to 24 points indicates normal cognition. Below this, scores can indicate severe (≤9 points), moderate (10-18 points), or mild (19-23 points) cognitive impairment. Only those participants who obtained a score of 24 and above on Mini Mental state examination (MMSE) (Folstein et al., 1975) were selected.

Table 3.1 *Demographic details of the clinical group (MS)*

Participant	**Age (in years)**	**Gender**	**SES***	**MMSE****	**Duration of disease (in months)**
P 1	42	F	4	20	48
P 2	43	F	4	30	12
P 3	34	F	5	30	24
P 4	47	M	4	25	36
P 5	29	M	4	29	24
P 6	37	M	4	30	10
P 7	35	F	3	21	24
P 8	23	F	5	27	7
P 9	46	F	4	27	96
P 10	29	M	4	30	96

**SES-Socio Economic Status Scale, **MMSE-Mini-Mental State Examination*

Table 3.2 *Demographic details of the control group*

Participant	**Age (in years)**	***Gender***	**SES***	**MMSE****
P 1	42	F	4	30
P 2	43	F	4	30
P 3	34	F	5	30
P 4	47	M	4	30
P 5	29	M	4	30
P 6	37	M	4	30
P 7	35	F	3	30
P 8	23	F	5	30
P 9	46	F	4	30
P 10	29	M	4	30

**SES-Socio Economic Status Scale, **MMSE-Mini-Mental State Examination*

Instrumentation:

Motor Speech Profile: The Motor Speech Profile (MSP) Model 5141 was used in this study to measure the diadochokinetic rate parameters. MSP is an integrated software and hardware system in conjugation with the Computerized Speech Lab (CSL) Model 4500 (KayPENTAX, Lincoln Park, New Jersey). It is a computer based program to extract and analyze the speech performance of individuals with motor speech disorders.

MSP is most commonly used with its built-in protocols to analyze the motor speech behavior in a systemic and automatic procedure. It provides a robust multi-dimensional analysis of motor speech behavior with graphic and numerical presentation of analysis results. There are several protocols to extract the following parameters: 1) Diadochokinetic Rate (DDK rate), 2) Second Formant Transition (F_2), 3) Voice and Tremor, 4) Intonation Stimulability, and 5) Standard Syllabic Rate.

Table 3.3 *Parameters present in Motor Speech Profile (Model 5141)*

Protocol	**Purpose**
Diadochokinetic Rate	Assesses the client’s ability to repeat consonant vowel combinations rapidly and rhythmically with brief pauses.
Second Formant Transition	Assesses the client’s ability to accurately, quickly, and rhythmically make target second formant transitions.
Voice and Tremor	Assesses the client voice quality to explore for voice problems associated with cycle-to-cycle variations (as used in phonatory function analysis) and more importantly to assess tremor characteristics commonly associated with motor speech disorders.
Intonation Stimulability	Assesses the client’s ability to listen to a target speech token and then verbally match the target’s intonation pattern.
Standard Syllabic Rate	Assesses the client’s speech rate using a standard target sentence.
Generic Syllabic Rate	Assesses the client’s speech rate using any target sentence. This protocol is only in the advanced version.

Each protocol provides the client prompts and model audio signals, records the client utterances, analyzes the data, and generates the analysis in the form of a report. It is a non-invasive and objective method to assess the speech motor characteristics.

Tools used:

AYJNIHH Speech Intelligibility Rating Scale: AYJNIHH Speech Intelligibility Rating Scale was used for the perceptual assessment of intelligibility. It provides a 7-point rating scale, where 0-indicates normal and 6-indicates severe impairment in intelligibility. The table 3.4 shows the speech intelligibility rating scale developed at AYJNIHH, Mumbai in 2008.

Amongst the ten participants, two of them had spastic dysarthria, one had ataxic dysarthria and the rest of them did not have any dysarthria. All the three dysarthric participants obtained a score of two, six participants obtained a score of one and one participant obtained a score of zero.

Table 3.4 *AYJNIHH Speech Intelligibility Rating Scale*

Description	**Score**
Normal	0
Can understand without difficulty; however feel the speech is not normal.	1
Can understand with little effort. Occasionally need to ask for few repetitions.	2
Can understand with circumstances and effort especially by sympathetic listener. Require a minimum of 2 or 3 repetitions.	3
Can understand with difficulty and concentration by family members, but not by others.	4
Can understand with efforts if content is known.	5
Cannot understand at all, even if content is known.	6

Procedure

All ethical considerations were met and a written consent was obtained from all the participants or the caregivers who were included in the study. A proper rapport was built with the participants by engaging them in casual conversation. The demographic data and detailed medical history were obtained. Following this, preliminary assessments and screening procedures were carried out. MMSE and NIMH socioeconomic status scales were administered on both the clinical and the control group. An informal Oral Peripheral Mechanism Examination (OPME) was carried out to investigate the structure and function of the oral structures. The samples of DDK were recorded using an audio recorder in a quiet environment with minimal auditory and visual distractions in a comfortable seated position. The audio recorder was placed at a distance of 10cm from the mouth. Prior to the sample recording, a standard set of instructions were provided to the participants for each recording. To record the samples, the subjects were instructed to produce multiple repetitions of /pa/, /ta/, /ka/ (Alternating Motion Rate) and /pa-ta-ka/ (Sequential Motion Rate) separately as rapidly as possible for at least 8 seconds. The participants were asked to listen to the model provided by the examiner for each task prior to the task. Two practice trials were given for familiarization purpose. A total of three trials were recorded for each task.

To measure the intelligibility of the participants, a spontaneous speech sample task was obtained and recorded. The spontaneous speech sample was based on their education and lifestyle. The participants were instructed to speak fluently in complete sentences for the spontaneous speech task. A minimum of 150-200 words were audio recorded for the intelligibility measure. The recorded samples were perceptually assessed for speech intelligibility using perceptual rating scale (AYJNIHH Speech Intelligibility Rating Scale) by three trained Speech-Language Pathologists (SLPs).

Analysis

All the parameters of DDK such as temporal and intensity were analyzed using the MSP module for both the AMR and SMR tasks. The recorded samples were cut and annotated using PRAAT-version 5.4.02 (Boersma & Weenik, 2000). The audio samples were then loaded to the software to carry out the analysis. The initial and the final portions of the samples were excluded from the analysis, approx. 5 seconds from each of the samples were analyzed. The MSP software captures several aspects such as rate, average period, various measures of perturbations in period, and intensity was used for this purpose. The Diadochokinetic Rate Analysis (DRA) is an automated built-in protocol of the MSP which generates 11 temporal and intensity DDK rate parameters. The DDK rate parameters have been provided in the Table 3.5. The DRA protocol works either with online recording or digital audiotaped recording of DDK. This protocol measures the client's ability to repeat a C-V combination (i.e., "pa…pa…pa…"etc.) in a fast, constant-level, and rhythmic manner. The DRA protocol generates the following parameters:

- **DDKavp (Average DDK period) /ms/** - This is the average DDK period of the client during this vocalization. The average period is the average time between the C-V (i.e., "pa") vocalizations. The period is inversely related to the rate.

- **DDKavr (Average DDK rate) /s/** - This is the average DDK rate of the client during this vocalization. The average rate is the number of the C-V (i.e., "pa") vocalizations per second. The rate is inversely related to the average period. Many motor disordered speakers show reduced DDK rates due to decreased articulatory motility.

- **DDKsdp (Standard Deviation of DDK Period) /ms/** - This is the standard deviation of the DDK period. A normal speaker can maintain periodic repetitions while many disordered voices show more variability in their repetition rate, therefore increased DDKsdp.

- **DDKcvp (Coefficient of Variation of DDK period) /%/** - This parameter measures the degree of rate variation in the period. If the C-V vocalization is repeated with little variation in rate, then this number is very small. However, as a speaker varies the rate of DDK during the seven-second-analysis window, this number increases. This parameter is assessing the client's ability to maintain a constant rate of C-V combinations. As differentiated from DDKjit, DDKcvp increases whether the variation is due to cycle-to-cycle changes or increases/decreases over the seven-second window.

- **DDKjit (Perturbations of DDK period) /%/** - This parameter measures the degree of cycle-to-cycle variation in the period. If the C-V vocalization is repeated with little variation in cycle-to-cycle rate, then this number is very small. However, as a speaker varies the rate of DDK during the seven-second-analysis window, this number increases. This parameter is assessing the client's ability to maintain a constant rate of C-V combinations.

- **DDKavi (Average DDK Peak Intensity) /dB/** - This is the peak intensity (i.e., amplitude or loudness) for the target vocalization (i.e., "pa pa..."). This number is only meaningful if the microphone position is fixed relative to the speaker.

- **DDKsdi (St. Deviation of DDK Peak Intensity) /dB/** - This is the standard deviation of the DDK peak intensity. This parameter assesses the ability of the subject to maintain a steady amplitude for the target vocalization. Higher values indicate less ability to maintain steady amplitude.

- **DDKcvi (Coefficient of Variation of DDK Peak Intensity) /%/** - This parameter measures the degree of intensity variation in the peak of each C-V vocalization. If the C-V vocalization is repeated with little variation in intensity, then this number is very small. However, as a speaker varies the intensity of DDK during the seven-second-analysis window, this number increases. This parameter is assessing the client's ability to maintain a constant amplitude (i.e., intensity) of C-V combinations.

- **DDKmxa (Maximum Intensity of DDK Sample) /dB/** - This is the maximum level of the peak amplitude in the signal. This maximum is a relative measurement unless input sensitivity is in known position and the microphone distance is at known distance.

- **DDKava (Average Intensity of DDK Sample) /dB/** - This is the average level of the peak amplitude in the signal.

- **DDKsla (Average Syllabic Intensity) /dB/** - This is the average level of the syllable.

Amongst the above explained DDK parameters, average DDK period, average DDK rate, standard deviation of DDK period, coefficient of variation of DDK period, and perturbation of DDK period were categorized under the DDK temporal parameters while the other parameters such as average DDK peak intensity, standard deviation of DDK peak intensity, coefficient variant of DDK peak intensity, maximum intensity of DDK sample, average intensity of DDK sample, and average syllabic intensity were categorized under the DDK intensity parameters.

Table 3.5: *DDK rate parameters.*

Sl. No.	Diadochokinetic Rate Parameters	Symbol	Unit
1.	Average DDK Period	DDKavp	ms
2.	Average DDK Rate	DDKavr	/s
3.	Standard Deviation of DDK Period	DDKsdp	ms
4.	Coefficient of Variation of DDK Period	DDKcvp	%
5.	Perturbation of DDK Period	DDKjit	%
6.	Average DDK Peak Intensity	DDKavi	dB
7.	Standard Deviation of DDK Peak Intensity	DDKsdi	dB
8.	Coefficient Variation of DDK Peak Intensity	DDKcvi	%
9.	Maximum Intensity of DDK Sample	DDKmxa	dB
10.	Average Intensity of DDK Sample	DDKava	dB
11.	Average Syllabic Intensity	DDKsla	dB

The MSP generates a graphic representation of all the parameters against its database (Deliyski & Gress, 1997). It also displays the analyzed parameters in a table that incorporates normative values to help identify potentially important clinical differences.

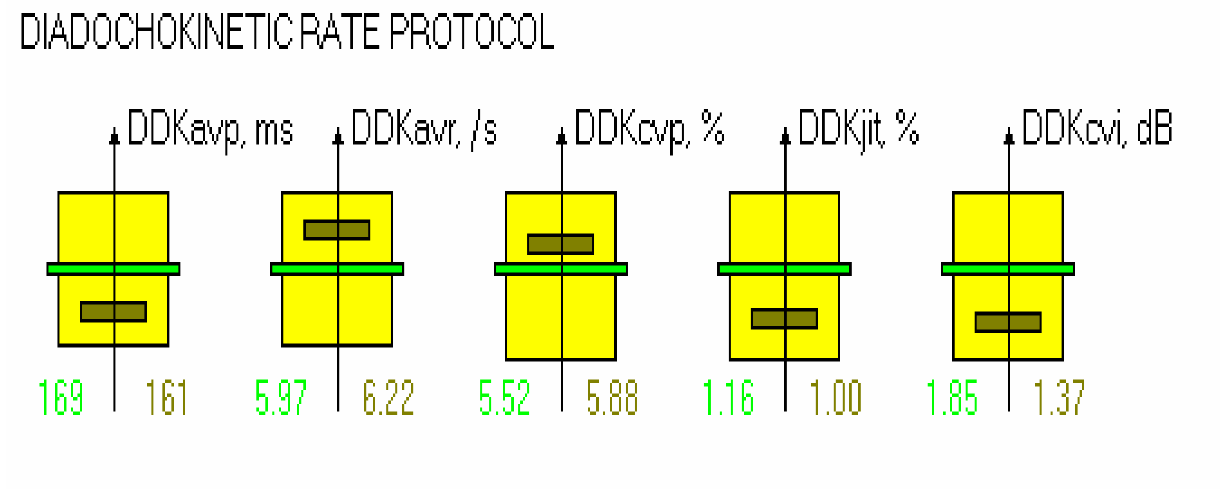

Figure 3.1: DDK rate graphic representation in MSP.

All the recorded samples were subjected to the DRA protocol. The recordings were analyzed by selecting a 5 second time frame from the 8 second recorded samples. The same was carried out for all the tokens and finally the average of the three trials was considered.

Test-retest reliability and Inter-rater agreement

Test-retest reliability was established for 12 participants (6 from the control group and 6 from the clinical group) selected for the study using Cronbach's Alpha reliability test. They were tested within a span of one to two weeks. Inter-judge agreement was found for the intelligibility rating using the Kappa's Coefficient test since an ordinal rating scale was used for the rating. The recorded samples of spontaneous speech task were rated by three trained SLPs with a minimum of two years' experience including the investigator. The annotated samples were randomized. The SLPs were familiarized on the perceptual rating and then the samples were played to the judges for the analysis. There was no time constraints applied to the judges for the analysis. The judges were allowed to play the samples as many times as needed for their judgement. The judges were blinded to the identity of the participants. The scores were collected from all the three judges and the reliability measures were calculated.

Statistical Analysis

After analysis, the parameters were tabulated and subjected to statistical analysis in Statistical Package for the Social Sciences (SPSS) software package (Version 21.0). Descriptive statistics was carried out to calculate mean, median and standard deviation. All the data was subjected to the normality test across the groups. The Shapiro-Wilk's test was employed to determine the normality of the data distribution. The result showed that most of the data did not follow the normal distribution principles. The principle of normality was violated due to the presence of outliers. Trimming of the outliers to bring about the normal distribution was not possible since, different outliers were observed for different parameters. Hence the non-parametric test, Mann Whitney U test was used to compare between the clinical and the control groups and the Wilcoxson's Signed Rank test was used for the matched pair-wise comparison between the clinical and the control groups. Finally, Spearman's rank correlation was used to find the correlation between the intelligibility measures and the duration of the disease with the DDK parameters.

CHAPTER IV

RESULTS

The present study investigated the speech motor coordination in individuals with remitting-relapsing Multiple Sclerosis using diadochokinetic tasks. The objective of the study was to compare the eleven diadochokinetic rate (DDK) parameters, obtained using the DRA protocol of the Motor Speech Profile (Model 5141) module, with age- and gender-matched neurotypical individuals. The study also aimed to investigate the effects of the duration of the disease and speech intelligibility on DDK performance.

A total of twenty Tamil speaking individuals between 18-50 years of age were selected for the study. Ten of them were individuals with remitting-relapsing Multiple Sclerosis (clinical group) and the remaining ten were neurotypical individuals (control group). There were 4 males and 6 females, each in both the groups. The participants were scored based on their performance on the DDK tasks and spontaneous speech tasks. The data obtained was analyzed using the MSP (model 5141) module in CSL (model 4500) and the values were tabulated in the SPSS software version 21.0 for further statistical analysis. The following statistical procedures were used:

- Cronbach's alpha reliability test was used to determine the test-retest reliability for the DDK parameters.
- Kappa's Coefficient was used to determine the inter-judge agreement for the intelligibility rating.
- Descriptive statistics was carried out to calculate the mean, median, and standard deviation for all the eleven parameters of DDK.

- Shapiro-Wilk's test was used to determine the normality of the data.

- Non-parametric tests were used since the normality principle was violated. Mann Whitney U test was employed for the group comparison and Wilcoxson's Signed Rank test was used for the matched pair wise comparison of the DDK parameters.

- Spearman's rank correlation coefficient was used to find the correlation between the intelligibility and the duration of the disease with the DDK parameters.

The results of the study have been presented under the following main sections:

I. Reliability

II. Group and pair wise comparison of the DDK parameters

III. Relationship between intelligibility and DDK parameters

IV. Relationship between the duration of the disease and DDK parameters

I. Reliability

a) Test retest reliability:

Test-retest reliability was established for 12 participants (6 from the control group and 6 from the clinical group) selected for the study. They were tested within a span of one to two weeks. Cronbach's alpha reliability test was considered for the reliability measure. The Cronbach's alpha was found to be more than 0.95 for all the parameters for both the clinical and the control group. This indicated that the test-retest reliability was good.

b) Inter-judge agreement:

Kappa's Coefficient was used to find the agreement between the judges in spontaneous speech for the clinical group, since the intelligibility rating was assessed using an ordinal scale. In the clinical group, the agreement between Judge 1 and Judge 2 was K=0.83, $p < 0.05$; agreement between Judge 1 and Judge 3 was K=1, $p < 0.05$; and the agreement between Judge 2 and Judge 3 was K=0.83, $p < 0.05$. Since moderate to good agreement was observed between the judges' intelligibility rating, the majority rating among the three judges was considered for further statistical analysis.

II. Group and pair wise comparison of the DDK parameters:

There were four different tasks in the diadochokinetic rate protocol such as the repetition of /pa/, /ta/, /ka/ (AMR), and /pa-ta-ka/ (SMR). The performance of the clinical and the control group on each task was analyzed. The data was subjected to descriptive statistical methods to obtain the mean, median and the standard deviation of different tasks and non-parametric tests were used for the group and matched pair wise comparison. The results have been presented according to each task below.

a) Comparison between the clinical and the control group for AMR task of repetition of /pa/:

Table 4.1 depicts the mean, standard deviation (SD) and the median values for the AMR task of repetition of /pa/ for the clinical and the control group. On comparison of the mean values, it was seen that the DDK rate was lower in the clinical group (mean DDKavr= 4.64±0.33) when compared with the control group (mean DDKavr= 6.03±0.12). The clinical group also presented with increased syllabic duration (mean DDKavp= 218.70±17.39) than the control group (mean DDKavp= 166.50±3.24). The intensity parameters of the DDK such as the average DDK peak intensity, standard deviation of the DDK peak intensity, maximum intensity of the DDK sample, and the average intensity of the DDK sample were lower in the clinical group than in the control group. All these mean values were subjected to Mann Whitney U test, to check for any significant difference between the control and the clinical group. The result indicated that there was a significant difference for all the eleven DDK parameters. The $|Z|$ values have been depicted in the Table 4.1. The results also revealed that the temporal and the intensity parameters were reduced with increased period and perturbation measures.

Table 4.1:

Mean, Standard deviation (SD), Median, and $|Z|$ values of both the clinical and the control groups for AMR task of repetition of /pa/

Parameter#	Clinical Group			Control Group			$\|Z\|$ value
	Mean	**SD**	**Median**	**Mean**	**SD**	**Median**	
DDKavp	218.70	17.39	216.50	166.50	3.24	166.50	3.78**
DDKavr	4.64	0.33	4.58	6.03	0.12	6.04	3.78**
DDKsdp	11.74	0.92	11.90	8.54	2.32	8.44	3.13**
DDKcvp	7.48	0.58	7.55	6.52	0.83	6.80	2.34*
DDKjit	2.13	0.44	2.30	1.27	0.46	1.28	3.06**
DDKavi	59.93	8.08	62.06	72.77	4.12	72.81	3.40**
DDKsdi	1.86	0.32	1.87	1.50	0.18	1.53	2.53**
DDKcvi	3.19	0.44	3.17	1.88	0.28	1.83	3.70**
DDKmxa	63.02	7.23	65.68	80.55	5.54	80.35	3.70**
DDKava	45.97	5.21	44.11	61.28	5.08	61.30	3.62**
DDKsla	54.36	5.79	54.46	67.21	4.54	67.24	3.47**

#DDKavp-Average DDK Period, DDKavr-Average DDK rate, DDKsdp-Standard Deviation of the DDK period, DDKcvp-Coefficient of Variation of DDK Period, DDKjit-Perturbation of DDK period, DDKavi-Average DDK Peak Intensity, DDKsdi-Standard Deviation of the DDK Peak Intensity, DDKcvi-Coefficient of Variation of DDK Peak Intensity, DDKmxa-Maximum Intensity of DDK Sample, DDKava-Average Intensity of DDK Sample, DDKsla-Average Syllabic Intensity.; $*p<0.05$, $**p<0.01$

Since all the DDK parameters for the task /pa/ had a significant difference between the clinical and the control group, Wilcoxson-Signed Rank test was used to compare the performance of /pa/ across the age-matched participants between the two groups. The result indicated a high significant ($p<0.01$) difference between the clinical and the control group which was in line with the results of the group comparison.

b) *Group comparison between the clinical and the control group for AMR task of repetition of/ta/:*

Table 4.2 depicts the mean, standard deviation (SD) and the median values for the AMR task of repetition of /ta/ for the clinical and the control group. On comparison of the mean values, it was seen that the DDK rate was lower in the clinical group (mean DDKavr= 4.35±0.74) when compared with the control group (mean DDKavr= 6.02±0.20). The clinical group also presented with increased syllabic duration (mean DDKavp= 235.70±56.54) than the control group (mean DDKavp= 166.60±5.75). The intensity parameters of the DDK such as the average DDK peak intensity, standard deviation of the DDK peak intensity, maximum intensity of the DDK sample, and average intensity of the DDK sample were lower in the clinical group than in the control group. All these mean values were subjected to Mann Whitney U test, to check for any significant difference between the control and the clinical group. The result indicated that there was a significant difference for all the eleven DDK parameters. The $|Z|$ values have been depicted in the Table 4.2. The results also revealed that the temporal and the intensity parameters were reduced with increased period and perturbation measures.

Table 4.2:

Mean, Standard deviation (SD), Median, and │Z│ values of both the clinical and the control groups for AMR task of repetition of /ta/

Parameters#	**Clinical Group**			**Control Group**			**│Z│ values**
	Mean	**SD**	**Median**	**Mean**	**SD**	**Median**	
DDKavp	235.70	56.54	230.50	166.60	5.75	169.00	3.79**
DDKavr	4.35	0.74	4.33	6.02	0.20	5.99	3.78**
DDKsdp	10.92	1.34	10.88	7.91	2.19	8.27	2.87**
DDKcvp	7.30	0.51	7.20	5.73	1.45	6.34	2.68**
DDKjit	2.12	0.34	2.11	1.22	0.20	1.19	3.78**
DDKavi	59.67	7.40	59.62	67.78	3.79	67.98	2.42*
DDKsdi	1.91	0.31	2.06	1.29	0.20	1.33	3.48**
DDKcvi	3.26	0.65	3.39	1.92	0.31	1.86	3.63**
DDKmxa	63.30	7.08	65.00	75.50	4.47	74.55	3.62**
DDKava	46.22	4.38	46.03	58.74	3.28	58.58	3.78**
DDKsla	55.73	5.11	57.30	64.32	2.88	63.67	3.79**

*#DDKavp-Average DDK Period, DDKavr-Average DDK rate, DDKsdp-Standard Deviation of the DDK period, DDKcvp-Coefficient of Variation of DDK Period, DDKjit-Perturbation of DDK period, DDKavi-Average DDK Peak Intensity, DDKsdi-Standard Deviation of the DDK Peak Intensity, DDKcvi-Coefficient of Variation of DDK Peak Intensity, DDKmxa-Maximum Intensity of DDK Sample, DDKava-Average Intensity of DDK Sample, DDKsla-Average Syllabic Intensity.; *$p<0.05$, **$p<0.01$*

Since all the DDK parameters for the task /ta/ had a significant difference between the clinical and the control group, Wilcoxson-Signed Rank test was used to compare the performance of /ta/ across the age-matched subjects between the two groups. The result indicated a high significant ($p<0.01$) difference between the clinical and the control group which was similar to the results of group comparison.

c) Group comparison between the clinical and the control group for AMR task of repetition of/ka/:

Table 4.3 depicts the mean, standard deviation (SD) and the median values for the AMR task of repetition of /ka/ for the clinical and the control group. On comparison of the mean values, it was seen that the DDK rate was lower in the clinical group (mean DDKavr= 4.32±0.57) when compared with the control group (mean DDKavr= 6.01±0.11). The clinical group also presented with increased syllabic duration (mean DDKavp= 236.00±36.30) than the control group (mean DDKavp= 166.10±3.78). The intensity parameters of the DDK such as the average DDK peak intensity, standard deviation of the DDK peak intensity, maximum intensity of the DDK sample, and average intensity of the DDK sample were lower in the clinical group than in the control group. All these mean values were subjected to Mann Whitney U test, to check for any significant difference between the control and the clinical group. The result indicated that there was a significant difference for all the eleven DDK parameters. The $|Z|$ values have been depicted in the Table 4.3. The results also revealed that the temporal and the intensity parameters were reduced with increased period and perturbation measures.

Table 4.3:

Mean, Standard deviation (SD), Median, and $|Z|$ values of both the clinical and the control groups for AMR task of repetition of /ka/

Parameters#	Clinical Group			Control Group			$\|Z\|$ values
	Mean	SD	Median	Mean	SD	Median	
DDKavp	236.00	36.30	221.50	166.10	3.78	167.00	3.78**
DDKavr	4.32	0.57	4.51	6.01	0.11	6.03	3.78**
DDKsdp	10.81	1.12	11.44	8.41	2.47	8.33	2.27*
DDKcvp	7.42	0.47	7.34	5.57	1.37	5.48	3.10**
DDKjit	1.99	0.22	2.02	1.21	0.50	1.11	3.25**
DDKavi	61.45	5.41	61.78	68.63	3.90	69.37	2.87**
DDKsdi	1.99	0.22	2.01	1.64	0.13	1.63	3.21**
DDKcvi	3.34	0.50	3.35	2.06	0.17	2.08	3.78**
DDKmxa	64.96	4.52	66.34	73.09	5.80	72.41	2.87**
DDKava	47.66	4.47	49.60	58.73	4.04	59.30	3.78**
DDKsla	57.57	4.02	57.54	64.98	3.69	65.38	3.17**

*#DDKavp-Average DDK Period, DDKavr-Average DDK rate,DDKsdp-Standard Deviation of the DDK period,DDKcvp-Coefficient of Variation of DDK Period, DDKjit-Perturbation of DDK period, DDKavi-Average DDK Peak Intensity, DDKsdi-Standard Deviation of the DDK Peak Intensity, DDKcvi-Coefficient of Variation of DDK Peak Intensity, DDKmxa-Maximum Intensity of DDK Sample, DDKava-Average Intensity of DDK Sample, DDKsla-Average Syllabic Intensity., *p<0.05, **p<0.01*

Since all the DDK parameters for the task /ka/ had a significant difference between the clinical and the control group, Wilcoxson-Signed Rank test was used to compare the performance of /ka/ across the age-matched subjects between the two groups. The result indicated a high significant ($p<0.01$) difference between the clinical and the control group which was similar to the results of group comparison.

d) Group comparison between the clinical and the control group for SMR task of repetition of /pa-ta-ka/:

Table 4.4 depicts the mean, standard deviation (SD) and the median values for the AMR task of repetition of /pa-ta-ka/ for the clinical and the control group. On comparison of the mean values, it was seen that the DDK rate was lower in the clinical group (mean DDKavr= 4.38±0.54) when compared with the control group (mean DDKavr= 6.56±0.14). The clinical group also presented with increased syllabic duration (mean DDKavp= 232.80±31.13) than the control group (mean DDKavp= 152.80±4.18). The intensity parameters of the DDK such as the average DDK peak intensity, standard deviation of the DDK peak intensity, maximum intensity of the DDK sample, average intensity of the DDK sample and the average syllabic rate were lower in the clinical group than in the control group. All these mean values were subjected to Mann Whitney U test, to check for any significant difference between the control and the clinical group. The result indicated that there was a highly significant difference for all the eleven DDK parameters. The $|Z|$ values have been depicted in the Table 4.4. The results also revealed that the temporal and the intensity parameters were reduced with increased period and perturbation measures.

Table 4.4:

Mean, Standard deviation (SD), Median, and |Z| values of both the clinical and the control groups for SMR task of repetition of/pa-ta-ka/

Parameters#	Clinical Group			Control Group			|Z| values**
	Mean	SD	Median	Mean	SD	Median	
DDKavp	232.80	31.13	232.00	152.80	4.18	152.00	3.11
DDKavr	4.38	0.54	4.34	6.56	0.14	6.57	3.78
DDKsdp	11.29	1.01	11.25	8.05	2.10	7.86	3.78
DDKcvp	7.44	0.44	7.45	5.85	1.11	5.72	3.17
DDKjit	2.11	0.40	2.12	1.17	0.33	1.07	3.17
DDKavi	61.50	5.78	62.13	69.68	4.73	70.02	3.48
DDKsdi	2.05	0.32	2.22	1.50	0.19	1.48	2.95
DDKcvi	3.26	0.66	3.42	2.10	0.25	2.08	3.11
DDKmxa	64.41	4.63	64.04	81.91	6.95	83.37	3.40
DDKava	46.72	3.84	47.56	59.31	4.82	59.58	3.33
DDKsla	56.62	3.45	56.72	65.91	4.31	65.76	3.63

*#DDKavp-Average DDK Period, DDKavr-Average DDK rate, DDKsdp-Standard Deviation of the DDK period,DDKcvp-Coefficient of Variation of DDK Period, DDKjit-Perturbation of DDK period, DDKavi-Average DDK Peak Intensity, DDKsdi-Standard Deviation of the DDK Peak Intensity, DDKcvi-Coefficient of Variation of DDK Peak Intensity, DDKmxa-Maximum Intensity of DDK Sample, DDKava-Average Intensity of DDK Sample, DDKsla-Average Syllabic Intensity, **p<0.01*

Since all the DDK parameters for the task /pa-ta-ka/ had a significant difference between the clinical and the control group, Wilcoxson-Signed Rank test was used to compare the performance of /pa-ta-ka/ across the age-matched subjects between the two groups. The result indicated a high significant ($p<0.01$) difference between the clinical and the control group which was similar to the results of group comparison.

e) Comparison between the average DDK rate on the AMR tasks in both the groups:

On visual inspection it was also noted that as the syllable proceeded from anterior to posterior, the average rate of the syllable reduced. This trend was seen in both clinical and the control group. From the Table 4.5 we can infer that the rate of /pa/ was the higher followed by /ta/ and /ka/, which shows a decreasing trend in the syllabic rates as the place of articulation moved back towards the soft palate.

Table 4.5:

Mean DDK rates and Standard deviation (SD) of /pa/, /ta/, and /ka/ for both the groups

DDK tasks	Clinical group		Control group	
	Mean	**SD**	**Mean**	**SD**
/pa/	4.64	0.33	6.03	0.12
/ta/	4.35	0.74	6.02	0.20
/ka/	4.32	0.57	6.01	0.11

III. Relationship between speech intelligibility measures and DDK parameters:

Kappa's Coefficient was used to find the agreement between the judges in spontaneous speech for the clinical group. Since moderate to good agreement was observed between the judges' intelligibility rating, the majority rating among the three judges was considered for further statistical analysis. Amongst the ten participants, two of them had spastic dysarthria, one had ataxic dysarthria and the rest of them did not have any dysarthria. All the three dysarthric participants obtained a score of two, six participants obtained a score of one and one participant obtained a score of zero. Using Spearman's rank correlation, the final intelligibility scores for spontaneous speech and the DDK parameters were subjected for correlation analysis.

Only few of the parameters had strong to very strong positive correlation and negative ($p<0.05$) with the intelligibility scores, while the other parameters had no correlation ($p>0.05$) with the intelligibility rating. Table 4.6 depicts the parameters that correlated with the spontaneous speech (SS) intelligibility scores. The average DDK peak intensity (DDKavi) of /pa/, /ta/ and /ka/, maximum intensity of the DDK sample (DDKmxa) of /ta/, and average syllabic intensity of DDK sample (DDKsla) of /ta/ correlated with the intelligibility rating, correlated with the intelligibility measures, while the other measures had no correlation with the DDK parameters.

Table 4.6:

DDK parameters correlating with the intelligibility scores (SS)

Parameters	Syllable	Spearman's rho	p values
DDKavi	/pa/	0.64	0.02*
	/ta/	0.70	0.01*
	/ka/	0.68	0.02*
DDKmxa	/ta/	0.82	0.00**
DDKsla	/ta/	0.81	0.00**

*#DDKavi-Average DDK Peak Intensity, DDKmxa-Maximum Intensity of DDK Sample, DDKsla-Average Syllabic Intensity. **p<0.01, *p<0.05*

From the above table it can be noted that the average DDK peak intensity of /pa/, /ta/ and /ka/had strong positive correlation ($p<0.05$), whereas the other parameters like maximum intensity of DDK sample and average syllable intensity of /ta/had very strong positive correlation ($p<0.01$) with the intelligibility rating of the spontaneous speech task.

IV. Relationship between the duration of the disease and the DDK parameters

Spearman's rank correlation was employed to determine the relationship between the duration of the disease and the DDK parameters. Strong to very strong positive and negative correlation was found only between few of the DDK parameters and the duration of the disease. Table 4.7 depicts the DDK parameters which were found to have correlation with the duration of the disease. Standard deviation of DDK period (DDKsdp) and average syllabic intensity (DDKsla) for the syllable /ta/, average intensity of DDK sample (DDKava) and standard deviation of DDK peak intensity (DDKsdi) for the syllable /pa/, average DDK peak intensity (DDKavi) and maximum intensity of DDK sample (DDKmxa) for all the DDK tasks (/pa/, /ta/, /ka/, and /pa-ta-ka/) correlated ($p<0.05$) with the duration of the disease, whereas the other parameters had no correlation ($p>0.05$) with the duration of the disease.

Table 4.7:

DDK parameters correlating with the duration of the disease

Parameters	Syllable	Spearman's rho	p values
DDKsdp	/ta/	0.69	0.02*
	/pa/	0.79	0.00**
DDKavi	/ta/	0.86	0.00**
	/ka/	0.86	0.00**
	/pa-ta-ka/	0.65	0.04*
DDKsdi	/pa/	-0.65	0.04*
	/pa/	0.73	0.02*
DDKmxa	/ta/	0.82	0.00**
	/ka/	0.77	0.00**
	/pa-ta-ka/	0.63	0.04*
DDKava	/pa/	0.63	0.04*
DDKsla	/ta/	0.81	0.00**

*#DDKsdp-Standard Deviation of the DDK period,DDKavi-Average DDK Peak Intensity, DDKsdi-Standard Deviation of the DDK Peak Intensity, DDKmxa-Maximum Intensity of DDK Sample, DDKava-Average Intensity of DDK Sample, DDKsla-Average Syllabic Intensity. *p<0.05, **p<0.01*

Only one DDK temporal parameter (standard deviation of the DDK period) and few intensity parameters (average DDK peak intensity, standard deviation of the DDK peak intensity, maximum intensity of DDK sample, average intensity of DDK sample, and average syllabic intensity of DDK sample) correlated with the duration of the disease. Among the parameters that correlated with the duration of the disease, parameters like standard deviation of the DDK period of /pa/, average DDK peak intensity of /pa-ta-ka/, maximum intensity of DDK sample of /pa/ and

/pa-ta-ka/, and average intensity of DDK sample of /pa/ had strong positive correlation ($p<0.05$), whereas the other parameters such as average DDK peak intensity of /pa/, /ta/ and /ka/, maximum intensity of DDK sample of /ta/ and /ka/, and average syllabic intensity of DDK sample of /ta/ had very strong positive correlation ($p<0.01$), and one DDK parameter, i.e., standard deviation of the DDK peak intensity of /pa/ had strong negative correlation ($p<0.05$).

In sum, there was a significant difference found between the clinical and control group in all the eleven parameters of DDK. The clinical group presented with lower DDK rates, increased SD, increased intervals between the syllables, reduced intensity within and across the syllable, increased variation coefficients and increased jitter ratio when compared with the control group. It was also noted that as the syllable proceeded from anterior to posterior, the average rate reduced for the syllables in both the clinical and the control group. Further, only a few intensity-related parameters of DDK correlated with intelligibility rating of spontaneous speech and duration of the disease. In addition, one DDK temporal parameter the standard deviation of the DDK period correlated with duration of the disease.

CHAPTER V

DISCUSSION

The current study aimed to investigate the motor speech coordination of Tamil speaking individuals with remitting-relapsing type of multiple sclerosis (MS) using MSP (model 5141). The diadochokinetic rate protocol (DRA) consisting of eleven parameters of DDK in MSP was used in analyzing the collected data. There were four different tasks for DDK which includes the rapid repetition of the syllables /pa/, /ta/, /ka/, and /pa-ta-ka/ sequentially and alternatively. The participants were asked to repeat the syllables as rapidly as possible without breaks for a minimum of 8 seconds. The samples were recorded using audio recorder and annotated using PRAAT (version 5.4.02) software. The samples were then analyzed using the DRA protocol in the MSP module (model 5141) of CSL (model 4500). The obtained values were tabulated in the SPSS version 21.0 for further statistical analyses. The analysis revealed the following:

- There was a significant difference between the clinical and control group in all the eleven temporal related and intensity parameters of DDK.
- The clinical group presented with lower DDK rates, increased standard deviation, increased syllabic duration, reduced intensity within and across the syllable, increased variation coefficients and increased jitter ratio when compared with the control group.
- It was also noted that as the syllable proceeded from anterior to posterior, the average rate reduced for the syllables in both the clinical and the control group.

- Only few intensity-related parameters of DDK correlated with the intelligibility and duration of the disease. In addition, one temporal related parameter (standard deviation of the DDK period) also correlated with the duration of the disease.

The discussion of the results obtained has been presented under the following headings:

I. Comparison between the clinical and the control group on the DDK parameters

II. Relationship between the DDK parameters and intelligibility rating

III. Relationship between the DDK parameters and duration of the disease

I. Comparison between the clinical and the control group

The outcome of the study revealed that there was a significant difference on all the eleven parameters, i.e. average DDK period (DDKavp), average DDK rate (DDKavr), standard deviation of DDK period (DDKsdp), coefficient of variation of DDK period (DDKcvp), perturbation of DDK period (DDKjit), average DDK peak intensity (DDKavi), standard deviation of DDK peak intensity (DDKsdi), coefficient variation of DDK peak intensity (DDKcvi), maximum intensity of DDK sample (DDKmxa), average intensity of DDK sample (DDKava) and average syllabic intensity (DDKsla) across the groups for all the four tasks. Significant difference was found in both the temporal and the intensity parameters for AMR (/pa/, /ta/, and /ka/) and SMR (/pa-ta-ka/) tasks indicating that these measures were affected in the MS group when compared with the neurotypical group.

a) Reduced syllabic rates:

AMR and SMR requires the production of a sequence of a syllable, such that only the two articulators, the jaw and the lips for /pa/, the jaw and the anterior tongue for /ta/ and the jaw and the posterior tongue for /ka/, are used continuously or alternatively. Since, individuals with MS have weakness in their oral structures, and the same articulators are used repeatedly in this task, fatigue may set it in resulting in a marked delay in the articulation rates in the syllable repetition task.

The reduced syllabic rate can be related to increased syllable duration. At the articulatory level, the syllable repetition trains consist of successive opening and closing gestures. Thus, slowed movement execution, consequent to weakness in oral structures, might contribute to the delayed transition between successive movements which in turn might contribute to the reduced syllabic rates (Mardsen 1982; Mardsen, 1989).

The findings of the present study are in agreement with the findings reported in the literature. Fletcher (1972) also indicated that motor disordered speakers show reduced DDK rates due to decreased articulatory motility. Klatt (1976) also indicated in his study that individuals with MS have a marked muscular weakness that affects respiration, causes breathy phonation and hypernasality and hence can result in reduced syllabic rate. He also notified that individuals with MS use a compensatory decrease in the speech rate to enhance intelligibility. Darley et al. (1972) reported that the four measures of oral diadochokinesis (/pa/, /ta/, /ka/, and /pa-ta-ka/) deviated from the normal (i.e. reduced syllabic rates) as the number of systems involved in the disease progression increased.

Hirose (1986) reported that individuals with MS have a reduced range of articulatory movement, inconsistency in the dynamic patterns of articulatory gestures, and a slow-down in the rate due to the presence of underlying neurological deficits. Tjaden and Watling (2003) suggested that the individuals with MS may use a slower rate in the DDK tasks to assure accurate syllable productions, to produce syllables more accurately and precisely.

Konstantopoulos et al. (2011) in their study reported that the articulation rate in the MS dysarthric group was significantly lower than in the control speakers. The lower articulation rate of the MS dysarthric group has been accounted to the slight incoordination of the muscles in the oropharyngeal area and fatigue, which are sum of the most significant neurological signs in the disability of MS. The authors also reported that the slower speech rate in the MS dysarthric group was mainly caused by significantly longer stop gap durations and the duration of the vowels, which also indicates fatigue and discoordination in the speakers with MS. The authors also concluded that the oral diadochokinesis (SMR and AMR) constitutes a very simple way of determining the speech imperfections in MS. The findings of the current study is also in par with the study done by Nishio and Niimi (2006), where they stated that repetition of a syllable at maximum speed directly reflects the neuromuscular function in normal speakers; whereas in individuals with dysarthria, the values of all parameters of DDK were found to be much lower than the control group. They also indicated that the AMR tend to directly reflect abnormalities in neuromuscular function.

b) *Reduction in the syllabic rate from /pa/ to /ka/:*

The results indicated that as the syllable production proceeded from anterior /pa/ to posterior /ka/, the syllabic rate reduced in both the clinical and the control group. The average DDK rates (DDKavr) of /pa/, /ta/, and /ka/ for the clinical group were 4.64sy/s, 4.35sy/s and 4.32/s respectively and the average DDK rates (DDKavr) of /pa/, /ta/, and /ka/ for the control group were 6.03sy/s, 6.02sy/s and 6.01sy/s respectively. This progressive reduction in the number of syllables uttered as the placement of the syllable went more posterior may be attributed to the effort needed to produce the syllables. The effort required to produce the labial phoneme /pa/ is the least followed by the tongue tip phoneme /ta/ and later by /ka/ (Deepa & Jayashree, 2012). These findings have been demonstrated in the literature for the normal and the disordered population.

Deepa and Jayashree (2012) in their study also found similar results. The authors reported that there was a reduction in the syllabic rate as the utterances were produced more posterior in the oral cavity. They attributed the reduction to the effort required for the production of the syllables and the increased number of muscles involved in the production of the syllables as the articulatory position moves backward. Prathanee (1998) has also commented that for the production of the bilabial sounds only the orbicularis muscles are involved, but for the production of the tongue tip and the back of the tongue sounds, several other muscles are involved. This indicates that more effort is required for the production of the posterior sounds when compared with the anterior sounds. Ziegler (2002) in his study also interpreted the slower syllabic rate of /ka/ when compared to the other syllables as an effect of the effort required to produce the /k/ onset syllable.

Tjaden and Marterl-Sauvageau (2017) also reported that the syllabic rate was higher for the anterior syllables than for the posterior sounds. They termed the effect as the position effect and indicated that it differed based on the strength of the articulators. Westbury and Dembowski (1991) also stated that the individuals with MS selected in their study showed higher rates for /pa/ and /ta/ (roughly equal) and slower rates for /ka/. A kinematic study by Hartelius and Lillvik (2003) indicated that the tongue function was significantly more severely affected than the lip function in MS individuals with and without dysarthria. This in turn affects the production of posterior syllables /ka/ and /ta/ resulting in a reduced syllabic rate.

c) *Increased syllable duration:*

The results indicated that the syllable duration was higher in the MS group when compared to the control group for all the four DDK tasks. This may be attributed to the neuromuscular incoordination and weakness of the oral structures seen in individuals with MS, which is essential for the production of the sequencing and alternating syllables and the articulatory breakdowns. The average syllable time is inversely related to the DDK rate, hence an increase in the syllable duration results in a decreased DDK rate.

These findings are also in consonance with the studies reported in the literature. Klatt (1976) also described similar results and attributed these increase in the inter-syllabic and syllabic duration to the underlying neuromotor dysfunction. The author suggested that individuals with dysarthria have a marked muscular weakness that affects respiration, causing breathy phonation, and loss of breath, eventually leading the subject to pause for inhalation. Hartelius et al. (2000) reported in their study that MS with dysarthria had slower than normal articulation rate with more frequent pausing than the typical adults. They stated that the pause duration was about 50% of the total utterance. House (1971) suggested that this increase in the duration of the syllables can be determined by several factors, including those attributable to the individual talker, the rate of speech, level of stress, and systematic influence of the phonetic environment (cited in Hirose, 1986).

A single site is constantly used in the task of syllable repetition, which can be difficult to produce for individuals with articulatory motor disorders and hence results in slower repetition rates. A series of kinematic studies (Hirose, Kiritani, & Sawashima, 1982; Hirose, 1986), revealed that dysarthric speakers tended to have lower velocity, increased syllable duration, and increased duration between the syllables during the DDK tasks. They attributed the results to the weakness in the muscles, decreased reciprocal inhibition of the antagonist muscles, impairment of movement and abnormality in the timing of muscle contraction.

d) *Reduced intensity:*

The intensity parameters such as the average DDK peak intensity (DDKavi), maximum intensity of DDK sample (DDKmxa), average intensity of DDK sample (DDKava) and average syllabic intensity (DDKsla) were found to be reduced in the clinical group when compared with the control group in all the DDK tasks. The reduction in the intensity parameters indicated that the DDK sample had reduced loudness. This reduction in loudness can be accounted for by the weakness, fatigue, and neuromuscular discoordination of the speech musculature.

Many studies reported of reduced loudness in persons with MS. Speech is perceived as slow, hypernasal and breathy, with reduced loudness and monotone in individuals with MS and PD associated with dysarthria (Hirose, 1986). Tjaden and Watling (2003) put forth that the energy maxima for the MS group tended to be reduced relative to the controls, which may be a general indicator of dysarthria. The reduction in the loudness level could be due to the inappropriate voicing or spirantization. Mulligan, Carpenter, Riddel, Delaner, Badger, Krusinski, and Tadan (1994) reported that the reducing loudness may be a compensatory strategy for weakness and fatigue followed by individuals with dysarthria.

Lundy, Roy, Xue, Casiano, and Jassir (2004) described that individuals with dysarthria are unable to produce adequate loudness in their connected speech and repetitions which may result in mono-loudness. The combination of respiratory and laryngeal control that regulates the loudness levels, due to the underlying neuromuscular condition, is lost and results in reduced loudness. Dogan et al. (2007) stated that reduction in loudness may be associated with both the laryngeal adduction and phonatory instability. The videolaryngoscopic (VLS) evaluation of their subjects revealed incomplete glottal closure resulting in the perception of breathy, asthenic voice with reduced loudness. Darley et al. (1969) stated that the most prominent speech deviations in the MS dysarthric group were impaired control of loudness and harshness, which was noted to some degree in more than 70% of the subjects. They attributed these findings with the underpinning neurological deficit.

e) *Increased standard deviation, perturbation, and coefficient of variation for the rate and intensity parameters:*

The standard deviation and the co-efficient of variation for the temporal and intensity parameters were found to be greater in the clinical population when compared with the control group. This is in consonance with the study by Dogan et al. (2007) who stated that reduction in loudness may be associated with both the laryngeal adduction and phonatory instability. Durational irregularity during oral diadochokinesis task is considered as a prominent sign of dysarthria (Portnoy & Aronson, 1982; Gentil, 1990). It has been assumed that the specific timing deficits following the CNS and PNS dysfunction may contribute to the increased variability in these instances (Keller, 1990).

Fletcher (1972) indicated that a normal speaker can maintain period repetitions while disordered speech show more variability in their repetition rate resulting in the increased standard deviation of the DDK period (DDKsdp). The standard deviation of the DDK period has a direct relationship with the coefficient of variation of DDK period (DDKcvp), indicating that when the DDKsdp increases the DDKcvp also increases. Perturbation measure assesses the ability of the individual to maintain a constant rate, hence this parameter also showed an increased trend in the clinical group. Similar to the DDK temporal parameters, the standard deviation, coefficient of variation for the intensity also showed increased values. Higher values for the standard deviation of DDK peak intensity (DDKsdi) and coefficient of variation of DDK peak intensity (DDKcvi) revealed that the individuals had lesser ability to maintain a steady amplitude.

Hartelius and Lillvik (2003) argued that the observed variations may be attributed to the difference in the degree and extent of the deficit in the motor pathways and sensory pathways. These wide variations maybe caused by the illness affecting different parts of the neuromotor system differently or from inherent differences in biomechanical properties of the articulators. MS speakers form a very heterogeneous group due to the variability of their disease, both in reference to the kind of neurological symptoms and the fluctuations in severity of symptoms (Hartelius et al., 2000). Wang et al. (2004) also indicated that the complexity of the speech motor deficits and its variability across individuals with dysarthria result in the heterogeneous grouping.

II. Relationship between the DDK tasks and the intelligibility rating

Kappa's Coefficient indicated that moderate to good agreement was present in the intelligibility rating for spontaneous speech (SS) among the three judges. The majority rating among the three judges was taken for further statistical analysis. The statistical analysis was done using the Spearman's rank correlation and the results indicated that correlation was found between only few of the intensity parameters of DDK and the intelligibility rating.

Only few of the parameters had strong to very strong positive correlation and negative ($p<0.05$) with the intelligibility scores, while the other parameters had no correlation ($p>0.05$) with the intelligibility rating. The average DDK peak intensity (DDKavi) of /pa/, /ta/ and /ka/, maximum intensity of the DDK sample (DDKmxa) of /ta/, and average syllabic intensity of DDK sample

(DDKsla) of /ta/ significantly correlated ($p<0.05$) with the intelligibility rating, while the other measures had no correlation ($p>0.05$) with the DDK parameters.

The result indicated that the average DDK peak intensity of /pa/, /ta/ and /ka/ had strong positive correlation ($p<0.05$), whereas the other parameters like maximum intensity of DDK sample and average syllable intensity of /ta/ had very strong positive correlation ($p<0.01$) with the intelligibility rating. The strong and very strong positive correlation between the DDK intensity parameters and the intelligibility rating indicated that as the value of the DDK intensity parameters increased, the intelligibility also increased. From this, we can infer that the participants in the clinical group could have used increasing the intensity as a compensatory mechanism to improve their intelligibility for the listener.

Several authors have reported that the temporal parameters correlated with the intelligibility scoring, i.e., poorer the intelligibility, lower the DDK rates. However, the findings of the current study were not in agreement with the studies reported in the literature. There was no correlation obtained between the temporal parameters such as the average DDK rate (DDKavr), average DDK period (DDKavp) and perturbation of DDK period (DDKjit) and intelligibility. This finding possibly could be attributed to the small sample size. Several studies have produced equivocal evidences for the correlation between the intelligibility parameters and the speech characteristics of individuals with MS.

Ziegler and Wessel (1996) indicated a high relationship between DDK rate and the intelligibility and the severity of the dysarthria, however, Kent et al. (2000) did not find a significant relationship between DDK rate and overall severity of dysarthria. Wang et al. (2004) reported significant relationship between DDK rate and overall severity, overall intelligibility, word intelligibility, and overall prosody of dysarthria in Traumatic Brain Injury (TBI), however, Ozwa et al. (2001) reported that DDK rate was not correlated with the overall intelligibility and dysarthria.

III. Relationship between DDK parameters and the duration of the disease

The statistical analysis was done using the Spearman's rank correlation and the results indicated strong to very strong positive and negative correlation between few of the intensity parameters of DDK and one DDK temporal parameter and the duration of the disease. Standard deviation of the DDK period of /pa/, average DDK peak intensity of /pa-ta-ka/, maximum intensity of DDK sample of /pa/ and /pa-ta-ka/, and average intensity of DDK sample of /pa/ had strong positive correlation ($p<0.05$), whereas the other parameters such as average DDK peak intensity of /pa/, /ta/ and /ka/, maximum intensity of DDK sample of /ta/ and /ka/, and average syllabic intensity of DDK sample of /ta/ had very strong positive correlation ($p<0.01$), and one DDK parameter, i.e., standard deviation of the DDK peak intensity of /pa/ had strong negative correlation ($p<0.05$).

The strong positive correlation between the standard deviation of DDK period with the duration of the disease indicated that as the duration of the disease increased, the variation in the utterances of the individual increased, resulting in an increase in the standard deviation of the DDK period. The very strong positive correlation between the average DDK peak intensity, maximum intensity of DDK sample and average syllabic intensity of DDK sample can be attributed to the variations in the duration of the disease in the participants included in the study. The duration of the disease in the participants varied from 7 months to 96 months, with two participants exhibiting MS since 96 months and eight participants exhibiting MS for an average duration of 23 months.

Since most of the participants had lesser duration of the disease, their intensity levels could have been higher, which resulted in a positive correlation.

Since these parameters were positively correlated, the standard deviation of the DDK peak intensity had a strong negative correlation. According to Fletcher (1972), the average DDK peak intensity is inversely proportional to the standard deviation of DDK peak intensity, a positive correlation in the average DDK peak intensity led to the negative correlation of standard deviation of DDK peak intensity with the duration of the disease.

Several studies have produced equivocal evidences for the correlation between the duration of the disease and the speech characteristics of individuals with MS. Hartelius et al. (2000) reported a positive correlation between the deviations present in the speech production to the overall severity of the neurological involvement, type of disease course, and the duration of the disease in MS. Hartelius, and Lillvik (2003) also confirmed that DDK rate was positively related to articulatory imprecision and moderately related to the disease progression, while other authors like Famakides and Boone (1960), Schliesser (1982), Kent et al., (1999) have proposed that the duration of the disease had no relation with the DDK rates.

Darley et al. (1969) reported that the severity of the dysarthria in multiple sclerosis and the speech symptoms are not related to the age of the patient or the duration of the illness but is positively related to the severity of neurological involvement. Most speech deviations become more prominent as additional motor systems become involved. Hartelius et al. (2000) also stated that the acoustic correlates of dysarthric characteristics in individuals in MS seem to mirror the underlying neuromotor dysfunction of each speaker.

In sum, the outcome of the present study revealed that all the eleven parameters showed a significant difference across the groups for all the four tasks (/pa/, /ta/, /ka/, and /pa-ta-ka/). A significant difference was found in both the temporal and the intensity parameters for AMR and SMR tasks indicating that these measures were affected in the MS group when compared to the neurotypical group. The lowered articulation rate of the MS group can be attributed to the slight incoordination of the muscles in the oropharyngeal area and fatigue, which are some of the most significant neurological signs in the disability of MS.

The results also indicated that as the syllable production proceeded from anterior /pa/ to posterior /ka/, the syllabic rate reduced in both the clinical and the control group, which has been accounted for by the effort required to produce these syllables. The effort required to produce the labial phoneme /pa/ is less, followed by the tongue tip phoneme /ta/, whereas the production of /ka/ requires more effort. These findings have been demonstrated many a time in the literature for the normal and the disordered population.

The results also indicated that the syllable duration was higher in the MS group when compared with the control group for all the four DDK tasks. This may be attributed to the neuromuscular incoordination and the articulatory breakdowns. The increased syllabic duration in turn reduces the syllabic rate as these two parameters are inversely proportional to each other.

The intensity parameters such as the average DDK peak intensity (DDKavi), maximum intensity of DDK sample (DDKmxa), average intensity of DDK sample (DDKava) and average syllabic intensity (DDKsla) were found to be reduced in the clinical group when compared with the control group in all the DDK tasks. This reduction in loudness can be accounted for by the weakness, fatigue, and neuromuscular discoordination of the speech musculature. Authors have reported that the reduction in loudness can also be used as a compensatory strategy by the individuals in dysarthria to produce clear speech.

The standard deviation and the co-efficient of variation for the temporal and intensity parameters were also found to be greater in the clinical population when compared with the control group. This could be attributed to the phonatory instability, durational irregularity and timing deficits following CNS and PNS dysfunction.

A correlation was found between only few of the intensity parameters of DDK and the intelligibility. This could be possibly due the fact that the participants in the clinical group used increasing intensity as a compensatory mechanism to improve their intelligibility. The correlation between the duration of the disease and the DDK parameters also mirrored the results w.r.t intelligibility, indicating that only a few intensity parameters correlated with the DDK parameters. In addition, one temporal related parameter-the standard deviation of the DDK period also correlated with duration of the disease. The duration of the disease in the participants varied from 7 months to 96 months, with two participants exhibiting MS since 96 months and eight participants exhibiting MS for an average duration of 23 months. Since most of the participants had lesser duration of the disease, their intensity levels could have been higher, which resulted in a positive correlation.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Speech is an important medium through which we humans communicate to exchange ours ideas, thoughts, and information. It is a unique, dynamic and complex motor activity which begins from birth and continues to develop till puberty. The attainment of adult speech motor control is dependent on maturation of the individual's nervous system. Speech motor control (SMC) refers to the systems and strategies that control the production of speech. The articulatory movements for the production of speech are solely under the neuromuscular control. The motor patterns of speech speculate the coordinated function of the central nervous system (CNS).

SMC is the most complex task when compared to other human motor tasks. One way of measuring this complex motor activity is by using the traditional task of diadochokinesis (Cohen & Waters, 1999). West and Ansberry (1968) stated that "The individuals who negotiate rapid shifts of muscle contraction inhibition, possess a high speed of oral diadochokinesis and make rapid articulatory movements" (p. 189). This proves that there exists a relationship between diadochokinetic movements and speech production.

Measurement of DDK can be manual or automated. Manual measurements are done by counting the number of iterations produced by the individual. Hand-measure is easy to be used by SLPs but the professional must be careful, with both the data collection and the analysis sequence. On the other-hand, DDK measured using an automatic DDK analyzer provides greater efficiency on the results, since in addition to quantifying the number of sequences produced the software is also able to make many different analyses.

The Motor Speech Profile (MSP) model 5141 manufactured by KayPENTAX accompanied with Computerized Speech Lab (CSL) introduces a new arena for obtaining information regarding various DDK parameters objectively. The Motor Speech Profile is a computer-based program that extracts and analyzes speech performance of patients with motor speech disorders. The MSP measures various aspects of speech including voice, tremor, diadochokinesis, second formant transition, intonation, and syllabic rate. It contains built-in protocols for eliciting specific speech samples, extracting desired parameters, and displaying results in numeric and graphical formats.

A number of available reports have acknowledged that individuals with motor speech disorders exhibit sluggish, inaccurate and inconsistent oral diadochokinesis due to the presence of an underlying neurological insult. Majority of the above-quoted reports highlighted the sensitivity of DDK task as a key indicator of motor speech impairment. Multiple Sclerosis is one such neurological variety where the speech motor control has been reported to be affected (Tjaden & Watling, 2003). Multiple Sclerosis (MS) involves an immune-mediated process in which an abnormal response of the body's immune system is directed against the Central Nervous System (CNS), specifically the myelin sheath, the fatty substance that surrounds and insulates the nerve fibers. The primary symptoms of MS include weakness, stiffness, and sensory disturbance of the limbs, problems with coordination, balance, and vision, and extensive fatigue, and speech impairment (Ryberg, 1989).

The need for the study was based on the idea that though several studies have been done to analyze DDK in several neurological impairments such as dysarthria secondary to cerebral palsy, amyotrophic lateral sclerosis, ataxic dysarthria, and basal ganglia disorders, the studies investigating DDK in individuals with MS are scanty. The application of objective acoustic measurements in clinical description and evaluation of individuals with neurogenic speech motor disorders, especially in MS, will open windows towards establishing guidelines needed to reliably rate the dysarthric speech and differential diagnosis.

The aim of the present study was to investigate the speech motor coordination in Tamil speaking individuals with remitting-relapsing Multiple Sclerosis using diadochokinetic tasks. The main objective of the study was to compare the DDK performance of individuals with remitting-relapsing MS, with a group of healthy controls. The second objective was to investigate the effects of the speech intelligibility and duration of disease on DDK performance in individuals with remitting-relapsing MS.

A total of 10 native Tamil speaking individuals diagnosed with definite Multiple sclerosis in the age range of 18 - 50 years was selected for the present study. The group consisted of 4 males and 6 females. They constituted the clinical group. The participants with specifically, the remitting-relapsing type of MS, diagnosed by an experienced neurologist were selected for the study from Multiple Sclerosis Society of India-Chennai chapter and Local hospitals located in Chennai. Ten age, gender and socio-economic status matched neurotypical healthy controls were considered as the control group.

All ethical considerations were met and a written consent was obtained from all the participants or the caregivers who were included in the study. The demographic data and detailed medical history were obtained. Following this, preliminary assessments and screening procedures were carried out. MMSE and NIMH socioeconomic status scales were administered on both the clinical and the control group. An informal Oral Peripheral Mechanism Examination (OPME) was carried out to investigate the structure and function of the oral structures.

The samples of DDK were recorded using an audio recorder in a quiet environment with minimal auditory and visual distractions in a comfortable seated position. The recorded data was analyzed using the Motor Speech Profile (MSP-model 5141) in the Computerized Speech Lab (CSL-model 4500). The task included both alternating motion rate (AMR) and sequential motion rate (SMR). The subjects were instructed to repeat the syllables (/pa/, /ta/, /ka/, and /pa-ta-ka/) as clearly and as quickly as possible. The samples were recorded and subjected to analysis using the Diadochokinetic rate protocol (DRA) in MSP. The DRA protocol consisted of eleven temporal and intensity related parameters such as average DDK period, average DDK rate, standard deviation of DDK period, coefficient of variation of DDK period, perturbation of DDK period average DDK peak intensity, standard deviation of DDK peak intensity, coefficient variant of DDK peak intensity, maximum intensity of DDK sample, average intensity of DDK sample, and average syllabic intensity. To measure the intelligibility of the participants a spontaneous speech sample task was provided and recorded. The spontaneous speech sample was based on their education and lifestyle. The recorded samples were perceptually assessed for speech intelligibility using perceptual rating scale (AYJNIHH Speech Intelligibility Rating Scale) by three trained Speech-Language Pathologists (SLPs) including the investigator.

To ensure the reliability of the analysis done, test-retest reliability was established for 12 participants (6 from the control group and 6 from the clinical group) selected for the study using Cronbach's Alpha reliability test. The Cronbach's alpha was found to be more than 0.95 for all the parameters for both the clinical and the control group. This indicated that the test-retest reliability was good. They were tested within a span of one to two weeks.

Inter-judge agreement was also found for the intelligibility rating using the Kappa's Coefficient test since an ordinal rating scale was used for the rating. Moderate to good agreement was observed between the judge's intelligibility rating and the majority rating among the three judges was considered for further statistical analysis.

The analyzed data were tabulated in the Statistical Package for the Social Science (SPSS) software package (version21.0) and subjected to further analyses. Descriptive statistics was carried out to calculate mean, median and standard deviation. All the data were subjected to the normality test across the groups. The Shapiro-Wilk's test was employed to determine the normality of the data distribution. The principle of normality was violated due to the presence of outliers. Hence the non-parametric test, Mann Whitney U test was used to compare between the clinical and the control groups and the Wilcoxson's Signed Rank test was used for the matched pair-wise comparison between the clinical and the control groups. Finally, Spearman's rank correlation was used to find the correlation between the intelligibility measures and the duration of the disease with the DDK parameters.

The outcome of the present study revealed that all the eleven parameters showed a significant difference across the groups for all the four tasks (/pa/, /ta/, /ka/, and /pa-ta-ka/). A significant difference was found in both the temporal and the intensity parameters for AMR and SMR tasks indicating that these measures were affected in the MS group when compared to the neurotypical group. The lowered articulation rate of the MS group can be attributed to the slight incoordination of the muscles in the oropharyngeal area and fatigue, which are some of the most significant neurological signs in the disability of MS.

The results also indicated that as the syllable production proceeded from anterior /pa/ to posterior /ka/, the syllabic rate reduced in both the clinical and the control group, which has been accounted for by the effort required to produce these syllables. The effort required to produce the labial phoneme /pa/ is less, followed by the tongue tip phoneme /ta/, whereas the production of /ka/ requires more effort. These findings have been demonstrated many a time in the literature for the normal and the disordered population.

The results also indicated that the syllable duration was higher in the MS group when compared with the control group for all the four DDK tasks. This may be attributed to the neuromuscular incoordination and the articulatory breakdowns. The increased syllabic duration in turn reduces the syllabic rate as these two parameters are inversely proportional to each other.

The intensity parameters such as the average DDK peak intensity (DDKavi), maximum intensity of DDK sample (DDKmxa), average intensity of DDK sample (DDKava) and average syllabic intensity (DDKsla) were found to be reduced in the clinical group when compared with the control group in all the DDK tasks. This reduction in loudness can be accounted for by the weakness, fatigue, and neuromuscular discoordination of the speech musculature. Authors have reported that the reduction in loudness can also be used as a compensatory strategy by the individuals in dysarthria to produce clear speech.

The standard deviation and the co-efficient of variation for the temporal and intensity parameters were also found to be greater in the clinical population when compared with the control group. This could be attributed to the phonatory instability, durational irregularity and timing deficits following CNS and PNS dysfunction.

The statistical analysis was done using the Spearman’s rank correlation and the results indicated that correlation was found between only few of the intensity parameters of DDK and the intelligibility. This could be possibly due the fact that the participants in the clinical group used increasing intensity as a compensatory mechanism to improve their intelligibility.

The correlation between the duration of the disease and the DDK parameters also mirrored the results w.r.t intelligibility, indicating that only a few intensity parameters correlated with the DDK parameters. In addition, one temporal related parameter-the standard deviation of the DDK period also correlated with duration of the disease. The duration of the disease in the participants varied from 7 months to 96 months, with two participants exhibiting MS since 96 months and eight participants exhibiting MS for an average duration of 23 months. Since most of the participants had lesser duration of the disease, their intensity levels could have been higher, which resulted in a positive correlation.

Implications of the study

The results of the current study indicated that the four simple tasks of oral diadochokinesis is sensitive enough to measure orofacial motor impairment in individuals with Multiple sclerosis (MS). It provides a quantitative support for the notion that the syllable repetition rates, a high effort speech task, can be used to differentiate the speech of individuals with MS from that of the normal speakers. Since significantly lower scores were obtained in these tasks, they would prove to be sensitive in detecting subtle speech impairment experienced in the early stages of the disease and will prove to be a crucial feature in the assessment of persons with MS. This may help in initiating intervention at an early stage, thereby reducing the rate of the disease in progress and will augment the communication abilities of persons with MS. This study added on to the ease and importance of the use of objective measures in obtaining the DDK parameters. However there are a few limitations of the study. The results of the current study are very preliminary in nature, due to the small sample size taken. A better control of the variables such as the duration of the disease, site of lesion, number of relapses, etc. could have been established.

Future directions

The study can be replicated in other languages, as language variations can affect the performance of DDK. The study can be replicated with different types and degrees of dysarthria in MS to investigate the specificity of the DDK tasks in identifying the type and degree.

References

Ackermann, H., Hertrich, I., & Hehr, T. (1995). Oral diadochokinesis in neurological dysarthrias. *Folia Phoniatrica et Logopaedica, 47*, 15-23.

Altintas, A., Demir, T., Ikitimur, H. D., & Yildirim, N. (2007). Pulmonary function in multiple sclerosis without any respiratory complaints. *Clinical Neurology and Neurosurgery, 109*(3), 242-246.

Ascherio, A., & Munger, K. L. (2007). Environmental risk factors for multiple sclerosis. Part II: Non-infectious factors. *Annals of Neurology, 61*(6), 504-513.

Atlas. (2008). *Multiple sclerosis resources in the world 2008*. World Health Organization and Multiple Sclerosis Federation.

AYJNIHH. (2008). *AYJNIHH speech intelligibility rating scale.* Mumbai.

Baken, R. J., & Orlikoff, R. F. (2000). Speech movements. In R. J. Baken, & R. F. Orlikoff, *Clinical measurements of speech and voice* (pp. 511-557). San Diego: Singular Thomson Learning.

Bauer, V., ZAleric, Jancic, E., VKnezevic, Prpic, D., & Kacavenda, A. (2013). Subjective and perceptual analysis of voice quality and relationship with neurological dysfunction in multiple sclerosis patients. *Clinical Neurology and Neurosurgery, 115*, S17-S20.

Bayles, K. A., & Tomeda, C. K. (1993). *Arizona battery for communiction disorders of dementia.* Tuscon, AZ: Cannyonlands.

Beukelman, D. R., Kraft, G. H., & Freal, J. (1985). Expressive communication disorders in persons with multiple sclerosis: A survey. *Archives of Physical Medicine and Rehabilitation*, *10*, 675-677.

Boersma, P., & Weenik, D. (2000). *PRAAT: Doing phonetics by computer.* Netherlands: University of Amsterdam.

Brain, L., & Walton, J. N. (1969). *Brain's diseases of the nervous system*. London: Oxford University Press.

Brown, R., DiMarco, A. F., Hoit, J. D., & Garshick, E. (2006). Respiratory dysfunction and management in spinal cord injury. *Respiratory Care*, *51*(8), 853-868.

Bruner, J. (1973). Organization of early skilled action. *Child Development, 44*, 1-11.

Byrd, D. (1994). Relation of gender and dialect to reduction in DDK. *Speech Communication, 15*, 39-54.

Canning, B. A., & Rose, M. F. (1974). Clinical measurement of the speed of tongue and lip movements in British children with normal speech. *British Journal of Disorders of Communication, 9*, 45-50.

Cannito, M. P., Suiter, D. M., Beveryly, D., Chorna, L., Wolf, T., & Pfeiffer, R. (2012). Sentence intelligibility before and after voice treatment in speakers with idiopathic Parkinson's disease. *Journal of Voice, 26*(2), 214-219.

Charcot, J. M. (1877). *Lecons sur les maladies du systeme nervux I.* Paris: Adrien Delahaye.

Chenery, H. J. (1998). Perceptual analysis of dysarthric speech. In B. E. Murdoch, *Dysarthria: A physiological approach to assessment and treatment*. Cheltenham: Stanley Thornes.

Cohen, W. W., & Waters, D. (1999). Measuring speech motor skills in normally developing and phonologically disordered pre-school children. *XIVth International Cogress of Phonetic Sciences. 1*, pp. 789-792. Edinburgh, San Fransisco: Queen Margaret University.

Danesh-Sani, S. A., Rahimdoost, A., Soltani, M., Ghiyasi, M., Haghdoost, N., & Sabzali-Zanjankhah, S. (2013). Clinical assessment of orofacial manifestations in 500 patients with multiple sclerosis. *Journal of Oral and Maxillofacial Surgery, 71*(2), 290-294.

Darley, F. L., Aronson, A. E., & Brown, J. R. (1969). Clusters of deviant speech dimensions in dysarthria. *Journal of Speech and Hearing Research, 12*, 462-496.

Darley, F. L., Brown, J. R., & Goldstein, N. P. (1972). Dysarthria in multiple sclerosis. *Journal of Speech and Hearing Research, 15*, 229-245.

Darley, F. L., Aronson, A. E., & Brown, J. R. (1975). *Motor speech disorders*. Philadelphia: Saunders.

Darley, F. L., Brown, J. R., & Goldstein, N. P. (2016). *Dysarthria in multiple sclerosis*. Rochester, Minnesota, Minnesota: Mayo Clinic.

deDios-Perez, B. (2016). *Anomia in people with relapsing-remittingmultiple sclerosis (Masters of Philosophy thesis)*. Manchester, UK: University of Manchester.

Deepa, N. D., & Jayashree, S. B. (2012). Oral diadokokinetic rate - An insight into speech motor control. *International Journal of Advanced Speech and Hearing Research*, 10-14.

Retrieved from http://medical.cloud-journals.com/index.php/IJASHR/article/view/Med-04

Deepthy, A. J. (2015). *Motor speech characteristics in 4-10 year old typically developing kannada speaking children*. Mysore: Unpublished Dissertation of AIISH.

Deliyski, D. D., & Gress, D. C. (1997). *Characteristics of motor speech performance: Normative data (ASHA)*. Boston: MA.

De-Pauw, A., Dejaeger, E., & D'hooghe, B. (2002). Dysphagia in multiple sclerosis. *Clinical Neurology and Neurosurgery, 104*(4), 345-351.

Dogan, M., Midi, I., Kocak, I., Gunal, D., & Sehitoglu, M. A. (2007). Objective and subjective evaluation of voice quality in multiple sclerosis. *Journal of Voice, 21*(6), 735-740.

Duffy, J. R. (1995). *Motor speech disorders: Substrates, differential diagnosis, and management*. St. Louis: Mosby.

Duffy, J. R. (2005). *Motor speech disorders: Substrates, differential diagnosis, and management*. St. Louis: Msoby.

Duffy, J. (2013). *Motor speech disorders: Substrates, differential diagnosis, and management* (3 ed.). St. Louis, MO, USA: Elsevier Mosby.

Dykstra, A. D., Hakel, M. E., & Adams, S. G. (2007). Application of the ICF in reduced speech intelligibility in dysarthria. *Seminars in Speech and Language, 28*(4), 301-311.

E'Jacewicz, R. A., O'Neil, C., & Salmons, J. (2009). Articulation rate across dialect, age, and gender. *Language Variation and Change*, *33*(5), 233-256. Retrieved from http://dx.doi.org/10.1017/S0954394509990093

Farmakides, M. N., & Boone, D. R. (1960). Speech problems of patients with multiple sclerosis. *Journal of Speech and Hearing Disorders, 25*, 385-390.

Feijo, A. V., Parente, M. A., Behlau, M., Haussen, S., de-Veccino, M. C., & Martignago, B. C. (2004). Acoustic analysis of voice in mutilple sclerosis patients. *Journal of Voice, 18*, 341-347.

Fink, B. R. (1986). *Complexity Science*. West Yorkshire: Emerald Group Publishing Limited.

Fitzgerald, F. J., & Chenery, H. J. (1987). Multiples sclerosis: Associated speech and language disorders. *Australian Journal of Human Communication Disroders, 9*, 50-56.

Fletcher, S. G. (1972). Time-by-count measurement of diadochokinetic syllable rate. *Journal of Speech and Hearing Research*, *15*(4), 763-70.

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). Mini-mental State: A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12*, 189-198.

Gadesmann, M., & Miller, N. (2009). Reliability of speech diadochokinetic test measurement. *International Journal of Lamguage & Communication Disorders, 43*(1), 41-54.

Gentil, M. (1990). Dysarthria in Friedreich disease. *Brain and Language, 38*, 438-448.

Gerald, F. J., Murdoch, B. E., & Chenery, H. J. (2014). Multiple sclerosis: Associated speech and language disorders. *Australian Journal of Human Communication Disorders, 15*(2), 15-35. Retrieved from https://doi.org/10.3109/asl2.1987.15.issue-2.02

Grasso, M. G., Lubich, S., Guidi, L., Rinnenburger, D., & Paolucci, S. (2000). Cerebellar deficit and respiratory impairment: A strong association in multiple sclerosis? *Acta Neurologica Scandinavia, 101*(2), 98-103.

Hartelius, L., Buder, E. H., & Strand, E. A. (1997). Long-term phonatory instability in individuals with multiple sclerosis. *Journal of Speech Language and Hearing Research, 40*, 1056-1072.

Harrington, J., Cox, F., & Evans, Z. (1997). An acoustic phonetic study of broad, general, and cultivated Australian English Vowels. *Australian Journal of Linguistics*, 155-184.

Hartelius, L., & Lillvik, M. (2003). Lip and tongue function differently affected in individuals with multiple sclerosis. *Folia Phoniatrica Logopedia, 55*, 1-9. doi:10.1159/000068057

Hartelius, L., Nord, L., & Buder, E. H. (1995). Acoustic analysis of dysarthria associated with multiple sclerosis. *Clinical Linguistics & Phonetics, 9*(2), 95-120.

Hartelius, L., Runmarker, B., & Andersen, O. (2000). Prevalence and characteristics of dysarthria in a multiple sclerosis incidence cohort: Relation to neurological data. *Folia Phoniatrica Logopaedica, 52*, 160-177.

Hartelius, L., & Svensson, P. (1994). Speech and Swallowing Symptoms Associated with Parkinson's Disease and Multiple Sclerosis: A Survey. *Folia Phoniatrica et Logopaedica, 46*, 9-17.

Hefter, H., Arendt, G., Stremmel, W., & Freund, H. J. (1993). Motor impairment in Wilson's disease. II. Slowness of speech. *Acta Neurologica Scandinavica, 87,* 148-160.

Hirose, H. (1986). Pathophysiology of motor speech disorders (Dysarthria). *Folia Phoniatrica, 38,* 61-88.

Hirose, H., Kiritani, S., & Sawashima, M. (1982). Patterns of dysarthric movement in patients with amyotrophic lateral sclerosis and pseudobulbar palsy. *Folia Phoniatrica*, 106-112.

Hixon, T., & Hoit, J. (2005). *Evaluation and management of speech breathing disorders: Principles and methos.* Tucson, AZ: Redington Brown.

Hooper, K. (2011). *Managing progressive MS.* New York, NY: National Multiple Sclerosis Society.

Icht, M., & Ben-David, B. M. (2014). Oral-diadochokinesis rates across languages: English and Hebrew norms. *Journal of Communication Disorders, 48*, 27-37.

Icht, M., Maltz, D., & Korecky, O. (2013). Diadochokinetic rate in young and elderly Hebrew speakers. *The Israeli Journal of Language, Speech & Hearing Disorders, 32*, 69-80.

Jensen, J. R. (1960). *A study of certain motor speech aspects of the speech of multiple sclerotic patients.* Unpublished doctoral thesis: University of Wisconsin.

John, J., Ganapathy, K., John, S., & Rajasekhar, B. (2014). Normative for motor speech profile in kannada-speaking adults. *Journal of Voice, 28*(1), 7-13.

Jung, K. H., Cho, Y. S., Cho, J. K., Park, G. Y., Kim, E. Y., Chung, S. H.-H., . . . Rubinstein, J. T. (2010). Clinical assessment of music perception in Korean cochlear implant listeners. *Acta Oto-Laryngologica*, 130:6, 716-723, DOI: 10.3109/00016480903380521.

KayPENTAX. (2008). *KayPENTAX. Software instruction manual motor speech profile.* Lincoln Park, New Jersey: KayPENTAX.

Keller, E. (1990). Speech motor timing. In W. J. Hardcastle, & A. Marchal, *Speech production and speech modelling* (pp. 343-364). Dordrecht: Kluwer.

Kent, R. D. (1976). Anatomical and neuromuscular maturation of the speech mechanism: Evidence from acoustic studies. *Journal of Speech and Hearing Research, 19*, 421-77.

Kent, R. D., Duffy, J. R., Kent, J. F., Vorperian, H. K., & Thomas, J. E. (1999). Quantification of motor speech abilities in stroke: Time-energy analyses of syllable and word repetition. *Journal of Medical Speech Language Pathology, 7*, 83-90.

Kent, R. D., Kent, J. F., Duffy, J. R., Thomas, J. E., Weismer, G., & Stuntebeck, S. (2000). Ataxic dysarthria. *Journal of Speech Language and Hearing Research, 43*, 1275-1289.

Kent, R. D., Miolo, G., & Bloedel, S. (1994). The intelligibility of children's speech: A review of evaluation procedures. *American Journal of Speech Language Pathology, 3*, 81-95. doi:doi:10.1044/1058-0360.0302.81

Kent, R. D., Weismer, G., Kent, J. F., & Rosenbek, J. C. (1989). Toward phonetic intelligibility testing in dysarthria. *Journal of Speech and Hearing Disorders, 54*, 482-489.

Kim, Y., & Kuo, C. (2012). Effect of level of presentation to listeners on scaled speech intelligibility testing in dysarthria. *Folia Phoniatrica et Logopedica, 64*(1), 26-33.

Klatt, D. H. (1976). Linguistic uses of segmental duration in English: Acoustc and perceptual evidence. *Journal of the Acoustical Scoiety of America, 59*, 1208-1221.

Konstantopoulos, K., Charalambous, M., & Verhoeven, J. (2011). Sequential motor rates in the dysarthria of multiple sclerosis: A temporal analysis. *Hong Kong*, 17-21.

Konstantopoulos, M., Vikelis, M., Seikel, J. A., & Mitsikostas, D. D. (2010). Theexistence of phonatory instability in multiple sclerosis: An acoustic and electrographic study. *Neurological Science, 31*, 259-268.

Kreul, E. J. (1972). Neuromuscular control examination (NMC) for Parkinsonism: Vowel prolongations and diadochokinetic and reading rates. *Journal of Speech and Hearing Research, 15*, 72-83.

Kurtze, J. F., Beebie, G. W., Nagler, B., Kurland, L. T., & Auth, T. L. (1968). Multiple sclerosis in United States veterans: Primary observations. In M. Alter, & J. F. Kurtze, *The epidemiology of multiple sclerosis* (pp. 26-34). Springfield, Illinois: Charles C Thomas.

Labov, W. (1966). *The social stratification of English in New York city*. Washington, DC.

Langmore, S. E., & Lehman, M. E. (1994). Physiologic deficits in the orofacial system underlying dysarthria in amyotrophic lateral sclerosis. *Journal of Speech and Hearing Research, 37*, 28-37.

Lass, N. J., & Sandusky, J. C. (1971). A stydy of the realtionship of diadochokinetic rate, speaking rate and reading rate. *Today's Speech, 19*(3), 49-54.

Levine, R. V. (1999). The pace of life in 31 countries. *Journal of Cross-Cultural Psychology, 30*(2), 178-205.

Linville, S. E. (1996). The Sound of senescence. *Journal of Voice, 10*, 190-200.

Louzada, T., Beraldinelle, R., Berretin-Felix, G., & Brasolotto, A. G. (2011). Oral and vocal fold diadochokinesis in dysphonic. *Jpurnal of Applied Oral Science, 19*(6), 567-572.

Lublin, F. D., Reingold, S. C., Cutter, G. R., Sorensen, P. S., Thompson, A. J., & Bebo, B. (2014). Defining the clinical course of multiple sclerosis. The 2013 revisions. *Neurology, 83*(3), 278-286.

Ludlow, C. L., Connor, N. P., & Bassich, C. J. (1987). Speech timing in Parkinson's and Huntington's disease. *Brain and Language, 32*, 195-214.

Lundy, D. S., Roy, S., Xue, J. W., Casiano, R. R., & Jassir, D. (2004). Spastic/spasmodic vs. tremulous vocal quality: Motor speech profile analysis. *Journal of Voice, 18*(1).

Mackenzie, C., & Green, J. (2009). Cognitive-linguistic defict and speech intelligibility in chronic progressive multiple sclerosis. *Internation Journal of Language and Communication Disorders, 44*(4), 401-420.

Marsden, C. D. (1982). The mysterious motor function fo the basal ganglia: The Robert Wartenberg lecture. *Neurology, 32*, 514-539.

Marsden, C. D. (1989). Slowness of movement in Parkinson's disease. *Movement Disorders, 4*(supplement 1), S26-S37.

Mason, R. M., Helmick, J. W., Under, J. W., Gattozzi, J. G., & Murphy, M. W. (1977). Speech screening ofchildren in the dental office. *Journal of American Dental Association, 94*, 708-712.

McAlpine, D., Lumsden, C. E., & Acheson, E. D. (1965). *Multiple sclerosis: A reappraisal.* London, England: E and S Livingstone.

Merson, R. M., & Rolnick, M. I. (1998). Speech-language pathology and dysphagia in multiple sclerosis. *Physical Medicine and Rehabilitation Clinics of North America, 9*, 631-641.

Meurer, E. M., Wender, M. C., Corleta, H. E., & Capp, E. (2004). Phono-articulatory variations of woment in reproductive age and postmenopausal. *Journal of Voice, 18*(3), 369-374.

Modolo, D. J. (2007). *Diadococinesia oral e laringea em criancas.* Sao Paulo: Faculadade de Odontologia de Bauru da Universidade de Sao Paulo.

Mulligan, M., Carpenter, J., Riddel, J., Delaner, M. K., Badger, G., Krusinski, P., & Tandan, R. (1994). Intelligibility and the acoustic characteristics of speech in amytrophic lateral sclerosis (ALS). *Journal of Speech and Hearing Research, 37*, 496-503.

Munson, B. (2013). The influence of actual and perceived orientation on diadochokinetic rate in women and men. *11th Annual Conference of the Internation Speech Communication Association: INTERSPEECH 2010*, (pp. 1525-1528). Chiba, Japan. Retrieved from http://www.tc.umn.edu/~munso005/Munson_inProceedings.pdf

Murdoch, B. E., & Theodoros, D. G. (2000). *Speech and language disorders in multiple sclerosis*. London: Whurr.

Murdoch, B. E., Chenery, H. J., Stokes, P. D., & Hardcastle, W. J. (1991). Respiratory kinematics in speakerswith cerebellar disease. *Journal of Speech Hearing and Research, 34*(4), 768-780.

Nishio, M., & Niimi, S. (2006). Comparison of speaking rate, articulation rate, and alternating motion rate in dysarthric speakier. *Folia Phoniatrica Lodopeadica, 58*, 114-131.

NMSS. (2000). *National Multiple Sclerosis Society of India*. Retrieved from National Multiple Sclerosis Society: https://www.nationalmssociety.org/

Nogues, M. A., Roncoroni, A. J., & Benarroch, E. (2002). Breathing control in neurological diseases. Clinical autonomic research. *Official Journal of the Clinical Autonomic Research Society, 12*(6), 440-449.

Ozawa, Y., Shiromoto, O., Ishizaki, F., & Watamori, T. (2001). Symptomatic differences in decreased alternating motin rates between individuals with spastic and with ataxic dysarthria: An acoustic analysis. *Folia Phoniatrica Logopeadica, 53*, 67-72.

Padvoni, M., Gielow, I., & Behlau. (2009). Phonarticulatory diadochokinesis in young and elderly individuals. *Arquivos de Neuro-Psiquiatria, 67*(1), 58-61.

Patil, G. S., & Manjula, R. (2013). *Development of normative database in adults for the motor speech profile*. Mysore: Project funded by AIISH Research Fund.

Platt, L. J., Andrewes, G., Young, M., & Neilson, P. D. (1978). The measurement of speech impairment of adults with cerebral palsy. *Folia Phoniatrica et Logopaedica, 30*, 50-58.

Polman, C. H., Reingold, S. C., Banwell, B., Clanet, M., Cohen, J. A., & Fillippi, M. (2011). Diagnostic criteria for multiple sclerosis: 2010 revisions to the McDonald criteria. *Annals of Neurology, 69*, 292-302.

Poorjavad, M., Derakhshandeh, F., & Etemandifar, M. (2010). Oropharyngeal dyspphagia in multiple sclerosis. *Multiple Sclerosis, 16*(3), 362-365.

Portnoy, R. A., & Aronson, A. E. (1982). Diadochokinetic syllable rate. *Journal of Speech and Hearing Research, 47*, 324-328.

Prathanee, B. (1998). Oral DDK rate in adults. *Journal of the Medical Association of Thailand, 81*(10), 784-87.

Prathanee, B., Thanaviratananich, S., & Pongjanyakul, A. (2003). Oral diadochokinetic rates for normal Thai children. *International Journal of Language and Communication Disorders, 38*(4), 417-428.

Ptacek, P. H., Sander, E. K., Maloney, W. H., & Jackson, C. C. (1966). Phonatory and related changes with advanced age. *Journal of Speech and Hearing Research, 9*, 353-360.

Robb, M. P., Hughes, M. C., & Frese, D. J. (1985). Oral diadochokinesis in hearing-impaired adolescents. *Journal of Communication Disorders, 18*(2), 79-89.

Robbins, J., & Klee, T. (1987). Clinical assessment of oropharyngeal moto development in young children. *Journal of Speech and Hearing Disorders, 52*, 271-277.

Rog, D., Burgess, M., Mottershead, J., Talbot, & Robinson, I. (2010). *Multiple sclerosis: Answers at your fingertips.* London: Class Pub.

Rosen, K. M., Goozee, J. V., & Murdoch, B. E. (2008). Examining the effects of multiple sclerosis on speech production: Does phonetic structure matter? *Journal of Communication Disorders, 41*, 49-69.

Rusz, J., Benova, B., Ruzickova, H., Novotny, M., Tykalova, T., Hlavnicka, J., . . . Horakova, D. (2017). Characteristics of motor speech phenotypes in multiple sclerosis. *Multiple Sclerosis and Related Disorders, 19*, 62-69.

Ryberg, B. (1989). Demyeliniserande sjukdomar. In S. M. Auilonius, & J. Fagius, *Neurology*. Stockholm: Almqvist & Wiksell.

Schliesser, H. F. (1982). Alternate motion rates of the speech articulators in adults with cerebral palsy. *Folia Phoniatrica er Logopaedica, 47,* 681-684.

Scolding, N., & Wilkins, A. (2012). *Multiple sclerosis.* UK: Oxford University Press.

Seifpanahi, S., Dadkhah, A., Dehqan, A., Bakhtiar, M., & Salmalian, T. (2008). Motor control of speaking rate and oral diadochokinesis in hearing impaired Farsi speakers. *Logopedics, Phoniatrics, Vocology, 33*, 153-159.

Shah, S. (1998). Modified barthel indenx or barthel index. In S. Salek, *Compendium of quality of life instruments Part II* (pp. 88-108). Chichester: Wiley.

Singhal, B. S. (1985). Multiple Sclerosis - Indian experience. *Annals of the Academy of Medicine, Singapore, 14*(1), 32-36.

Singhal, B. S., & Adyani, H. (2015). Multiple Sclerosis in India: An overview. *Annals of Indian Academy of Neurology, 18*(1). doi:10.4103/0972-2327.164812

Smeltzer, S. C., Utell, M. J., Rudick, R. A., & Herndon, R. M. (1988). Pulmonary function and dysfunction in multiple sclerosis. *Archives of Neurology, 45*(11), 1245-1249.

Smith, A., & Goffman, L. (1998). Stability and patterning of movement sequences in children and adults. *Journal of Speech, Language, & Hearing, 41*, 18-30.

Stipancic, K. L., Tjaden, K., & Wilding, G. (2015). Comparison of intelligibility measures for adults with Parkinson's disease, adults with Multiple sclerosis, and healthy controls. *Journal of Speech, Language and Hearing Research, 59*, 230-238.

Tatsumi, I. F., Sasanuma, S., Hirose, H., & Kiritani, S. S. (1979). Acoustic properties of ataxic and Parkinsonian speech in syllable repetition tasks. *Annual Bulletin of the Research Institute of Logopedics, 13*, 99-104.

Theodoros, D. G., Murdoch, B. E., & Chenery, H. J. (1994). Perceptual speech characteristics of dysarthric speakers following severe closed head injury. *Brain Injury, 8*, 101-124.

Tjaden, K., & Martel-Sauvageau, V. (2017). Consonant acoustics in Parkinson's disease and Multiple sclerosis: Comparison of clear and loud speaking conditions. *American Journal of Speech Language Pathology, 26*, 569-582. doi:10.1044/2017_AJSLP-16-0090

Tjaden, K., & Watling, E. (2003). Characteristics of diadochokinesis in multiple sclerosis and parkinson's disease. *Folia Phoniatrica et Logopaedica, 55*, 241-259. doi:10.1159/000072155

Tjaden, K., Sussman, J. E., & Wilding, G. E. (2014). Impact of clear,loud, and slow speech on scaled intelligibility and speech severity in Parkinson's disease and multiple sclerosis. *Journal of Speech, Language, and Hearing Research, 57*, 779-792.

Topbas, O. (2010). *Effects of diadochokinetic rate on vocal fundamental frequency and intensity in normally speaking young adults.* (Unpublished thesis) West Virginia University.

Trudgill, P. (1974). *The social differentiation of english in norwich.* Cambridge, UK: Cambridge University Press.

Tuomi, S. K., & Winter, N. M. (1977). Diadochokinesis and articulation impairment. *Human Communication*, 141-150.

Venkatesan, S. (2011). Socio economic status scale - 2011. *Revised version of "NIMH Socio Economic Status Scale - 1993"*. Mysore, Secunderabad: NIMH.

Wang, Y. T., Kent, R. D., Duffy, J. R., Thomas, J. E., & Weismer, G. (2004). Alternating motion rate as an index of motor speech disorder in traumatic brain injury. *Clinical Linguistics and Phonetics, 18*, 57-84.

Wang, Y., Kent, R. D., Duffy, J. R., & Thomas, J. E. (2009). Analysis of Diadochokinesis in Ataxic Dysarthria Using the Motor Speech Profile Program. *Folia Phoniatrica et Logopaedica, 61*(1), 1-11. doi:10.1159/000185539

Weinshenker, B. G. (1995). The natural history of multiple sclerosis. *Neurologic Clinics*, *13*, 119-146.

Weismer, G., & Liss, M. J. (1991). Acoustic perceptual taxonomies of speech production deficits in motor speech disorders. In C. A. Mobre, K. M. Yorkston, & D. K. Beukelman, *Dysarthria and Apraxia of Speech: Perspective on management* (pp. 245-270). Baltimore, MD: Paul H. Brookes Publishing.

Weismer, G., & Martin, R. E. (1992). Acoustic and perceptual approaches to the study of intelligibility. In R. D. Kent, *Intelligbility in speech disorders: Theory, measurement and management* (pp. 68-118). Amsterdam: John Benjamins.

Wertzner, H. F., Pagan-Neves, L. d., Alves, R. R., & Barrozo, T. F. (2013). Implications of diadochokinesia in children with speech sound disorder. *Communication Sciences and Disorders, 25*(1), 52-58.

West, R. W., & Ansberry, Y. M. (1968). *The rehabilitation of speech* (4 ed.). New York: Harper.

Westbury, J. R., & Dembowski, J. (1991). Articulatory kinematics of normal diadochokinetic performance. *Annal Bulletin of the Research Institute of Logopedics and Phoniatrics, 27*, 13-36.

William, P., & Stackhouse. (2000). Rate, accuracy and consistency: Diadochokinetic performance of young normally developing children. *Clinical Linguistics and Phonetics*, *14*(4), 267-93.

Wohlert, A. B., & Smith, A. (1998). Apatiotemporal stability of lip movements in older adult speakers. *Journal of Speech Language and Hearing Research, 41*, 41-50.

Wong, A. W., Allegro, J., Tirado, Y., Chada, N., & Campisi, P. (2011). Objective measurement of motor speech characteristics in the healthy pediatric population. *International Journal of Pediatric Otorhinolaryngology, 160*, 4-11.

Yamout, B., Fuleihan, N., Hajj, T., Sibai, A., Sabra, O., Rifai, H., & Hamdan, A. L. (2009). Vocal symptoms and acoustic changes in relation to the expanded disability status scale, duration and stage of disease in patients with multiple sclerosis. *European Archives of Oto-Rhino-Laryngology, 266*, 1759-1765.

Yaruss, J. S., & Logan, K. J. (2002). Evaluting rate, accuracy, and fluency of young children's diadochokinetic productions: A preliminary investigation. *Journal of Fluency Disorders, 27*(1), 65-85.

Yorkston, K. M., & Beukelman, D. R. (1984). *Assessment of intelligibility in dysarthric speech.* Austin: Pro-ed.

Yorkston, K., Beukelman, D. R., & Tice, R. (1996). *Sentence intelligibility test [Measurement instrument]*. Lincoln,NE: Tice Technologies.

Yorkston, K. M., Klasner, E. R., & Swanson, K. M. (2001). Communication in context: A qualititative study of the experiences of individuals with multiple sclerosis. *American Journal of Speech Language Pathology*, *10*(2), 126-137.

Ziegler, W. (2002). Task-related factors in oral motor control: Speech and oral diadochokinesis in dysarthria and apraxia of speech. *Brain and Language, 80,* 556-575. doi:10.1006/brln.2001.2614

Ziegler, W., & Von-Cramon, D. Y. (1986). Spastic dysarthria after acquired brain injury: An acoustic study. *British Journal of Disorders of Communication, 21*, 173-187.

Ziegler, W., & Wessel, K. (1996). Speech timing in ataxic disorders: Sentence production and rapid repetitive articulation. *Neurology, 47*, 208-214.