NORMATIVE OF MOTOR SPEECH PROFILE IN TYPICAL KANNADA SPEAKING ADOLESCENTS

JILDA SULTHANA CP

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University of Mysore, Mysuru

All India Institute of Speech and Hearing

Manasagangothri, Mysuru - 570 006

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CERTIFICATE

This is to certify that this Dissertation entitled "**Normative of Motor speech profile in typical Kannada speaking adolescents"** is a bonafide work submitted in part fulfilment for the degree of Master of Science (Speech-Language Pathology) student with Registration Number P01II22S123013. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru

July, 2024

Dr. M. Pushpavathi

Director

All India Institute of Speech and Hearing,

Mansagangothri, Mysuru - 570006

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Mysuru

July, 2024

Dr. Mahesh BVM

Guide

Assistant Professor,
Department of Speech Language Pathology
All India Institute of Speech and Hearing
Mansagangothri, Mysuru - 57000

DECLARATION

This is to certify that this Dissertation entitled "**Normative of Motor speech profile in typical Kannada speaking adolescents"** is a result of my study under the guidance of Dr. Mahesh BVM, Assistant professor at 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.

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Abstract

This study investigated articulatory motor performance in Kannada-speaking adolescents using the advanced Motor Speech Profile (MSP) module of the Computerized Speech Laboratory. The main purpose of this study is to establish normative data on 80 (N =80) adolescent Kannada native speakers on Motor Speech Profile in the age range of 10-18 years with two subgroups namely 10-13 (n = 40) and 14-18 years (n = 40) with 20 males and 20 females across the groups. The MSP module assessed five protocols: diadochokinetic rate, second formant transition, voice and tremor parameters, intonation stimulability, and standard syllabic rate. Results showed that DDK rate increased with age across specific syllables, with significant differences between adolescent and adult males. Females stabilized earlier and had lower variability. In F2 transition, females showed higher F2magn and F2aver values, and males showing higher F2reg and F2rate. As expected, fundamental frequency (F0) was higher in females. Males showed decreased F0, with marginally higher variability, in young adolescent males. Tremor related parameters were higher in males compared to females. Intonation stimulability mirrored voice and tremor trends. Females exhibited higher pitch range and variability, indicating greater pitch control. Males showed higher standard syllabic rate with age suggesting age related changes in speaking rate. Several parameters measured across protocols were higher in adolescents than adults indicating continuous improvement across phonatory and articulatory motor control. The normative developed from this study could be used to judge the speech motor variations across phonatory and articulatory dimensions, thereby aiding in diagnosing and treating speech motor disorders.

Keywords: Age, Gender, Adolescents, Motor Speech Profile, Diadochokinetic rate, Second formant transition

Chapter 1

Introduction

From birth to adolescence, children gradually develop the ability to control their speech musculature. With the increase in age, most of the communication efficiency, accuracy and fluency in speech production, and the voice quality gets enhanced (Linville, 1996; Wohlert & Smith, 1998). In contrast to the prevailing notion that the brain has completed the majority of its development by the onset of adolescence, some studies have revealed that substantial levels of neural growth, development and activity, parallels with the growth and development in language and communication in the adolescent brain (Nippold, 2007).

The neuronal maturation is quite rapid in the early years of life and this rate gradually reduces and gets refined in the adolescent period. Adolescent development studies typically focus on white matter changes and gray matter changes. The changes refer to the increase or decrease of neuronal content, including axons, myelin sheaths, dendrites, cytons, and synapses. Memory storage and learning depend on "synaptogenesis" (forming new synapses) and "synaptic pruning" (removing unwanted ones) (Elihami et al., 2017). The white matter changes lead to faster conduction of neural impulses (Giedd, 2015).

With increase in age and neuronal maturation, parallel development in speech and language processing could also be observed. Better overall control in the speech motor processes leads to accurate articulatory productions, faster coupling between various speech subsystems that work together to achieve a common motor goal. Several studies have shown age related increase in the performance of speech motor variables including Diadochokinetic rate (Canning & Rose, 1974; Knujit et al, 2019; Robbins & Klee, 1987; Shin et al, 2008; Stackhouse, 2000), voice related measures

(Kahane, 1982; Harries et al, 1998; Stathopoulos et al., 2011) and speaking rate (Kowal et al, 1975; Wong et al., 2011).

In typical children, DDK rate has been found to be increasing with age (Fletcher, 1972; Stackhouse, 2000) and few investigations posited adult like DDK productions in 15-year-old participants (Fletcher, 1972). Contrary to the above, few studies have shown higher overall variability within and between participants for the DDK rate at young age (Canning & Rose, 1974; Stackhouse, 2000). Additionally, few studies have reported continuous increase in DDK performance till 4th decade of life (Knujit et al, 2019; Shin et al, 2008). Therefore, by considering the above findings, DDK may be considered as a sensitive measure to understand the age-related changes from children to adults and beyond in the articulatory motor control of speech.

The transitions that occur when articulatory movements change from vowels to vowels or vowels to adjacent consonants is termed as second formant transition. It occurs due to resonant frequencies of the vocal tract and helps in shaping different speech sounds. These formant changes are crucial in distinguishing and perceiving the speech sounds (Sharf & Hemeyer, 1972). It indirectly indicates the position of the tongue in the oral cavity, with high F2 indicates anterior oral and low F2 corresponding to posterior articulatory constrictions. Research conducted on F2 transitions in adolescents has revealed values that are closer to those observed in adults, while not entirely identical (Cooksey, 2000).

Dramatic changes in the internal structures of vocal fold will take place during puberty. Consequent to the hormonal changes, lengthening and thickening of the vocal cords, thickening of the laryngeal cartilages and laryngeal descent have been reported (Kahane, 1982; Harries et al, 1998). These events cause lowering of the fundamental frequency, typically more pronounced in males than in females (Eguchi & Hirsh, 1969; Huber et al, 1999; Peterson & Barney, 1952; Stathopoulos & Sapienza, 1997).

Prosody involves the musical aspect of the speech, that includes variations in the pitch, loudness, and duration of spoken utterances. One of the prosodic aspects, the intonation, is the changes observed in pitch patterns over a phrase or a sentence. As per some of the reports, development of intonation either coincides with grammatic development (Snow & Balog, 2002; Snow, 2006) or with changes in pragmatics (Bates, Camaioni & Volterra, 1975). Gender effects on the relative rise of the intonation pattern were observed across genders in the same age range (Deepthy, 2015). Though intonation development undergoes near level of mastery to adults at the age of 5, finer aspects of intonation continue to mature till 10-13 years (Wells & Peppe, 2004).

The rate of spoken utterances is important in understanding the normal development of motor control and coordination as well as for the identification and management of disordered motor speech control (Kent, 1984). An increase in the average rate of utterance from 2 syllable/sec at the age of 6 years to 4 syllable/sec at the age of 14 years was observed (Kowal, O'Connell & Sabin, 1975). Previous studies, with improvised syllabic rate measurements, have reported a change of 4.24/sec to 5.54/sec from 4 to 18 years (Wong et al., 2011). Recent studies observed slower speaking rates in older adults compared to younger speakers (Tuomainen & Hazan, 2018) relating this finding mainly to longer syllable or word durations (Harnsberger et al, 2008).

Normative Studies on Motor Speech Profile

The above-described parameters that relates to the speech motor characteristics could be easily captured using a single software program called Motor Speech Profile developed by Deliyski and Gress, a module in the Computerized Speech Laboratory

(CSL 4500; KayPENTAX. Lincoln Park, New Jersey). Past studies have reported normative of speech motor characteristics in selected populations (Deliyski & Gress, 1997; Patil & Manjula, 2014; Wong et al., 2011). Deliyski and Gress (1997) developed normative data using MSP (model 4341) in healthy adults from 18 to 61 years and presented this as a poster presentation. The results indicated significant gender differences for parameters including second formant transition (average F2 values and maximum F2), fundamental frequency parameters (F0, High and Low F0 and SD of F0), which were expected due to the anatomical differences across gender in the laryngeal structures. Age did not influence the measured dependent variables across the protocols included.

Wong et al. (2011) developed normative data for MSP in healthy children, including adolescents, both males and females in the age range of 4 to 18 years. The evidence demonstrates that diadochokinetic rate increases with age in both men and women. Males' second-formant transition declined more than females with age. No significant age effect or gender effect was observed in intonation stimulability. No significant age or gender differences were seen in frequency or amplitude parameters. Syllable and pause durations decreased with age, indicating a slightly increased syllabic rate in males.

Patil and Manjula (2014) obtained normative data for Telugu speaking healthy adults (age range: 20-60 years). The research identified notable variations in average values between the gender for specific variables, including DDK Peak Intensity. Age was found to have a substantial influence on parameters such as the percentage of speaking time, average pause duration, and DDK period. The magnitude of the second formant transition exhibited a significant age effect in both males and females. Females were significantly affected by age in fundamental frequency, whereas males were not.

Across genders, the average syllabic rate was greatest between the ages of 20 and 30 for males and 40 and 50 for females, but it failed to show gender or age effect. The age group of 40-50 years exhibited the maximum standard deviation of F0 (STD) among both males and females.

John et al. (2014) established normative for 18 parameters under the protocols diadochokinetic rate, second formant (F2) transition, and voice and tremor parameters in MSP, for Kannada speaking adults for individuals aged 20 to 60 years. Among these age groups, it was found that except average DDK rate, all other parameters tend to increase with age for both genders. Males showed faster rate of diadochokinetic rate than females. In second formant transition, females had greater magnitude of F2 transition and rate whereas, male speakers had the most F2 regularity. Most parameters of voice and tremor showed an increase with an increase with age, except for F0. However, F_0 shows a decreasing trend. Clear gender effect was reported for the F0 related parameters and male speakers shown greater variability of F_0 and tremor related parameters.

Need for the Study

Many neuroanatomical changes that occur in the adolescents are quite specific in adolescents. Several anatomical changes occur in the adolescent brain: the frontal and temporal gray matter increases in its volume till 16 years of age; white matter tracts continue to develop till late adolescence; myelin sheath maturation as well as dendritic branching continues till middle age (Lenroot & Giedd, 2006). Paralleling the above course of development some of the physiological studies in speech production have reported longer time course of speech motor development (Smith & Goffman, 1998; Smith & Zelaznik, 2004). Normal-developing adolescents have more varied oral movement trajectories than adults (Smith & Zelaznik, 2004; Walsh & Smith, 2002).

The motor control of speech during this stage is known to be in the 'refinement period' where lung capacity continues to improve along with the maturation of laryngeal structures (Maassen et al, 2010)**.**

As previously thought, the speech motor control processes may not assume adult like parameters until the child is 10 to 12 years (Tingley & Allen, 1975). Therefore, it is not feasible to use children/adult normative on adolescent population due to neuroanatomical/physiological and structural changes that would parallel behavioural changes in adolescents. Some of the important speech motor parameters could be readily measured using dedicated software programmes such as Motor Speech Profile (KayPENTAX. Lincoln Park, New Jersey) A series of standardized protocols included in the MSP, measures diadochokinesis (DDK), voice quality, tremor, intonation, and syllabic rate. In order to mitigate the potential limits of the perceptual analysis, the instrumental approach has frequently been employed in addition to perceptual methods. Further, instrumental analysis also helps in removing the inter-rater bias.

As per our knowledge, the normative data on MSP protocols are currently available in Kannada speaking children and adults (Deepthy, 2015; John et al., 2014). No normative is established for the adolescent population. Additionally, as no previous studies have compared the speech-motor characteristics between adolescents and adults, it will be one of our aims in the current study, as the findings of our investigation will be compared with the study by John et al. (2014). This would help in capturing the developmental trends that differ between adolescents and adults across a range of speech motor behaviours. Furthermore, establishing normative for speech motor characteristics in adolescents will help in describing the magnitude of speech motor deviations in individuals with compromised speech motor control (e.g., adolescents with cerebral palsy, Down syndrome, etc.). Finally, we have chosen the age range between 10 and 18 years with two subgroups (10-14 & 14-18 years) having larger age gap considering the slower neuromotor/physiological changes that occur in this population (Smith & Zelaznik, 2004; Walsh & Smith, 2002).

Aim of the study

This study aims to examine the normal speech motor characteristics of typical Kannada-speaking adolescents using the five protocols of the Motor Speech Profile (MSP) software.

Objectives of the study

1. To develop the normative on the speech motor characteristics of typical Kannada adolescents as a factor of *age* using MSP for

   a) Diadochokinetic rate protocol

   b) Second formant transition

   c) Voice and tremor protocol

   d) Intonation Stimulability protocol

   e) Standard Syllabic rate protocol

2. To develop the normative on the speech motor characteristics of typical Kannada adolescents as a factor of *gender* using MSP for

   a) Diadochokinetic rate protocol

   b) Second formant transition

   c) Voice and tremor protocol

   d) Intonation Stimulability protocol

   e) Standard Syllabic rate protocol

3. To compare the adolescent speech motor normative as a factor of age and gender with that of typical Kannada adults.

Hypotheses

1. There will be no statistically significant effect of age on

a) Diadochokinetic rate protocol

b) Second formant transition

c) Voice and tremor protocol

d) Intonation Stimulability protocol

e) Standard Syllabic rate protocol

2. There will be no statistically significant effect of gender on

a) Diadochokinetic rate protocol

b) Second formant transition

c) Voice and tremor protocol

d) Intonation Stimulability protocol

e) Standard Syllabic rate protocol

3. There will be no statistically significant difference between adolescent and adult speech motor normative as a factor of age and gender

Chapter 2

Review of Literature

The development of speech motor control is a slow process which extends from childhood through adolescence to early adulthood. With the increase in age, most of the communication efficiency, accuracy and fluency in speech production, and the voice quality gets enhanced (Linville, 1996; Wohlert & Smith, 1998). The early assertions were the processes involving in speech motor control will attain adult-like by the end of childhood (Smith & Gartenburg, 1984). Entailing the above hypothesis was the presumption which was before the availability of physiological studies that the articulatory movement control reaches full maturity by the age of 10–12 years (Tingley & Allen, 1975; Walsh & Smith, 2002; Case & Grigos, 2016).

Acquiring speech motor control involves imitating the acoustic patterns mediated by adults and establishing auditory and somatosensory patterns to speech movements and postures. Contrary to the previous investigations, few studies have revealed that substantial levels of neural growth, development and activity, parallels with the growth and development in language and communication in the adolescent brain (Nippold et al., 2007). Recent research, by Walsh & Smith (2002) and Cheng et al. (2007), has indicated that the process of achieving mature, adult-like speech motor characteristics continues into late adolescence. This means that the movement characteristics of the articulatory system, are not fully developed until late adolescence. As a result, the coordination and precision of articulatory movements needed for fluent speech are still maturing during this period. Although, the rate of speech motor development slows significantly in later years compared to the rapid changes seen during childhood (Smith & Zelaznik, 2004), speech differences are still evident in 16-year-olds, when compared to young adults (Walsh & Smith, 2004). Thus, it is important to understand the prolonged developmental trajectory towards attaining adult speech motor control processes and to explore the factors contributing to it.

Speech is the means by which discrete and precise linguistic messages are converted into a perceivable acoustic signal for a listener. Arguably, the process of speech production is complicated than most other motor acts. It requires more motor fibers than any other human motor activity (Fink, 1986). The basic requirement of speech production involves the coordinated action of respiration, phonation and articulation. Besides, a coordinated and controlled movement of vocal tract, fluctuations in the pressure and flow is also required in producing the acoustic signal that a listener hear as speech. The prosodic changes in the speech is the outcome of this interplay between the different subsystems involved.

Stages in Speech Motor Development

Speech motor development involves several discrete series of events or stages including *differentiation* and *integration*. During differentiation stage a preexisting behavior gets modified into more specialized one and during integration stage a previously stabilized behavior gets consolidated with a new one. The stage of *refinement* is a period between these two stages in which matured behaviors undergo continual refinement. Green et al. (2002) and Cheng et al. (2007) have described variations in speech motor control mechanisms after the age of 10 to 12 years as "refinements" of established patterns. According to Green et al (2002), the beginning stages of speech motor development are characterized by non-uniform control over the articulators. Also, the development of the jaw precedes the lips. On observing the developmental patterns, it was found that the characteristics of the oral motor control system remarkably influence the pattern of acquisition of speech sounds. The tongue and jaw movements exhibit changes until the age of 8–11 years and continues to undergo refinement into late adolescence (Cheng et al., 2007).

The coordination of speech involves differentiation, integration and refinement of vocal tract components and with each stage having a specific effect on a child's speech producing abilities. Children's movement kinematics are different from that of adults at different ages. Kent (1992) also discusses the issue of whether the speech motor development better understood as a process in which child just simplifies the mature behavior or the child progressively refine into the mature behavior. He reviewed the study of Hay (1979) in which it was reported that, there was a non-linear progression in the proficiency of reaching movements across 5, 7- and 9-year olds wherein a progressive improvement in behavioural accuracy in stepping movements were achieved by older children. Acoustic investigations of speech development generally lead to the conclusion that variability in speech motor control gradually decreases until 8 to 12 years of age, at which point adult like stability is reached. The precise age at which minimal variability is reached is likely dependent on a number of variables, but two are particularly significant: (1) the child's unique motor development pattern, and (2) the specific speaking behavior that is being studied (Kent, 1976; Lenneberg, 1967).

Apart from this, changes in motor speech development occur due to alterations in anatomy, physiology, sensory feedback, and speech processing at the central nervous system level throughout an individual's lifespan. Kahane (1981) summarized the data from many studies that discusses age related changes in structures that contribute to speech physiological changes across gender, it was reported that, with increasing age, the mobility of rib cages tends to decrease which results in reduced respiratory function in the geriatric population. Reduced diadochokinesis is observed which correlates with the predicted atrophy of muscle groups in the articulators with ageing. To clearly understand all the facets of age-related changes in the speech mechanism, the studies should be elaborated into a wider age range, that is from childhood to very old adults. This is important as neural and musculoskeletal developments are continuous in the period of transition from childhood to adolescence with early emphasis on achieving the spatial aspects of motor-acoustic goals and later emphasis on optimizing the speaking rate (Netsell, 1979). Very few models explain how the speech motor productions takes place and deliberates on the processes involved in this (Guenther et al, 1998; Netsell, 1979).

Netsell's Model

Speech motor control (SMC) is hierarchically organized control structure in which peripheral somatic sensory information interacts with central motor representations. Netsell's model describes the development of SMC (Netsell, 1979). It is hypothesized that the normal child learns to talk by listening, watching and imitating an external model. The model provides both auditory and visual afferent cues (AFFa and AFFv), which the child attempts to imitate with his or her own movements and vocalizations (EFF, efferent). This EFF has two important consequences. First, it generates the auditory patterns that return to the ears of the model and to the child himself. Later, the auditory feedback closes the important motor – auditory loop. Secondly, EFF creates feedback associated with the speech movements and postures (AFFm+p) that the child pairs with his own auditory patterns. In this, he hears and feels his speech movements as they are being developed. This tight sensorimotor and auditory coupling presumably is the key to the refinement of the child's output (EFF) to approximate the external model. By this process, the child eventually develops internal representation in his nervous system of these sensorimotor – auditory patterns. It is not clear at this point whether child uses conscious control of speech movements in learning to talk. Additional research has been conducted to elucidate the neural mechanisms underlying speech motor control, resulting in the development of a computational model known as the DIVA model, which explains speech acquisition and production (Guenther, 1994; Guenther, Ghosh & Tourville, 2006; Guenther, Hampson & Johnson, 1998).

The DIVA Model (Directions into Velocities of Articulators)

The DIVA model, a neural network framework, offers a detailed explanation of the neural processes involved in controlling speech movements quantitatively. The model focuses on how the brain converts desired movement directions (in sensory space) into articulatory velocities. It posits that higher-level brain areas translate linguistic intentions into a sequence of speech sounds. Motor sequencing circuits then activate specific nodes within a speech sound map, which serves as the highest processing level in the DIVA model.

Production of a speech sound in the DIVA model starts with activation of a node representing that particular sound in a *speech sound map*. The left ventral premotor cortex (vPMC), which includes the rostral part of the ventral precentral gyrus as well as adjacent regions in the posterior inferior frontal gyrus and anterior insula, is thought to be the primary home of the ensemble of neurons that correspond to each speech sound map node. This node's activation results in motor commands which propagate via the feedforward and feedback control networks to the motor cortex. Two additional subsystems comprise the feedback control system: the somatosensory feedback control subsystem and the auditory feedback control subsystem. Speech sound motor programs that have been previously taught are generated by the feedforward control system, which has two components. Executing the motor program at the right instant in time is the responsibility of the first component. The second component of the feedforward control system comprises the motor programs themselves, which are responsible for generating feedforward commands for producing previously learned speech sounds. The auditory feedback control subsystem is responsible for detecting and correcting differences between the desired auditory signal for a speech sound and the current auditory feedback. Such feedback and feedforward loops envisaged in DIVA model gets continuously refined, consequent to a repeated practise thereby making the overall act of speech as an over learnt movement patterns. These movement patterns get matured and refined differently with increase of age, and potential interaction of age with gender cannot be undermined as certain neurophysiological changes occurs rapidly in specific genders with time. In the next section the anatomical and physiological changes during early childhood and adolescence restricted to articulatory and phonatory systems is discussed as the protocols under Motor Speech Profile that are used to understand the changes in adolescent speakers mainly focuses on these two subsystems.

Anatomical and Physiological Changes

a) Articulatory system

During early development, the refinement of speech breathing progresses gradually, with minimal changes observed in speech breathing behaviours between the ages of 4 and 6 years (Boliek, 2009). The frequency with which the velopharynx closes during syllable utterances increases significantly with age, and continues to develop till 6 months of age (Thom, 2006). The variability in the duration of lip-opening movements, lip-open postures, jaw-opening movements, jaw-open postures, the difference between the timing of lower lip opening and the timing of jaw opening decreased between the child and adult groups. Children use varying combinations of muscle activity to achieve phonetic goals. Even at age 12 years, children were not adult-like in their performance. By assessing the variation in lower lip and jaw movements, the development of speech motor skill was investigated. The production of syllables [mae] and [bae] were repeated 20 times each by five adults and five children aged 4, 7, and 10. Between the adult and the child groups, there was less variation in the length of the lip-opening movements and postures and jaw-opening movement and postures, and the timing of the onset of opening of lower lip and jaw. Between the child groups, there were no discernible variations in the variability of these indicators. Not between any other age groups, but between the 4- and 7-year-old groups, there was a substantial decrease in the variability of lower lip displacement. The variability of jaw displacement did not differ significantly among the groups. There were not any significant differences in variability between [bae] and [mae]. It is hypothesised that the variety of speech motions at early, intermediate, and later ages is influenced by distinct developmental motor processes (Sharkey & Folkins, 1985).

To help build a more complete model of speech motor development, Wohlert et al (2002) looked at the trajectories of the upper lip, lower lip, and jaw movements to find out if (a) articulatory motor control changes in late adolescence; (b) sex differences occur during this developmental period, possibly because of differences in craniofacial growth rates; (c) jaw motion control becomes adultlike earlier than upper and lower lip control; and (d) articulatory movement control co-develops in adolescence. There were fifteen boys and fifteen females in each group, ages twelve, fourteen, and sixteen, as well as young adults (mean age, 21.2 years). For the upper lip, lower lip, and jaw movements, a measure representing spatiotemporal consistency in trajectory development for repeated productions of a phrase was estimated. Adolescents had a higher overall trajectory variability than young adults. Jaw trajectories were less variable than upper or lower lip trajectories, but as age grew, all effectors had parallel declines in variability, indicating that adult performance of jaw movement control does not come before adult performance of lip control. Adolescents exhibited considerably longer movement durations, lower velocities, smaller displacements, and higher variability on separate temporal and spatial measurements compared to young adults. This long developmental time course may not be explained by peripheral growth factors, as there were no changes in any of the measures between the sexes. These findings offer preliminary proof of significant shifts in speech motor control mechanisms throughout adolescence (Wohlert & Smith, 2002).

The variability of the speech movement during sentence production reduced across development. This maturational trend was most apparent from age 6 years to adulthood. Additionally, the 6- to 7- year old, 8- to 11-year old and adolescents demonstrated significantly higher variability compared with adults (Murdoch, 2011). It appears that adolescent speakers continue to use significantly more variable speech motor output than adult speakers, providing support for an extended course of speech motor maturation.

b) Phonatory system

Dramatic changes in the internal structures of vocal fold will take place during puberty. Consequent to the hormonal changes, lengthening and thickening of the vocal folds, thickening of the laryngeal cartilages and laryngeal descent have been reported (Kahane, 1982; Harries et al, 1998). These events cause lowering of the fundamental frequency, typically more pronounced in males than in females. Previous study also had found that as age advances formant frequency declines (Eguchi & Hirsh, 1969). In addition, a study was carried out to examine the amplitudes, formant frequencies, and fundamental frequency of a group of adults and children of various ages that is 4, 6, 8, 10, 12, 14, 16, 18 years and adults. The subjects were 10 males and 10 females in each age range. A trend of decreasing F0 was examined as the age increases, and the trend was more prominent in male. It may be concluded that in men, the vocal tract has a significant growth spurt between the ages of 12 and 14 and then a slower, more gradual increase in size until the ages of 16 or 18. According to the research, female maturation is largely finished by the age of 12 (Huber et al,1999).

Instrumental Analysis of Speech Motor Control

Past studies by various researchers have used motor speech approach to analyse the subsystems of speech and thereby quantify the perceptual speech output (Bruner, 1973; Kent & Moll, 1975; Smith, 1978). Instrumental assessments, especially acoustic analysis, have been widely employed to augment and reduced their inherent limitations (Collins, 1984). Acoustic analysis serves as a valuable adjunct to perceptual evaluation, providing confirmatory evidence and enhancing assessment reliability (Kent et al., 1999). Acoustic analysis using instrumental methods eliminates inter-rater bias and significantly contributes to the quantification, description, and understanding of typical and atypical speech motor outputs. Furthermore, acoustic analysis visualizes speech signals, yielding baseline data that facilitates the tracking of longitudinal changes and serves as a feedback mechanism during therapeutic interventions. The computerized software, Motor Speech Profile (MSP) assess the motor speech measures, such as Diadochokinetic rate, Second Formant (F2) transition, voice and tremor parameters, intonation stimulability and syllabic rate.

Normative values were developed by Deliyski and Gress (1997) for the Motor Speech Profile (MSP) Model 4341 in healthy individuals (18–60 years old) across gender. Significant differences in acoustic parameters indicating gender effects were reported, such as fundamental frequency (F0) and F2 characteristics. These findings are consistent with physiological differences in the structure of the larynx and vocal tract between males and females. Significant associations between age and acoustic features of speech were not observed, indicating that these measurements hold steady throughout maturity in healthy adults. Several other studies have developed the normative for MSP in children, adults and elderly population (Deepthy, 2015; Shashank & Mahesh, 2023; Wong et al., 2011; Patil & Manjula, 2014)

Few studies that are relevant to understand the development of each parameters under Motor Speech Profile protocols across different age groups and gender are discussed below.

DDK

Oral DDK is included in most available test of motor-speech functions as well as in screenings for speech-language pathology cases as part of oral–motor examination (Lombard & Solomon, 2020). In a study of oral diadochokinetic performance in sixty-four typically developing Cantonese pre-school children, it was found that monosyllabic units were produced much faster, regular and accurately than multisyllabic units (Gao, Yuen & Li, 2023). Increasing DDK rate with age in typical children has been reported (Fletcher, 1972; Stackhouse, 2000) and few investigations posited adult like DDK productions in 15-year-old participants (Fletcher, 1972). Contrary to the above, few studies have shown higher overall variability within and between participants for the DDK rate at the young age indicating scope for further stabilization in the syllable production rates during late adolescence (Canning & Rose, 1974; Robbins & Klee, 1987; Stackhouse, 2000).

Normative data have been reported on DDK rates for 4.5 years to 14.5 years old participants (Canning & Rose, 1974). The study established maximum repetition rates for the DDK task for the production of monosyllables containing /t/, /j/, /k/, /1/, /w/, /p/

and trisyllabic sequences of /p/–/t/–/k/ or "buttercup" for 300 subjects (150 F, 150 M) in native British English speakers. Results indicated that children's DDK rates increase as their motor systems mature, with adult-like rates being achieved by age 9–10 (Canning & Rose, 1974). Contrary to the above results few studies have documented continuous increase in DDK performance till 4^{th} decade of life (Knujit et al, 2019; Shin et al, 2008). Knujit et al (2019) conducted a cohort study in 224 adults of age range 18-80 for maximum performance tasks. He observed that the maximum rate of repetition was slower for /ka/ compared to /pa/, /ta/, and /pataka/. /Pataka/ was the fastest sequence and significant age-related decline only observed after 60 years. Shin et al (2008) conducted a study aimed to provide standardized scores from 120 normal Korean adults aged 18 to 59 for regularity and accuracy of articulation during diadochokinesis. The study also measures maximum phonation time (MPT) and diadochokinetic (DDK) rates. Results showed that total scores were significantly higher in the 50-59 age group compared to the 20-29 age group, but there was no significant difference between genders. Therefore, by considering the above findings, DDK could be assessed to understand its age-related changes from children to adults and beyond.

F2 transition

The transitions that occur when articulatory movements change from vowels to vowels or vowels to adjacent consonants is termed as second formant transition. It occurs due to resonant frequencies of the vocal tract and helps in shaping different speech sounds. These formant changes are crucial in distinguishing and perceiving the speech sounds (Sharf & Hemeyer, 1972). It indirectly indicates the position of the tongue in the oral cavity, with high F2 indicates anterior oral and low F2 corresponding to posterior articulatory constrictions. In a study to examine F2 transition characteristics of /l/ by young children and adults, result showed F2 transitions of adults having a great similarity across and within speakers, while those of young children showed greater variability, but became increasingly similar to those of adults with increasing age (Chung & Weismer, 2021). The participants in the study were 17 children (ages 2-5) with typically developing speech, and 10 female adult speakers of Southern American English. Chung & Weismer (2021) observed that Adult patterns of /l/ production can serve as reliable references for evaluating children's /l/ productions. Research conducted on F2 transitions in adolescents has revealed values that are closer to those observed in adults, while not entirely identical (Cooksey, 2000). Cooksey (2000), in a 3-year longitudinal study of 86 early-adolescent boys proposed a universal process for male voice change occurring in six invariant stages which are Unchanged, Mid Voice I, Mid Voice II, Mid Voice IIA (the climax of the change), New Voice and Emerging Adult. Each stage has specific pitch ranges, resonance characteristics and average speaking fundamental frequency (SF0) ranges, though the timing and rate of progression vary for each individual. He observed that the resonance characteristics among adolescents itself varies among themselves.

Voice and tremor

Dramatic changes in the internal structures of vocal fold will take place during puberty. Consequent to the hormonal changes, lengthening and thickening of the vocal folds, thickening of the laryngeal cartilages and laryngeal descent have been reported (Kahane, 1982; Harries et al, 1998). These events cause lowering of the fundamental frequency, typically more pronounced in males than in females (Eguchi & Hirsh, 1969; Huber et al, 1999; Kent, 1976; Peterson & Barney, 1952; Stathopoulos & Sapienza, 1997). As a factor of hormonal development the fundamental frequency of voice changes with age from childhood through puberty to adulthood. Children tend to speak around 250-400 Hz on average. The frequency of the normal speaking voice in adolescent females ranges from 200 Hz, and that of adolescent males around 150 Hz (Pederson, Agersted & Jonsson, 2015). However, in a study conducted in paediatric population variations in fundamental frequency during speech did not change significantly with age for both males and females (Wong et al, 2011).

Intonation stimulability

Prosody involves the musical aspect of the speech, that includes variations in the pitch, loudness, and duration of spoken utterances. One of the prosodic aspects, the intonation, is the changes observed in pitch patterns over a phrase or a sentence. As per some of the reports the development of intonation either coincides with grammatic development (Snow & Balog, 2002; Snow, 2006) or with changes in pragmatics (Bates, Camaioni & Volterra, 1975). A Normative study of Kannada Speaking children by Deepthy & Jayakumar (2015) found significant differences in most parameters across different age groups. The mean values for Running speech fundamental frequency (rFO), Highest fundamental frequency (rFhi), and Amplitude variability (rvAm) decreased with age. The most substantial changes in frequency parameters were observed between the ages of 6 and 10. Additionally, no significant gender differences were noted across the age groups (Deepthy & Jayakumar, 2015). Though intonation development undergoes near level of mastery to adults at the age of 5, finer aspects of intonation continue to mature till 10-13 years (Wells & Peppe, 2004).

Syllable rate

The rate of spoken utterances is important in understanding the normal development of motor control and coordination as well as for the identification and management of disordered motor speech control (Kent, 1984). An increase in the mean rate of utterance from 2 syllables per second at the age of 6 years to 4 syllables per second at the age of 14 years was observed (Kowal, O’Connell & Sabin, 1975). Previous studies, with improvised syllabic rate measurements, have reported a change of 4.24/sec to 5.54/sec from 4 to 18 years (Wong et al., 2011). Tuomainen and Hazan (2018) examined how older adults adjust their speech in various speaking situations. The study included 83 speakers of Southern British English, with 57 older adults aged 65-84 and 26 younger adults aged 18-26. They found that older adults had slower speaking rates compared to the younger adults, attributing this primarily to longer syllable or word durations. Harnsberger et al (2008) compared the speech rate in older and younger adults. The purpose of this study was to determine the effect of vocal aging by examining the mean fundamental frequency and speaking rate. Participants included 30 males and the task was to read the "Rainbow Passage." Sixteen participants were older adults aged 74-88 years (mean age of 82 years), and 14 were younger adults aged 21-29 years (mean age of 24 years). Results showed that, on average, older speakers took 33% more duration to produce the stimulus materials than younger speakers. This difference was most pronounced in sentence duration, which increased by 58% for the older group.

Speech rate development is delayed, and it is frequently noted that children have lower speech rates than adults until they reach adolescence, at which point they tend to talk more slowly (Kowal et al., 1975). According to Kowal, O'Connell, and Sabin (1975) the speech rate (syllables per second) of English-speaking children in storytelling and conversational tasks, grew with age until roughly 14 years and 1 month of age,. Furthermore, researchers assessed English-speaking kids using four distinct activities and discovered that the speech rates of children, grew steadily until they turned 13 years old (Nip & Green, 2013).

Nip and Green (2013) also conducted a comprehensive study examining the factors contributing to the age-related increase in speaking rate among participants aged 4, 7, 10, 13, 16 years, and young adults of both genders. Their research involved a range of speaking tasks that varied in cognitive, linguistic, and motor processing demands. The study revealed that speaking rate increased with age, characterized by fewer pauses and reduced articulator displacements, without an increase in articulator movement speed. Movement speed did not seem to limit speaking. Instead, the rise in speaking rate with age is due to enhanced cognitive and linguistic processing and better speech motor control, indicating that non-motor factors, such as cognitive development, play a significant role in shaping speech rate development. This research provides valuable insights into the complex interplay of factors influencing speech rate development across childhood and adolescence.

Normative Studies on Motor Speech Profile

The above-described parameters that relates to the speech motor characteristics could be easily captured using a single software program called Motor Speech Profile developed by Deliyski and Gress, a module in the Computerized Speech Laboratory (CSL 4500; KayPENTAX. Lincoln Park, New Jersey). Few past studies have reported normative of speech motor characteristics across children, adults and elderly population (Deliyski & Gress, 1997; Patil & Manjula, 2014; Shashank & Mahesh, 2023; Wong et al., 2011). Deliyski and Gress (1997) developed normative data using MSP (model 4341) in healthy adults from 18 to 61 years. The results indicated significant gender differences for parameters including second formant transition (average F2 values and maximum F2), fundamental frequency parameters (F0, High and Low F0 and SD of F0), which were expected due to the anatomical differences in male/female laryngeal structures. Age did not influence the measured dependent variables across the protocols included. The study by Deliyski and Gress (1977) is not a publication, but a poster presented in motor speech and world congress and hence other methodological details could not be found.

In contrast, Wong et al. (2011) developed normative data for MSP in healthy children, including adolescents, both males and females in the age range of 4 to 18 years. The evidence demonstrates that diadochokinetic rate increases with age in both men and women. Males' second-formant transition declined more than that of females with age. No significant age or gender effect was observed in intonation stimulability. No significant age or gender differences were seen in frequency or amplitude parameters. Syllable and pause durations decreased with age, indicating a slightly increased syllabic rate, which was statistically significant only in males.

Patil and Manjula (2014) obtained normative data for Telugu speaking healthy adults (age range: 20-60 years). The research identified notable variations in average values between the gender for specific variables, including DDK Peak Intensity. Age was found to have a substantial influence on specific parameters, such as the percentage of speaking time, average pause duration, and DDK period. The magnitude of the second formant transition exhibited a significant age effect in both males and females. Females were significantly affected by age in fundamental frequency, whereas males were not. For both genders, the average syllabic rate was greatest between the ages of 20 and 30 for males and 40 and 50 for females, but it failed to show gender or age effect. The age group of 40-50 years exhibited the maximum standard deviation of F0 (STD) among both males and females.

Shashank & Mahesh (2023) assessed the effectiveness of maximal articulatory task performance in healthy elderly population of Kannada speakers aged 61 to 80 years. The study included 60 healthy participants, evenly divided between males and females. The analysis focused on the Diadochokinetic rate (DDK) and second formant transition (F2) parameters, following the recommended protocols of the Motor Speech Profile, for the elderly participants in this study. In DDK parameters, the average rate and average syllabic intensity were found to be more in males compared to females. No age effect was observed for the DDK parameters. Similarly, for second formant parameters, higher F2 rate was observed for males whereas higher magnitude of the second formant was observed in females.

John et al. (2014) established normative for 18 parameters under the protocols DDK rate, second formant transition, and voice and tremor characteristics in MSP, for Kannada speaking adults between the age of 20 and 60 years. Across age groups, it was found that except average DDK rate, all other parameters are in ascending trend for both genders. Males showed faster rate of diadochokinetic rate than females. In second formant transition, females had greater magnitude of F2 transition and rate whereas, male speakers had the most F2 regularity. Most parameters of voice and tremor showed an increase with an increase with age, except for F0. However, F_0 shows a decreasing trend. Clear gender effect was reported for the F0 related parameters and male speakers shown greater variability of F_0 and tremor related parameters.

Chapter 3

Method

Participants

A total of 80 adolescents in the age range of 10-18 years were participated in the study. The sample size for this study was obtained by using the diadochokinetic rate parameters of John et al's study (2014) using G*3.1 power software (Faul et al., 2009) with the alpha being set at 0.05, and power (β)at 0.95. The analysis revealed 40 samples for each age range and hence we included 80 as the total sample size in our study. The study population further divided into two subgroups of age ranges 10-14 years and 14-18 years, with 40 samples in each group with equal gender representation. All participants were native Kannada speakers and were predominantly Mysore residents. Selection of participants was through known contacts, from schools in and around Mysore, from park and those who came with bystanders of patients in the institution (AIISH). Participants were asked for their written informed consent before enrolling themselves in the study.

The inclusion criteria of participants were, the subjects should be

(a) Native speakers of Kannada.

(b) No history of speech and language deficits.

(c) No history of hearing loss and oro-motor structural deficits.

(d) No known history of voice disorders

The exclusion criteria of the participants;

(a) Participants having very poor academic performance

(b) Individuals with articulatory errors.

(c) Individuals with a history of neurological disorders affecting articulatory motor control.

(d) Individuals with articulatory disorders.

Instrumentation

The research will utilize the Computerized Speech Laboratory (CSL 4500) by KeyPENTAX. Within the CSL, the advanced Motor Speech Profile (MSP) module will be employed to assess the subject's articulatory motor performance reliably. All the 5 protocols in the MSP are used in this study which are 1) Diadochokinetic rate, 2) Second formant transition, 3) Voice and Tremor parameters, 4) Intonation stimulability protocol, 5) Standard syllabic rate protocol. The sampling rate used for the audio recording will be 22 KHz.

Research design: Cross Sectional, Normative study.

Recording

The data was recorded individually, using the Computerised Speech Lab (CSL 4500; KayPENTAX. Lincoln Park, New Jersey) software and the company recommended microphone. All the recordings will be performed in a quiet room for all the protocols of Motor Speech Profile (MSP). The participant was seated at 10 centimetres distance from the microphone. Also, to provide familiarity a pre-recorded sample of an adult was introduced. A total of three trials was recorded for each stimulus, and the highest value will be tabulated (wherever necessary). The subjects' participation across the protocols were counterbalanced. Additionally, a rest period of 10-20 seconds was provided across each trial within a protocol to reduce motor fatigue. The voice sample selected was up to 8 seconds long for each stimulus, after trimming initial and final few milliseconds. The MSP analysis was performed later for the each saved acoustic sample and the acoustic variables will be displayed. The stimulus and instructions for each protocol is given below.

Procedure

Prior to the recording, the participants underwent informal screening for exclusion for the study. The screening was carried out for cognitive abilities, voice problems and oral peripheral motor abilities. Written consent (Appendix-1) was obtained from the participants (directly from the parents and also through teachers) for taking part in the study after giving a brief description about the objective of the study. Before proceeding to sample recording, a standard instruction for each protocol were given orally and two practice trials were given as test familiarization. The participants were asked to listen to the recorded stimuli of a native female Kannada adult for the protocols intonation stimulability and standard syllabic rate which will be discussed below.

Protocols

A wide range of analytic programs were considered for motor speech analysis for each parameter. The MSP software offers the provision of analysing five protocols: Diadochokinetic rate (DDK), second formant transition, voice and tremor protocol, intonation stimulability and standard syllabic rate protocol. The subjects were provided with verbal instructions for each protocol.

1. **Diadochokinetic rate**

The production of sustained syllables in DDK, requires the integrity of several speech musculatures that need to work in coordinated and unison manner. Under DDK, the software captures several aspects such as rate, average period, various measures of perturbations in period and intensity. In this task, adolescents were instructed to produce multiple repetitions of/pa/, /ta/, /ka/ (Alternate Motion Rate) and /pataka/ (Simultaneous Motion Rate) separately as quickly as possible for 8 seconds.

2. Second formant transition

The F2 transition is an important measure of coarticulation. Under this parameter, various aspects of F2 magnitude, rate, and regularity are studied. Children were instructed to repeat /i-u/ as quickly, regularly and clearly as possible for 8 seconds. As the F2 transition for young adolescents were not smooth as older subjects, band limit was not considered for them.

3. Voice and tremor

Under voice and tremor parameters various measures of frequency, intensity and perturbation measures like jitter, shimmer etc. are captured. These parameters reflect the physiological variations in speech production with development. For this parameter the given task was to phonate the vowel /a/ for minimum 6 seconds after taking a deep breath.

4. **Intonation stimulability**

The intonation parameters addressed in the study includes various domains of Fundamental frequency range, variations in FO and intensity during speech production. The stimulus sentence was translated version of English sentence "Are you leaving today or tomorrow?". The stimuli were of a native Kannada female speaker with speaking fundamental frequency (SF0) 228. Children were instructed to imitate the model sample as much as possible.

Stimulus token: "/Nīvu indu athavā nāḷe horaḍuttīrā? /".

5. Standard syllabic rate

This is an important aspect of development as reported by various researches. There are variations in the different variables of rate of speech with an increase in age. Parameters like syllabic rate, syllable duration, percentage speaking time, pause duration etc. are studied. The stimuli used for this task was Translated version of English sentence "We knew you were away all year". The speaking fundamental frequency 230. Children were instructed to listen to the model sample and to repeat them at their comfortable rate.

Stimulus token: “/Nīvu varṣapūrti dūra iruviri endu namage tiḷidittu/”.

The included parameters of MSP and the symbols used along with the units of measurement are tabulated in Table 3.1.

Table 3.1

Details on the acoustic parameters measured across the five MSP protocol

Acoustic Variables	Symbol
Diadochokinetic Rate Parameters	
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 of 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
Second formant transition parameters	
1) Magnitude of F2 variation	F2magn, Hz
2) Rate of F2 variation	F2rate, /s
3) Regularity of F2 variation	F2reg, %

4) Average of F2 value	F2aver, Hz
5) Minimum F2 value	F2min, Hz
6) Maximum F2 value	F2max, Hz
Voice and Tremor parameters	
1) Average fundamental frequency	F0 in Hz
2) Average pitch period	T0 in ms
3) Highest fundamental frequency	Fhi in Hz
4) Lowest fundamental frequency	Flo in Hz
5) Standard deviation of fundamental frequency	STD in Hz
6) Coefficient of variation of fundamental frequency	vF0 in %
7) Coefficient of variation of amplitude	vAm in %
8) Magnitude frequency tremor	Mftr, %
9) Magnitude amplitude tremor	Matr, %
Intonation stimulability parameters	
1) Running speech fund. Frequency	rF0, Hz
2) Running speech pitch period	rT0, ms
3) Highest F0	rFhi, Hz
4) Lowest F0	rFlo, Hz
5) Standard deviation of F0	rSTD, Hz
6) Frequency variability	rvF0, %
7) Amplitude variability	rvAm, %
Syllabic rate parameter	
1) Average syllabic rate	SSrate, /s
2) Average syllabic duration	SSsdur, ms

3)	Average pause duration	SSpdur, ms
4)	Percent speaking time	SSspk, %
5)	Percent pause time	SSpau, %

Analysis

All parameters underwent analysis using the MSP Advanced module. To analyse each parameter, samples were inputted into the software, and the analysis was conducted using the 'MSP Advanced' within the module. For each parameter, samples were carefully chosen and assessed over a consistent time span of 5 seconds, excluding the initial and final portions of the sample. This 5-second time window was maintained to ensure uniformity in the analysis across two age groups, as the span of production varies among the subjects. MSP then compiled the numerical results and presented them in a report format, facilitating the study of changes over time. The report is available in MSP both in graphic format and Numeric format.

Figure 3.1

A sample screenshot of graphic output obtained for voice and tremor protocol

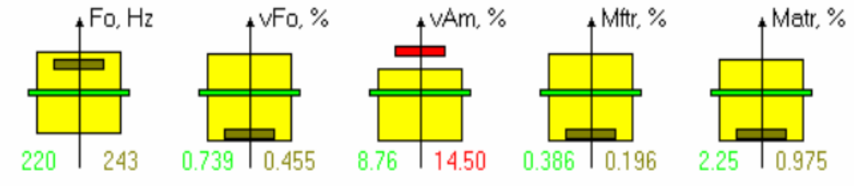
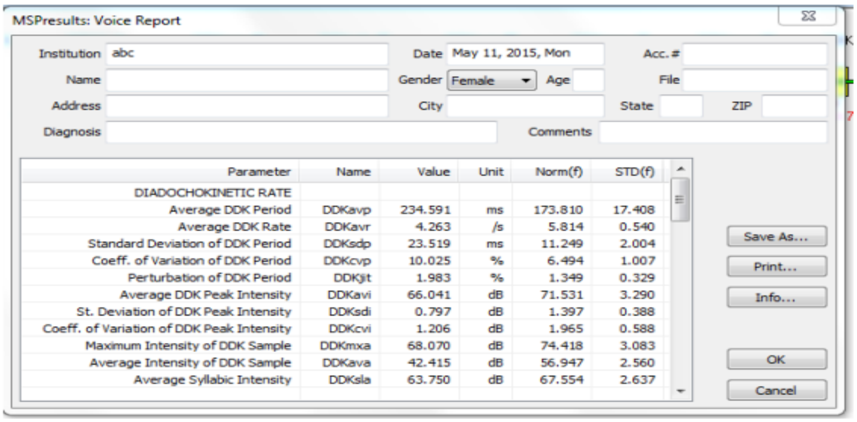


Figure 3.2

A sample screenshot of numerical report for Diadochokinetic rate protocol



For inter-judge reliability, the recorded samples were analysed by a second speech-language pathologist and dependent variable of the study was documented. 10% of the data were reanalysed by the study's investigator for intra-judge reliability after a one-week gap to check the reliability of the calculated dependent variable.

Statistical Analysis

SPSS 26 was used for statistical analysis. Descriptive statistics was done to observe the mean and standard deviation across age and gender. All the data were subjected to the normality test across age and gender. The Shapiro-Wilk test was employed to determine the normality of the data distribution. The result showed that most of the data were not following the normal distribution. Hence non- parametric test was used to check the age group and gender comparison. The Mann Whitney U test was used to see the overall age and gender effect. To compare the present study normative of adolescent with that of adults (John et al, 2013), we opted Wilcoxon Signed Rank test.

Chapter 4

Results

Our study aimed to understand the speech motor characteristics in Kannada speaking typical adolescents as measured through the 5 protocols of Motor Speech Profile software. Prior to the inferential statistical analyses, a test of normality was carried out using Kolmogorov Smirnov's test of normality. As majority of the parameters across 5 different protocols were non-normally distributed, Mann-Whitney U test was used to analyze the results. A total of 80 participants with 40 in each age range of 10-13- and 14-18-years years were included. Each age range consisted of 20 males and 20 females.

The inter-judge reliability was assessed using the Intra Class Coefficient correlation test, which analyze the agreement between judge 1(investigator) and judge 2 (another qualified speech language pathologist), both of whom independently assessed samples from 10% of the randomly selected participants (2 from each age group and gender). Inter-judge reliability for DDK measures ranged from 0.63 to 0.75; F2 transition ranged from 0.56 to 0.74; voice and tremor protocol ranged from 0.70 to 0.90; intonation and syllabic rate protocol ranged from 0.69 to 0.86.

In order to evaluate intra-judge reliability, the investigator's initial analysis was repeated on a subset of 10% of the participants, two from each age group and two from each gender, with a one-week gap between the two analyses.

The effect of age and gender on all the five protocols of motor speech profile are discussed separately.

4.1 The Effect of Age on Motor Speech Profile protocols in typical Kannada speaking adolescents

4.1.1a Effect of Age on Diadochokinetic Rate Protocol: Alternating Motion Rates of syllable /pa/

Eleven dependent variables were measured for the alternating motion rates (AMRs) of the syllable /pa/. These were, 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 of variation of DDK peak intensity (DDKcvi), Maximum intensity of DDK sample (DDKmxa), Average intensity of DDK sample (DDKava), Average syllabic intensity (DDKsla). Since the data was non-normally distributed Mann-Whitney U test was used to analyze the data for the age groups 10-14 and 14-18.

DDKavp indicated average time gap between the successive productions of syllable /pa/ for both the gender whereas DDKavr indicated average rate of the syllable vocalizations per second. DDKsdp reflects the speaker's ability to maintain periodic repetitions whereas DDKcvp shows speaker's ability to maintain constant rate of CV (Consonant-Vowel i.e; /pa/ in this case) combinations. Perturbations or cycle-to-cycle variations in the CV vocalizations were reflected by DDKjitt. Results of Mann Whitney U test showed no statistical significance between the two age groups in both genders for DDKavp , DDKavr, DDKsdp , DDKcvp and DDKjitt.

The rest parameters are related to the intensity of target vocalization i.e; /pa/ in this case. DDKavi reflects the amplitude of the individual, DDKsdi is the ability to maintain steady intensity, DDKcvi contrasts DDKsdi and measures variations in the intensity which ultimately reflects on ability to maintain steady intensity. DDKmxa and DDKava are maximum and average intensity of the DDK sample respectively whereas, DDKsla is the average level of the syllable. Results of Mann Whitney U test showed no statistical significance for DDKavi, DDKsdi, DDKcvi, DDKsdi, DDKcvi DDKmxa and DDKsla. In males, it can be inferred from Mann Whitney U test that DDKava showed significant difference between both the age groups whereas no such trend observed in females. The average intensity of the DDK tend to increase with age in males.

Table 4.1

Descriptive Statistics for the AMR of Syllable /pa/ in Male Participants Across Age Groups

Parameters	10-13 years				14-18 years			
	Male							
	Mean	Md.	SD	IQR	Mean	Md.	SD	IQR
DDKavp	189.55	184.5	24.82	21.75	176.2	179.5	17.24	20.75
DDKavr	5.34	5.42	0.59	0.64	5.63	5.57	0.72	0.66
DDKsdp	28.20	16.8	25.24	25.03	28.95	17.30	26.53	20.77
DDKcvp	14.47	9.42	11.68	12.06	17.69	10.91	14.78	18.94
DDKjitt	2.57	1.79	2.19	2.42	3.09	2.50	1.98	3.17
DDKavi	65.99	66.20	4.64	8.06	67.98	67.77	4.56	8.12
DDKsdi	1.88	1.68	0.67	1.06	2.49	2.14	1.30	1.59
DDKcvi	2.87	2.5	1.04	1.68	3.69	3.04	1.94	2.35
DDKmxa	70.27	70.22	5.05	8.91	72.7	71.46	5.25	8.57
DDKava	52.73	52.68	5.19	7.19	57.72	57.52	4.35	8.02
DDKsla	63.35	63.49	3.44	5.55	64.14	64.15	2.54	4.54

Md. = Median; SD = Standard Deviation; IQR = Inter Quartile Range

Table 4.2

Descriptive Statistics for the AMR of Syllable /Pa/ In Female Participants Across Age Groups

Parameters	10-13 years				14-18 years			
	Female							
	Mean	Md.	SD	IQR	Mean	Md.	SD	IQR

DDKavp	183.8	184.5	14.11	21.50	177.9	176.5	17.11	29.75
DDKavr	5.46	5.42	0.42	0.63	5.66	5.63	0.53	0.96
DDKsdp	20.69	14.56	16.91	9.69	17.7	12.93	16.98	5.88
DDKcvp	11.07	8.03	8.30	5.58	10.19	6.72	8.49	4.21
DDKjitt	1.95	1.42	1.37	1.28	1.70	1.43	0.86	0.53
DDKavi	65.56	66.33	3.55	5.45	66.31	66.67	4.69	4.06
DDKsdi	2.02	1.69	0.83	1.05	1.77	1.45	0.78	1
DDKcvi	3.08	2.81	1.19	1.60	2.64	2.29	1.04	1.41
DDKmxa	69.74	70.21	3.37	5.52	70.15	69.82	5.54	4.53
DDKava	51.29	51.82	4.29	4.86	54.41	54.01	5.32	6.68
DDKsla	62.89	63.38	2.59	3.73	63.36	63.41	3.69	2.83

From the descriptive statistics, for both genders, the average DDK rate (DDKavp) tends to decrease slightly with age, possibly indicating a stabilization of motor skills. Variability measures (DDKcvp & DDKsdp) generally indicate more consistency in the older age group. Amplitude and intensity measures (e.g., DDKavi, DDKava) tend to increase slightly with age, indicating possibly stronger or more controlled articulatory movements.

Table 4.3

Mann-Whitney Results for the Age Effect in Males and Females for AMR /pa/

Parameters	**Males**			**Females**		
	U	Z	*p* value	U	z	*p* value
DDKavp	139	-1.65	0.09	156	1.19	.23
DDKavr (/s)	148	-1.41	0.16	158	-1.13	.25
DDKsdp	192	-0.22	0.83	137	-1.70	.08
DDKcvp	179.5	-0.55	0.58	139.5	-1.63	.10
DDKjitt (%)	157	-1.16	0.24	199.5	-.01	.98
DDKavi	151	-1.32	0.18	194	-.16	.87
DDKsdi (dB)	142.5	-1.56	0.12	156	-1.19	.23

DDKcvi (%)	144.5	-1.50	0.13	152	-1.29	.19
DDKmxa	149	-1.38	0.17	198	-.05	.95
DDKava(dB)	95.5	-2.83	<0.01*	132	-1.84	.06***
DDKsla(dB)	172	-0.76	0.44	196	-.108	.91

*= Significant at 0.01 level of significance
***= Marginally significant

4.1.1b Effect of Age on Diadochokinetic Rate Protocol: Alternating Motion Rates of Syllable /ta/

Eleven dependent variables were measured for the alternating motion rates (AMRs) of the syllable /ta/ which are same as that for syllable /pa/. Since the data was non-normally distributed Mann-Whitney U test was used to analyze the data across age groups. Table 4.4 and 4.5. shows the descriptive statistics for the AMR of syllable /ta/ across the age groups.

Table 4.4

Descriptive Statistics for the AMR of Syllable /ta/ in Male Participants Across Age Groups

Parameters	10-13 years				14-18 years			
	Mean	Md.	SD	IQR	Mean	Md.	SD	IQR
DDKavp	180.29	193	24.11	43.50	174	173	16.45	31
DDKavr	5.59	5.2	0.72	1.26	5.8	6.02	0.66	0.93
DDKsdp	24.5	17.6	11.9	19.68	19.4	17.98	7.47	8.77
DDKcvp	14.3	8.8	8.88	13.29	11.5	10.02	4.97	8.61
DDKjitt	2.4	1.78	1.60	2.28	2.18	2.15	1.25	1.57
DDKavi	65.55	65.91	3.72	5.37	66.52	66.46	3.69	6.50
DDKsdi	2.1	2.25	0.69	1.37	2.21	1.81	1.85	0.74
DDKcvi	3.2	3.67	1.22	2.05	3.27	2.64	2.77	0.71
DDKmxa	70.01	68.76	5.30	9.39	69.60	68.23	4.90	5.76

DDKava	56.6	55.24	4.33	7.77	56.76	56.46	4.28	8.45
DDKsla	63.2	62.8	2.68	5.75	63.68	63.56	2.66	4.11

Md. = Median; SD = Standard Deviation; IQR = Inter Quartile Range

The effect of age on males were mostly insignificant at 95% confidence intervals. Though the median values did vary between the age groups, it was not statistically significant.

Table 4.5

Descriptive Statistics for the AMR of Syllable /ta/ in Female Participants Across Age Groups

Parameters	10-13 years				14-18 years			
	Mean	Md.	SD	IQR	Mean	Md.	SD	IQR
DDKavp	191.61	196	18.16	19	188.9	195	19.99	31.75
DDKavr	5.24	5.10	0.58	0.51	5.25	5.1	0.73	1.06
DDKsdp	34.59	36.19	16.26	27.80	20.41	19	6.67	10.62
DDKcvp	16.8	18.57	8.63	17.41	10.4	10.55	3.60	5.35
DDKjitt	3.2	2.97	1.69	2.46	2.6	1.81	1.97	2.18
DDKavi	65.08	65.42	5.62	7.22	65.14	65.80	4.32	8.17
DDKsdi	1.63	1.66	0.54	0.81	2.39	1.58	2.03	1.79
DDKcvi	2.44	2.25	0.92	1.59	2.83	1.94	3.08	1.56
DDKmxa	69.23	68.67	6.10	8.12	67.87	65.90	4.49	5.77
DDKava	54.80	54.57	6.43	10.14	54.31	54.37	5.63	3.76
DDKsla	62.37	62.69	4.34	5.35	60.84	59.87	4.46	7.10

Table 4.6

Mann-Whitney Results for the Age Effect in Males and Females for AMR /ta/

Parameters	Males			Females		
	U	z	p value	U	z	p value
DDKavp (ms)	97	-0.87	0.38	132	-0.09	0.93
DDKavr (/s)	95	-0.95	0.34	120	-0.54	0.58

DDKsdp (ms)	95	-0.95	0.34	62	-2.63	<0.01*
DDKcvp (%)	108	-0.43	0.66	78	-2.06	0.03**
DDKjitt (%)	111	0.32	0.75	92	-1.55	0.12
DDKavi (dB)	109	-0.39	0.69	127	-0.28	0.77
DDKsdi (dB)	87.5	-1.25	0.21	114	-0.76	0.44
DDKcvi (%)	96	-0.91	0.36	115	-0.70	0.48
DDKmxa (dB)	111	-0.32	0.75	112	-0.83	0.40
DDKava(dB)	118	-0.4	0.96	125	-0.36	0.72
DDKsla(dB)	102	-0.67	0.49	119	-0.58	0.56

*=Significant at 0.01 level of significance
** = Significant at 0.05 level of significance

The Mann Whitney results showed in Table 4.6 age effect in females for certain temporal parameters related to DDK (DDKsdp and DDKcvp) but these were not significant for males. In females, standard deviation in the DDK period (DDKsdp) and coefficient of variation in DDK period was longer in the older adolescent group. The differences observed indicate that age-related changes in motor control and speech production may vary by gender and specific aspects of the diadochokinetic task.

4.1.1c Effect of Age on Diadochokinetic Rate Protocol: Alternating Motion Rates of Syllable /ka/

Eleven dependent variables were measured for the alternating motion rates (AMRs) of the syllable /ka/ which are same as that for other two syllables. Since the data was non-normally distributed Mann-Whitney U test was used to analyze the data across the two age groups (10-13 and 14-18 years). Table 4.3.1 and 4.3.2 shows the descriptive statistics for the AMR of syllable /ka/ for males and females. Though the mean differed between the age groups in males for certain durational parameters (DDKavp, DDKavr, DDKsdp, DDKcvp, and DDKjitt) and few intensity measures (DDKsdi, DDKmxa and DDKsla), Mann-Whitney results shown in Table 4.3.3 revealed significant age differences between DDKjit and DDKava in males. Also, DDKavr showed to have marginally significant difference in males.

Table 4.7

Descriptive Statistics for the AMR of Syllable /ka/ in Male Participants Across Age Groups

Parameters	10-13 years				14-18 years			
	Mean	Md.	SD	IQR	Mean	Md.	SD	IQR
DDKavp	186.17	186	12.89	12.50	174.2	173	16.45	31
DDKavr	5.39	5.44	0.51	0.35	5.80	6.02	0.66	0.93
DDKsdp	34.49	27.57	19.09	38.52	19.43	17.98	7.47	8.77
DDKcvp	18.13	15.9	9.93	20.38	11.52	10.02	4.97	8.61
DDKjitt	4.50	4.44	2.04	3.39	2.18	2.15	1.25	1.57
DDKavi	66.10	66.12	4.15	4.20	66.52	66.46	3.69	6.50
DDKsdi	2.14	1.83	0.91	1.17	2.21	1.81	1.85	0.74
DDKcvi	3.09	2.86	1.26	1.70	3.27	2.64	2.77	0.71
DDKmxa	70.55	71.62	3.93	3.58	69.60	68.23	4.90	5.76
DDKava	54.82	52.9	4.15	6.56	56.76	56.46	4.28	8.45
DDKsla	63.38	63.35	2.63	2.73	63.68	63.56	2.66	4.11

Table 4.8

Descriptive Statistics for the AMR of Syllable /ka/ in Female Participants Across Age Groups

Parameters	10-13 years				14-18 years			
	Mean	Md.	SD	IQR	Mean	Md.	SD	IQR
DDKavp	194.72	195	16.77	18	188.93	195	19.99	31.75
DDKavr	5.17	5.14	0.52	0.98	5.25	5.1	0.73	1.06
DDKsdp	34.62	34.39	21.69	26.44	20.41	19	6.67	10.62
DDKcvp	14.67	13.97	7.75	14.51	10.40	10.55	3.60	5.35
DDKjitt	3.24	2.82	1.58	2.19	2.65	1.81	1.97	2.18
DDKavi	66.44	67.30	5.31	10.04	65.14	65.80	4.32	8.17

DDKsdi	1.56	1.49	0.51	0.73	2.39	1.58	2.03	1.79
DDKcvi	2.34	2.35	0.66	0.83	2.83	1.95	3.08	1.56
DDKmxa	70.07	69.33	6.08	11.35	67.87	65.90	4.49	5.77
DDKava	55.95	57.13	5.06	6.75	54.31	54.37	5.63	3.76
DDKsla	63.32	64.17	3.67	7.09	60.84	59.87	4.46	7.10

In the observed differences, younger adolescents showed slower in average DDK rate (DDKavr), higher overall perturbation of DDK period (DDK jit) and lower average intensity of DDK sample (DDKava) compared to the older adolescents.

Table 4.9

Mann-Whitney Results for the Age Effect in Males and Females for AMR /ka/

Parameters	Males			Females		
	U	z	p value	U	z	p value
DDKavp (ms)	93	-1.03	0.30	134.5	-0.02	0.98
DDKavr (/s)	72.5	-1.85	0.06***	113.5	-0.77	0.43
DDKsdp (ms)	103.5	-0.61	0.53	86	-1.77	0.07
DDKcvp (%)	114	-0.19	0.84	102	-1.19	0.23
DDKjitt (%)	64	-2.18	0.02**	93.5	-1.5	0.13
DDKavi (dB)	111.5	-0.29	0.76	116	-0.68	0.49
DDKsdi (dB)	119	0	1	95	-1.44	0.14
DDKcvi (%)	115	-0.15	0.87	87	-1.73	0.08
DDKmxa (dB)	115	-0.15	0.87	107	-1.01	0.31
DDKava(dB)	69.5	-1.96	0.04**	80	-1.98	0.04**
DDKsla(dB)	107	-0.47	0.6	121	-0.50	0.61

** = Significant at 0.05 level of significance
***= Marginally significant

In females, only DDK ava results were significant where in the younger adolescent female showed higher DDKava compared to the older adolescent group. These results highlight that certain DDK parameters are influenced by age differently in males and females.

4.1.1d Effect of Age on Diadochokinetic Rate Protocol: Alternating Motion Rates of Syllable /pataka/

Eleven dependent variables were measured for the SMR of the syllable /pataka/ which are same as that for the AMRs. Since the data was non-normally distributed Mann-Whitney U test was used to analyze the data for the age groups 10-14 and 14-18. Descriptive statistics for the age groups are shown in Table 4.8 and 4.9 and the Mann Whitney test results as Table 4.10.

Table 4.10

Descriptive Statistics for the SMR of Syllable /pataka/ in Male Participants Across Age Groups

Parameters	10-13 years				14-18 years			
	Mean	Md.	SD	IQR	Mean	Md.	SD	IQR
DDKavp	152.41	147	20.07	14.50	159.33	161	21.48	45
DDKavr	6.72	6.79	0.90	1.11	6.60	6.95	0.94	2.07
DDKsdp	44.54	58.22	25.25	51.54	25.87	23.93	14.58	18.74
DDKcvp	28.67	28.62	16.18	29.63	17.03	15.71	10.64	6.16
DDKjitt	5.44	4.80	3.28	6.07	3.17	2.14	2.63	2.35
DDKavi	66.80	66.54	4.36	6.43	66.01	67.33	3.63	7.04
DDKsdi	2.78	2.37	0.94	1.20	2.33	1.86	1.20	1.96
DDKcvi	4.18	3.69	1.52	2.12	3.44	2.98	1.77	3.49
DDKmxa	70.76	70.08	4.87	6.61	70.02	72.32	3.46	6.53
DDKava	54.90	55.67	3.73	4.16	56.81	56.6	3.99	5.01
DDKsla	62.85	62.89	3.50	6.25	63.27	61.96	4.32	5.38

For males, a significant age effect was observed for DDKjitt and DDKcvp, wherein younger adolescents showed higher values across these measures compared to older groups. This indicated that temportal variability was higher in the younger group compared to older group in adolescent males. In females, significant age effects were found for DDKavr and DDKmxa, indicating that as age increases, adolescent females could perform the DDK task faster and with lower maximum intensity for the entire DDK sample.

Table 4.11

Descriptive Statistics for the SMR of Syllable /pataka/ in Female Participants Across Age Groups

Parameters	10-13 years				14-18 years			
	Mean	Md.	SD	IQR	Mean	Md.	SD	IQR
DDKavp	153.27	154.5	16.19	22.75	145.06	145	11.59	18
DDKavr	6.68	6.71	0.70	1	7.14	7.13	0.55	1.03
DDKsdp	33.32	26.39	18.16	32.79	2.69	25.84	12.29	20.78
DDKcvp	21.75	17.49	11.54	23.33	15.95	15.48	7.89	13.64
DDKjitt	3.76	3.86	1.77	3.17	3.11	2.55	1.75	3.52
DDKavi	66.69	66.83	4.48	4.96	64.71	65.92	3.58	4.54
DDKsdi	2.32	2.5	0.69	0.93	2.09	2.22	0.94	1.49
DDKcvi	3.57	3.7	1.02	1.22	3.37	3.67	1.30	2.49
DDKmxa	70.67	71.61	4.95	7.61	66.69	67.42	3.79	5.46
DDKava	54.66	53.30	4.17	6.14	53.43	53.46	4.60	5.27
DDKsla	62.88	63.47	2.55	4.31	62.05	61.67	2.83	3.16

Table 4.12

Mann-Whitney Results for the Age Effect in Males and Females for SMR /pataka/

Parameters	Males			Females		
	U	z	p value	U	z	p value
DDKavp (ms)	99	-0.79	0.42	90.5	-1.61	0.10
DDKavr (/s)	112	-0.27	0.78	82	-1.91	0.05**
DDKsdp (ms)	78	-1.62	0.10	93	-1.51	0.12
DDKcvp (%)	73	-1.82	0.06***	86.5	-1.75	0.07
DDKjitt (%)	69	-1.98	0.04**	95	-1.44	0.15
DDKavi (dB)	105	-0.55	0.57	95	-1.42	0.15
DDKsdi (dB)	74	-1.78	0.07	113	-0.79	0.42
DDKcvi (%)	83	-1.43	0.15	129	-0.21	0.83
DDKmxa (dB)	109	-0.39	0.69	75	-2.17	0.03**

DDKava(dB)	93	-1.03	0.30	131	-0.14	0.88
DDKsla(dB)	111	-0.31	0.75	106	-1.05	0.29

** = Significant at 0.05 level of significance
***= Marginally significant

4.1.2 The effect of age on Second Formant Transition

A total of six dependent variables were analyzed for second formant transition. These were Magnitude of F2 variation (F2magn), Rate of F2 variation (F2rate), Regularity of F2 variation (F2reg), Average of F2 value (F2aver), Minimum F2 value (F2min), Maximum F2 value (F2max). The data was analyzed using Mann Whitney U test.

F2magn, F2rate and F2reg reflects the motility of the articulator, the ability to vary the positions of articulator and ability to maintain regular periodic transitions respectively. Results of Mann Whitney U test showed no statistical significance for these parameters for female participants of this study. F2magn, F2avr, F2min and F2max showed statistical significance in males across the age groups.

However, only F2min showed age effect in females. Descriptive statistical data are shown in Table 4.13 and 4.14 for males and females respectively. In the observed differences, F2aver, F2min and F2max tend to decrease with age across gender.

Table 4.13

Descriptive Statistics for the F2 Transition in Male Participants Across Age Groups

Parameters	10-13 years				14-18 years			
	Mean	Md.	SD	IQR	Mean	Md.	SD	IQR
F2magn	644.8	686	122.82	188.25	584.8	589.5	95.96	90.25
F2rate	2.35	2.42	0.28	0.31	2.37	2.35	0.28	0.34
F2reg	84.11	90.86	15.6	17.97	83.21	84.16	7.81	11.69

F2aver	1979.9	2021.5	316.3	316.75	1631.6	1679.5	233.5	347
F2min	822.5	856.5	264.3	355.75	540.7	444.5	229.4	445.2
F2max	3057.6	3040	287.48	440	2669.7	2555	308.4	555.2

Table 4.14

Descriptive Statistics for the F2 Transition in Female Participants Across Age Groups

Parameters	10-13 years				14-18 years			
	Mean	Md.	SD	IQR	Mean	Md.	SD	IQR
F2magn	719.35	728.5	154.98	176.2	688.1	680.5	98.51	153
F2rate	2.08	2.1	0.42	0.64	2.17	2.27	0.41	0.26
F2reg	81.79	83.60	10.63	15.76	88.12	90.16	7.69	8.26
F2aver	1926.5	1949	364.72	414.5	1905.7	1898	190.9	308.2
F2min	768.65	797.5	191.26	203.5	640.7	610	164.1	265.2
F2max	3166.4	3193.5	264.01	346.2	3015.1	3057	273.3	399.2

Table 4.15

Mann-Whitney Results for the Age Effect in Males and Females for F2 transition

Parameters	Male		Female	
	Z	p	Z	p
F2magn	-2.07	0.03**	-1.12	0.26
F2rate	-0.26	0.8	-1.38	0.16
F2reg	-1.58	0.1	-1.8	0.07
F2aver	-3.59	<0.01*	-0.75	0.45
F2min	-3.23	<0.01*	-2.1	0.03**
F2max	-3.38	<0.01*	-1.8	0.07

*=Significant at 0.01 level of significance
** = Significant at 0.05 level of significance

4.1.3 The effect of age on Voice and Tremor protocol

Nine dependent variables were measured and analyzed in voice and tremor protocol. These were, Average fundamental frequency (F0), Average pitch period (T0), Highest fundamental frequency (Fhi), Lowest fundamental frequency (Flo), Standard deviation of fundamental frequency (STD), Coefficient of variation of fundamental frequency (vF0), Coefficient of variation of amplitude (vAm), Magnitude frequency tremor (Mftr), Magnitude amplitude tremor (Matr).

The results of Mann Whitney U test showed statistically significant effect for F0, T0, for both the gender. F0 values tend to decrease from the age group 10-13 to 14-18. A trend opposite to this was observed for T0. Fhi. Flo and STD showed a statistically significant effect in male with a descending pattern from age group 10-13 to 14-18, whereas the effect was not statistically significant in females. Rest of the variables showed no statistically significant effect in either of the gender, with an exception of Matr in female.

Table 4.16

Descriptive Statistics for the Voice and Tremor Protocol in Male Participants Across Age Groups

Parameters	10-13 years				14-18 years			
	Mean	Md.	SD	IQR	Mean	Md.	SD	IQR
F0	215.8	238.5	50.57	62.75	144.6	136.5	36.86	29
T0	4.98	4.19	1.61	1.52	7.21	7.32	1.48	1.84
Fhi	241.85	251.5	84.05	77.5	152.6	139	37.61	39.75
Flo	207.65	230	49.51	61.25	138.49	128.5	36.84	31.25
STD	3.36	2.71	1.78	2.05	1.95	1.74	0.86	1.54
vF0	1.54	1.30	0.65	0.68	1.36	1.42	0.59	1.02
vAm	18.02	18.05	7.50	9.42	15.20	14.6	6.08	8.10
Mftr	0.46	0.44	0.22	0.30	0.44	0.40	0.19	0.35
Matr	3.1	2.81	1.58	2.22	4.24	3.79	2.08	2.98

Table 4.17

Descriptive Statistics for the Voice and Tremor Protocol in Female Participants Across Age Groups

Parameters	10-13 years				14-18 years			
	Mean	Md.	SD	IQR	Mean	Md.	SD	IQR
F0	250.75	255	32.32	23.5	236.9	238	21.66	30.75
T0	4.08	3.92	0.78	0.37	4.25	4.20	0.40	0.54
Fhi	264.45	262.5	40.55	27	252.9	248.5	32.18	39.50
Flo	235.65	244.5	42.77	32.75	226.75	227	23.49	25.50
STD	3.41	2.65	2.11	2.12	2.42	2.39	0.74	0.95
vF0	1.35	1.2	0.75	0.84	1.07	1.08	0.33	0.42
vAm	15.79	15.2	7.57	7.48	17.01	16.33	3.51	4.68
Mftr	0.31	0.26	0.13	0.20	0.32	0.30	0.11	0.17
Matr	2.92	2.74	0.99	1.28	2.24	2.18	0.87	1.47

The descriptive statistics indicate notable differences in voice and tremor parameters across age groups for both males and females. In males, there is a marked decrease in fundamental frequency (F0) and other related measures (Fhi, Flo and STD), along with increased stability (lower SD and perturbation measures) as they age from 10-13 years to 14-18 years. Females show more subtle decrease in F0 and related measures (F0, T0, Flo and Matr), with a slight increase in stability.

Table 4.18

Mann-Whitney Results for the Age Effect in Males and Females for voice and tremor protocol

Parameter	Male	Female

	U	Z	p value	U	Z	p value
F0	59	-3.82	<0.01*	120	-2.16	0.03**
T0	60.5	-3.77	0.01*	120	-2.16	0.03**
Fhi	60	-3.79	0.01*	141	-1.6	0.11
Flo	63	-3.71	0.01*	128.5	-1.93	0.05***
STD	93	-2.89	<0.01*	152	-1.3	0.19
vF0	165	-0.95	0.34	164.5	-0.96	0.33
vAm	153.5	-1.26	0.21	151	-1.37	0.18
Mftr	191	-0.24	0.81	182	-0.49	0.62
Matr	132.5	-1.83	.07	117.5	-2.23	0.02**

*=Significant at 0.01 level of significance
** = Significant at 0.05 level of significance
***= Marginally significant

4.1.4 The effect of age on intonation Stimulability Parameters

The seven dependent variables measured were, running speech fundamental frequency (rF0), running speech pitch period (rT0), Highest F0 (rFhi), Lowest F0 (rFlo), Standard deviation of F0 (rSTD), Frequency variability (rvF0), Amplitude variability (rvAm). These parameters provide information about the change of pitch during running speech. Since most of the variables were non-normally distributed, the data were analyzed using Mann Whitney U test.

The results of Mann Whitney U test showed statistically significant age effect for the variables rF0, rT0, rFhi and rFlo in both the gender group. rF0 decrease significantly from the age group 10-13 to 14-18 whereas an opposite trend was observed for rT0 in both the gender group. Both rFhi and rFlo decreased with age in both the gender. The statistics showed no statistically significant effect for rSTD, rvF0 and rvAm.

Table 4.19

Descriptive Statistics for the Intonation Stimulability Protocol in Male Participants Across Age Groups

Parameters	10-13 years				14-18 years			
	Mean	Md.	SD	IQR	Mean	Md.	SD	IQR
rF0	239.85	248.5	45.04	61.5	170.4	151.5	49.16	68
rT0	4.33	4.01	0.94	1.10	6.24	6.60	1.54	2.91
rFhi	322.65	325	49.26	52.50	224.25	196	67.26	125.5
rFlo	174.60	189.5	50.49	87.50	116.71	111.5	34.15	30.16
rSTD	32.88	28.89	15.61	15.41	27.01	17.75	19.76	32.46
rvF0	14.29	11.77	7.77	6.74	15.01	11.98	9.95	14.40
rvAm	36.09	35.05	5.19	7.33	38.32	38.25	5.23	5.02

Table 4.20

Descriptive Statistics for the Intonation Stimulability Protocol in Female participants cross Age Groups

Parameters	10-13 years				14-18 years			
	Mean	Md.	SD	IQR	Mean	Md.	SD	IQR
rF0	271.9	279.5	31.46	34.75	227.4	226	32.03	55.5
rT0	3.73	3.57	0.54	0.46	4.47	4.43	0.63	1.09
rFhi	353.55	345.5	32.73	62.75	316.25	302	50.01	77.75
rFlo	196.35	214	49.77	93.75	167.10	176	49.02	90.50
rSTD	35.64	32.04	14.16	17.07	37.29	29.98	21.08	29.60
rvF0	13.71	11.62	7.35	5.74	17.24	12.63	11.02	18.80
rvAm	36.88	35.63	6.01	9.55	38.97	38.19	5.65	7.28

The descriptive statistics reveal similar trend as that of voice and tremor protocol for rF0, rT0, rFhi & rFlo.

Table 4.21

Mann-Whitney Results for the Age Effect in Males and Females for intonation stimulability protocol

Parameters	Male			Female		
	U	Z	p value	U	z	p value
rF0	65.5	-3.639	<0.01*	58.500	-3.829	<0.01*
rT0	67.5	-3.584	<0.01*	59.500	-3.801	<0.01*
rFhi	51	-4.031	<0.01*	105.000	-2.571	<0.01*
rFlo	77.5	-3.314	<0.01*	118.500	-2.205	.02**
rSTd	139	-1.650	.09	192.000	-.216	.82
rvF0	197	-.081	.93	173.000	-.730	.46
rvAm	145	-1.488	.13	149.000	-1.380	.16

*=Significant at 0.01 level of significance

4.1.5 The effect of age on standard syllabic rate parameters.

The variables analyzed were, Average syllabic rate (SSrate), Average syllabic duration (SSrdur), Average pause duration (SSpdur), Percent speaking time (SSspk), Percent pause time (SSpau). Mann Whitney U test was used to analyze the data.

In males, Mann Whitney U test results revealed SSrdur has no statistically significant age effect. Whereas, SSrate, SSpdur, SSspk, SSpau showed statistically significant effect. SSrate and SSspk increased with age whereas SSpdur and SSpau decreased. In Females, SSrate, SSrdur, SSspk, an SSpau showed no statistically significant effect. Whereas SSpdur showed a statistically significant effect. A trend of reducing the SSpdur was observed from age group 10-13 to 14-18. These changes indicate that the overall speaking rate increases with age and the average pause duration (SSpdur) and percent pause time (SSpau) decreases with age indicating increased overall speaking time, particularly in males. In females, only the average pause duration decreased in older adolescents which may facilitate increased speaking rate.

Table 4.22

Descriptive Statistics for the Standard Syllabic Rate Protocol in Male Participants Across Age Groups

Parameters	10-13 years				14-18 years			
	Mean	Md.	SD	IQR	Mean	Md.	SD	IQR
SSrate	2.29	2.08	0.68	0.61	2.60	2.41	0.63	0.72
SSrdur	360.80	366	79.85	115.5	376.7	380.5	64.47	112.25
SSpdur	185.4	151.5	95.28	54.25	105.15	128.5	73.49	163.25
SSspk	78.75	79.6	12.04	11.53	91.87	92.27	7.5	11.87
SSpau	21.24	20.4	12.04	11.53	7.13	7.51	6.01	11.10

Table 4.23

Descriptive Statistics for the Standard Syllabic Rate Protocol in Female Participants Across Age Groups

Parameters	10-13 years				14-18 years			
	Mean	Md.	SD	IQR	Mean	Md.	SD	IQR
SSrate	2.31	2.28	0.43	0.52	3.63	2.16	6.18	0.31
SSrdur	365.3	372.5	66.56	45.25	352.11	389	127.51	130
SSpdur	176.75	177	45.14	46.75	123.55	140.5	67.98	55
SSspk	82.55	86.24	10.94	18.40	86.51	87.92	12.46	16.86
SSpau	17.44	13.75	10.94	18.40	13.31	12.08	12.31	16.86

Descriptive statistics indicate that both male and female participants showed an increase in syllable production rate (SSrate) and a decrease in pause duration (SSpau) as they aged from 10-13 years to 14-18 years.

Table 4.24

Mann-Whitney Results for the Age Effect in Males and Females for standard syllabic rate

Parameters	Male			Female		
	U	Z	p value	U	z	p value
SSrate	124.500	-2.043	.04**	178.000	-.595	.552
SSsdur	189.000	-.298	.766	192.000	-.216	.829
SSpdur	95.000	-2.845	.004*	112.000	-2.382	.01**
SSspk	70.000	-3.522	.000*	153.000	-1.272	.203
SSpau	57.000	-3.875	.000*	151.000	-1.326	.185

*=Significant at 0.01 level of significance
** = Significant at 0.05 level of significance

4.2. The Effect of Gender on Motor Speech Profile protocols in typical Kannada speaking adolescents

4.2.1a Effect of gender on Diadochokinetic rate protocol: Alternating Motion Rates of syllable /pa/

The eleven dependent variables under the protocol DDK rate were measured and analyzed. Since the data was non-normally distributed Mann-Whitney U test was used to analyze the data for the gender groups. The descriptive statistical data for the effect of gender on DDK protocol (for syllable /pa/, /ta/, /ka/ and /pataka/) for participants of 10-13 years and 14-18 years are presented in the below table

Table 4.25

Descriptive statistics for the AMR of syllable /pa/ in participants of age range 10-13 across gender

Parameters	Male				Female			
	Mean	Md.	SD	IQR	Mean	Md.	SD	IQR
DDKavp	189.55	184.5	24.82	21.75	183.8	184.5	14.11	21.50
DDKavr	5.34	5.42	0.59	0.64	5.46	5.42	0.42	0.63
DDKsdp	28.20	16.8	25.24	25.03	20.69	14.56	16.91	9.69
DDKcvp	14.47	9.42	11.68	12.06	11.07	8.03	8.30	5.58
DDKjitt	2.57	1.79	2.19	2.42	1.95	1.42	1.37	1.28

DDKavi	65.99	66.20	4.64	8.06	65.56	66.33	3.55	5.45
DDKsdi	1.88	1.68	0.67	1.06	2.02	1.69	0.83	1.05
DDKcvi	2.87	2.5	1.04	1.68	3.08	2.81	1.19	1.60
DDKmxa	70.27	70.22	5.05	8.91	69.74	70.21	3.37	5.52
DDKava	52.73	52.68	5.19	7.19	51.29	51.82	4.29	4.86
DDKsla	63.35	63.49	3.44	5.55	62.89	63.38	2.59	3.73

Table 4.26

Descriptive statistics for the AMR of syllable /pa/ in participants of age range 14-18 across gender

Parameters	Male				Female			
	Mean	Md.	SD	IQR	Mean	Md.	SD	IQR
DDKavp	176.2	179.5	17.24	20.75	177.9	176.5	17.11	29.75
DDKavr	5.63	5.57	0.72	0.66	5.66	5.63	0.53	0.96
DDKsdp	28.95	17.30	26.53	20.77	17.7	12.93	16.98	5.88
DDKcvp	17.69	10.91	14.78	18.94	10.19	6.72	8.49	4.21
DDKjitt	3.09	2.50	1.98	3.17	1.70	1.43	0.86	0.53
DDKavi	67.98	67.77	4.56	8.12	66.31	66.67	4.69	4.06
DDKsdi	2.49	2.14	1.30	1.59	1.77	1.45	0.78	1check
DDKcvi	3.69	3.04	1.94	2.35	2.64	2.29	1.04	1.41
DDKmxa	72.7	71.46	5.25	8.57	70.15	69.82	5.54	4.53
DDKava	57.72	57.52	4.35	8.02	54.41	54.01	5.32	6.68
DDKsla	64.14	64.15	2.54	4.54	63.36	63.41	3.69	2.83

Among the 10-13-year old, there were no significant gender-based differences observed in any of the parameters analyzed. However, in the 14-18-year-old adolescents, statistically significant differences between genders were found in several parameters, including DDKsdp, DDKcvp, DDKjitt, DDKsdi, DDKcvi, and DDKava.

For the reported differences, DDKsdp, DDKcvp, DDKsdi, DDKcvi DDKjit, and DDKava showed higher mean values in males of 14-18 group.

Table 4.27

Mann-Whitney Results for the Gender Effect in 10-13 years and 14-18 years for AMR /pa/

Parameters	10-13			14-18		
	U	z	p	U	z	p value
DDKavp (ms)	186.5	-0.36	0.71	196	-0.11	0.91
DDKavr (/s)	187	-0.35	0.72	199	-0.02	0.98
DDKsdp (ms)	171	-0.78	0.43	113	-2.35	0.02**
DDKcvp (%)	172	-0.75	0.45	127	-1.97	0.05**
DDKjitt (%)	178.5	-0.58	0.56	122	-2.11	0.03**
DDKavi (dB)	192.5	-0.20	0.83	162	-1.03	0.3
DDKsdi (dB)	181	-0.51	0.61	123.5	-2.07	0.04**
DDKcvi (%)	172.5	-0.74	0.46	127	-1.97	0.05**
DDKmxa (dB)	193	-0.19	0.85	157	-1.16	0.24
DDKava(dB)	173	-0.73	0.46	125	-2.03	0.04**
DDKsla(dB)	188	-0.32	0.74	168	-0.86	0.4

** = Significant at 0.05 level of significance

Overall, it could be seen that gender does not significantly affect the measured parameters in younger adolescents (10-13 years), but does have a significant effect on several parameters in older adolescents (14-18 years).

4.2.1b Effect of gender on Diadochokinetic rate protocol: Alternating Motion Rates of syllable /ta/

The descriptive statistical data for the effect of gender on DDK protocol for syllable /ta/ for participants of 10-13 years and 14-18 years are presented in tables 4.28 and 4.29.

Table 4.28

Descriptive statistics for the AMR of syllable /ta/ in participants of age range 10-13 across gender

Parameters	Male				Female			
	Mean	Md.	SD	IQR	Mean	Md.	SD	IQR
DDKavp	180.29	193	24.11	43.50	191.61	196	18.16	19
DDKavr	5.59	5.2	0.72	1.26	5.24	5.10	0.58	0.51
DDKsdp	24.5	17.6	11.9	19.68	34.59	36.19	16.26	27.80
DDKcvp	14.3	8.8	8.88	13.29	16.8	18.57	8.63	17.41
DDKjitt	2.4	1.78	1.60	2.28	3.2	2.97	1.69	2.46
DDKavi	65.55	65.91	3.72	5.37	65.08	65.42	5.62	7.22
DDKsdi	2.1	2.25	0.69	1.37	1.63	1.66	0.54	0.81
DDKcvi	3.2	3.67	1.22	2.05	2.44	2.25	0.92	1.59
DDKmxa	70.01	68.76	5.30	9.39	69.23	68.67	6.10	8.12
DDKava	56.6	55.24	4.33	7.77	54.80	54.57	6.43	10.14
DDKsla	63.2	62.8	2.68	5.75	62.37	62.69	4.34	5.35

In 10-13 years, females showed higher variability in DDKsdp indicating higher durational variability. Whereas males in same age group showed higher median values for DDKsdi and DDKcvi indicating more variability in the intensity measures.

Table 4.29

Descriptive statistics for the AMR of syllable /ta/ in participants of age range 14-18 across gender

Parameters	Male				Female			
	Mean	Md.	SD	IQR	Mean	Md.	SD	IQR
DDKavp	174	173	16.45	31	188.93	195	19.99	31.75
DDKavr	5.8	6.02	0.66	0.93	5.25	5.1	0.73	1.06
DDKsdp	19.4	17.98	7.47	8.77	20.41	19	6.67	10.62
DDKcvp	11.5	10.02	4.97	8.61	10.4	10.55	3.60	5.35
DDKjitt	2.18	2.15	1.25	1.57	2.6	1.81	1.97	2.18
DDKavi	66.52	66.46	3.69	6.50	65.14	65.80	4.32	8.17
DDKsdi	2.21	1.81	1.85	0.74	2.39	1.58	2.03	1.79

DDKcvi	3.27	2.64	2.77	0.71	2.83	1.94	3.08	1.56
DDKmxa	69.60	68.23	4.90	5.76	67.87	65.90	4.49	5.77
DDKava	56.76	56.46	4.28	8.45	54.31	54.37	5.63	3.76
DDKsla	63.68	63.56	2.66	4.11	60.84	59.87	4.46	7.10

Table 4.30

Mann-Whitney Results for the Gender Effect in 10-13 years and 14-18 years for AMR /ta/

Parameters	10-13			14-18		
	U	Z	p value	U	z	p value
DDKavp (ms)	116	-1.22	0.22	54	-2.22	0.02**
DDKavr (/s)	115	-1.25	0.21	58	-2.05	0.04**
DDKsdp (ms)	96	-1.88	0.06***	96.5	-0.37	0.71
DDKcvp (%)	131	-0.71	0.47	95	-0.43	0.66
DDKjitt (%)	100	-1.74	0.08	101	-0.17	0.86
DDKavi (dB)	134.5	-0.61	0.54	93.5	-0.50	0.13
DDKsdi (dB)	86	-2.21	0.02**	101	-0.17	0.27
DDKcvi (%)	89.5	-2.09	0.03**	71	-1.48	0.54
DDKmxa (dB)	150	-0.09	0.92	80	-1.09	0.27
DDKava(dB)	128.5	-0.80	0.41	91	-0.61	0.54
DDKsla(dB)	130	-0.75	0.44	64	-1.79	0.07

** = Significant at 0.05 level of significance
***= Marginally significant

In 10-13 years, females, on the other hand show higher variability in performance measures, like DDKsdp indicating higher durational variability. Whereas males in same age group showed higher median values for DDKsdi and DDKcvi indicating more variability in the intensity measures. Whereas, in 14-18 years significant gender differences are observed in DDKavp and DDKavr, with females taking longer time to produce the syllable /ta/. Other parameters in this age group show no significant gender differences.

4.2.1c Effect of gender on Diadochokinetic rate protocol: Alternating Motion Rates of syllable /ka/

The descriptive statistical data for the effect of gender on DDK protocol for syllable /ka/ for participants of 10-13 years and 14-18 years are presented in tables 4.31 and 4.32. Statistically significant differences were observed in DDKavp, DDKavr, DDKjitt, DDKsdi and DDKcvi in 10-13-year-old adolescents. In the older adolescents, differences were observed in DDKsdp and DDKcvp variability measures.

Table 4.31

Descriptive statistics for the AMR of syllable /ka/ in participants of age range 10-13 across gender

Parameters	Male				Female			
	Mean	Md.	SD	IQR	Mean	Md.	SD	IQR
DDKavp	186.17	186	12.89	12.50	194.72	195	16.77	18
DDKavr	5.39	5.44	0.51	0.35	5.17	5.14	0.52	0.98
DDKsdp	34.49	27.57	19.09	38.52	34.62	34.39	21.69	26.44
DDKcvp	18.13	15.9	9.93	20.38	14.67	13.97	7.75	14.51
DDKjitt	4.50	4.44	2.04	3.39	3.24	2.82	1.58	2.19
DDKavi	66.10	66.12	4.15	4.20	66.44	67.30	5.31	10.04
DDKsdi	2.14	1.83	0.91	1.17	1.56	1.49	0.51	0.73
DDKcvi	3.09	2.86	1.26	1.70	2.34	2.35	0.66	0.83
DDKmxa	70.55	71.62	3.93	3.58	70.07	69.33	6.08	11.35
DDKava	54.82	52.9	4.15	6.56	55.95	57.13	5.06	6.75
DDKsla	63.38	63.35	2.63	2.73	63.32	64.17	3.67	7.09

In the age group 10-13, males show a slightly lower median values for DDKavp and higher DDKavr compared to females. This indicated faster overall delivery of the syllable /ka/ compared to females. However, both durational (DDKcvp, DDKjitt) and intensity parameter values (DDKsdi and DDKcvi) were higher in males indicating poorer stability compared to females. In the older adolescent group (14-18 years), females showed higher median values for DDKsdp and DDKcvp indicating poorer stability in the durational attributes of DDK measures.

Table 4.32

Descriptive statistics for the AMR of syllable /ka/ in participants of age range 14-18 across gender

Parameters	Male				Female			
	Mean	Md.	SD	IQR	Mean	Md.	SD	IQR
DDKavp	174.2	173	16.45	31	188.93	195	19.99	31.75
DDKavr	5.80	6.02	0.66	0.93	5.25	5.1	0.73	1.06
DDKsdp	19.43	17.98	7.47	8.77	20.41	19	6.67	10.62
DDKcvp	11.52	10.02	4.97	8.61	10.40	10.55	3.60	5.35
DDKjitt	2.18	2.15	1.25	1.57	2.65	1.81	1.97	2.18
DDKavi	66.52	66.46	3.69	6.50	65.14	65.80	4.32	8.17
DDKsdi	2.21	1.81	1.85	0.74	2.39	1.58	2.03	1.79
DDKcvi	3.27	2.64	2.77	0.71	2.83	1.95	3.08	1.56
DDKmxa	69.60	68.23	4.90	5.76	67.87	65.90	4.49	5.77
DDKava	56.76	56.46	4.28	8.45	54.31	54.37	5.63	3.76
DDKsla	63.68	63.56	2.66	4.11	60.84	59.87	4.46	7.10

Table 4.33

Mann-Whitney Results for the Gender Effect in 10-13 years and 14-18 years for AMR /ka/

Parameters	10-13			14-18		
	U	Z	p value	U	z	p value
DDKavp (ms)	90.5	-2.06	0.03**	97	-0.34	0.72

DDKavr (/s)	99.5	-1.76	0.07***	100	-0.21	0.82
DDKsdp (ms)	141	-0.39	0.69	52	-2.31	0.02*
DDKcvp (%)	124	-0.95	0.33	59	-2.01	0.04**
DDKjitt (%)	95	-1.91	0.05**	92	-0.56	0.57
DDKavi (dB)	143	-0.33	0.74	100	-0.21	0.82
DDKsdi (dB)	96	-1.88	0.06***	90.5	-0.63	0.52
DDKcvi (%)	81	-2.37	0.01*	92	-0.56	0.57
DDKmxa (dB)	144	-0.29	0.76	85	-0.87	0.38
DDKava(dB)	129	-0.79	0.42	72	-1.44	0.15
DDKsla(dB)	138	-0.49	0.62	73	-1.39	0.16

*=Significant at 0.01 level of significance
** = Significant at 0.05 level of significance
***= Marginally significant

4.2.1d Effect of gender on Diadochokinetic rate protocol: Sequential Motion Rates of syllable /pataka/

The descriptive statistical data illustrating the effect of gender on the DDK protocol for the syllable /pataka/ among participants aged 10-13 years and 14-18 years are presented in the tables 4.34 and 4.35.

Table 4.34

Descriptive statistics for the SMR of syllable /pataka/ in participants of age range 10-13 across gender

Parameters	Male				Female			
	Mean	Md.	SD	IQR	Mean	Md.	SD	IQR
DDKavp	152.41	147	20.07	14.50	153.27	154.5	16.19	22.75
DDKavr	6.72	6.79	0.90	1.11	6.68	6.71	0.70	1
DDKsdp	44.54	58.22	25.25	51.54	33.32	26.39	18.16	32.79
DDKcvp	28.67	28.62	16.18	29.63	21.75	17.49	11.54	23.33
DDKjitt	5.44	4.80	3.28	6.07	3.76	3.86	1.77	3.17
DDKavi	66.80	66.54	4.36	6.43	66.69	66.83	4.48	4.96
DDKsdi	2.78	2.37	0.94	1.20	2.32	2.5	0.69	0.93

DDKcvi	4.18	3.69	1.52	2.12	3.57	3.7	1.02	1.22
DDKmxa	70.76	70.08	4.87	6.61	70.67	71.61	4.95	7.61
DDKava	54.90	55.67	3.73	4.16	54.66	53.30	4.17	6.14
DDKsla	62.85	62.89	3.50	6.25	62.88	63.47	2.55	4.31

Table 4.35

Descriptive statistics for the SMR of syllable /pataka/ in participants of age range 14-18 across gender groups

Parameters	Male				Female			
	Mean	Md.	SD	IQR	Mean	Md.	SD	IQR
DDKavp	159.33	161	21.48	45	145.06	145	11.59	18
DDKavr	6.60	6.95	0.94	2.07	7.14	7.13	0.55	1.03
DDKsdp	25.87	23.93	14.58	18.74	2.69	25.84	12.29	20.78
DDKcvp	17.03	15.71	10.64	6.16	15.95	15.48	7.89	13.64
DDKjitt	3.17	2.14	2.63	2.35	3.11	2.55	1.75	3.52
DDKavi	66.01	67.33	3.63	7.04	64.71	65.92	3.58	4.54
DDKsdi	2.33	1.86	1.20	1.96	2.09	2.22	0.94	1.49
DDKcvi	3.44	2.98	1.77	3.49	3.37	3.67	1.30	2.49
DDKmxa	70.02	72.32	3.46	6.53	66.69	67.42	3.79	5.46
DDKava	56.81	56.6	3.99	5.01	53.43	53.46	4.60	5.27
DDKsla	63.27	61.96	4.32	5.38	62.05	61.67	2.83	3.16

Table 4.36

Mann-Whitney Results for the Gender Effect in 10-13 years and 14-18 years for SMR /pataka/

Parameters	10-13			14-18		
	U	Z	p	U	z	p value
DDKavp (ms)	132.5	-0.67	0.49	62.5	-1.85	0.06***

DDKavr (/s)	138	-0.49	0.62	69.5	-1.55	0.12
DDKsdp (ms)	117	-1.18	0.23	103	-0.08	0.93
DDKcvp (%)	119	-1.12	0.26	103	-0.08	0.93
DDKjitt (%)	112	-1.35	0.17	98	-0.30	0.76
DDKavi (dB)	147	-0.19	0.84	87.5	-0.76	0.44
DDKsdi (dB)	119	-1.12	0.26	104	-0.04	0.96
DDKcvi (%)	127	-0.85	0.39	97	-0.34	0.72
DDKmxa (dB)	150	-0.09	0.92	57	-2.09	0.03**
DDKava(dB)	122	-1.02	0.30	65	-1/74	0.08
DDKsla(dB)	146	-0.23	0.81	99	-0.26	0.79

** = Significant at 0.05 level of significance
***= Marginally significant

The Mann Whitney U test revealed that in the 10-13 years age group, there were no significant gender differences observed across all parameters. In the 14-18 years age group, there was a marginally significant gender difference in average syllable duration (DDKavp), and significant differences in maximum intensity (DDKmxa). Males tend to have slightly higher median values for DDKmxa and DDKavp indicating higher maximum intensity but slower delivery of the SMR repetitions.

4.2.2 The Effect of Gender on F2 Transition

Six dependent variables were analyzed for second formant transition. The analysis was carried out using Mann Whitney U test.

Table 4.37

Descriptive statistics for the F2 transition in participants of age range 10-13 across gender

Parameters	Male				Female			
	Mean	Md.	SD	IQR	Mean	Md.	SD	IQR
F2magn	644.8	686	122.8	188.25	719.35	728.5	154.9	176.25
F2rate	2.35	2.42	0.28	0.31	2.08	2.1	0.42	0.64
F2reg	84.11	90.86	15.6	17.97	81.79	83.60	10.63	15.76

F2aver	1979.9	2021.5	316.3	316.75	1926.5	1949	364.7	414.5
F2min	822.5	856.5	264.3	355.75	768.65	797.5	191.2	203.5
F2max	3057.6	3040	287.4	440	3166.4	3193.5	264.0	346.25

Table 4.38

Descriptive statistics for the F2 transition in participants of age range 14-18 across gender groups

Parameters	Male				Female			
	Mean	Md.	SD	IQR	Mean	Md.	SD	IQR
F2magn	584.8	589.5	95.96	90.25	688.1	680.5	98.51	153
F2rate	2.37	2.35	0.28	0.34	2.17	2.27	0.41	0.26
F2reg	83.21	84.16	7.81	11.69	88.12	90.16	7.69	8.26
F2aver	1631.6	1679.5	233.5	347	1905.7	1898	190.95	308.25
F2min	540.7	444.5	229.4	445.25	640.7	610	164.15	265.25
F2max	2669.7	2555	308.4	555.25	3015.1	3057	273.32	399.25

Table 4.39

Mann-Whitney Results for the Gender Effect in 10-13 years and 14-18 years for F2 transition

Parameters	10-13		14-18	
	z	p	z	p
F2magn	-1.73	0.08	-3.32	<0.01*
F2rate	-2.08	0.03**	-1.41	0.15
F2reg	-1.04	0.29	-1.94	0.05**
F2aver	-0.73	0.46	-3.38	<0.01*
F2min	-0.88	0.37	-1.59	0.10
F2max	-1.04	0.29	-3.11	<0.01*

*=Significant at 0.01 level of significance
** = Significant at 0.05 level of significance

The results indicate that gender differences in the F2 transition parameters are more pronounced and statistically significant in the 14-18 years age group compared to the 10-13 years age group. Specifically, in the 14-18 years group, significant gender effects were found for F2magn, F2 aver, and F2max at the 0.01 level, and for F2reg at the 0.05 level. This indicated that females consistently exhibit higher F2 magnitudes and averages than males, suggesting that females generally produce larger F2 transitions. In contrast, only the F2rate parameter showed a significant gender effect in the 10-13 years group at the 0.05 level. This change in F2 rate indicated that males were changing the articulatory positions faster than females while repeating /i/ and /u/ vowels alternatively. However, such changes in F2rate were not seen in older adolescent groups. This suggests that gender differences in F2 transition parameters become more pronounced as children age into later adolescence.

4.2.3 The Effect of Gender on Voice and Tremor protocol

Mann Whitney U test revealed significant gender differences in fundamental frequency (F0), average pitch period (T0), highest frequency (Fhi), lowest frequency (Flo), and mean frequency tremor (Mftr) in 10-13 age group. Similarly, Significant gender differences are observed in fundamental frequency (F0), tremor frequency (T0), highest frequency (Fhi), lowest frequency (Flo), and mean frequency tremor (Mftr) in 14-18 age group. Additionally, mean amplitude tremor (Mftr) were marginally significant.

Table 4.40

Descriptive statistics for the voice and tremor protocol in participants of age range 10-13 across gender groups

Parameters	Male				Female			
	Mean	Md.	SD	Range	Mean	Md.	SD	Range
F0	215.8	238.5	50.57	62.75	250.7	255	32.32	23.5
T0	4.98	4.19	1.61	1.52	4.08	3.92	0.78	0.37
Fhi	241.85	251.5	84.05	77.5	264.4	262.5	40.55	27

Flo	207.65	230	49.51	61.25	235.6	244.5	42.77	32.75
STD	3.36	2.71	1.78	2.05	3.41	2.65	2.11	2.12
vF0	1.54	1.30	0.65	0.68	1.35	1.2	0.75	0.84
vAm	18.02	18.05	7.50	9.42	15.79	15.2	7.57	7.48
Mftr	0.46	0.44	0.22	0.30	0.31	0.26	0.13	0.20
Matr	3.1	2.81	1.58	2.22	2.92	2.74	0.99	1.28

Table 4.41

Descriptive statistics for the voice and tremor protocol in participants of age range 14-18 across gender groups

Parameters	Male				Female			
	Mean	Md.	SD	Range	Mean	Md.	SD	Range
F0	144.6	136.5	36.86	29	236.9	238	21.66	30.75
T0	7.21	7.32	1.48	1.84	4.25	4.20	0.40	0.54
Fhi	152.6	139	37.61	39.75	252.9	248.5	32.18	39.50
Flo	138.49	128.5	36.84	31.25	226.7	227	23.49	25.50
STD	1.95	1.74	0.86	1.54	2.42	2.39	0.74	0.95
vF0	1.36	1.42	0.59	1.02	1.07	1.08	0.33	0.42
vAm	15.20	14.6	6.08	8.10	17.01	16.33	3.51	4.68
Mftr	0.44	0.40	0.19	0.35	0.32	0.30	0.11	0.17
Matr	4.24	3.79	2.08	2.98	2.24	2.18	0.87	1.47

For the 10-13 years age group, females showed higher fundamental frequencies (F0), higher values in highest frequency (Fhi) and lowest frequency (Flo), while males demonstrate higher median fundamental tremor rate (Mftr).

In the 14-18 years age group, the gender differences become more pronounced. Males show a substantial decrease in F0 and Fhi, while females maintain higher values in these parameters. Females showed lower median values for Amplitude (Matr) and frequency tremor (Mftr) indicating better voice stability than male counterparts. Fundamental frequency, Flo, Fhi were higher in females whereas amplitude and frequency tremor was lower compared to males. Overall, the data showed that gender has a significant effect on certain voice and tremor parameters in both age groups, with some parameters being more affected in older adolescents.

Table 4.42

Mann-Whitney Results for the Gender Effect in 10-13 years and 14-18 years for voice and tremor protocol

Parameter	10-13			14-18		
	U	Z	p value	U	z	p value
F0	78	-3.3	<0.01*	18.5	-4.91	<0.01*
T0	78	-3.3	<0.01*	18.5	-4.91	<0.01*
Fhi	127	-1.97	<0.05**	18	-4.92	<0.01*
Flo	97	-2.78	<0.01*	22	-4.8	<0.01*
STD	190.5	-0.25	0.8	134.5	-1.77	0.07
vF0	154	-1.24	0.2	146.5	-1.44	0.15
vAm	162	-1.03	0.3	150	-1.35	0.18
Mftr	109	-2.46	<0.05**	129	-1.92	0.055***
Matr	196.5	-0.09	0.9	73	-3.43	<0.01*

*=Significant at 0.01 level of significance
** = Significant at 0.05 level of significance
***= Marginally significant

4.2.4 The Effect of Gender on Intonation Stimulability Protocol

In 10-13 age group, statistically significant gender differences are observed in rF0, rT0, and rFhi when analyzed using Mann Whitney U test, indicating that gender influences these intonation parameters in children aged 10-13 years. Similar gender differences were found in 14-18 years group with an addition of parameters rFlo, and rSTD. These results indicate that gender differences in these parameters become more pronounced in adolescents aged 14-18 years.

The parameters rF0, rFhi, rFlo, and rSTD were higher in females when compared to males across age groups. rT0 was greater in males for both the age groups. As laryngeal development is robust in selected age ranges of this study, considerable differences across gender could be seen for acoustic correlates. Both voice and tremor protocol as well as intonation stimulability protocol depends on laryngeal changes and therefore gender difference were robust in these protocols.

Table 4.43

Descriptive statistics for intonation stimulability in participants of age range 10-13 across gender groups

Parameters	Male				Female			
	Mean	Md.	SD	IQR	Mean	Md.	SD	IQR
rF0	239.85	248.5	45.04	61.5	271.9	279.5	31.46	34.75
rT0	4.33	4.01	0.94	1.10	3.73	3.57	0.54	0.46
rFhi	322.65	325	49.26	52.50	353.55	345.5	32.73	62.75
rFlo	174.60	189.5	50.49	87.50	196.35	214	49.77	93.75
rSTD	32.88	28.89	15.61	15.41	35.64	32.04	14.16	17.07
rvF0	14.29	11.77	7.77	6.74	13.71	11.62	7.35	5.74
rvAm	36.09	35.05	5.19	7.33	36.88	35.63	6.01	9.55

Table 4.44

Descriptive statistics for the intonation stimulability in participants of age range 14-18 across gender groups

Parameters	Male				Female			
	Mean	Md.	SD	Range	Mean	Md.	SD	Range
rF0	170.4	151.5	49.16	68	227.4	226	32.03	55.5
rT0	6.24	6.60	1.54	2.91	4.47	4.43	0.63	1.09
rFhi	224.25	196	67.26	125.5	316.25	302	50.01	77.75
rFlo	116.71	111.5	34.15	30.16	167.10	176	49.02	90.50
rSTD	27.01	17.75	19.76	32.46	37.29	29.98	21.08	29.60
rvF0	15.01	11.98	9.95	14.40	17.24	12.63	11.02	18.80
rvAm	38.32	38.25	5.23	5.02	38.97	38.19	5.65	7.28

Table 4.45

Mann-Whitney Results for the Gender Effect in 10-13 years and 14-18 years for intonation stimulability

Parameters	10-13					
	U	Z	p value	U	z	p value
rF0	106	-2.54	<0.05**	72.5	-3.4	<0.01*
rT0	106.5	-2.52	<0.05**	79	-3.2	<0.01*
rFhi	123	-2.08	<0.05**	70	-3.5	<0.01*
rFlo	139.5	-1.63	0.1	91	-2.9	<0.01*
rSTd	163	-1	0.32	125	-2.02	<0.05**
rvF0	197	-0.08	0.93	166	-0.92	0.36
rvAm	194	-0.16	0.87	189.5	-0.28	0.78

*=Significant at 0.01 level of significance
** = Significant at 0.05 level of significance
***= Marginally significant

4.2.5 The Effect of Gender on Standard Syllabic Rate Protocol

In both the age groups, Mann Whitney U test results revealed no significant gender differences in any of the measured parameters, suggesting that gender does not significantly affect the standard syllabic rate and its related parameters, particularly in the age between 10-18 years. This indicates that average syllabic rate collected from a running speech sample may not vary across gender in the adolescents.

Table 4.46

Descriptive statistics for the standard syllabic rate in participants of age range 10-13 across gender groups

Parameters	Male				Female			
	Mean	Md.	SD	IQR	Mean	Md.	SD	IQR
SSrate	2.29	2.08	0.68	0.61	2.31	2.28	0.43	0.52
SSsdur	360.80	366	79.85	115.5	365.3	372.5	66.56	45.25
SSpdur	185.4	151.5	95.28	54.25	176.75	177	45.14	46.75
SSspk	78.75	79.6	12.04	11.53	82.55	86.24	10.94	18.40
SSpau	21.24	20.4	12.04	11.53	17.44	13.75	10.94	18.40

Table 4.47

Descriptive statistics for the standard syllabic rate in participants of age range 14-18 across gender groups

Parameters	Male				Female			
	Mean	Md.	SD	IQR	Mean	Md.	SD	IQR
SSrate	2.60	2.41	0.63	0.72	3.63	2.16	6.18	0.31
SSsdur	376.7	380.5	64.47	112.25	352.11	389	127.51	130
SSpdur	105.15	128.5	73.49	163.25	123.55	140.5	67.98	55
SSspk	91.87	92.27	7.5	11.87	86.51	87.92	12.46	16.86
SSpau	7.13	7.51	6.01	11.10	13.31	12.08	12.31	16.86

Table 4.48

Mann-Whitney Results for the Gender Effect in 10-13 years and 14-18 years for standard syllabic rate

Parameters	10-13			14-18		
	U	Z	p value	U	z	p value
SSrate	168	-0.86	0.38	133	-1.81	0.07
SSsdur	195	-0.12	0.9	194	-0.16	0.87
SSpdur	184	-0.43	0.66	170.5	-0.80	0.42
SSspk	157	-1.16	0.24	148	-1.41	0.15
SSpau	157	-1.16	0.24	137	-1.72	0.08

III. Comparison of the adolescent speech motor normative as a factor of age and gender with that of typical Kannada adults

The Current study's findings were compared with the norms developed by John et al (2014) for adults of age range 20-40 years across gender using Wilcoxon's signed rank test. The median values and SDs of this study were compared with the mean of the previous study (John et al., 2013) as some of our data was non-normally distributed.

Additionally, the previous study had run parametric test without subjecting their data for normality check and the same was confirmed during a personal communication with one of the authors.

A. The effect of age and gender on DDK rate parameters between adolescents and adults

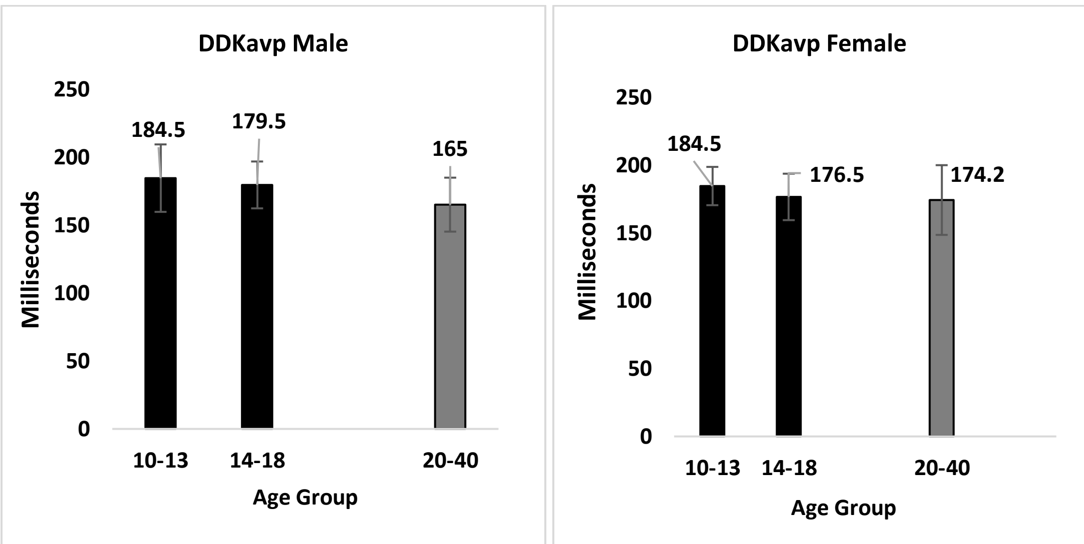
In the adult study the DDK norms were developed for AMR: /pa/. The parameters analyzed under this measure were DDKavp, DDKavr, DDKcvp, DDKjitt and DDKcvi.

i) Average DDK period (DDKavp)

Wilcoxon's signed rank test was used to compare all the measures of DDK. In males, statistically significant differences were seen between the age groups [10-13 years: z = 188, $p < 0.01$; 14-18 years: z = 174, $p = 0.01$]. In females, results were statistically significant only for the age group of 10-13 years [z = 172, $p = 0.01$] whereas the DDKavp values of 14-18 years group [z = 128, $p = 0.39$] didn't differ with the adults. Descriptive statistical comparisons are shown in Figure 1.

Figure 4.1

Descriptive values for DDKavp across studies for age and gender



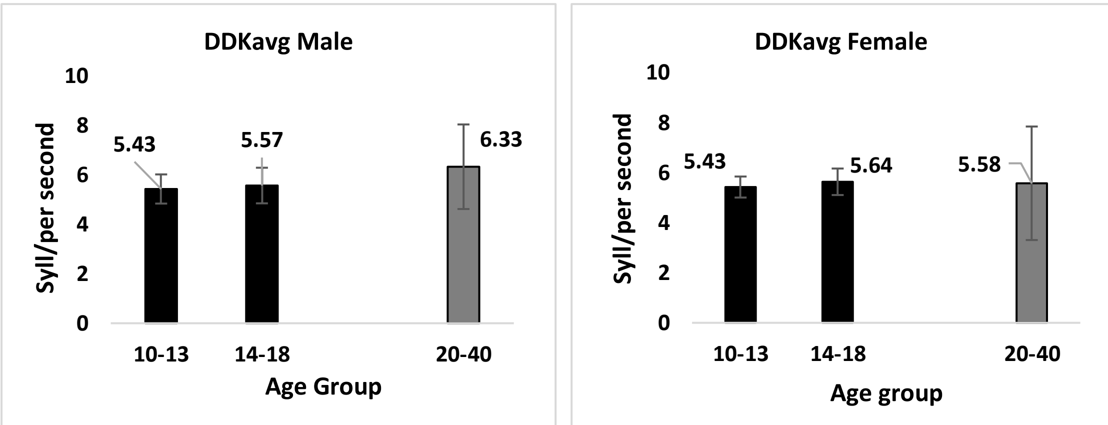
It was observed that average duration of syllables decreased with age from adolescence to adulthood.

ii)Average DDK rate (DDKavr)

With regard to DDKavr, adolescent males significantly differed with the adults in the rate of production of syllable /pa/ [10-13 years: z = 0, p = 0;14-18years: z = 14, $p < 0.01$. Whereas in females, both the younger [10-13 years: z =74, p = 0.25] and older [14-18years z = 119.5, p = 0.58] adolescent groups had comparable syllable rate with the adult group. Descriptive data across studies is shown as Figure 2

Figure 4.2

Descriptive values for DDKavg across studies for age and gender

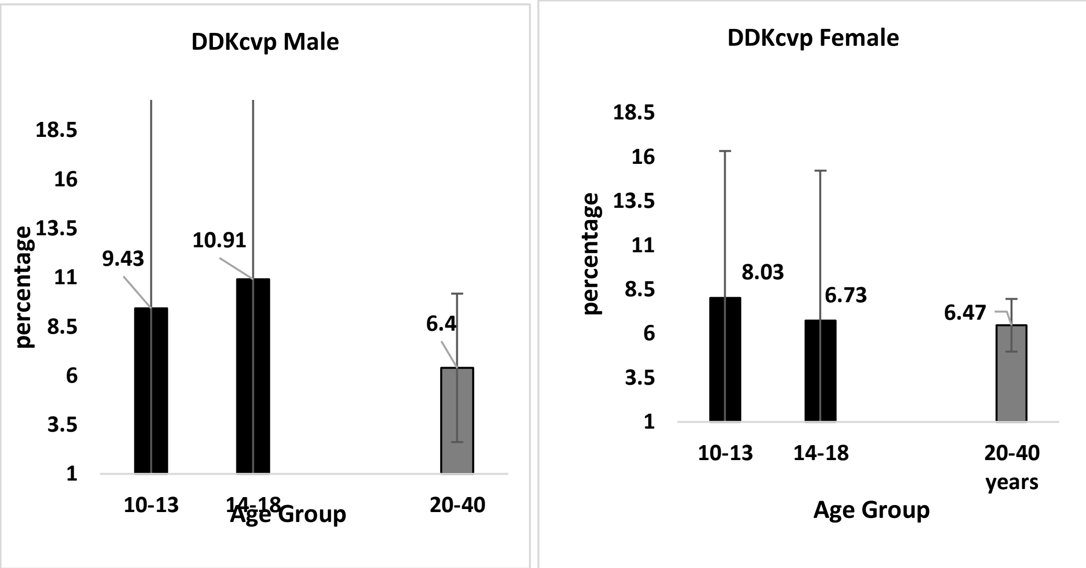


iii) Coefficient of variation of DDK period (DDKcvp)

In males, DDKcvp analysis revealed statistically significant differences in both 10-13 years (z = 189.5, p <0.01) and 14-18 years (z = 193, p < 0.01). In females, the Wilcoxon signed rank test revealed statistical significance for the younger adolescent group of 10-13 years [z = 199, p <0.01], whereas no such significance was observed for older adolescents [z = 149, p = 0.1].

Figure 4.3

Descriptive values for DDKcvp across studies for age and gender



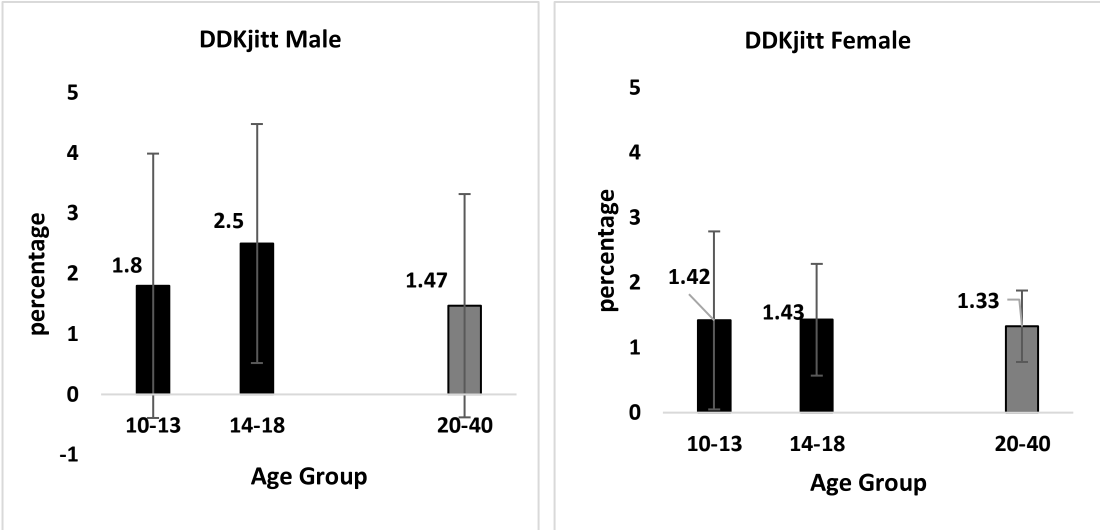
In males, the DDKcvp value increases from early adolescence (10–13 years) to late adolescence (14–18 years) and then significantly decreases in adulthood (20–40 years). In females, the trend indicated a consistent decrease in values from early adolescence (10–13 years) through to adulthood (20–40 years); the decrease from 14–18 to 20–40 years was less pronounced.

iv) Perturbation of DDK period (DDKjitt)

For the age group 10-13 in males the null hypothesis was retained [z = 154, p = 0.06] while for the age group 14-18 years statistically significant difference observed [z = 181, p < 0.01]. But for females there was no statistical significance inferred for 10-13 years [z = 145, p = 0.13] and 14-18 years [z = 153, p = 0.07]

Figure 4.4

Descriptive values for DDKjitt across studies for age and gender



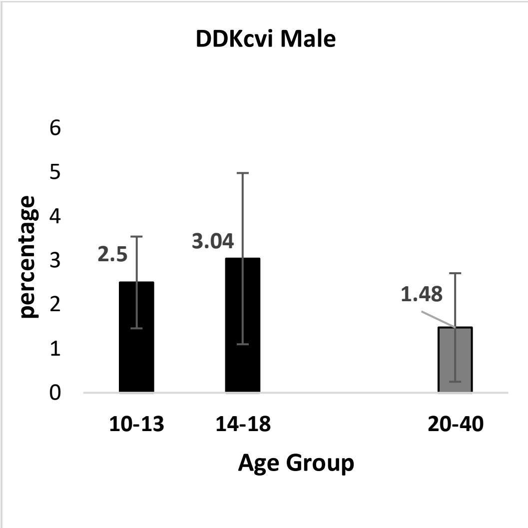
The DDKjitt tends to increase from ages 10-13 years to ages 14-18 years in males, suggesting variability in articulatory movement ability during adolescence. However, in females, the articulatory movements were mostly stable from young adolescent period.

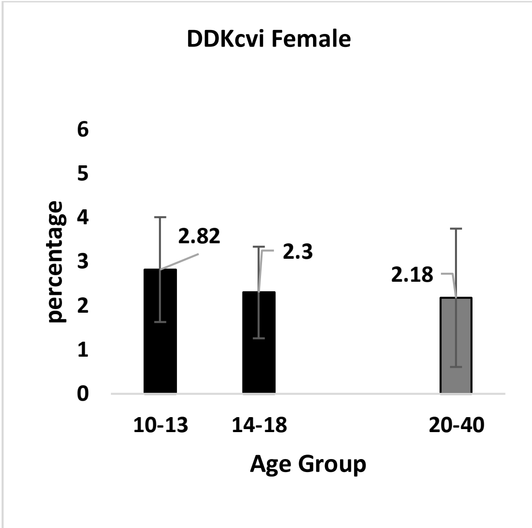
v) Coefficient of variation of DDK peak intensity (DDKcvi)

For males, both the age group showed high DDKcvi compared to adults [10-13 years: z = 210, p <0.01, 14-18 years: z = 189, p <0.01]. Whereas in females, only the younger adolescent group had higher DDKcvi (z = 181, p <0.01), whereas the older adolescents did not differ with adult group (z = 144, p =0.14).

Figure 4.5

Descriptive values for DDKcvi across studies for age and gender





In males, the pattern observed for DDKcvi was similar to that of DDKjitt with most variability observed in older adolescents. In females, it consistently decreased from adolescence to adulthood.

B) The effect of age and gender on F2 transition parameters between adolescents and adults

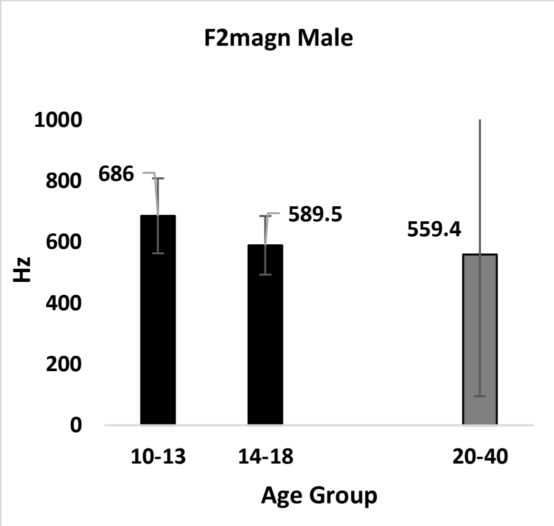
Second Formant (F2) transition and their related parameters were developed for alternate production of sound/i-u/. The parameters analyzed under this measure were F2magn, F2rate, F2reg and F2aver. Wilcoxon's signed rank test was used for all the parameters under this protocol to test for significance.

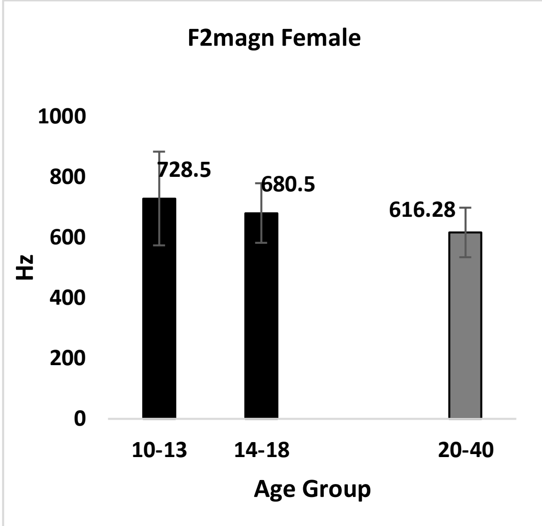
i) Magnitude of F2 variation (F2magn)

In males, magnitude of F2 variation differed only for the age group 10-13 years [z = 174, $p = 0.01$]. But no such statistical significance was observed for the age group of 14-18 years [z = 146, $p = 0.12$]. With regard to females, both 10-13 years [z = 175, $p < 0.01$] and 14-18 years [z = 188, $p < 0.01$] differed significantly from the adult group.

Figure 4.6

Descriptive values for F2magn across studies for age and gender





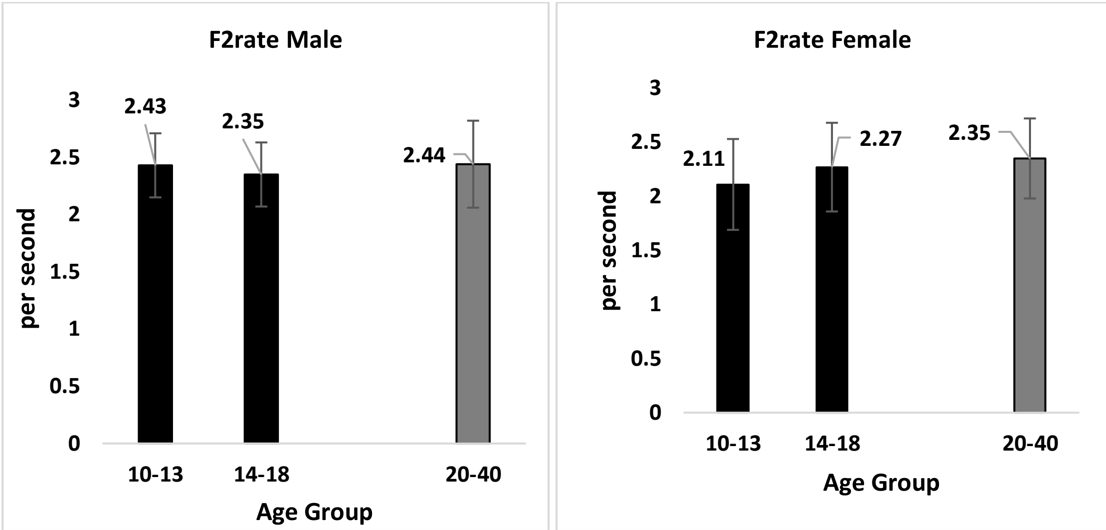
The data suggests that F2magn decreases consistently with age in males, with more pronounced reduction from younger to older adolescents. F2magn decreases with age in females.

ii) Rate of F2 variation (F2rate)

In males, F2 rate did not change between adolescents and adult groups [10-13 years: z = 28.5, *p* = 0.23, 14-18 years: z = 53, *p* = 0.26]. The trend was similar for females too [10-13 years [z = 7, p =0.12] and 14-18 years [z = 42, *p* = 0.06]. Hence the null hypothesis is retained. This finding suggests that the rate of change of articulatory movements while producing /i -u/ combination does not change with age and it showed consistency from early adolescent period.

Figure 4.7

Descriptive values for F2rate across studies for age and gender

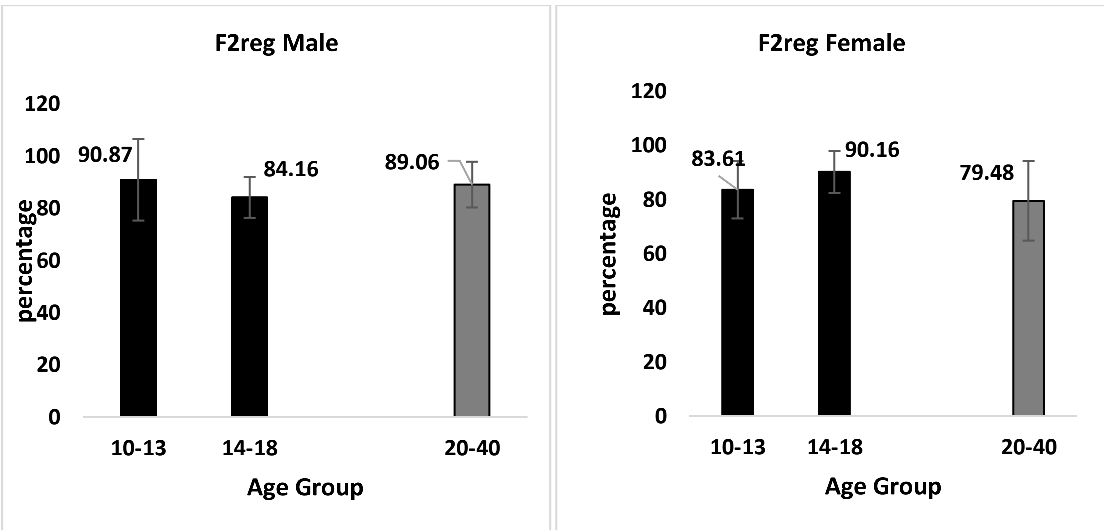


iii) Regularity of F2 variation (F2reg)

Across both the genders, young adolescents did not show any difference in the regularity of F2 variations with the adult group [Males: $z = 66$, $p = 0.92$; Females: $z = 24$, $p = 0.4$]. However, a significant effect of age and gender was observed between older adolescents and adults [Males: $z = 24$, $p < 0.01$; Females: $z = 174$, $p < 0.01$].

Figure 4.8

Descriptive values for F2reg across studies for age and gender.



The trend observed for F2reg is similar to that of F2rate, with least regularity observed for the older adolescent group. In females the pattern shows an increase in F2 from early to mid-adolescence, followed by a decrease into adulthood.

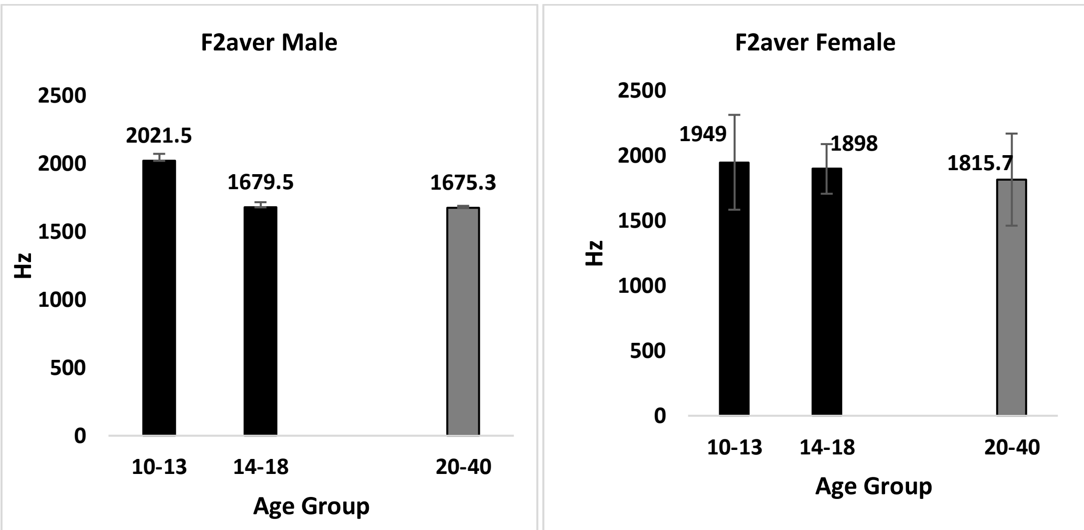
iv) Average of F2 value (F2aver)

A statistically significant difference was observed in males for the age group 10-13 years [z = 188, p <0.0.1] at the level of significance α = 0.01. The null hypothesis is retained for the age range 14-18 years [z = 82, p = 0.39]. In females, no significant difference was observed for the parameter F2aver for the age range 10-13 years [z = 154, p =0.07] and 14-18 years [z =155, p = 0.06].

Male adolescents showed overall higher F2aver compared to adults whereas this trend was not observed in females.

Figure 4.9

Descriptive values for F2aver across studies for age and gender



C) The effect of age and gender on Voice and Tremor Protocol between adolescents and adults

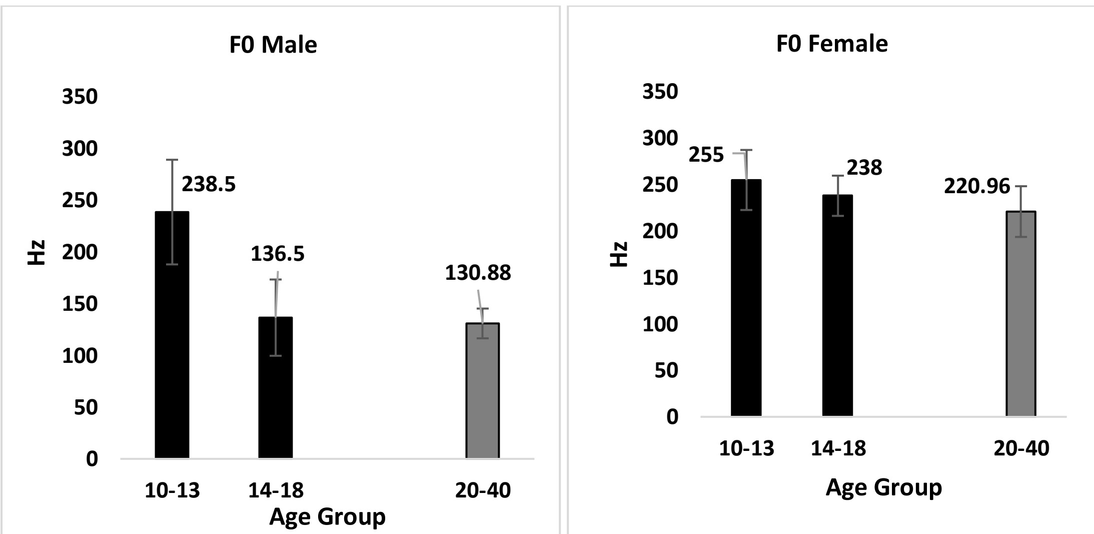
Across the studies, F2 transition norms were developed for sustained production of vowel /a/. The parameters analyzed under this measure were F0, vF0, vAm, Mftr and Matr. Wilcoxon's Signed rank test was used to compare all the parameters under this protocol.

i) Average Fundamental Frequency (F0)

For F0, there was a statistically significant effect in males for the young adolescent group [z = 204, p <0.01] whereas, in older adolescents no such effect was observed [z = 133, p = 0.29]. With regard to females, both the younger adolescents i.e., 10-13 years [z = 189, p <0.01] and older adolescents i.e., 14-18 years [z = 181, p < 0.01] showed statistically significant difference when compared with adults of 20-40 years.

Figure 4.10

Descriptive values for F0 across studies for age and gender



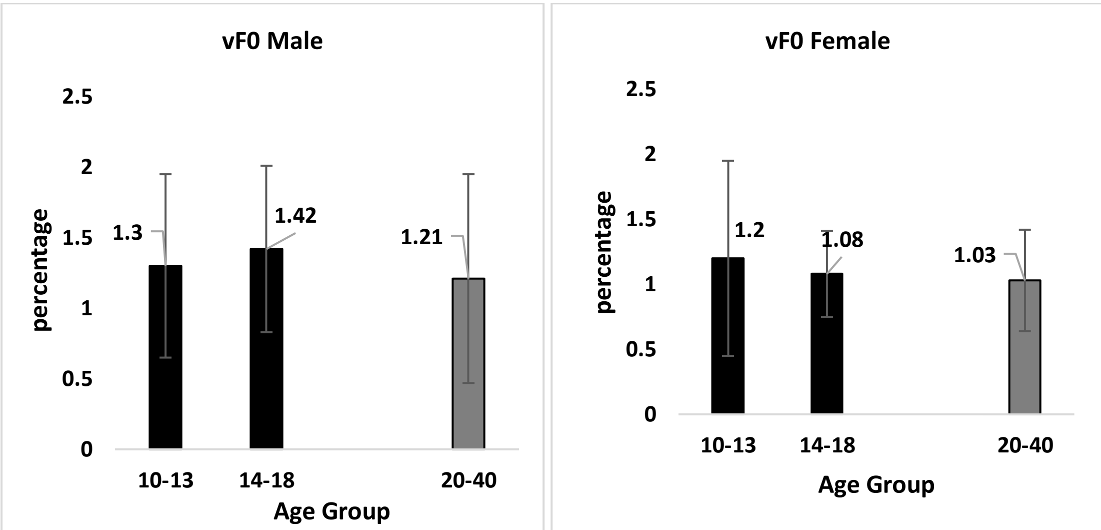
A sudden decrease in F0 was observed in males from young adolescence to older adolescence period with no such changes thereafter. From young adolescence to adulthood, females showed a small but consistent decrease in F0.

ii) Coefficient of variation of fundamental frequency (vF0)

No statistically significant difference observed for either of the age ranges in males [10-13 years: z = 132, *p* = 0.06, 14-18 years: z = 133, *p* = 0.29]. Similar trends were seen even for females [10-13 years (z =144, *p* =0.14), 14-18 years (z =114, *p* = 0.72)].

Figure 4.11

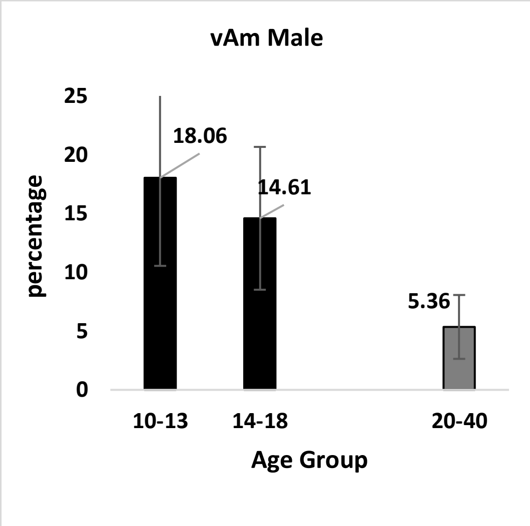
Descriptive values for vF0 across studies for age and gender

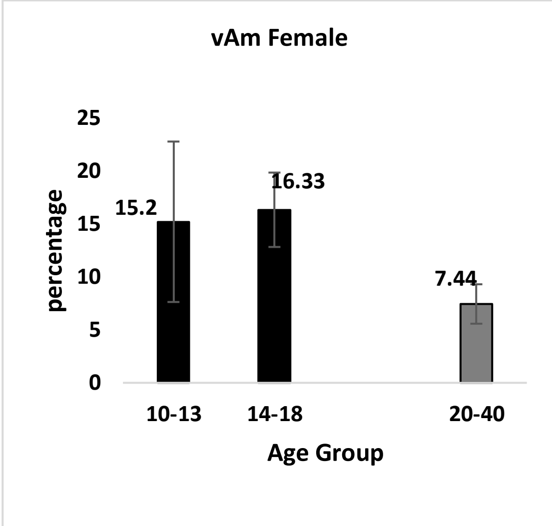


iii) Coefficient of variation of amplitude (vAm)

Figure 4.12

Descriptive values for vAm across studies for age and gender





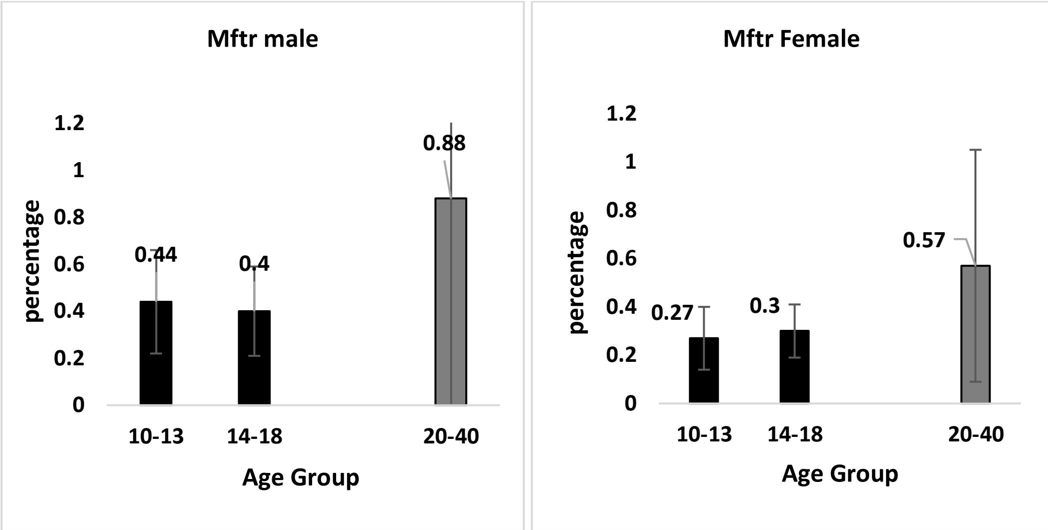
Statistically significant difference observed in both the age groups at level of significance α = 0.01 [10-13 years: z = 210, p <0.01, 14-18 years: z = 210, p <0.01] in males. Likewise in females, both the younger adolescents i.e., 10-13 years [z =205, p <0.01] and older adolescents i.e., 14-18 years [z = 210, p < 0.01] showed statistically significant difference. The study shows a significant decrease in vAm from young adolescence to adulthood, with the highest variability observed in younger adolescents. In females the vAm values show an increasing trend from early to late adolescence, followed by a sharp decrease in adulthood.

iv) Magnitude frequency tremor (Mftr)

The study found significant differences in younger and older adolescent males [10-13 years, z = 3, *p* <0.01, 14-18 years, z =0, *p* <0.01], and in females [10-13 years, z = 0, *p* < 0.01, 14-18 years, z = 3, p < 0.01. In both genders, notable increase in Mftr values were seen from adolescence to adulthood.

Figure 4.13

Descriptive values for Mftr across studies for age and gender

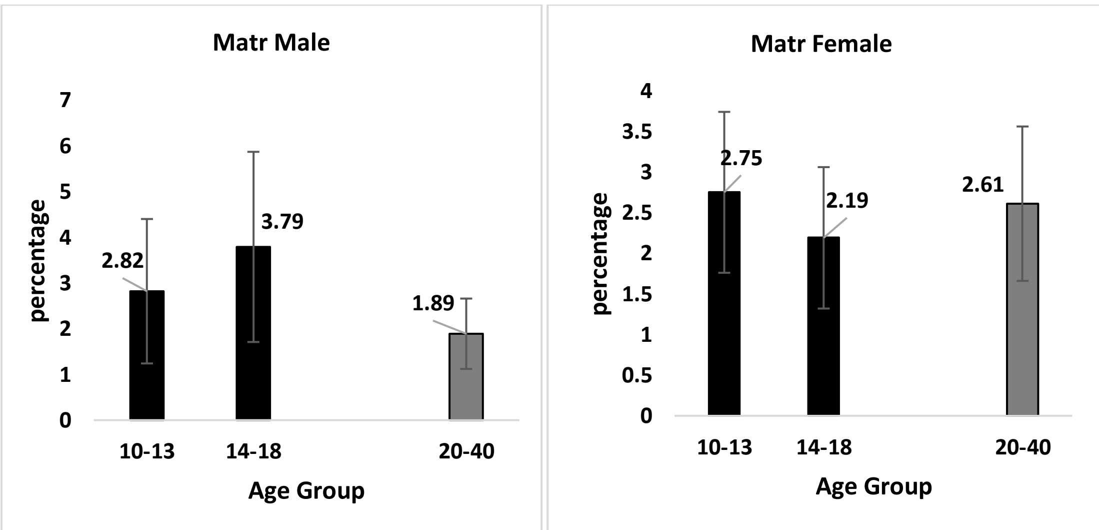


v) Magnitude amplitude tremor (Matr)

In males, statistically significant effect was found between adolescents and adult groups [10-13 years: z = 183.5, $p < 0.01$, 14-18 years: z = 207, $p < 0.01$]. In females, no such differences were observed [10-13 years,z = 138.5, $p = 0.21$, 14-18 years, z = 53, $p = 0.06$]. There is an increase in Matr for males during adolescence and it further decreases through adulthood. No consistent trends were observed in females.

Figure 4.14

Descriptive values for Matr across studies for age and gender



Chapter 5

Discussion

For this study, it was of interest to understand the speech motor characteristics in typical adolescents as measured through the five protocols of Motor Speech Profile software in Kannada speaking adolescents. With this purpose in view, a total of 80 participants in the age range of 10-18 years were selected, consisting of two age groups (10-13 years and 14-18 years). The protocols provided in the software included diadochokinetic rate (DDK), second formant (F2) transition, Voice and tremor protocol, intonation stimulability, and standard syllabic rate protocol. The objective of this study was to generate normative as a factor of age as well as gender and to compare the adolescents normative with that of Kannada speaking adults, which was already developed for the first three protocols of MSP by John et al., (2014). Mann Whitney U test was done to see the overall effect of age as well as gender. For the comparison of normative of this study with the previously conducted study on adults (John et al. 2014), one sample Wilcoxon's signed rank test was used.

Diadochokinetic Rate (DDK)

The tasks for the DDK were in total four, which were repeated productions of the syllables /pa, /ta/, /ka/ and /pataka/ separately. Normative is generated and compared for age ranges 10-13 years and 14-18 years (male and female). We can divide the 11 dependent variables of DDK into three major types. They are a) DDK rate measures (DDKavr, DDKavp), b) Perturbation of DDK rate/period measures (DDKsdp, DDKcvp, DDKjitt) and c) Perturbation of DDK intensity measures (DDKavi, DDKsdi, DDKcvi. DDKmxa, DDKava, and DDKsla).

a) Age effect in adolescents

With regard to the DDK rate, differences were seen between the age groups for only syllable /ka/ (mostly in males) and /pataka/ (in females). In both the cases, the rate increased from younger adolescent to older adolescent age groups. This shows that across gender, refinement is occurring in the speed of specific syllable productions from young adolescence to late adolescent period. As DDKavp is a reciprocal measure of DDKavr, increased DDKavr will always reduce the duration of syllable production. No changes were observed for the DDKavr and DDKavp of /pa/ and /ta/ which may indicate that these syllables would not change in their rate of delivery during adolescent period. Similar research has been done on the performance of DDK tasks in adolescents (Fletcher, 1972; Canning & Rose, 1974; Jeng, 2022) and their findings mirrored with the findings in our study.

The outcome of this study revealed almost similar pattern across each task from younger adolescents to older adolescents. DDKavp which represents average syllable duration decreases with age in both gender and this correlates with the increase in DDKavg (which represent rate of syllable repetition) with age in both the gender. A significant amount of research has been done on the performance of DDK tasks in a variety of age groups, including children (Canning & Rose, 1974; Jang et al, 2020; Jeng, 2022), adolescents (Fletcher, 1972; Canning & Rose, 1974; Jeng, 2022), young adults (Knujit et al., 2018; Jothi & Amritha, 2019; Jang et al, 2020), and the elderly (Pierce et al., 2013; Jeng, 2020). The most notable finding indicates a progressive rise in the DDK rates from childhood to middle adulthood.

With regard to the *perturbation of DDK rate* measures in DDK, the overall results indicate that there was a significant reduction in the perturbation in the rate (period) measures across the stimulus between the age groups. That is, DDKcvp, DDKsdp, DDKjit reduced their values as age increased. This could be attributed to the increased stability in the late adolescent's consequent to better control arising with maturational changes.

With regard to the *perturbation of DDK intensity measures,* males produced syllables /pa/ and /ka/ with high DDKava (average intensity of DDK sample) values in later adolescence. Females, reduced the DDKava and DDKmxa (maxium intensity of DDK sample) for /ka/ and /pataka/. This indicate that the overall loudness in the production of syllables were high in older male adolescents compared to females, which were specific to a given DDK syllable. This hints for syllabic specific variations in the perturbation of DDK intensity measures.

b) Gender Effect in Adolescents

For the age group 10-13 years, no significant gender effect was found in DDK rate parameters for the syllables /pa/, /ta/ and /pataka/. Whereas, for the syllable /ka/, males show lower values for DDKavp and higher DDKavr compared to females. This indicated faster overall delivery of the syllable /ka/ compared to females. Modolo et al (2011) found that the number of utterances per second of 'ta' was higher for girls than for boys of age range 8-10 years. No significant gender effect observed for Perturbation of DDK rate/period parameters or perturbation of DDK intensity parameters for tasks of repetition of syllables /pa/ and /pataka/. However, for the task /ta/, females, on the other hand show higher variability in performance measures, like DDKsdp indicating higher durational variability. Whereas males in same age group showed higher median values for DDKsdi and DDKcvi indicating more variability in the intensity measures. For /ka/ both durational (DDKcvp, DDKjitt) and intensity parameter values (DDKsdi and DDKcvi) were higher in males, however the differences were significant only for durational measures indicating poorer temporal stability compared to females.

For the age group 14-18 years there were no significant gender effect for DDK rate parameters for the production of syllable /pa/. In research analyzing articulation rates using oral-DDK, Lass and Sandusky (1971) found no differences between genders. In females, however in our study, it was noted that the rate was slower for the production of /ta/ compared to males. In the production of /pa/ and /ka/, significant effect was observed for perturbation of DDK rate/period parameters like DDKsdp, DDKcvp and DDKjitt. Males had higher values for /pa/ whereas female showed greater variability for /ka/. With regard to perturbation of DDK intensity measures, significant gender effect was found for the parameters DDKsdi, DDKcvi and DDKava in the production of /pa/, /ka/ and /pataka/. Overall higher mean values for males observed for these parameters as well when compared to females. Overall, the perturbation for period/rate was clearly observed between the genders across the age ranges than the intensity variations. This indicate that temporal aspects of speech production are still undergoing refinement, particularly in male adolescent population.

c) Comparison between adolescents and adults

When compared for the DDK between our study and a previous study by John et al., (2014), it was compared only for the syllable /pa/ as the previous study did not provide values for any other DDK measure. In this study, when compared with adults, adolescent males shown significant difference for the parameter DDKavp and DDKavr. DDKavp decreased and DDKavr increased from 10-13 years to 20-40 years continuously. While in females, older adolescents (14-18 years) and adults (20-40 years) were having almost similar DDKavp and DDKavg values. This is in contrary to the studies which claimed that DDK of adults is comparable to that of the productions in 15-year-old male adolescent group (Fletcher, 1972). Male adolescents continuously improve their syllable production of /pa/ from early adolescence to adulthood. Compared to males, female adolescents stabilize the rate of articulation between 14-18 years which is much earlier than the maturation of syllable rate for /pa/ in male. Data from different research vary, but generally, children's DDK rates increase with age, at least until they are between the ages of 7 and 12 years old. But according to Huang et al. (2005), the study with the biggest sample size (N = 900, 60 participants per year) showed that DDK rates were highest for kids aged 7–13, lowest for 5-year-olds, and subsequently started to decline after 13 years of age.

For the intensity perturbation parameters i.e., DDKcvi production of syllabic intensity reduces from adolescence to adulthood in males. Whereas the intensity variability is restricted to the younger adolescent group for females (10-13 years). This goes against a previous study compared DDK rates and intensity between males and females, observing similar trends in intensity parameters across genders with slight increases with age (Zraick et al., 2005).

DDK perturbation of period which includes DDKjitt and DDKcvp were generally higher in younger groups for females. Older female adolescents were always comparable to that of adults. However in males, overall findings revealed higher variability of DDKjit and DDKcvp in adolescent males than adults, with slightly higher variability seen for older adolescent males. This might be due to anatomical and physiological changes occurring in male’s vocal tract during puberty. However, between adult subgroups (20-60 years), females showed higher coefficient of variation than males (John et al, 2014).

In this study, when compared with adults, males shown most variability during 14-18 years than adults or younger group whereas, females consistently showed reduced variability with age. The decrease in variability with age, indicate more stable speech patterns in older groups. This variability during DDK task also correlate with the variability of the speech movement during sentence production which reduces across age groups. This maturational trend was most apparent from age 6 years to adulthood. Additionally, the 6- to 7- year old, 8- to 11-year old and adolescents demonstrated significantly higher variability compared with adults (Murdoch, 2011).

F2 Transition

F2 transition indirectly indicates the position of the tongue in the oral cavity, with high F2 indicates anterior oral and low F2 corresponding to posterior articulatory constrictions. The alternate production of vowel /i/ and /u/ was used to measure the F2 transition parameters.

a) Age Effect in Adolescents

No statistical significance found for age effect for most parameters in female participants. However, significant differences were found in F2magn, F2aver, F2min, and F2max for males across the age groups. In females, only F2 minimum (F2min) showed a significant age effect which was found to be decreasing with age. Wong et al. (2011) found a similar reduction in F2magn with age in males.

b) Gender Effect in Adolescents

The results of this study reveal that gender differences in F2 transition parameters become more pronounced and statistically significant as children progress into later adolescence. In the 14-18 years age group, significant gender effects were found for several parameters that are F2magn, F2aver, F2max, and F2reg. These findings indicate that females in this age group consistently exhibit higher F2 magnitudes and averages than males, suggesting that females generally produce larger

F2 transitions. This pattern underscores the consistent nature of vocal tract length differences between the gender, that gets pronounced in the late adolescent period.

In contrast, the only parameter showing a significant gender effect in the 10-13 years group was F2rate. This suggests that in early adolescence, males were changing articulatory positions faster than females when alternating between /i/ and /u/ vowels. However, such differences in F2 rate were not observed in the older adolescent group, indicating that the faster articulatory movements seen in younger males do not persist into later adolescence. In other words, the rate of F2 transitions would be higher in males than females only in early adolescence which gets plateaued in the late adolescent period. Overall, it was found that while younger adolescents exhibit some differences, particularly in F2 rate, it is in the later adolescent years that these differences become more robust and consistent across multiple parameters. This highlights the developmental trajectory of speech production differences between males and females, with more pronounced distinctions emerging as adolescents grow older.

Simpson (2001) studied the higher second formant rate in females and reasoned that differences in vocal tract cross-section require males and females to move different articulatory distances to achieve the same phonetic target. Males with a larger cross section in the vocal tract, developmentally learn to move to the target positions quicker than females and this could explain why males showed faster F2 rate in young adolescent age.

c) Comparison Between Adults and Adolescents

In males, when compared with adults, the magnitude of F2 (F2magn) variation showed a significant difference in the 10-13 years age group, while no significant difference was observed in the 14-18 years age group. In females, both the 10-13 years and 14-18 years age groups exhibited significant differences from the adult group.

Current findings are contrary to an earlier report by Turnbough et al. (1985) who found that children coarticulate more than adults, indicating a higher F2magn and slower F2rate in younger age groups. However, Sereno et al. (1987) found higher coarticulatory effects in older age groups compared to younger ones, aligning with the present study. These variations across studies suggest that formant transition is not uniform across age groups or genders and is highly influenced by factors such as accent, cultural, and linguistic backgrounds. Cox (2006) observed that differences between males and females are not uniform in magnitude across different vowels.

With regard to F2 rate, both the genders did not differ with adults indicating adult like F2 transition rates in adolescent period. However, slight decrease in F2 regularity (measured in percentage) could be observed than females possibly to accommodate the significant anatomical changes seen in males.

Average F2 did not change from adolescent to adulthood in females whereas this trend was seen only after late adolescence in males further highlight maturational changes in the vocal tract of males.

Voice and Tremor Protocol

The internal structures of vocal folds largely contribute to the voice and tremor characteristics of an individual. The task for measuring parameters under this protocol was to sustain the phonation of /a/. A total of nine parameters were studied under this protocol which are related to fundamental frequency, tremor and their variabilities.

a) Age Effect in Adolescents

Fundamental Frequency (F0) tends to decrease from age group 10-13 years to 14-18 years, with a more significant reduction observed in males compared to females. Frequency of tremor (T0) shows an opposite trend to F0, that is it tends to increase with age. Highest and lowest fundamental freuqncies (Fhi and Flo) decreases from early to late adolescence. Same trend is observed for standard deviation of F0. Even in females, age related differences were observed from early to late adolescence wherein F0, Flo, and magnitude of amplitude tremor reduces as age increases. Overall, frequency dynamics change with age, with significant decreases in F0 and other parameters observed during adolescence, reflecting physiological changes such as the lengthening and thickening of the vocal folds and laryngeal descent. Deliyski and Gress (1997) found that age did not influence voice and tremor parameters in adults from 18 to 61 years, suggesting stabilization of pubertal changes occurs after 18 years. However, some studies argue that hormonal development continues to influence F0 from childhood through adulthood (Pederson, Agersted & Jonsson, 2015). Stathopoulos et al. (2011) observed nonlinear and gender-specific trends in voice parameters, supporting the significant variation in voice production due to anatomical, physiological, and motor control factors.

b) Gender Effect in Adolescents

Fundamental Frequency (F0) was consistently higher in females compared to males across the age groups. A similar trend was observed for highest F0 (Fhi) and lowest F0 (Flo) both higher in females compared to males. Tremor related measures such as Matr and Mftr was higher in males compared to females across 10-13 and 14-18 years. The observed changes in the F0 and other related measures could be attributed to the lengthening and thickening of the vocal folds, thickening of laryngeal cartilages, and laryngeal descent lead to a lowering of F0, more pronounced in males than in females (Kahane, 1982; Harries et al., 1998; Eguchi & Hirsh, 1969; Huber et al., 1999; Kent, 1976; Peterson & Barney, 1952; Stathopoulos & Sapienza, 1997).

c) Comparison Between Adults and Adolescents

A dramatic decrease in F0 from younger adolescents to adults in males was observed, with a less pronounced transition from older adolescents to adults. The reduction in F0 in females is less dramatic, however it decreased consistently from young adolescent to adulthood in females. For variations in fundamental frequency (vF0), there was no age or gender effect indicating adolescents not showing higher variaitons in their F0 compared to adults. However, vAm reduces from adolescence to adulthood across the genders

With regard to magnitude of frequency tremors (Mftr), both genders show increase in median values from young adolescence to adulthood but this was observed only for males in the magnitude of amplitude tremors. This indicates that certain variations in tremors could be expected as a natural behavior across genders in adults. In a perceptual testing by Harnsberger et al (2008), to identify the acoustic and perceptual correlates of voice as a factor of age, it was observed that voice quality (both tremor and noise) and speaking rate are all perceptually relevant cues of age in male voice.

Intonation Stimulability Protocol

Intonation is the changes observed in pitch patterns over a phrase or a sentence. A Kannada sentence "/Nīvu indu athavā nāḷe horaḍuttīrā? /" which is a direct translation of the English stimulus "Are you leaving today or tomorrow" was used to study this protocol. The intonation parameters addressed in the study includes various domains of Fundamental frequency range, variations in F0 and intensity during speech production. Similar trends as voice and tremor protocol is observed for intonation and stimulability parameters.

a) Age effect in adolescents

There is a statistically significant decrease in running speech fundamental frequency (rF0) from the 10-13 years age group to the 14-18 years age group for both the genders. In contrast, running speech pitch period (rT0) shows a significant increase with age in both gender groups. This is expected as pitch period is a reciprocal measure of rF0. Both rFhi and rFlo, which also represent the high and low pitch range respectively, exhibit a significant decrease with age across both genders. No statistically significant effects were observed for rSTD, rvF0, and rvAm. The results of this study are aligning well with the finding that, although intonation mastery approaches adult levels by age 5, the finer aspects of intonation continue to develop up to age 10-13 years, with differences between genders becoming more pronounced as individuals age (Deepthy, 2015; Snow & Balog, 2002; Snow, 2006; Bates et al., 1975).

b) Gender effect in adolescents

Statistically significant gender differences were observed in rF0, rT0, and rFhi in age group 10- 13 years. Similar gender differences were observed, with additional significant differences in rFlo and rSTD in 10-14 years also. This suggests that gender differences in these parameters become more pronounced during late adolescence, particularly between ages 14-18 years. It was found that rF0, rFhi, rFlo, and rSTD were consistently higher in females compared to males across both age group.

These findings reflect the robust changes in laryngeal development during the studied age ranges, leading to pronounced gender differences in acoustic parameters. Both the voice and tremor protocol and the intonation stimulability protocol are influenced by these laryngeal changes, resulting in significant gender differences in the measured parameters. The study indicates that females generally show greater pitch range and flexibility, which are essential for effective intonation control. According to

Stathopoulos et al. (2011), voice production capabilities, including intonation flexibility, vary across the lifespan, with females typically exhibiting greater control and range.

Standard Syllabic rate Protocol

The rate of spoken utterances is important in understanding the normal development of motor control and coordination. This is an important aspect of development as reported by various researches. There are variations in the different variables of rate of speech with an increase in age. Parameters like syllabic rate, syllable duration, percentage speaking time, pause duration etc are studied. The participants repeated a Kannada sentence "/Nīvu varṣapūrti dūra iruviri endu namage tiḷidittu/" which is a direct translation of the stimulus in English.

a) Age effect in adolescents

The results of this study found an increased average syllabic rate (SSrate) with age which is more pronounced in males than females. The results of this study show clear differences between age groups across genders in terms of syllabic rate and variability in syllable duration. Generally, older adolescents (14-18 years) exhibit higher syllabic rates compared to younger ones (10-13 years), indicating improved speech motor control and fluency as they mature. Due to increase in syllable rate with age, the percent speaking time also increased (SSspk) and there was a consequent reduction in the percent pause time (SSpau).

An increase in the mean rate of utterance from 2 syllables per second at the age of 6 years to 4 syllables per second at the age of 14 years was observed (Kowal, O'Connell & Sabin, 1975). Previous studies, with improvised syllabic rate measurements, have reported a change of 4.24/sec to 5.54/sec from 4 to 18 years (Wong et al., 2011). One of the studies also observed slower speaking rates in older compared to younger speakers (Tuomainen & Hazan, 2018) relating this finding mainly to longer syllable or word durations in the younger populations (Harnsberger et al, 2008). In storytelling and conversational tasks, the speech rate (syllables per second) of English-speaking children grew with age until roughly 14 years and 1 month of age, according to Kowal, O'Connell, and Sabin (1975). Furthermore, researchers assessed English-speaking kids using four distinct activities and discovered that kids' speech rates, or syllables per second, grew steadily until they turned 13 years old (Nip & Green, 2013).

b) Gender effect in adolescents

The results revealed no significant gender differences in any of the measured parameters in standard syllabic rates, suggesting that gender does not significantly affect the standard syllabic rate and its related parameters, particularly in the age between 10-18 years. This indicates that average syllabic rate collected from a running speech sample may not vary across gender in the adolescents. It is to be noted that despite there are differences across the DDK repetitions in adolescents, speaking rate differences were insignificant. This may partially support the finding of few of the previous studies that DDK rate and speaking rate has no clear correlations.

Thus to conclude, these parameters reveals age and gender related improvements in speech fluency and motor control. These findings underscore the complexity of speech development and highlight the importance of considering age and gender factors in clinical settings.

Chapter 6

Summary and Conclusions

This study aimed to understand the speech motor characteristics in typical Kannada speaking adolescents as measured through the five protocols of Motor Speech Profile (MSP) software. We chose 80 adolescents in the age range of 10 to 18 years with two subgroups (10-13 & 14-18 years). Both the gender (male and female) were equally represented in across subgroups. Informal evaluation of speech, hearing and cognitive abilities were performed in order to eliminate any communication difficulties, if present. The five protocols of MSP software were followed in order to develop normative as a factor of age gender for Kannada speaking adolescents. Also the developed normative in this study were compared with a previously published adult normative by John et al. (2014) in Kannada, for three protocols namely DDK rate, F2 transition and Voice and Tremor.

The primary findings from this study are:

1) Diadochokinetic Rate

a. Age Effect in Adolescents

- Average DDK period (DDKavp) decreases with age for both genders.
- As average DDK rate (DDKavr) is reciprocal to the average DDK period, it shows an opposite trend, increasing with age. Particularly, the average DDK rate increases in /ka/ for males and /pataka/ for females with increase in age. But /ta/ and /pa/ does not show increase in rate. These findings indicate refinement in the speed of specific syllable productions from young adolescence to late adolescent period

- Perturbation of DDK period measures such as DDKcvp, DDKsdp, DDKjit reduced their values as age increased. This could be attributed to the increased stability in the late adolescent's consequent to better control arising with maturational changes.
- In DDK intensity Perturbation, males produced syllables /pa/ and /ka/ with high average intensity of DDK sample (DDKava) values in later adolescence whereas females, reduced the DDKava and DDKmxa (maximum intensity of DDK sample) for /ka/ and /pataka/.
- In comparison to adults, DDKavr of syllable /pa/ increased from 10-13 years to 20-40 years continuously in males. While in females, older adolescents (14-18 years) and adults (20-40 years) were having almost similar DDKavp and DDKavr values. This supported continuously improved syllable production of /pa/ in male adolescents from early adolescence to adulthood. However females had stable and comparable productions of syllable /pa/ with adults from young adolescence onwards.

b. Gender Effect

- Syllable /ka/ and /ta/ had higher syllabic rate in males than female across 10-13 years and 14-18 years respectively.
- For DDKsdp, DDKcvp, and DDKjitt males showed higher values for /pa/ whereas female showed greater variability for /ka/.
- With regard to DDK intensity perturbation, males showed higher median values than females in DDKsdi, DDKcvi and DDKava in the production of /pa/, /ka/ and /pataka/. Females consistently show lower variability compared to males during adolescence.

c. Adolescents vs Adults

- Adolescent were slower in production of DDK rate for syllable /pa/ which improved only with age.
- Older adolescent and adult females exhibit similar values for DDKavp and DDKavr, suggesting earlier stabilization of syllabic rate in females.
- Both young and old adolescent males show DDK period perturbations (DDKcvp and DDKjit) whereas this was observed only for young adolescent females.
- DDK intensity perturbations (DDKcvi) reduced with age in adolescent males, whereas in females only younger adolescent group showed intensity perturbations.

2) F2 Transition

a. Age Effect in Adolescents

- Only males showed significant age effect for F2avr, F2min, and F2max.
- Young adolescent males showed higher median for across F2magn, F2rate, F2reg, and F2aver.

b. Gender Effect

- Gender effect is significant in late adolescence (14-18 years) with females showing overall higher F2magnitude, average F2, F2reg and F2max than males.
- In younger adolescents, F2 rate is generally higher in males compared to females indicating a compensation in males to travel longer articulatory distances due to large cross section areas of the vocal tract. Differences in vocal tract cross-section between males and females may require different articulatory distances to achieve the same phonetic target.

c. Adolescents vs Adults

- F2reg values improves in males whereas decreases in females while traversing from adolescence to adulthood.
- F2magn consistently reduced from adolescents to adulthood across gender. F2aver reduces from adolescence to adulthood which is consistently observed for males; whereas in females average F2 values remains comparable between the age groups.

3) Voice and Tremor Protocol

The internal structures of vocal folds significantly contribute to an individual's voice and tremor characteristics. In this study, parameters were measured during sustained phonation of /a/, revealing several key findings:

a. Age Effect in Adolescents

- Fundamental frequency (F0) decreases in adolescents with increase in age, across gender. The period of F0 (T0) shows an opposite trend, with higher values observed in males.
- Standard deviation of fundamental frequency is higher in younger adolescent males.
- Amplitude tremors (Maftr) observed in females gradually decreases its median values from young to older adolescence.

b. Gender Effect

- Fundamental frequency (F0) and their revealed measures such as Fhi and Flo tends to be higher in females compared to males across the adolescent groups.
  - Differences in vocal fold lengthening and thickening, along with laryngeal cartilage modifications would contribute to gender differences in fundamental frequency and related parameters

- Overall, both amplitude (Matr) and frequency tremors were higher in males compared to females.

c. Adolescents vs Adults

- A dramatic decrease in F0 from younger adolescents to adults is noted in males, while the decrease in females is less pronounced.
- For variations in fundamental frequency (vF0), there was no age or gender effect indicating adolescents not showing higher variations in their F0 compared to adults.
- vAm reduces from adolescence to adulthood across the genders.

With regard to magnitude of frequency tremors (Mftr), both genders show increase in median values from young adolescence to adulthood whereas magnitude of amplitude tremors decreased consistently in females. Males showed comparable Matr across the age groups.

4) Intonation Stimulability

Intonation parameters, including Fundamental Frequency (F0) range and intensity variations during speech production, were studied. Findings from voice and tremor parameters align with intonation stimulability parameters.

a. Age Effect in Adolescents

- rF0, rFhi & rFlo decreased significantly with age in both genders.
- rT0 showed an opposite trend, increasing from age group 10-14 to 14-18 in both genders.

b. Gender Effect in Adolescents

- Females consistently showed higher values in rF0, rFhi, and rSTD, indicating greater pitch range and variability.

- Males exhibited lower values in rT0 and rvF0 compared to females.
- Females demonstrated greater flexibility and control over pitch in the intonation stimulability protocol, consistent with gender-specific vocal control trends observed across the lifespan.

5) Standard Syllabic rate

a. Age Effect in Adolescents

- Average syllabic rate (SSrate) increases with age, particularly more pronounced in males than females.
- No statistically significant effect was found for SSpdur for both genders
- Older adolescents (14-18 years) generally exhibit higher syllabic rates compared to younger adolescents (10-13 years), suggesting improved speech motor control and fluency with maturity.

b. Gender Effect in Adolescents

- In both the age groups no significant gender differences observed in any of the measured parameters. This suggested that gender does not significantly affect the standard syllabic rate and its related parameters, particularly in the adolescent age group. These findings supported for potential differences the rates of DDK and standard syllabic rate in adolescents.

Implications of the Study

- The findings of this study provide normative for Kannada speaking adolescents within the age range of 10-18 years for all the five protocols of motor speech profile.

- This study will contribute to closing the gap in the developmental trends of numerous speech motor characteristics from childhood to adulthood by providing data on the adolescent population.
- The values can be compared with disordered population for the purpose of clinical intervention as well as for understanding the differences between typical and disordered maturational process.

Limitations of the study

- The sample size of 80 participants, though adequate, may limit the generalizability of findings to the broader population of Kannada-speaking adolescents across various dialects.
- Without MSP software sophistication, no future replications can compare their findings to this study. We compared the study findings to only young adults (20-40 years) and not with older adult groups.

Future Directions

- Longitudinal studies could be conducted to understand the developmental changes in the speech motor skills across the adolescent age groups.
- The research can be extended to include cross-cultural/dialectal comparisons between Kannada-speaking adolescents.
- Replications of the current findings could be compared with freely available software for certain parameters of a few speech motor protocols.

References

Bates, E., Camaioni, L., & Volterra, V. (1975). The acquisition of performatives prior to speech. *Merrill-Palmer Quarterly of Behavior and Development, 21*(3), 205-226.

Boliek, C. A., Hixon, T. J., Watson, P. J., & Jones, P. B. (2009). Refinement of speech breathing in healthy 4- to 6-year-old children. *Journal of Speech, Language, and Hearing Research, 52*(4), 990-1007. https://doi.org/10.1044/1092-4388(2009/07-0214)

Canning, B. A., & Rose, M. F. (1974). Clinical measurements of the speed of tongue and lip movements in British children with normal speech. *British Journal of Disorders of Communication, 9*(1), 45-50.

Case, J., & Grigos, M. I. (2016). Articulatory control in childhood apraxia of speech in a novel word-learning task. *Journal of Speech, Language, and Hearing Research, 59*(6), 1253–1268. https://doi.org/10.1044/2016_JSLHR-S-14-0261

Cheng, H. Y., Murdoch, B. E., Goozée, J. V., & Scott, D. (2007). Physiologic development of tongue–jaw coordination from childhood to adulthood.

Chung, H., & Weismer, G. (2021). Formant trajectory patterns of American English /l/ produced by adults and children. *Journal of Speech, Language, and Hearing Research*, *64*(3), 809–822. https://doi.org/10.1044/2020_JSLHR-20-00345

Cooksey, J. (2000). Voice transformation in male adolescents. *Bodymind and voice: Foundations of lifespan voice education. Iowa: National Center for Voice and Speech*.

Cox, F. (2006). The acoustic characteristics of/hVd/vowels in the speech of some Australian teenagers. *Australian journal of linguistics*, *26*(2), 147-179.

Deepthy, A. (2015). Motor speech characteristics in 4-10-year-old typically developing Kannada speaking children. Retrieved from http://203.129.241.86:8080/xmlui/handle/123456789/1334

Deliyski, S. A. X. D. (2001). Effects of aging on selected acoustic voice parameters: Preliminary normative data and educational implications. *Educational Gerontology*, *27*(2), 159-168.

Eguchi, S., & Hirsh, I. J. (1969). Development of speech sounds in children. *Acta Oto-Laryngologica. Supplementum*, *257*, 1–51.

Elihami, I. (2017). Increasing students' reading comprehension through cognitive strategies of senior high school of Sidenreng Rappang Regency. *Edumaspul - Jurnal Pendidikan*, *2*(2), 61-70.

Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, *41*, 1149-1160.

Fentress, J. C. (1984). The development of coordination. *Journal of Motor Behaviour*, *16*, 99-134.

Fink, B. R. (1986). Complexity. *Science, 231*(4736), 319. https://doi.org/10.1126/science.231.4736.319-b

Fletcher, S. G. (1972). Time-by-count measurement of diadochokinetic syllable rate. *Journal of Speech and Hearing Research, 15*(4), 763-770.

Giedd, J. N. (2015). The amazing teen brain. *Scientific American, 312*(6), 32–37. https://doi.org/10.1038/scientificamerican0615-32

Groenen, P., Maassen, B., & Crul, T. (1998). Formant transition duration and place perception in misarticulating children and adolescents. *Clinical Linguistics & Phonetics, 12*(6), 439-457.

Green, J. R., Moore, C. A., & Reilly, K. J. (2002). The sequential development of jaw and lip control for speech. *Journal of Speech, Language, and Hearing Research, 45*, 66–79.

Guenther, F. H., Hampson, M., & Johnson, D. (1998). A theoretical investigation of reference frames for the planning of speech movements. *Psychological Review, 105*(4), 611.

Harnsberger, J. D., Shrivastav, R., Brown, W. S., Rothman, H. B., & Hollien, H. (2008). Speaking rate and fundamental frequency as speech cues to perceived age. *Journal of Voice, 22*(1), 58–69. https://doi.org/10.1016/j.jvoice.2006.07.004

Harries, M., Hawkins, S., Hacking, J., & Hughes, I. (1998). Changes in the male voice at puberty: Vocal fold length and its relationship to the fundamental frequency of the voice. *The Journal of Laryngology & Otology, 112*(5), 451-454.

Hay, L. (1979). Spatial-temporal analysis of movements in children: Motor programs versus feedback in the development of reaching. *Journal of Motor Behavior, 11*(3), 189-200.

Hirano, M., & McCormick, K. R. (1986). *Clinical examination of voice*. College-Hill Press.

Holcomb, P. J., Coffey, S. A., & Neville, H. J. (1992). Visual and auditory sentence processing: A developmental analysis using event-related brain potentials. *Developmental Neuropsychology*, *8*(2-3), 203–241. https://doi.org/10.1080/87565649209540525

Huang, Z., Du, X., Wan, P., & Chen, Q. (2005). The norm establishment of diadochokinetic rate for Chinese normal children. Journal of Audiology and Speech Pathology, 13(6), 400–403

Huber, J. E., Stathopoulos, E. T., Curione, G. M., Ash, T. A., & Johnson, K. (1999). Formants of children, women, and men: The effects of vocal intensity variation. *The Journal of the Acoustical Society of America*, *106*(3 Pt 1), 1532–1542. https://doi.org/10.1121/1.427150

Jeng, J. Y. (2022). Changes in indicator values of speech function across lifespan. *Bull. Educ. Psychol*, *51*, 613-637.

Jeng, J. Y. (2020). The vocal phonation and oral diadochokinetic movement in the elderly. *J. Med. Health*, *9*, 41-51.

John, J., Ganapathy, K., John, S., & Rajashekhar, B. (2014). Normative for motor speech profile in Kannada-speaking adults. *Journal of Voice, 28*(1), 7–13. https://doi.org/10.1016/j.jvoice.2013.06.009

Jothi, S., & Amritha, M. (2019). Comparison of diadochokinetic rate between Malayalam and Tamil native speakers. *International Journal of Research and Review*, *6*(5), 144-8.

Kahane, J. C. (1982). Growth of the human prepubertal and pubertal larynx. *Journal of Speech, Language, and Hearing Research*, *25*(3), 446-455.

Kent, R. D. (1976). Anatomical and neuromuscular maturation of the speech mechanism: Evidence from acoustic studies. *Journal of Speech and Hearing Research, 19*(3), 421-447.

Kent, R. D. (1992). The biology of phonological development. In C. A. Ferguson, L. Menn, & C. Stoel Gammon (Eds.), *Phonological development: Models, research, implications* (pp. 65-90). York Press.

Kent, R. D., Kim, Y., & Chen, L. (2022). Oral and laryngeal diadochokinesis across the life span: A scoping review of methods, reference data, and clinical applications. *Journal of Speech, Language, and Hearing Research, 65*(2), 574–623. https://doi.org/10.1044/2021_jslhr-21-00396

Knuijt, S., Kalf, J., Van Engelen, B., Geurts, A., & de Swart, B. (2019). Reference values of maximum performance tests of speech production. *International Journal of Speech-Language Pathology, 21*(1), 56-64.

Kowal, S., O'Connell, D. C., & Sabin, E. J. (1975). Development of temporal patterning and vocal hesitations in spontaneous narratives. *Journal of Psycholinguistic Research, 4*(3), 195–207. https://doi.org/10.1007/BF01066926

Lass, N. J., & Sandusky, J. C. (1971). A study of the relationship of diadochokinetig rate, speaking rate and reading rate. *Communication Quarterly*, *19*(3), 49-54.

Lenneberg, E. H. (1967). *Biological foundations of language*. John Wiley & Sons, Inc.

Lenroot, R. K., & Giedd, J. N. (2006). Brain development in children and adolescents: Insights from anatomical magnetic resonance imaging. *Neuroscience and Biobehavioral Reviews, 30*(6), 718–729. https://doi.org/10.1016/j.neubiorev.2006.06.001

Linville, S. E. (1996). The sound of senescence. *Journal of Voice, 10*(2), 190-200.

Liss, J. M., Weismer, G., & Rosenbek, J. C. (1990). Selected acoustic characteristics of speech production in very old males. *Journal of Gerontology, 45*(2), P35-P45.

Liss, J. M., & Weismer, G. (1992). Qualitative acoustic analysis in the study of motor speech disorders. *The Journal of the Acoustical Society of America, 92*(5), 2984-2987.

Lombard, L., & Solomon, N. P. (2020). Laryngeal diadochokinesis across the adult lifespan. *Journal of Speech, Language, and Hearing Research, 63*(3), 742–752. https://doi.org/10.1044/2019_jslhr-19-00170

Mackay, I. R. A., & Tsukada, K. (2020). Segmental duration and speaking rate in native and non-native speakers of Canadian English and Canadian French. *The Journal of the Acoustical Society of America, 148*(6), EL494–EL499. https://doi.org/10.1121/10.0002764

Mahendra, M. (2007). *A study of the performance of children with articulation disorder on diadochokinesis rate and repetition tasks*. Retrieved from http://202.141.128.172/xmlui/handle/123456789/1343

McAllister Byun, T., Tiede, M., & Mochida, T. (2018). The use of ultrasound biofeedback to facilitate acquisition of rhotic sounds. *Journal of Speech, Language, and Hearing Research, 61*(3), 422–437. https://doi.org/10.1044/2017_JSLHR-S-17-0044

Mech, E. (2002). Assessment of speech rate in children using standard articulation tests. *International Journal of Language & Communication Disorders*, *37*(3), 277-289.

Mefferd, A. S., & Green, J. R. (2010). Articulatory-to-acoustic relations in response to speaking rate and loudness manipulations. *Journal of Speech, Language, and Hearing Research*, *53*(5), 1206-1219.

Modolo, D. J., Berretin-Felix, G., Genaro, K. F., & Brasolotto, A. G. (2011). Oral and vocal fold diadochokinesis in children. *Folia Phoniatrica et Logopaedica*, *63*(1), 1-8.

Nakashima, T., Uemura, T., & Matsumoto, H. (2013). Temporal analysis of articulatory movements in children with cerebral palsy. *Folia Phoniatrica et Logopaedica, 65*(2), 71-77.

Nippold, M. A., Mansfield, T. C., & Billow, J. L. (2007). Peer conflict explanations in children, adolescents, and adults: Examining the development of complex syntax.

Nip, I. S., & Green, J. R. (2013s). Increases in cognitive and linguistic processing primarily account for increases in speaking rate with age. *Child development*, *84*(4), 1324-1337.

Özbek, Y. (2021). Temporal and spectral speech characteristics in preschool-aged children: A comparison of typically developing children and children with speech sound disorders. *Clinical Linguistics & Phonetics*, *35*(9), 812-827. https://doi.org/10.1080/02699206.2021.1921334

Parnell, M. M., & Amerman, J. D. (1978). Oral diadochokinetic rate in 20- to 49-year-old adults. *American Journal of Speech-Language Pathology, 17*(2), 139-146.

Pierce, J. E., Cotton, S., & Perry, A. (2013). Alternating and sequential motion rates in older adults. *International journal of language & communication disorders*, *48*(3), 257-264.

Redle, E. E., Andrianopoulos, M. V., & Kuo, H. Y. (2022). Developmental changes in the oral diadochokinetic rates of Cantonese-speaking children. *International Journal of Speech-Language Pathology*, *24*(5), 524-533. https://doi.org/10.1080/17549507.2021.2014897

Rigoulot, S., & Pell, M. D. (2012). Seeing emotion in your voice: Facial expressions influence the processing of vocal affective bursts. *Cognitive, Affective, & Behavioral Neuroscience, 12*(2), 386-392.

Ryan, W. J., & Burk, K. W. (1974). Perceptual and acoustic correlates of aging in the speech of males. *Journal of Communication Disorders, 7*(2), 181–192. https://doi.org/10.1016/0021-9924(74)90030-5

Scherer, K. R., Banse, R., & Wallbott, H. G. (2001). Emotion inferences from vocal expression correlate across languages and cultures. *Journal of Cross-Cultural Psychology, 32*(1), 76-92.

Sereno, J. A., Baum, S. R., Marean, G. C., & Lieberman, P. (1987). Acoustic analyses and perceptual data on anticipatory labial coarticulation in adults and children. *The Journal of the Acoustical Society of America*, *81*(2), 512-519.

Shin, M. J., Kim, J. O., Lee, S. B., & Lee, S. Y. (2008). A preliminary study of developing Korean Oro-motor Mechanism Screening Examination (KOMSE) in normal adults. *Speech Sciences, 15*(4), 171-188.

Sihvonen, P., Lehtinen, H., & Ahonen, E. (2007). Normative data for laryngeal diadochokinesis in Finnish adults. *Logopedics Phoniatrics Vocology, 32*(2), 93–97. https://doi.org/10.1080/14015430601158200

Simms, A., & Watson, P. J. (2007). An acoustic analysis of the speech of men with neurological diseases and deep brain stimulation. *Journal of Speech, Language, and Hearing Research, 50*(6), 1497–1512. https://doi.org/10.1044/1092-4388(2007/103)

Simpson, A. P. (2001). Dynamic consequences of differences in male and female vocal tract dimensions. *The journal of the Acoustical society of America*, *109*(5), 2153-2164.

Smith, A., & Zelaznik, H. N. (2004). Development of functional synergies for speech motor coordination in childhood and adolescence. *Developmental Psychobiology*, *45*(1), 22-33.

Stackhouse, P. W. J. (2000). Rate, accuracy and consistency: diadochokinetic performance of young, normally developing children. *Clinical linguistics & phonetics*, *14*(4), 267-293. https://doi.org/10.1080/02699200050023985

Stathopoulos, E. T., Huber, J. E., & Sussman, J. E. (2011). Changes in acoustic characteristics of the voice across the life span: Measures from individuals 4–93 years of age. https://doi.org/10.1044/1092-4388(2010/10-0036)

Stathopoulos, E. T., & Sapienza, C. M. (1997). Developmental changes in laryngeal and respiratory function with variations in sound pressure level. *Journal of Speech, Language, and Hearing Research*, *40*(3), 595-614. https://doi.org/10.1044/jslhr.4003.595

Sullivan, K. E., Coppen, G., & Schwanenflugel, P. J. (2021). Cross-linguistic differences in the effect of segmental structure on diadochokinetic rates. *Journal of Speech, Language, and Hearing Research*, *64*(4), 1217-1233.

Tani, K., & Tani, M. (2018). Development of maximum performance tasks in speech motor control. *Journal of Voice*, *32*(5), 552-558. https://doi.org/10.1016/j.jvoice.2017.06.008

Thorson, E. (2013). Speech breathing and speech intelligibility in young children. *Journal of Speech, Language, and Hearing Research, 56*(3), 842-852.

Thyme, J. B., & Carding, P. N. (2010). Development and validation of a novel assessment protocol for speech motor control. *Journal of Speech, Language, and Hearing Research, 53*(4), 1173–1193. https://doi.org/10.1044/1092-4388(2009/08-0023)

Tingley, M. E. (2020). Laryngeal diadochokinesis in healthy adults: A cross-linguistic investigation. *Journal of Voice, 34*(5), 843.e1–843.e8. https://doi.org/10.1016/j.jvoice.2019.01.010

Turnbaugh, K., Daniloff, R., & Hoffman, P. (1983). Stop-vowel coarticulation in the speech of normal 3-and 5-year-olds. *The Journal of the Acoustical Society of America*, *73*(S1), S29-S29.

Turner, G. S., & Weismer, G. (1993). Characteristics of speaking rate in the dysarthria associated with amyotrophic lateral sclerosis. *Journal of Speech and Hearing Research, 36*(6), 1134-1144.

Van Lieshout, P., & Spauwen, P. (1996). Spectral characteristics of consonant-vowel transitions in normal and cleft palate speakers. *Journal of Speech and Hearing Research, 39*(2), 273-284.

Wang, Y., Green, J. R., Nip, I. S. B., Kent, R. D., & Kent, J. F. (2010). Breath group analysis for reading and spontaneous speech in individuals with amyotrophic lateral sclerosis. *Journal of Speech, Language, and Hearing Research, 53*(6), 1542–1552. https://doi.org/10.1044/1092-4388(2010/09-0233)

Yairi, E., & Clifton, N. S. (1972). Disfluencies of normal speech. *Journal of Speech and Hearing Research, 15*(1), 43-54.

Yunusova, Y., Weismer, G., Westbury, J. R., & Lindstrom, M. J. (2008). Articulatory movements during vowels in speakers with dysarthria and healthy controls. *Journal of Speech, Language, and Hearing Research, 51*(3), 485-507. https://doi.org/10.1044/1092-4388(2008/035)

Zraick, R. I., Wendel, K., & Smith-Olinde, L. (2005). The effect of speaking task on perceptual judgment of the severity of dysphonic voice. *Journal of Voice, 19*(4), 574-581. https://doi.org/10.1016/j.jvoice.2004.08.009

Appendix-1

All India Institute of Speech and Hearing, Naimisham Campus, Manasagangothri, Mysore-570006.

INFORMATION AND CONSENT FORM

I am Jilda Sulthana C.P, a second year MSc speech-language pathology student, doing dissertation under the guidance of Dr. Mahesh B V M, Assistant Professor, All India Institute of Speech and Hearing, Mysuru. We are doing research on Normative of Motor Speech Profile in Typical Kannada Speaking Adolescents. For the purpose of the study, we need school going children within the age range of 10-18 years to participate. Students will be asked to produce some consonants such as /pa/, /ta/, ka/, and some vowels such as e-u. It will take around 5-10 minutes to complete the task.

The identity of the participant will not be revealed at any time and will be maintained confidential. This procedure is harmless and only has research benefits. I request you to participate in the present study with the assurance that the assessment sessions will be audio recorded and will be used for educational purposes. Your participation in this research is entirely voluntary. It is your choice whether to participate or not.

INFORMED CONSENT

I have been informed about the aims, objectives and the procedure of the study. I have read the foregoing information, or it has been read to me in the language I understand. I have had the opportunity to ask questions about it, and any questions that I have asked have been answered to my satisfaction. I consent voluntarily to participate in this study.

I, ____, the parent/guardian of ______________________, give my consent for him/her to participate in this investigation/study.

Signature of the parent | **Signature of the investigator**

Name: | **Name of the investigator:**

Contact number: