COMPARISON OF VELOCITY PROFILES AND SPATIO - TEMPORAL INDICES (STI) OF TYPICAL ADULTS FOR SPEECH AND VOLITIONAL NON-SPEECH TASK

Rahul, K.

Register No: 15SLP022

A Dissertation Submitted in Part Fulfilment for the degree of

Master of Science (Speech – Language Pathology)

University of Mysore, Mysuru

ALL INDIA INSTITUTE OF SPEECH AND HEARING

MANASAGANGOTHRI

MYSURU – 570006

MAY – 2017

Certificate

This is to certify that this dissertation entitled **“Comparison of Velocity Profiles and Spatio - Temporal Indices (STI) of Typical Adults for Speech and Volitional Non-Speech Task”** is a bonafide work in part fulfilment for the Degree of Master of Science (Speech – Language Pathology) of the student (Registration No. 15SLP022). 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.

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

Mysuru
May – 2017

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Mysuru
May – 2017

Ms. Yashomathi
Guide
Lecturer in Speech Pathology
Department of Speech – Language Pathology
All India Institute of Speech and Hearing
Manasagangothri, Mysuru - 570006

Declaration

This dissertation entitled **“Comparison of Velocity Profiles and Spatio - Temporal Indices (STI) of Typical Adults for Speech and Volitional Non-Speech Task”** is a result of my own study under the guidance of Ms. Yashomathi, Lecturer in Speech – Pathology, Department of Speech – Language Pathology, All India Institute of Speech and Hearing, Mysuru, and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru
May – 2017 Register No. 15SLP022

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ACKNOWLEDGEMENTS

My sincere thanks to the Director, for giving me this opportunity to carry out this work of research.

This work would never have taken its form, without you **Dr. R. Manjula ma’am**.

For my guide, Ms. Yashomathi, for her constant support.

To Santhosh sir, on timely help with numbers.

To participants, for their active participation

INTRODUCTION

The craniofacial and masticatory musculatures are one of the highly complex muscular systems. They are distinct from other motor systems, especially the limb muscles in both biomechanical and histological properties. The craniofacial and masticatory musculatures comprise of variety of muscle types, that are unique to speech and other oral motor patterns (Kent, 2004). Non-speech behaviors include actions such as communicative and non - communicative facial gestures, biting, chewing and swallowing, which are commonly termed as Non – speech orofacial movements (NSOM) (Kent, 2015; Bunton, 2008). Kent, (2015) opined that these non-speech behaviors are accomplished using many of the same muscles as in speech, but with different patterns of activation (Kent, 2015). The motor control that sub serves the functions of speech and NSOMs has been debated extensively and research findings have revealed that, the motor control underlying the functions of both speech and NSOMs involve the same/partially the same musculatures (Folkins, Moon, Luschei, Robin, Murray & Moll, 1995; Ziegler, 2003; Ballard, Robins & Folkin, 2003). However, there is no substantial evidence that addresses the relationship between speech and NSOM tasks, as there is no explicit, universally accepted set of criteria to distinguish between them. Further, there exists a lack of definitional and methodological consensus among studies that have compared the underlying motor control across these two tasks.

Defining the boundaries between speech and NSOMs has been complex and is not conclusive. Among the studies that have compared speech and NSOMs, the investigators have selected certain tasks, which in their opinion or within the parameter of specific application were used to categorize as speech and NSOMs. Perkell et al., (1997) defined speech and NSOM based on movement characteristics, where speech movements were considered to be directed toward generation of an acoustic signal that can be interpreted linguistically and NSOM were considered as goals that are related to an external visual-spatial or proprioceptive target. Wohlert (1993) studied labial movements of normal adults in three conditions: a) lip pursing as a non - speech task, b) lip rounding as a speech like task, and c) production of a word containing a rounded phoneme. Solomon, Robin and Luschei (1994) studied the lingual movements of individuals with Parkinson's disease, where maximum non – speech repetition rates of tongue, jaw and lip was considered as non – speech and speaking rate was considered as speech task. These studies suggested that speech and NSOMs have been defined operationally based on the purpose of interest by the investigators. Despite the efforts from several researchers to distinguish between the speech and non-speech behaviors, there exists a lack of defined parameters to distinguish and define typical tasks that are equivocal and balanced in speech and NSOM categories.

In contrary to this, few research findings have also suggested that the motor functions sub serving speech and NSOM share the same neurological principles. Ballard, Robin, and Folkins (2003); Ballard, Solomon, Robin, Moon and Folkins (2009) argued that the motor control processes for speech and NSOM lie along a continuum and is integrated into the functioning of general motor system. Grillner (2000) opined that the existence of discrete, separate motor systems for speech and volitional non - speech movements is not possible, as the final output must go through the brainstem and spinal cord. The findings that suggest an integrated functioning of motor control irrespective of speech or volitional non - speech movements had also been reported by Wang and Robin (1997). Contradicting this view, Ziegler (2002, 2003) proposed that speech is a complex process and the functions specialized for the act of speaking are different from those that control non - speech oral motor tasks. Authors like Moore and

Ruark (1996), Weismer and Liss (1991) also have reported that speech and non – speech oral movements do not share a common sensorimotor system. This lack of agreement among researchers regarding motor control of speech and non – speech tasks at the central level form the crux of studies in speech motor control.

A wide variety of techniques ranging from neuroimaging studies and visuomotor tracking (VMT) paradigm (Ballard, Granier & Robin, 2000; Clark & Robin, 1998; Hageman, Robin, Moon, & Folkins, 1994; McClean et al., 1987; Moon et al., 1993; to behavioral paradigms (Robin et al., 2000; Zebrowski, Moon, & Robin, 1997) have been used to investigate the differences between speech and NSOMs. Using functional magnetic resonance imaging (fMRI), Loucks, Poletto, Simoyan, Reynolds and Ludlow (2007) showed an overlap within the cortical center of orofacial region for both speech and NSOMs. In a meta-analysis of 54 neuroimaging studies of non - speech tasks involving respiration, lip movement, tongue movement and swallowing, Takai, Brown and Liotti (2010), reported that there is a somatotophy for speech and non – speech tasks at the motor cortex, indicating a possible existence of different cortical areas being responsible for speech and volitional non - speech movements. Franz, Zelaznik and Smith (1992) studied similarity of timing patterns for speech and NSOMs, and concluded that behaviorally there exists a difference between speech and NSOMs. Thus, these evidences using varying paradigms of investigation have supported both the sides of the continuum.

Need for the study

One of the physiological paradigms used in speech motor control research is kinematic analysis which has received less attention with respect to the question of similarities or differences in terms of underlying motor control for speech versus NSOMs. Shaiman, McNeil and Szuminsky (2001) investigated the differences in articulatory dynamics for volitional non –

speech movements using IOWA intra oral pressure instrument (IOPI) where they measured the pressure differences and the shape of intra oral pressure waveform for speech and volitional non - speech oral movements. The authors concluded that there were no significant differences between the kinematics intra oral pressure waveforms of speech and NSOMs. Sowman, Flavel, McShane, Sakuma, Miles and Nostrodam (2009) measured tongue strength, endurance and stability in individuals with Parkinson's disease across speech and NSOMs using IOWA intra oral pressure instrument (IOPI). The results reported no significant differences across tasks. It may be noted that the studies by Shaiman et al., (2001); Sowman et al., (2009) have either addressed static kinematic measure such as tongue strength, endurance and intra oral pressure or compared the operationally defined speech stimuli with that of non – speech stimuli. None of these studies have addressed the differences in the dynamic feature of articulatory kinematics in speech and NSOMs.

Further, it is known that there are notable gender differences in speech and language performances of males and females. In a meta-analysis of 165 participants, Hyde and Linn (1988) reported superior speech production abilities in girls compared to boys of the same age. Similar findings have been reported for the non – speech oral motor tasks between males and females. Sadagopan and Smith (2008), Smith and Zelaznik (2004), Walsh and Smith (2002) have reported significant gender differences in non - speech oral motor performance, with females performing better than males. However, to the best of the investigator's knowledge, there are no studies that compare the performances of speech and NSOMs as a factor of gender within the individuals.

Smith, Goffman, Zelaznik, Ying and McGillem, (1995) suggested that Spatio temporal index (STI) and velocity profiles are widely used derived measures in kinematics to study and describe patterning and stability of motor system. The STI is defined as the sum of standard deviations of kinematic waveforms from multiple repetitions of an utterance, which are time and amplitude normalized (Smith et al., 1995). Velocity profile of movements across production conditions in which the spatial and temporal dimensions of movements are varied, provide information about the variable motor control that exists between productions (Hogan, 1984; Nelson, 1983). Hence these measures are highly suitable to study the differences between speech and NSOMs, but to the best of the knowledge of the investigator, there are no studies that employ these measures to study the difference in velocity profiles of speech and NSOMs.

Kuehn and Moon (1994) reported the differences in EMG activation of levator veli palatine muscle for speech and NSOMs. In their study, blowing was considered to be a non – speech task whereas production of a nasal continuant /m/ and bilabial plosive /p/ were considered for speech task. It may be noted that the experimental paradigm used by Kuehn and Moon (1994) includes blowing activity as a task in NSOM in which the lip movements are not equivalent to the movement pattern of lips for production of the bilabial plosive /p/. Also, the study did not address gender differences in the performance of the two tasks.

Bunton and Weismer (1994) expressed the need to select NSOMs that are similar to that of the speech task with respect to the movement involved. Amongst the active articulators, lips are one the major active articulators that are accessible for easy placement of sensors to study the articulatory dynamics. This could be the reason why studies (Kuehn & Moon, 1994; Shaiman, McNeil & Szuminsky, 2001; Sowman et al., 2009) have often addressed the movements of bilabial gestures to compare the differences in kinematics across speech and non - speech tasks. Research findings that have investigated the differences between speech and NSOMs (Kuehn & Moon, 1994; Shaiman, McNeil & Szuminsky, 2001; Sowman et al., 2009) lack control with respect to equating the speech and non - speech task and hence this is considered as a factor influencing the conclusions drawn in these studies. In order to address this limitation, the study aimed to analyze and compare the kinematic measures of STI and Velocity profiles in bilabial utterance of /pa/ (defined speech task) and an equivalent NSOM task i.e., bilabial gesture of opening and closing the lips as in /pa/ syllable using Electro Magnetic Mid Sagittal Articulograph (EMMA) AG 501 equipment in typical participants.

Aim of the study

The study aimed to analyze and compare Velocity Profiles and Spatio Temporal Index (STI) of lips in a selected speech task (utterance of bilabial /pa/ syllable) and volitional non - speech orofacial movements (NSOM) task (bilabial gesture of opening and closing the lips as in /pa/ syllable, but without uttering the /pa/ syllable) across gender in typical adults in the age range of 18 to 25 years, using EMMA (AG -501).

Objectives of the study

To compare the Velocity Profiles and Spatio - Temporal Index (STI) of lips across task (speech and NSOM) and gender in the following axis of the EMMA (AG -501):

a) Y – axis (inferior-superior)

b) Z – axis (posterior-anterior)

Hypothesis

There would be no difference in the STI and velocity profiles in both Y and Z axis across speech and NSOM tasks and gender.

Method

Ten typical individuals in the age range of 18 – 25 years were included in the present study. These participants performed a speech task (utterance of bilabial syllable /pa/ in isolation) iterated 20 times per participant and a volitional NSOMs task (bilabial gesture of opening and closing the lips as in /pa/ syllable, but without uttering the /pa/ syllable), iterated 20 times. The kinematic traces of the upper lip and lower lip, for both the tasks were obtained using 5 channels (5 sensors:3 test sensors on upper lip, lower lip and jaw and two reference sensors on the forehead and the mastoid) with a resolution of five degrees of freedom (5 DOF) in 500 mm cube field in the EMMA (AG -501) System. The appropriateness of the position data recorded on the EMMA (AG -501) system was visualized using VisArtico software (Version V.0.9.9 - February 2015) and the data was analyzed using the MATLAB script of the Speech Movement Analysis, Statistics and Histograms (SMASH) tool (version 0.6) developed by Greene, Wang and Wilson (2013).

Limitations

1) The number of participants included in the study is less. There were 5 males and 5 females in the present study.
2) The study addressed speech and volitional NSOMs only in typical individuals.
3) The study addressed only the upper and the lower lip, kinematic movements of the jaw are not considered for the present study.

Implications

1) The present study is the first to consider dynamic kinematic paradigm to look into the possible differences that might exist between speech and volitional NSOMs.

REVIEW OF LITERATURE

The craniofacial and masticatory musculature are one among the most organized and complex muscular motor system in human beings, probably no other motor system in the human body has such a variety of muscle types (Kent, 2004). These craniofacial and the masticatory musculature are biomechanically grouped into structural-functional classes, that includes the following (a) joint-related muscles (the muscles of the jaw, such as the masseter and the digastricus), (b) sphincteric muscles (the orbicularis oris muscle of the lips and the constrictor muscles of the pharynx and velopharynx), (c) a muscular hydrostat (the intrinsic muscles of the tongue).

Functionally, the craniofacial and masticatory musculatures are responsible for two main physiological events that include speech and other non - speech oral movements (NSOMs). Activities that are communicative in nature are categorized to be speech whereas activities of non - communicative behaviors such as facial gestures, biting, chewing, swallowing, licking, and ventilation are termed to be NSOMs (Bunton, 2008; Kent, 2015). These are opined to be two extremely different physiological events but which are brought about by the same group of musculatures.

Studies on the histological properties of these musculature by Gea (1997); Liu, Shlumberger, Wirth, Schmidtbleicher and Steinecker (2003) have demonstrated that these musculatures are adaptive in nature and can be functionally trained to take up various functions through specific training methods. These studies have demonstrated that one function that is brought about by the same group of musculatures such as speech; can further be strengthened or facilitated by training the other function such as NSOMs.

These interesting research findings on the physiological and histological properties of craniofacial and the masticatory musculature have resulted in the use of NSOMs to facilitate the aspects of speech. This philosophy of using NSOMs to facilitate and bring about changes in speech function have been questioned by several researchers (Riecker, Ackermann, Wildgruber, Dogil, & Gross, 2000; Ziegler, 2003) whereas few other researchers (Ballard, Robin, & Folkins, 2003) are in favor of this philosophy. This lack of equivocal opinion on the use of NSOMs to facilitate speech have resulted in a decade long research aimed at looking into the possible differences that might exist between speech and NSOMs.

Issues in defining speech and non – speech oral movements

Perplexity about the definitions of speech and non - speech arises in part because there is no explicit, universally accepted set of criteria for their distinction. The most recent definition of NSOMs was given by Kent (2015), who defined NSOMs as “motor acts performed by various parts of the speech musculature to accomplish specified movement or postural goals that are not sufficient in themselves to have phonetic identity”. Kent (2015), further reported that the major difficultly that the researchers come across while comparing speech and non - speech oral movements is achieving ‘equivalency’ between the two.

To overcome this issue of equivalency between non - speech oral movements and speech tasks, investigators have selected certain tasks, to categorize as speech and NSOMs. The following are the few measures adopted by researchers:

(1) Shaiman et al. (2004; 2006) suggested the following three levels to equate speech and non - speech behaviors. (a) The non - speech task must require the use of a sequence of overlapping gestures. Normal speakers naturally integrate chains of individual oral movements required for sound production into overlapping, coarticulated gestures.

Rather than involving segregated and individualized gestures, non - speech tasks must require the production of movement sequences that demand comparable integration and coarticulation. (b) Non - speech tasks must possess a level of automatic processing and execution. (c) The goal of a non - speech task should be somewhat analogous to the goal of speech.

(2) Lof (2008) cited the following two definitions for NSOMs to attain equivalency. (a) Lof (2008) stated that NSOMs “can be defined as any movements that do not require the production of speech. (b) The second definition cited by Lof is from McCauley, Strand, Lof, Schooling, and Frymark (2009), who defined NSOMs as ‘activities that involve sensory and motor actions of the lips, jaw, tongue, soft palate, larynx, and respiratory muscles that are intended to influence the physiologic underpinnings of the oropharyngeal mechanism.

Even though several authors (Shaiman et al, 2004; 2006; Lof, 2008; Kent, 2015) have attempted to define speech and NSOMs, there still exists a lack of clear boundaries between them. Further, there exists a lack of definitional and methodological consensus among studies that have tried to define these two entities. Added to the definitional complexity between speech and NSOMs, there also exists the debate on underlying motor control of these two entities.

Issues in motor control for speech and NSOMs

It is widely known that the speech is an overlaid function; the systems that are responsible for biological functions such as respiration, airway protection and mastication have been adopted for the purpose of speech production. Like any other motor behavior, speech behaviors can also be further divided into smaller, separate tasks. Tasks can be reduced further into subtasks or goals, such that goals constitute the successful completion of a task of any size (Folkins et. al, 1995) i.e. a particular speech sound production can be broken down into individual non - speech movements. This task defined nature of speech system, where a speech behavior can be broken down into subsequent non – speech movements has resulted in varied views on speech motor control among the researchers. This brings back a century of debate in motor control literature and years of discussion in the field of speech motor control regarding the control of speech and non – speech movements.

Many researchers have examined underlying sensorimotor control systems for speech versus non - speech tasks, with some contending that speech and non - speech do not share a common sensorimotor system (i.e. Moore & Ruark, 1996; Weismer & Liss, 1991; Ziegler, 2003), and with others arguing for shared sensorimotor control (i.e. Ballard, Robin and Folkins, 2003; Wang & Robin, 1997). Underlying sensorimotor control mechanisms and neurological organization can be investigated through the comparison of speech and volitional non - speech oral movements.

Ballard, Robin, and Folkins (2003) agreed to the notion that speech can be broken down into individual motoric movements of the articulators at the periphery but do not agree with the same in case of central representation. They proposed a general motor system that has a same representation for both speech and NSOMs, which are controlled independently with different patterns of activation. This view which proposed that the non – speech tasks share same neurological principles as of speech and the speech motor system where it is integrated into the functioning of general motor system is known as "*The integrative model".*

Contradicting to this, Ziegler (2003) proposed that, speech is special and the control of motor behavior is task specific. This view is known as "*the task-specific model*" of motor control. According to this model, the motor control/functions specialized for the act of speaking are different from those that control non - speech oral motor tasks. This controversial question regarding motor control of speech and non – speech tasks at the central level form the crux of studies in speech motor control, which basically refers to the systems and strategies that control production of speech (Kent, 2000).

A much-debated model of motor control is Zeigler's "task-dependent" model, which segregates motor functioning into vegetative, speech, emotional, and novel volitional motor activities, thus implying separate sensorimotor control for speech and non - speech tasks (Zeigler, 2003). Included in the evidence to support the task-dependent model is the plethora of literature remarking the dissociation between nonverbal oral apraxia and apraxia of speech (i.e. Bizzozero et al., 2000; Kramer, Delis & Nakada, 1985; LaPointe & Wertz, 1974; Maeshima et al., 1997). This literature indicated that nonverbal oral apraxia and apraxia of speech are independent of each other, supporting task-dependent motor control (Zeigler, 2003).

Zeigler (2003) provided clinical evidence to demonstrate that the motor control for speech and NSOMs are different through his experiments on diadokinetic (DDK) rates and speaking rate in dysarthric speakers. The assumption for his study was that, dysarthria represents a disorder of general motor control; if the motor control for speech and NSOMs were brought about by the same 'integrated' motor control; there would be equally poor performance on (DDK) rates and speaking rate in dysarthric speakers. But the results of his study revealed a disparity between diadokinetic rates and speaking rate in dysarthric speakers. However, the speaking rates were much lower than that of the NSOMs rate. This disparity between the rates of speech and NSOMs provides further evidence that the representation of motor control for speech and non – speech is not integrated and occurs more in a task specific manner.

Additionally, it has been suggested that cortical activation sites differ for non - speech and speech movements. Wildgruber et al. (1996) used functional magnetic resonance imaging (fMRI) to compare the underlying cortical activation of vertical tongue movements in speaking and non - speech tasks. They found that the speech task resulted in increased activation of the left motor strip, whereas the non - speech task resulted in bilateral symmetric activation. Riecker, Ackermann, Wildgruber, Dogil, and Grodd (2000) conducted a similar fMRI study in which lateral tongue gestures, which were considered as NSOMs were associated with bilateral cerebellar activation whereas speaking resulted in unilateral cerebellar activation.

Additional research has been documented by Moore, Smith, and Ringel (1988). The study investigated electromyographic (EMG) activity in mandibular muscle tasks and the results revealed differing activation patterns for speech versus non - speech tasks, providing further evidence of task-specificity. The authors found differing coordinative organization of the upper and lower lip for speech versus purposeful non - speech behaviors, such as lip protrusion and sucking.

On the other hand, some researchers contended that the task-dependent model falters in the notion that, the motor control system is organized around the production of tasks rather than functions (Keele & Ivry, 1987). Ballard, Robins, and Folkins (2003) proposed an “integrative” model in which the “speech motor system is integrated into the functioning of a more general motor system”. This model claimed that motor control is neither task dependent nor task-independent, but rather that certain non - speech oral tasks may share properties with speech and others may not. Ballard and colleagues (2003) stated, “We hypothesize that, at complex behavioral levels, there must be overlapping functional components and therefore overlapping and integrative neural pathways or networks”.

One argument supporting an integrative model is the use of volitional non - speech tasks in the diagnosis of motor speech disorders. The use of non - speech tasks in speech assessment is not supported in the task-dependent model, Ballard et al. (2003) highlighted the clinical utility of non - speech tasks, such as sustained phonation tasks and diadokinetic rates, in the differential assessment of dysarthria type. An integrative model of motor control accounts for the use of non - speech tasks in the assessment of speech functioning.

Also, supporting integrative motor control is evidence of transfer of motor skills across anatomic structures. A study conducted by Wang and Robin (1997) examined transfer of learning across finger and jaw movements. The authors found that training of either a finger or jaw movement resulted in better initial performance of the movement when executed by the untrained structure than when the movement had not been previously trained. This evidence of transfer does not support discrete motor programming that is organized by task categories, but rather a motor system that overlaps across tasks.

To investigate the possible differences that might exist between speech and non - speech oral movements, a wide variety of techniques ranging from neuroimaging studies and visuomotor tracking (VMT) paradigm (Ballard, Granier & Robin, 2000; Clark & Robin, 1998; Hageman, Robin, Moon, & Folkins, 1994; McClean et al.,1987; Moon et al., 1993; to behavioral paradigms (Robin et al., 2000; Zebrowski, Moon, & Robin, 1997) have been used. These studies have pointed out several useful dimensions that may be helpful in defining the similarities and dissimilarities between them.

Neuroimaging studies on motor control for speech and NSOMs.

Riecker, Ackermann, Wildgruber, Dogil, and Gross (2000) used fMRI to examine the neural basis of speech motor control for speech and NSOMs. Their experiment included eight healthy subjects with German as native language using two tasks, 1) oral diadochokinetic tasks and 2) sentence utterance task at a controlled tempo. Subjects performed these two different tasks within the MRI scanner and the responses were analyzed for blood oxygen level–dependent (BOLD) signal changes. The BOLD reports suggested that speaking was accompanied by unilateral right-sided activation of the cerebellum, whereas non - speech lateral tongue movements were associated with bilateral cerebellar activation. This differential activation of cerebellar regions indicated that speech and NSOMs may have a different neural basis.

Wildgruber et al. (1996) used functional magnetic resonance imaging (fMRI) to compare cortical activation during speaking to the non - speech task of vertical tongue movements. They found that the speech task resulted in increased activation of the left motor strip, whereas the non - speech task resulted in bilateral symmetric activation. These findings supported the notion of speech and NSOMs may have different neural sites of origin.

Grafton, Woods, Mazziotta and Phelps (1991) performed non - invasively estimated cerebral blood flow (CBF) measure using positron emission tomography (PET) on twelve normal subjects who performed motor tracking of speech and NSOMs. The results suggested a unilateral and focal activation for speech tracking whereas a bilateral diffuse activation for NSOMs tracking.

Horwitz (2003) from the findings of PET data reported lateralization differences in PET activation data for speech production compared to a non - speech motor control task that involved laryngeal and oral articulatory movements associated with sounds (i.e., a non - speech task that employed all of the muscle groups activated in speech but was devoid of meaning).

Using functional magnetic resonance imaging (fMRI), Loucks, Poletto, Simoyan, Reynolds and Ludlow (2007) showed an overlap within the cortical center of orofacial region for both speech and NSOMs. In a meta-analysis of 54 neuroimaging studies of non - speech tasks involving respiration, lip movement, tongue movement and swallowing, Takai, Brown and Liotti (2010), reported that there is a somatotophy for speech and non – speech tasks at the motor cortex.

Event Related Potentials (ERP) studies on motor control for speech and NSOMs.

Wohlert (1993) used EEG to study the readiness potential (RP) that occurred before a speech and a NSOM task. He defined readiness potential to be a premovement slowly increasing negative slope, which occurs 1 second approximately before a specific voluntary movement at the pre Rolandic sites and becomes sharply negative at final milliseconds before movement onset. From the group of 7 female subjects in the age range of 21 to 30, RPs were recorded for both speech, which included a single word production task and NSOM task which included a lip pursing and a lip rounding task. The results reveal that speech task had greater negative amplitudes compared to that of NSOMs indicating an increased readiness of the motor system for speech compared to that of NSOMs.

EMG* studies *on motor control for speech and NSOMs.

Several researchers (Moore, Smith, & Ringel, 1988; Ruark & Moore, 1997; Gentil & Gay, 1984) have used electromyography (EMG) to study the differences in activations of craniofacial muscles during speech and NSOMs. Moore, Smith, and Ringel (1988) quoted that electromyographic (EMG) activity in mandibular muscle tasks pinpoints differing activation patterns for speech versus non - speech tasks, providing further evidence of task-specificity

Ruark and Moore (1997) used EMG recordings to examine upper and lower lip activity in two-year-old children during the production of speech and non - speech tasks. The authors found differing coordinative organization of the upper and lower lip for speech versus purposeful non - speech behaviors, such as lip protrusion and sucking.

Gentil and Gay (1984) studied the activation patterns of mandibular muscle for speech and NSOMs using EMG. The study aimed at determining the neuromuscular specialization for speech and NSOMs in relation to mandibular function, for the purpose activity from following 8 muscles groups: masseter superficial layer, masseter deep layer, medial pterygoid, lateral pterygoid superior head, lateral pterygoid inferior, temporalis anterior, temporalis posterior and anterior belly of digastricus using hooked wire EMG electrodes.

The activity of above mentioned 8 muscles were recorded from three English speaking subjects who performed a speech task that included production of CVC utterance and NSOMs included chewing. Results indicated that the jaw spaces for speech was most restricted compared to that of NSOM and further the movement activation pattern for speech was much simpler and more temporally synchronous pattern. The authors concluded that the speech and NSOMs utilize distinctly different strategies rather than a set of universal neuromotor rules and different patterns of muscle activity can bring about same end results.

Arnold, MacPherson and Smith (2014) assessed autonomic arousal associated with speech and non - speech tasks in school-age children and young adults. The measures of autonomic arousal (electrodermal level, electrodermal response amplitude, blood pulse volume, and heart rate) were recorded prior to, during, and after the performance of speech and non - speech tasks by twenty 7- to 9-year-old children and twenty 18- to 22-year-old adults. The results indicated that across age groups, autonomic arousal (peak electrodermal response amplitude and blood pulse volume) was higher for speech tasks compared to non - speech tasks.

These differences in autonomic activation, where speech is activated more than non – speech indicate that speech is a powerful elicitor of sympathetic arousal, compared to non - speech oral motor tasks. The processes that support speech - including, but not limited to, cognitive - linguistic planning and oral motor execution - likely contribute to this arousal. In contrast, non - speech oral motor tasks do not require the cognitive - linguistic element, which is known to elicit autonomic arousal absent overt speech requirements.

Kinematic profile studies on motor control of speech and NSOMs

Shaiman and Gracco (2002) opined that speech motor control system is organized in a task specific manner and there exists a task specific gating of sensory information. To validate this claim experimentally, they recorded EMG and kinematic profiles of upper lip and lower lip from 6 typical females in the age range of 18 to 30. The experimental task was to produce a speech and speech like NSOMs. The results revealed phasic differences between speech and NSOMs task, indicating not only a difference in neural organization but also in movement properties and sensori motor gating of information. The study concludes that speech and NSOMs are not only different at organizational level but also at a modulatory level of sensory information.

Shaiman, McNeil, and Szuminsky (2001) used a static kinematic paradigm to look into the possible differences that might exist between speech and NSOMs of tongue. They used IOWA Intra oral performance instrument (IOPI) to determine if the intraoral pressure waveform characteristics of a volitional, learned complex non - speech task were similar to those of a speech task. The participants of the study were instructed to produce learned complex non - speech task and a moment equivalent volitional speech task which were as follows:

The non - speech task comprised of 15 sequential gestures, beginning with the lips at rest. These included: 1) relax; 2) lips apart; 3) lips together; 4) lips apart; 5) lips together; 6) lips apart; 7) tongue up, lips spread; 8) relax; 9) tongue up, lips rounded; 10) relax; 11) lips together; 12) lips apart; 13) lips together; 14) lips apart; 15) relax and an equivalent speech task that paralleled the non - speech task, with the exact same gestures as in the non - speech stimuli produced as speech sounds. The sequence of 15 gestures, beginning with the lips at rest, was: 1) relax; 2) /a/; 3) /p/; 4) /a/; 5) /p/; 6) /a/; 7) /t/; 8) /i/; 9) /t/; 10) /u/; 11) /p/; 12) /a/; 13) /p/; 14) /a/; 15) relax (that is, /a pa patitu pa pa/). The results did not reveal any statistical differences between speech and NSOMs supporting to the notion of a common generalized motor program for speech and non - speech behaviors.

Sowman et al., (2009) measured tongue strength, endurance and stability in individuals with Parkinson’s disease across speech and NSOMs using IOWA intra oral pressure instrument (IOPI). The results reported no significant differences across tasks. One of the physiological paradigms used in speech motor control research is kinematic analysis. This paradigm has received less attention with respect to the question of similarities or differences that would exist in the motor control for speech versus NSOMs.

It may be noted that the studies by Shaiman et al., (2001); Sowman et al., (2009) have either addressed static kinematic measure such as tongue strength, endurance and intra oral pressure or compared the operationally defined speech stimuli with that of non - speech stimuli. Within the knowledge of the investigator, none of the studies have addressed the differences in the dynamic feature of articulatory kinematics in speech and NSOMs. Spatio temporal index

(STI) and velocity profiles are widely used derived measures in kinematics to study and describe patterning and stability of motor system (Smith, Goffman, Zelaznik, Ying, & McGillem, 1995).

The STI is defined as the sum of standard deviations of kinematic waveforms from multiple repetitions of an utterance, which are time and amplitude normalized (Smith et al., 1995). Velocity profile of movements across production conditions in which the spatial and temporal dimensions of movements are varied, provide information about the variable motor control that exists between productions (Hogan, 1984; Nelson, 1983). Hence these measures are highly suitable to study the differences between speech and NSOMs, but to the best of the knowledge of the investigator, there are no studies that employ these measures to study the difference in velocity profiles of speech and NSOMs.

METHOD

Study design: Standard group comparison

Participants

Ten typical adult participants (5 males and 5 females) in the age range of 18 – 25 years were selected for the study. Written informed consent was obtained from each participant prior to the testing. Only those participants without any history of hearing, vision, intellectual and neurological problems or any communication disorders were considered for the study. Further the participants were selected based on the following inclusionary criteria:

1. Participants had no systemic illness at the time of testing.
2. Participants had no artificial dentures, sores in the mouth or lips or any other oral pathology at the time of testing.

Task and instructions

The study included two tasks as follows:

1. ***Speech task:***

   This required the participants to utter a bilabial syllable /pa/ at isolation which was iterated 20 times per participant. For the speech task, each of the participants were instructed to utter the target stimuli 'as clearly as possible' after every visual prime display. They were also instructed to repeat each stimulus of /pa/ to a minimum of 20 iterations. More practice trials were provided if the participant was unable to follow the instruction.

2. ***A volitional non - speech task:***

   This required the participants to utter a movement equivalent matched to the speech task in terms of bilabial movement pattern of the lips. The participants were made to perform a non – speech bilabial gesture of opening and closing the lips as in /pa/ syllable, but without uttering the /pa/ syllable. For the volitional non-speech task, each of the participants were instructed to utter the moment equivalent of the target stimuli ‘as clearly as possible’ and without ‘exaggerating the movement’ after every visual prime display. They were also instructed to repeat each of the non – speech gesture to a minimum of 20 iterations. More practice trials were provided if the participant was unable to follow the instruction.

Procedure*:*

1. The electromagnetic mid - sagittal articulograph (EMMA) AG501 (Carstens Medizinelec- tronik, Lenglern, Germany) facilitates a three-dimensional view (3D) of articulatory movements. It is a motion capture system which is specifically designed to track the real-time articulatory oro-facial movements as a non – line off sight motion capture system. The instrument is specifically designed to track speech related articulatory orofacial movements and articulatory kinematic plots in three dimensions of space: The *x*, *y*, and *z* axes correspond to the medial-lateral, inferior-superior, and posterior-anterior directions, respectively (Ji, Johnson & Berry, 2012). The present study utilized the capabilities of an articulograph to capture 3 - dimensional data with respect to spatial and temporal domains of a movement. These movements are dynamic in nature which provides better visualization as well as spatio – temporal representations of speech and NSOMs.

2. VisArtico software (Ouni, Mangeonjean & Steiner, 2012) is an articulatory data visualization and extraction tool that provides visual information of the data in 3D spatial view, midsagittal view, and temporal view. This was used to extract the kinematic data of speech and NSOMs for further analysis.
3. SMASH (Speech Movement Analysis for Speech and Hearing research) (Green et al., 2015) is a customized MATLAB (The Mathworks of Natick, Massachusetts, USA) program tool that can be used to analyze and visualize kinematic data and also to derive velocity profiles and STI measures. For the present study, SMASH was used to analyze the kinematic data and also to obtain velocity profiles and spatio temporal indices (STI) for speech and NSOMs.
4. Both VisArtico and MATLAB shall be installed in a Windows 8 based laptop and data analysis shall be carried out in the same.

Set up and environment: The data recording was carried out in a quiet laboratory setting and data from each participant was collected individually. A noise free environment with adequate lighting and ventilation and minimal distractions in the environment was ensured. The entire procedure of data recording was carried out in following 4 stages:

1. Calculation of habitual rate of speech
2. Calibration of the instrument
3. Instrumental set up
4. Recording of the data

1. *Calculation of habitual rate of speech and non – speech oral movements:* Participants were made to read the standard rainbow passage, and the reading were audio recorded

using a digital audio recorder. The recorded speech sample were analyzed for syllables per second using the formula: *Number of syllables/time taken = number of syllables per sec.* This rate was used as a norm to instruct the participants to move the lips as required for the NSOM task also, that is, opening and closing the lips as in /pa / utterance without producing the sound (defined in this study as being equivalent to the speech task of saying /pa/ sound.

2. *Calibration of AG 501:* The instrument along with the 5 test sensors (2 reference and 3 test sensors) were calibrated as specified by the prescribed procedure of the manufacturers *(Carste*ns Medizinelec- tronik, Lenglern, Germany) before collecting data from each participant.
3. *Set up and placement of sensors to extract kinematic data:* Once the sensors (test sensors and the reference sensors) were calibrated, each participant was tested individually by making him/her to sit comfortably within the electromagnetic cubicle of the AG 501. The calibrated sensors were placed on the participants as follows:
    - *i.* The two reference sensors were placed on the nasal bridge and mastoid respectively and the three test sensors were placed on the mid border of upper lip, lower lip and mid position of lower jaw (below and in line with the sensor in the lower lip) respectively and these were secured firmly in the point of interest using an epi glue adhesive and biotape.
    - *ii.* *Presentation of the Stimuli and instruction to the participants:* Before the commencement of the actual recording procedure each participant was provided with practice trials to ensure the correct articulation of the selected stimuli at their respective habitual rate of utterance for speech and non - speech task as determined

a priori (as described in the earlier paragraphs). After ensuring that the participants could utter the stimuli in the correct manner with appropriate rate, they were instructed to look at the computer monitor placed in front of them where a visual prime was displayed (set to their respective habitual rate) to facilitate and help the participants monitor the production of speech and non - speech gesture. In order to rule out order effect, the order of production of the tasks of speech and non - speech across the participants were randomized across participants and tasks.

4. *Recording of the data:* Before the actual recording the investigator created an individual file for each of the participant within the AG 501 control unit, where each of the recorded files were saved. Once an individual file was created and the control window had been set to ‘real time display’ the participant received the start command from the investigator. Upon which the participant started producing the stimuli as per the task and matched their iterated productions with the visual prime that was displayed. Upon successful completion of the recording, the data was extracted in both Y axis (superior-inferior) and Z axis (anterior-posterior). The extracted data of each participant was stored in the device as designated files.

Analysis

Analysis of the extracted data were carried out in following steps:

Step 1: Identification of stable motor behaviors.

The first five and the last 5 iterations from the 20 iterated utterances were excluded from the data to avoid initial and terminal lags in the motor gestures. The middle 10 iterations were considered as stable motor gestures for both speech and NSOMs.

Step 2: Extraction of data

Once the stable motor gestures were identified, the corresponding data was extracted from the articulograph (AG - 501) using *VisArtico software* (Ouni, Mangeonjean & Steiner, 2012). By specifying the sensor orientations, the corresponding data was extracted in terms of time (s), displacement of y and z axes (mm) and their corresponding velocity data (cm/s). The extracted data was fed into microsoft excel sheets.

Step 3: Analysis of velocity profiles and STI

a) The extracted data from VisArtico was transferred and fed into 'SMASH' (Green et al, 2015) to analyze and visualize kinematic data and also to derive velocity profiles and STI measures.

Step 4: Extraction of STI and velocity profiles

Both STI and the velocity profiles were extracted using the default calculation method within the SMASH applications.

RESULTS

The study was proposed to analyze and compare Velocity Profiles and Spatio Temporal Index (STI) of lips in a selected speech task (utterance of bilabial /pa/ syllable) and volitional non - speech oral movements (NSOM) task (bilabial gesture of opening and closing the lips as in /pa/ syllable, but without uttering the /pa/ syllable) across gender in typical adults in the age range of 18 to 25 years, using EMMA (AG -501). With respect to the specific objectives of the study following statistical measures were employed:

1. The first objective of the study was to compare Velocity Profiles and Spatio Temporal Index (STI) of lips across task (speech and NSOM).

   Shapiro Wilk's test of normality was administered for task data irrespective of gender, that is, when both male and female groups were considered as a whole. The test results revealed that the task data irrespective of gender followed standard normal distribution ($p>0.05$); therefore, parametric paired t - test statistics was run for task wise comparison irrespective of gender.

2. The second objective of the study was to look into the effect of gender on task, that is, to compare the Velocity Profiles and Spatio Temporal Index (STI) of lips across and within males and females

   For the above - mentioned objective, the gender specific data was subjected to Shapiro Wilk's test of normality. The results of the test revealed that the gender specific data did not follow standard normal distribution. Thus, gender specific data was subjected to non – parametric Wilcoxon sign ranked test for comparison of task within the gender. Further, to look into the effect of gender on speech and NSOMs, a non - parametric Mann Whitney u test was administered.

Descriptive statistics was used to obtain mean, median and standard deviation (SD) of STI across tasks and gender. The means were subjected to statistical verifications using paired t – test and medians were statistically verified using Mann Whitney u test and Wilcoxon sign ranked test. The results are presented under following sections:

I. Comparison across tasks (speech and NSOMs) irrespective of gender:

The first objective of the study was to compare across speech and NSOMs. For this purpose, both males and females were considered as a single group and the respective results are presented under the following headings.

A. Comparison of velocity profiles across tasks in the y – axis (superior - inferior dimension).
B. Comparison of spatio temporal indices across tasks in the y – axis (superior - inferior dimension)
C. Comparison of velocity profiles across tasks in the z – axis (anterior – posterior dimension)
D. Comparison of spatio temporal indices across tasks in the z – axis (anterior – posterior dimension)

II. Gender wise comparison of task:

The second objective of the present study was to look into the effect of gender on speech and NSOMs. The gender wise results are presented under the following headings

1. Across gender comparison of task

A. Comparison of velocity profiles of speech across males and females in the y – axis (superior - inferior dimension).

B. Comparison of spatio temporal indices of speech across males and females in the y – axis (superior - inferior dimension).
C. Comparison of velocity profiles of speech across males and females in the z – axis (superior - inferior dimension).
D. Comparison of spatio temporal indices of speech across males and females in the z – axis (superior - inferior dimension).
E. Comparison of velocity profiles of NSOMs across males and females in the y – axis (superior - inferior dimension).
F. Comparison of spatio temporal indices of NSOMs across males and females in the y – axis (superior - inferior dimension).
G. Comparison of velocity profiles of NSOMs across males and females in the z – axis (superior - inferior dimension).
H. Comparison of spatio temporal indices of NSOMs across males and females in the z – axis (superior - inferior dimension).

2. Within gender comparison of task

A. Comparison of velocity profiles of speech and NSOMs within males in the y – axis (superior - inferior dimension).
B. Comparison of spatio temporal indices of speech and NSOMs within males in the y – axis (superior - inferior dimension) for NSOM task.
C. Comparison of velocity profiles of speech and NSOMs within males in the z – axis (superior - inferior dimension).
D. Comparison of spatio temporal indices of speech and NSOMs within males in the z – axis (superior - inferior dimension) for NSOM task

E. Comparison of velocity profiles of speech and NSOMs within females in the y – axis (superior - inferior dimension).

F. Comparison of spatio temporal indices of speech and NSOMs within females in the y – axis (superior - inferior dimension) for NSOM task.

G. Comparison of velocity profiles of speech and NSOMs within females in the z – axis (superior - inferior dimension).

H. Comparison of spatio temporal indices of speech and NSOMs within females in the z – axis (superior - inferior dimension) for NSOM task.

I. Comparison across tasks (speech and NSOMs) irrespective of gender

A. Comparison of velocity profiles across tasks in the y – axis (superior - inferior dimension).

The kinematic wave morphology of upper lip for speech and volitional NSOMs tasks were distinct as revealed in figure 1 that compared speech (left panel) and NSOMs (right panel) tasks. The velocity profiles of speech task were more synchronous and clear compared to that of NSOMs. Spatially, the velocity profiles for NSOMs were higher in amplitude and lower on the temporal domain compared to that of speech. This indicated that the time taken by participants to perform a NSOMs task was lesser than that of speech that, which was reflected as NSOMs velocity profile being longer on the temporal domain.

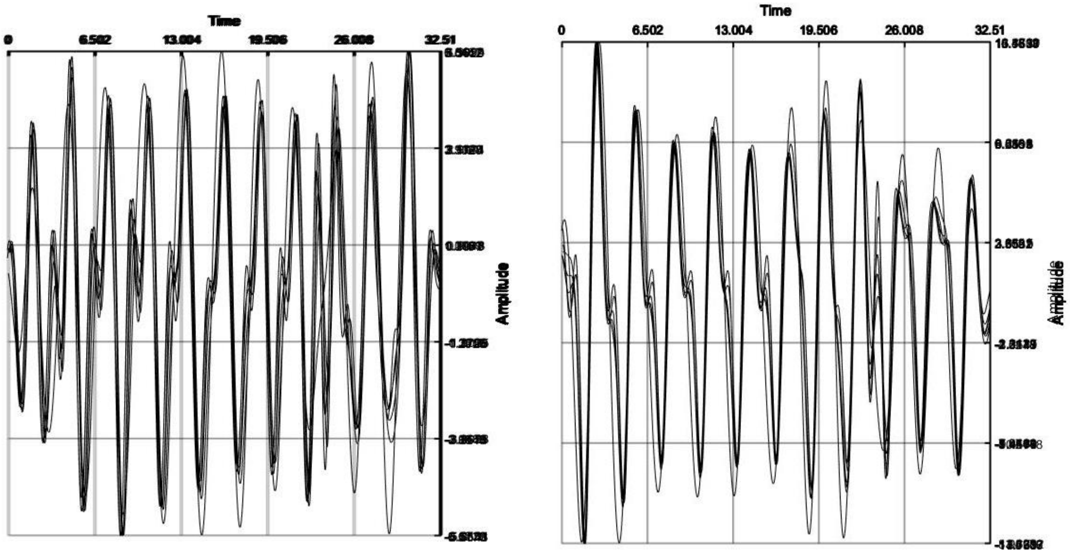

Figure 1: amplitude and time normalized velocity profiles of upper lip in y – axis for the participants in speech task (left panel) and non - speech task (right panel).

There was a distinct kinematic wave morphology, even for the lower lip for speech and NSOM tasks. This has been reflected in figure 2 that compares velocity profile wave morphology of speech (left panel) and NSOMs (right panel). The velocity profiles of speech task were more synchronous and clear compared to that of NSOMs. Spatially, the velocity profiles for NSOMs were higher in amplitude and lower on the temporal domain compared to that of speech. This indicated that the time taken by participants to perform a NSOMs task was lesser than that of speech that, which was reflected as NSOMs velocity profile being longer on the temporal domain.

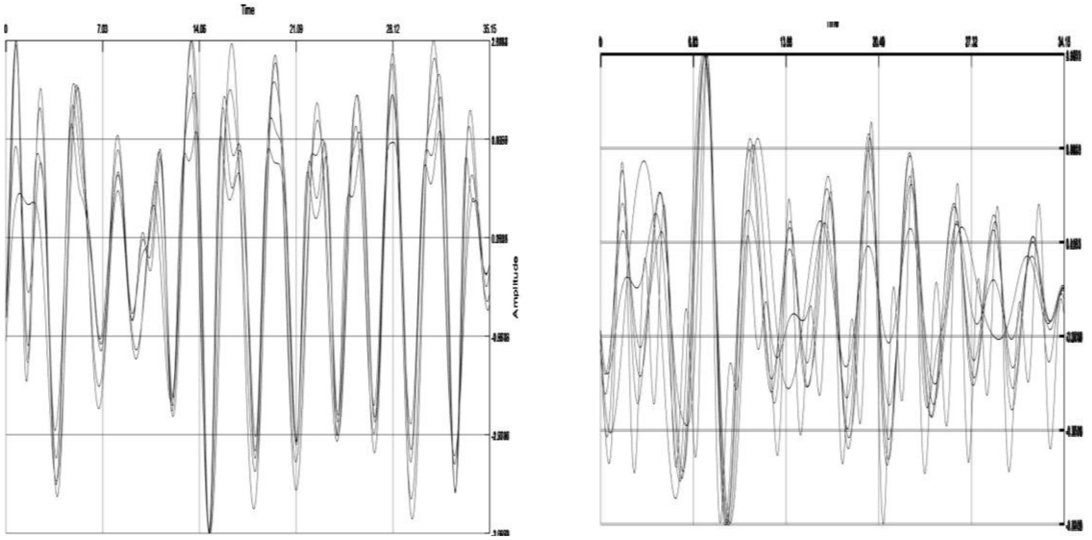

Figure 2: amplitude and time normalized velocity profiles of lower lip in y – axis for the participants in speech task (left panel) and non - speech task (right panel).

When the performance of the upper and the lower lip were compared, as in figure 1 and 2, it revealed distinct kinematic wave morphology for both the tasks. For the speech task, upper lip and the lower lip were in a relatively less out of phase condition when compared to that of NSOMs. The performance of upper and the lower lip for NSOMs were more robust and high in amplitude compared to that of speech task. This increased amplitude for NSOMs indicated that the spatial movements of upper lip and the lower lip were higher compared to that of the speech task. The variations of amplitude were high for the NSOMs task compared to that of the speech task. This was reflected through crests and the troughs of the velocity profile of NSOMs being more irregular in amplitude compared to that of speech task. Whereas the velocity profiles of speech task appeared more regular and synchronous.

B. Comparison of spatio temporal indices across tasks in the y – axis (superior - inferior dimension):

Table 1:

Mean, median and standard deviation (SD) of upper lip and lower lip for speech and NSOMs task in the y – axis

	Speech		NSOMs	
	Lower lip	Upper lip	Lower lip	Upper lip
Mean STI	3.19	4.16	6.21	5.80
median	3.06	4.01	6.18	5.68
SD	0.97	1.29	1.83	1.72

Note: STI = Spatio-Temporal Index, NSOMs = Non speech oral movements.

In general, the STI of NSOMs of the participants (n =10) were higher compared to that of speech task; as observed in table 1. This suggested that the variability of speech motor control of the participants is higher for non – speech tasks as reflected through higher values of STI. The comparison of STIs of upper lip and lower lip revealed that upper lip showed higher STI values compared to that of lower lip in the both the tasks.

When the tasks were considered irrespective of gender, the data followed a normal distribution. Hence these findings were statistically verified using a parametric paired sample test. There was a statistically significant difference between speech and NSOMs of the upper lip (t = |3.98|; p = 0.003) and also for the lower lip (t = |2.5|; p = 0.034) in the y – axis.

C. Comparison of velocity profiles across tasks in the z – axis (anterior – posterior dimension)

The overall wave morphology of z – axis is higher in amplitude compared to that of y – axis across both the articulators of upper lip and lower lip as well as tasks of speech and NSOMs. As observed from figure 3, the kinematic wave morphology of upper lip is distinct for the speech task (right panel) and the volitional NSOMs task (left panel). The velocity profiles of speech task of the participants (n =10) were more synchronous and clear compared to that of NSOMs. Spatially, the velocity profiles for NSOMs were higher in amplitude and lower on the temporal domain compared to that of speech. This indicated that the time taken by participants to perform a NSOMs task was lesser than that of speech that, which was reflected as NSOMs velocity profile being longer on the temporal domain.

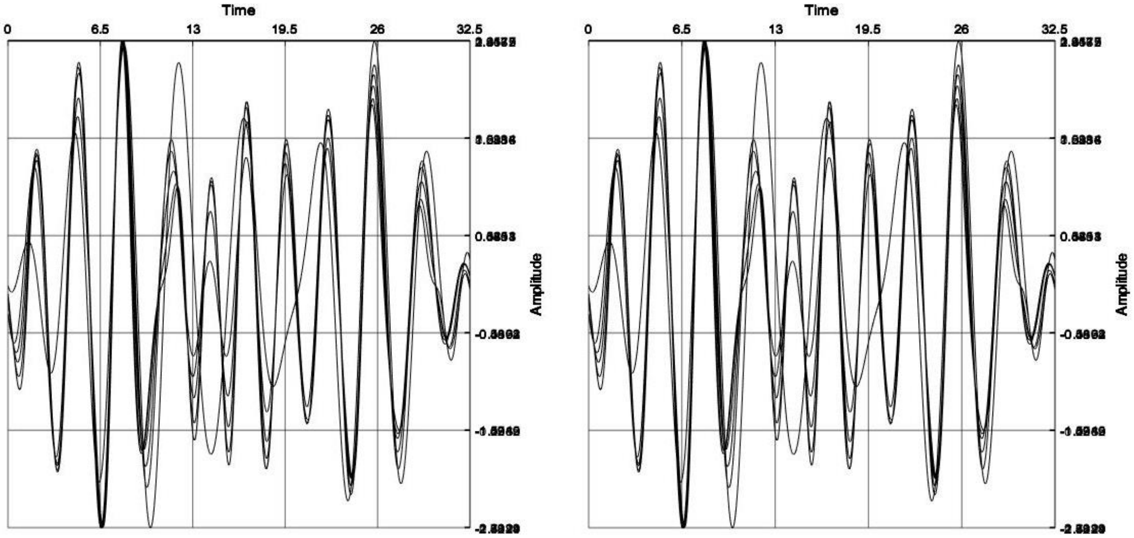

Figure 3: amplitude and time normalized velocity profiles of upper lip in z – axis for the participants in speech task (left panel) and non - speech task (right panel).

There was a distinct kinematic wave morphology, even for the lower lip for the two tasks. This has been reflected in figure 4, that compares velocity profile wave morphology of speech (left panel) and non – speech (right panel). The velocity profiles of speech task of the participants (n =10) were more synchronous and clear compared to that of NSOMs. Spatially, the velocity profiles for NSOMs were higher in amplitude compared to that of speech and on the temporal domain they were lower. This indicated that the time taken by participants to perform a NSOMs task was lesser than that of speech that, which was reflected as NSOMs velocity profile being longer on the temporal domain.

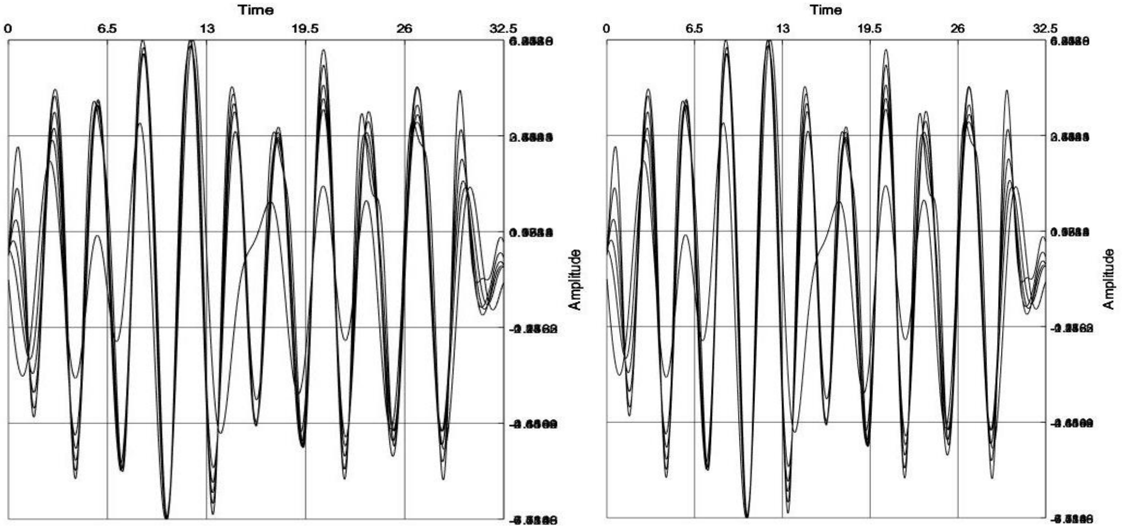

Figure 4: amplitude and time normalized velocity profiles of lower lip in z – axis for the participants in speech task (left panel) and non - speech task (right panel).

When the performance of the upper and the lower lip were compared, as in figure 3 and 4, it revealed distinct kinematic wave morphology for both the tasks. For the speech task, upper lip and the lower lip were in a relatively less out of phase condition when compared to that of NSOMs. The performance of upper and the lower lip for NSOMs were more robust and high in amplitude compared to that of speech task. This increased amplitude for NSOMs indicates that the spatial movements of upper lip and the lower lip are high compared to that of the speech task. The variations of amplitude are high for the NSOMs task compared to that of the speech task. This is reflected through crests and the troughs of the velocity profile of NSOMs being more irregular compared to that of speech task.

D. Comparison of spatio temporal indices across tasks in the z – axis (superior - inferior dimension):

Table 2*:*

Mean, median and standard deviation (SD) of upper lip and lower lip for speech and NSOMs task in the z – axis

	Speech		NSOMs	
	Lower lip	Upper lip	Lower lip	Upper lip
Mean STI	3.20	2.71	5.67	6.25
Median	2.95	2.76	5.04	6.28
SD	1.3	0.98	1.78	1.03

Note: STI = Spatio-Temporal Index, NSOMs = Non - speech oral movements

The STI of NSOMs were higher compared to that of speech task, as revealed from table 2. This suggested that the variability of speech motor control was higher for non – speech tasks as reflected through higher values of STI. The comparison of STIs of upper lip and lower lip revealed that upper lip showed higher STI values compared to that of lower lip in the both the tasks.

When the tasks were considered irrespective of gender, the data followed a normal distribution. Hence these findings were statistically verified using a parametric paired sample test. There was a statistically significant difference between speech and

NSOMs of the upper lip (t = |4.29|; p = 0.002) and also for the lower lip (t = |8.58|; p = 0.000) in the z – axis.

II. Gender wise comparison of task

1. Across gender comparison of task

A. Comparison of velocity profiles of speech task across males and females in the y – axis (superior - inferior dimension).

The kinematic wave morphology of upper lip across gender were distinct, when comparison was made between male (left panel) (n = 5) and female (right panel) (n = 5) as revealed from figure 5. The velocity profiles of females were more synchronous and clear compared to that of males. Spatially, the velocity profiles for males were higher in amplitude compared to that of females and on the temporal domain they were lower. This indicated that the time taken by the female participants to perform speech task was longer than that of males, which was reflected as the velocity profile of females being longer on the temporal domain.

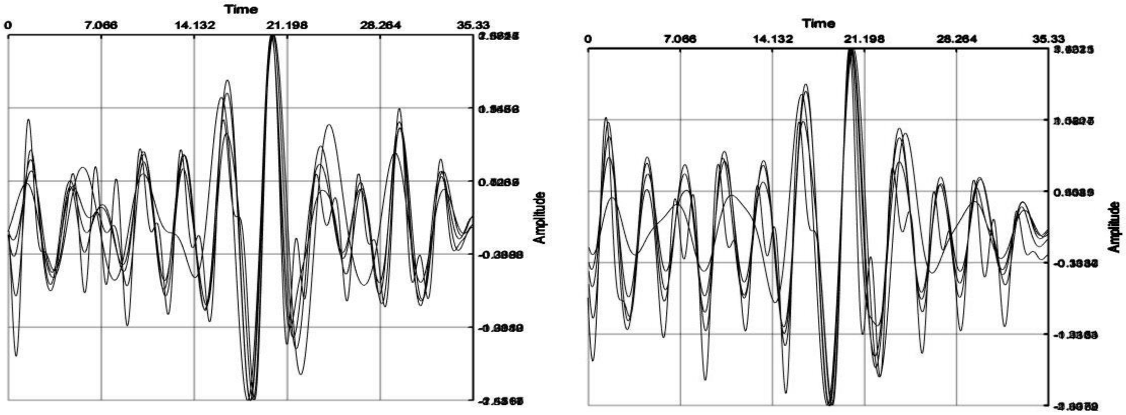

Figure 5: amplitude and time normalized velocity profiles of upper lip in y – axis for five male participants (left panel) and five female participants (right panel) for speech task.

When the kinematic wave morphology of lower lip was compared across gender, they were found to be distinct. These are reflected from the comparison of velocity waveforms of male (left panel) and female (right panel) as in figure 6. The velocity profiles of females were more synchronous and clear compared to that of males for speech task. Spatially, the velocity profiles for males were higher in amplitude and lower on the temporal domain on speech task when compared to that of females. This indicated that the time taken by female participants to perform a speech task was longer than that of males, which was reflected as velocity profile of females being longer on the temporal domain compared to that of males.

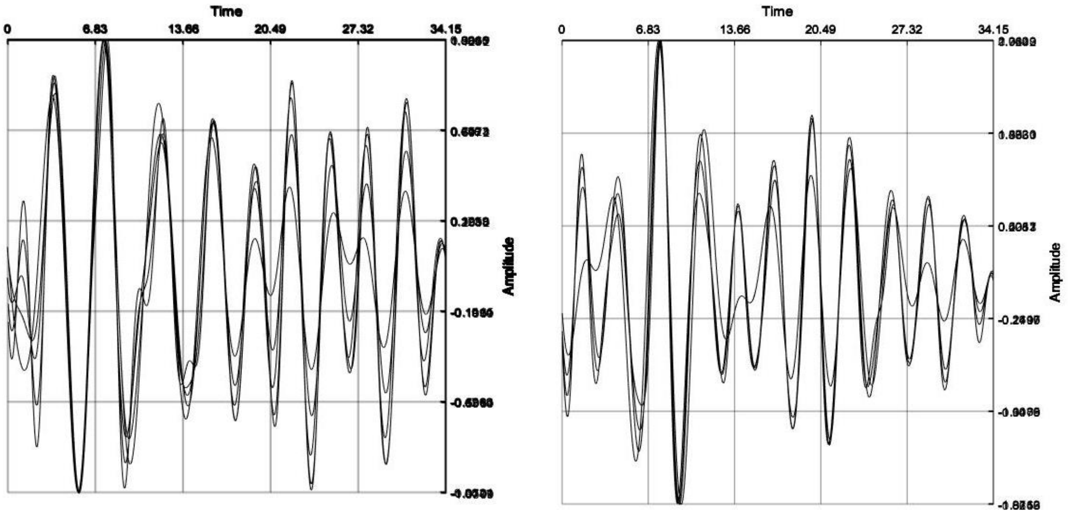

Figure 6: amplitude and time normalized velocity profiles of lower lip in y – axis for five male participants (left panel) and five female participants (right panel) for speech task.

When the performance of upper and the lower lip for speech task was compared across gender as in figure 5 and 6, it revealed distinct kinematic wave morphology for both the cognate articulators. For the speech task, upper lip and the lower lip were in a relatively less out of phase condition in females when compared to that of males.

The performance of upper and the lower lip for were more robust and high in amplitude among males than females. This increased amplitude among males indicated that the spatial movements of upper lip and the lower lip were high compared to that of the speech task. The variations of amplitude were high for males for both the task compared to that of females. This was reflected through crests and the troughs of the velocity profile of males being more irregular in amplitude compared to that of females. Whereas the velocity profiles of females appear more regular and synchronous.

B. Comparison of spatio temporal indices for speech task across males and females in the y – axis (superior - inferior dimension).

Table 3:

Mean, median and standard deviation (SD) of upper lip and lower lip for the speech task across gender in the y – axis.

	Males		Females	
	Lower lip	Upper lip	Lower lip	Upper lip
Mean STI	3.76	4.67	2.62	3.64
Median	3.55	5.44	3	3.76
SD	0.97	1.51	0.6	0.9

Note: STI = Spatio-Temporal Index, NSOMs = Non speech oral movements

The STI of males (n = 5) were higher compared to that of female (n = 5) for speech task, as observed from table 3. This suggests that the variability of speech motor control was higher in males for the speech task as reflected through higher values of STI. This trend of males showing a higher STI than that of females were also evident across articulators, where the STI of males were higher for both the lower lip and the upper lip compared to that of females for the speech task.

When gender wise comparison of tasks was carried out, the data did not follow a standard normal distribution. Hence these findings were statistically verified using a non – parametric Mann – Whitney u test. There was a no statistically significant difference between males and females for the upper lip ($Z = |1.98|$; $p > 0.05$) and also for the lower lip ($Z = |0.94|$; $p > 0.05$) in the y – axis for speech task.

C. Comparison of velocity profiles of speech across males and females in the z – axis (superior - inferior dimension).

The kinematic wave morphology of upper lip across gender were distinct, when comparison was made between male (left panel) (n = 5) and female (right panel) (n = 5) as revealed from figure 7. The velocity profiles of females were more synchronous and clear compared to that of males. Spatially, the velocity profiles for males were higher in amplitude compared to that of females and on the temporal domain they were lower. This indicated that the time taken by the female participants to perform speech task was longer than that of males, which was reflected as the velocity profile of females being longer on the temporal domain.

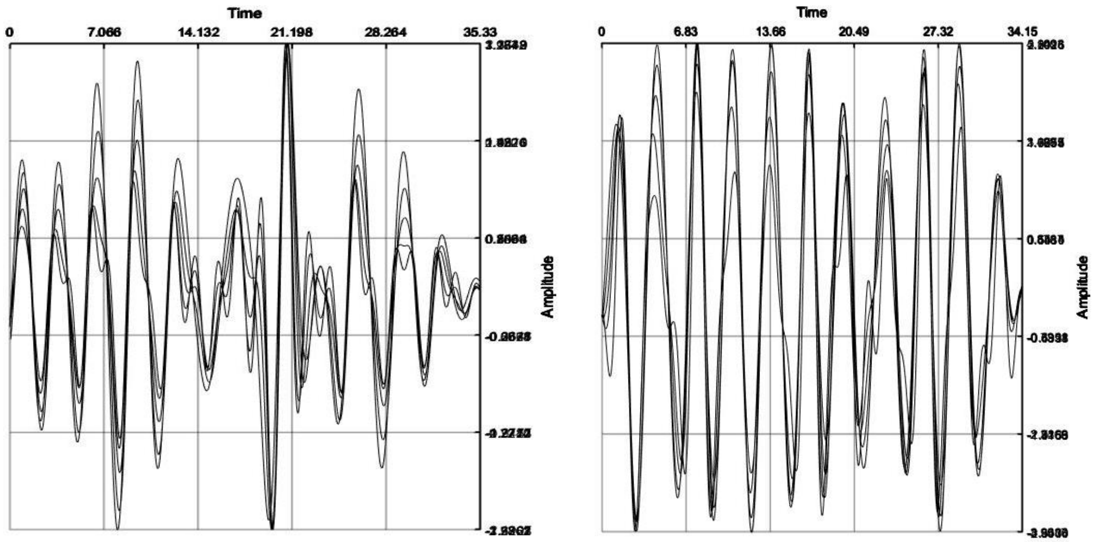

Figure 7: amplitude and time normalized velocity profiles of upper lip in z – axis for five male participants (left panel) and five female participants (right panel) for speech task.

When the kinematic wave morphology of lower lip was compared across gender, they were found to be distinct. These are reflected from the comparison of velocity waveforms of male (left panel) and female (right panel) as in figure 8. The velocity profiles of females were more synchronous and clear compared to that of males. Spatially, the velocity profiles for males were higher in amplitude compared to that of females and on the temporal domain they were lower. This indicated that the time taken by female participants to perform a speech task was longer than that of males, which was reflected as velocity profile of females being longer on the temporal domain compared to that of males.

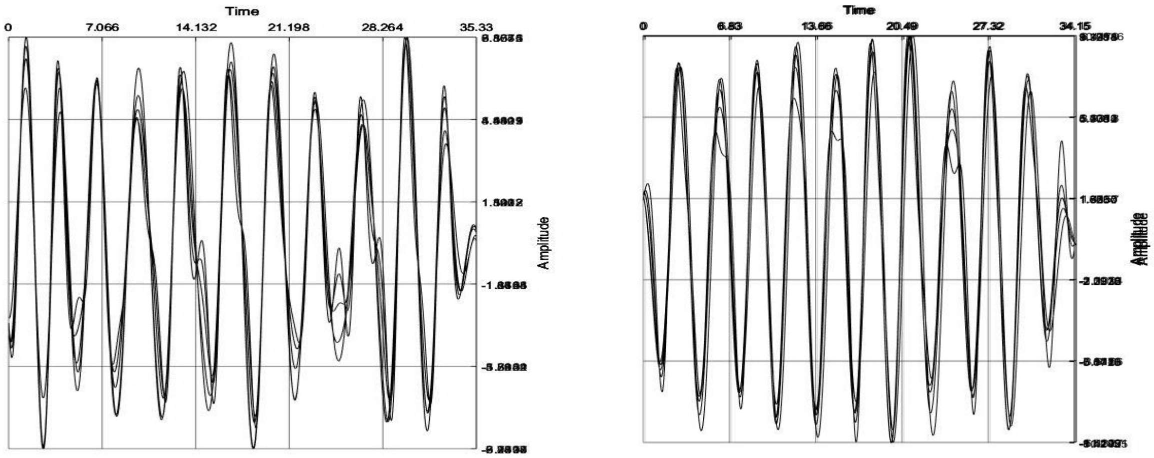

Figure 8: amplitude and time normalized velocity profiles of lower lip in z – axis for male participants (left panel) and female participants (right panel) for speech task.

When the performance of upper and the lower lip for speech task was compared across gender as in figure 7 and 8, it revealed distinct kinematic wave morphology for both the cognate articulators. For the speech task, upper lip and the lower lip were in a relatively less out of phase condition in females when compared to that of males. The performance of upper and the lower lip for were more robust and high in amplitude among males than females. This increased amplitude among males indicated that the spatial movements of upper lip and the lower lip were high compared to that of the speech task. The variations of amplitude were high for males for both the tasks compared to that of females. This was reflected through crests and the troughs of the velocity profile of males being more irregular in amplitude compared to that of females. Whereas the velocity profiles of females appear more regular and synchronous.

D. **Comparison of spatio temporal indices for speech task across males and females in the z – axis (superior - inferior dimension).**

Table 4:

Mean, median and standard deviation (SD) of upper lip and lower lip for the speech task across gender in the z – axis.

	Males		Females	
	Lower lip	Upper lip	Lower lip	Upper lip
Mean STI	2.18	3.01	4.21	2.41
Median	2.11	3.43	4.3	2.66
SD	0.48	1.08	1	0.88

Note: STI = Spatio-Temporal Index, NSOMs = Non speech oral movements

The STI of males (n = 5) were higher compared to that of female (n = 5) for speech task, as observed from table 4. This suggested that the variability of speech motor control was higher in males for the speech task as reflected through higher values of STI. This trend of males showing a higher STI than that of females were also evident across articulators, where the STI of males were higher for both the lower lip and the upper lip compared to that of females for the speech task.

When gender wise comparison of tasks was carried out, the data did not follow a standard normal distribution. Hence these findings were statistically verified using a non – parametric Mann – Whitney u test. There was a no statistically significant difference between males and females for the upper lip ($Z = |2.61|$; $p > 0.05$) and also for the lower lip ($Z = |0.94|$; $p > 0.05$) in the z – axis for speech task.

E. Comparison of velocity profiles of NSOM task across males and females in the y – axis (anterior – posterior dimension).

The kinematic wave morphology of upper lip was compared for NSOM task across gender and they were found to be distinct. These are reflected from the comparison of velocity waveforms of male (left panel) (n = 5) and female (right panel) (n = 5) as in figure 10. The velocity profiles of upper lip for females were more synchronous and clear when compared to that of males. Spatially, the velocity profiles of upper lip for males were higher in amplitude and lower on the temporal domain when compared to that of females on NSOMs task. This indicated that the time taken by the female participants to perform NSOMs task was longer than that of males, which was reflected as the velocity profile of females being longer on the temporal domain

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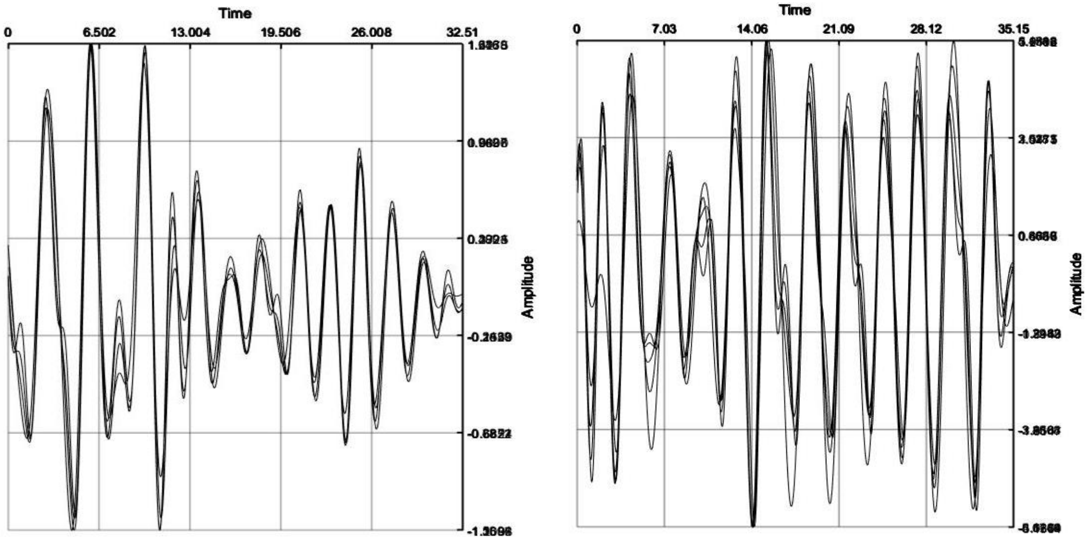

Figure 9: amplitude and time normalized velocity profiles of upper lip in y – axis for male participants (left panel) and female participants (right panel) for non - speech task.

When the kinematic wave morphology of lower lip was compared across gender, they were found to be distinct on NSOMs task. These are reflected from the comparison of velocity waveforms of male (left panel) (n = 5) and female (right panel) (n = 5) as in figure 10. The velocity profiles of lower lip for females were more synchronous and clear compared to that of males on NSOMs task. Spatially, the velocity profiles of lower lip for males were higher in amplitude and lower on the temporal domain when compared to that of females on NSOMs task. This indicated that the time taken by female participants to perform NSOMs was longer than that of males, which was reflected as velocity profile of females being longer on the temporal domain compared to that of males.

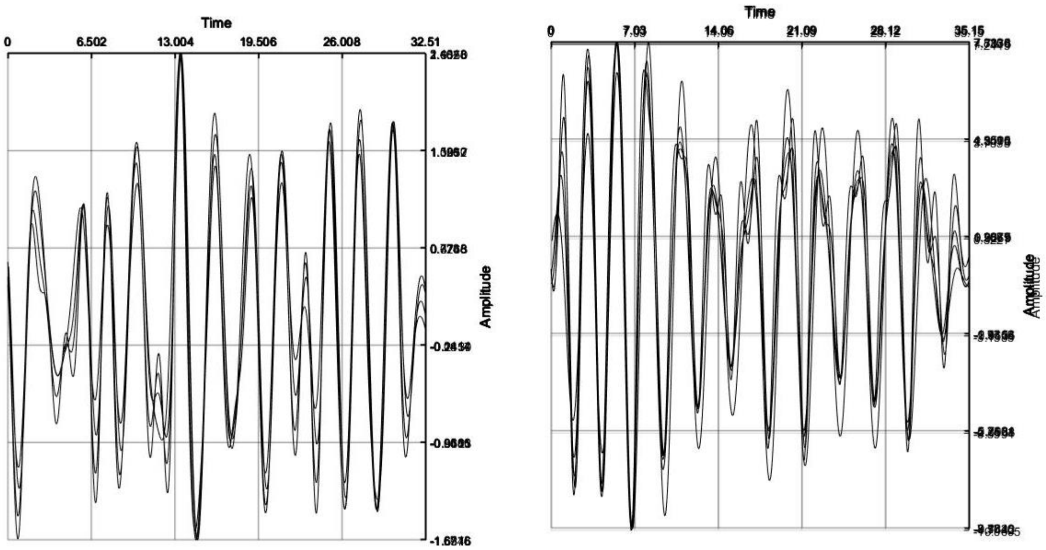

Figure 10: amplitude and time normalized velocity profiles of lower lip in y – axis for male participants (left panel) and female participants (right panel) for non - speech task.

When the performance of upper and the lower lip for speech task was compared across gender as in figure 9 and 10. It revealed distinct kinematic wave morphology for both the cognate articulators. For the NSOMs task, upper lip and the lower lip were in a relatively less out of phase condition in females when compared to that of males. The performance of upper and the lower lip for were more robust and high in amplitude among males than females. This increased amplitude among males indicated that the spatial movements of upper lip and the lower lip were high compared to that of the NSOMs task. The variations of amplitude were high for males for both the tasks compared to that of females. This was reflected through crests and the troughs of the velocity profile of males being more irregular in amplitude compared to that of females. Whereas the velocity profiles of females appear more regular and synchronous.

F. Comparison of spatio temporal indices for NSOM task across males and females in the y – axis (anterior – posterior dimension).

Table 5:

Mean, median and standard deviation (SD) of upper lip and lower lip for the NSOMs task across gender in the y – axis.

	Males		Females	
	Lower lip	Upper lip	Lower lip	Upper lip
Mean STI	5.64	4.82	6.79	6.78
Median	5.7	5.09	6.95	6.46
SD	1.9	1.38	1.72	1.53

Note: STI = Spatio-Temporal Index, NSOMs = Non speech oral movements

The STI values of males (n = 5) were higher compared to that of female (n = 5) for NSOMs task, as observed from table 5. This suggested that the variability of speech motor control was higher in males for the NSOMs task as reflected through higher values of STI. This trend of males showing a higher STI than that of females were also evident across articulators, where the STI of males were higher for both the lower lip and the upper lip compared to that of females for the NSOMs task in the y - axis.

When gender wise comparison of tasks was carried out, the data did not follow a standard normal distribution. Hence these findings were statistically verified using a non – parametric Mann – Whitney u test. There was a no statistically significant difference between males and females for the upper lip ($Z = |0.34|$; $p > 0.05$) and also for the lower lip ($Z = |0.11|$; $p > 0.05$) in the y – axis for NSOMs task.

G. Comparison of velocity profiles for NSOM task across males and females in the z – axis (anterior – posterior dimension).

The kinematic wave morphology of upper lip across gender were distinct, when comparison was made between male (left panel) and female (right panel) as revealed from figure 11. The velocity profiles of females were more synchronous and clear compared to that of males. Spatially, the velocity profiles for males were higher in amplitude compared to that of females and on the temporal domain they were lower. This indicated that the time taken by the female participants to perform NSOMs task was longer than that of males, which was reflected as the velocity profile of females being longer on the temporal domain.

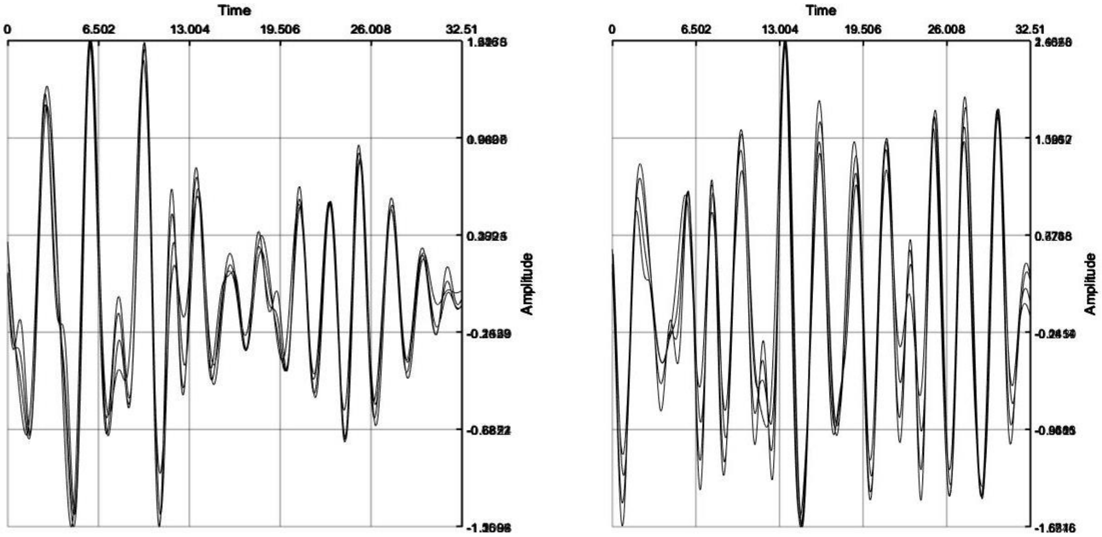

Figure 11: amplitude and time normalized velocity profiles of upper lip in z – axis for five male participants (left panel) and five female participants (right panel) for non - speech task.

When the kinematic wave morphology of lower lip was compared across gender, they were found to be distinct. These are reflected from the comparison of velocity waveforms of male (left panel) and female (right panel) as in figure 12. The velocity profiles of females were more synchronous and clear compared to that of males. Spatially, the velocity profiles for males were higher in amplitude compared to that of females and on the temporal domain they were lower. This indicated that the time taken by female participants to perform a NSOMs was longer than that of males, which was reflected as velocity profile of females being longer on the temporal domain compared to that of males.

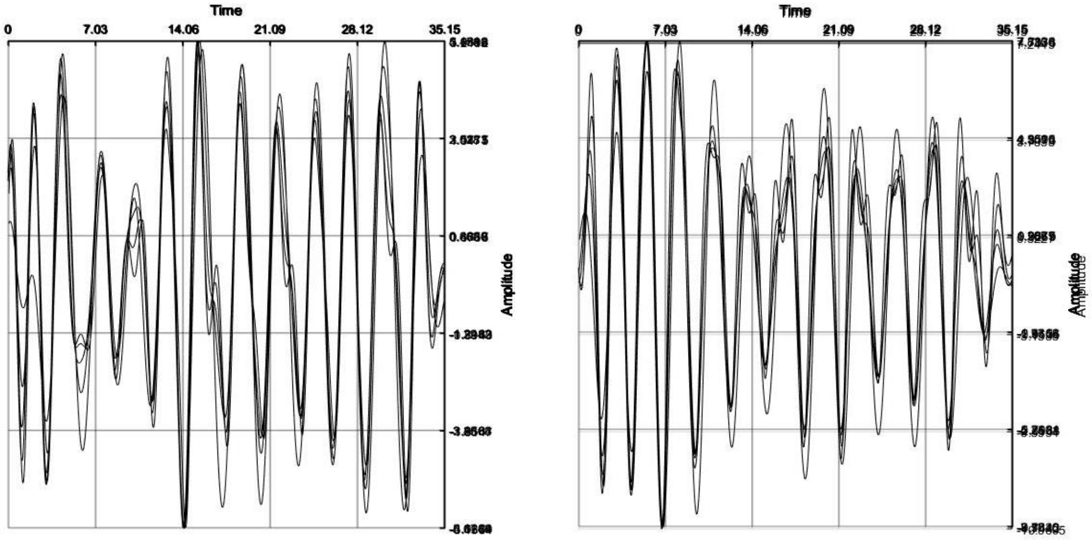

Figure 12: amplitude and time normalized velocity profiles of lower lip in z – axis for male participants (left panel) and female participants (right panel) for non - speech task

When the performance of upper and the lower lip for speech task was compared across gender as in figure 11 and 12. It revealed distinct kinematic wave morphology for both the cognate articulators. For the NSOMs task, upper lip and the lower lip were in a relatively less out of phase condition in females when compared to that of males. The performance of upper and the lower lip for were more robust and high in amplitude among males than females. This increased amplitude among males indicates that the spatial movements of upper lip and the lower lip are high compared to that of the NSOMs task. The variations of amplitude were high for males for both the tasks compared to that of females. This was reflected through crests and the troughs of the velocity profile of males being more irregular in amplitude compared to that of females. Whereas the velocity profiles of females appear more regular and synchronous.

H. Comparison of spatio temporal indices for NSOM task across males and females in the z – axis (anterior – posterior dimension).

Table 6:

Mean, median and standard deviation (SD) of upper lip and lower lip for the NSOMs task across gender in the z – axis.

	Males		Females	
	Lower lip	Upper lip	Lower lip	Upper lip
Mean STI	4.74	6.01	6.60	6.48
Median	4	6.25	6.1	6.20
SD	1.3	0.91	1.8	1.03

Note: STI = Spatio-Temporal Index, NSOMs = Non speech oral movements

The STI of males (n = 5) were higher compared to that of female (n = 5) for NSOMs task, as observed from table 6. This suggested that the variability of speech motor control was higher in males for the NSOMs task as reflected through higher values of STI. This trend of males showing a higher STI than that of females were also evident across articulators, where the STI of males were higher for both the lower lip and the upper lip compared to that of females for the NSOMs task in the z - axis.

When gender wise comparison of tasks was carried out, the data did not follow a standard normal distribution. Hence these findings were statistically verified using a non – parametric Mann – Whitney u test. There was a no statistically significant difference between males and females for the upper lip ($Z = |2.61|$; $p > 0.05$) and also for the lower lip ($Z = |0.73|$; $p > 0.05$) in the z – axis for NSOMs task.

2. Within gender comparison of tasks

A. Comparison of velocity profiles of speech and NSOMs within males in the y – axis (superior - inferior dimension).

The kinematic wave morphology of upper lip for speech and volitional NSOMs tasks were distinct as revealed in figure 13, that compares speech (left panel) and non – speech (right panel) tasks. The velocity profiles of speech task were more synchronous and clear compared to that of NSOMs. Spatially, the velocity profiles for NSOMs were higher in amplitude compared to that of speech and on the temporal domain they were lower. This indicated that the time taken by the male participants to perform a NSOMs task was lesser than that of speech that, which was reflected as NSOMs velocity profile being longer on the temporal domain within males. Align the figures below in a row.

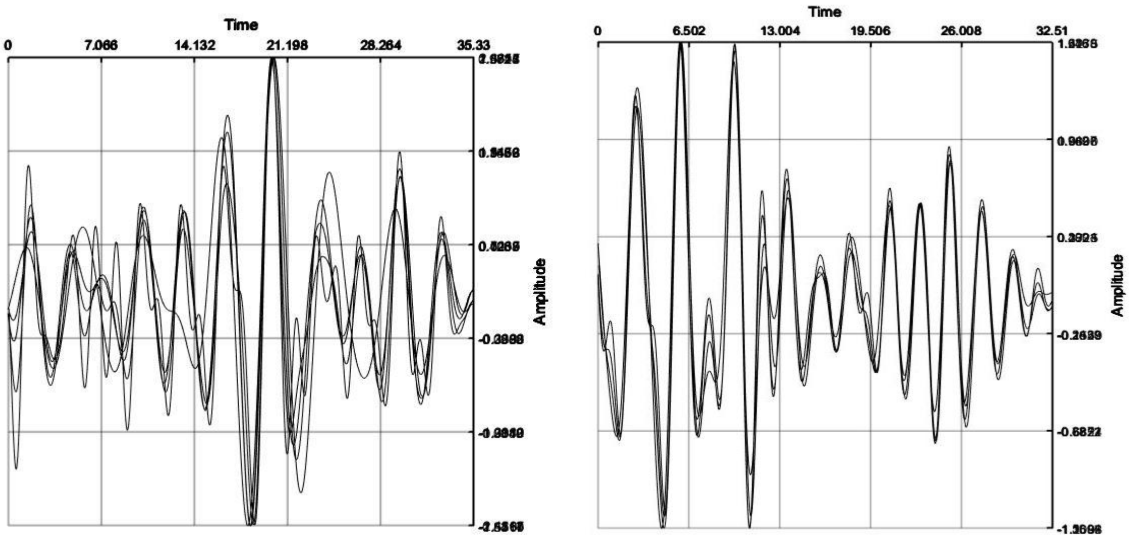

Figure 13: amplitude and time normalized velocity profiles of upper lip in y – axis for speech (left panel) and NSOMs (right panel).

There was a distinct kinematic wave morphology, even for the lower lip for the two tasks. This has been reflected in figure 14, that compares velocity profile wave morphology of speech (left panel) and non – speech (right panel). The velocity profiles of speech task were more synchronous and clear compared to that of NSOMs. Spatially, the velocity profiles for NSOMs were higher in amplitude compared to that of speech and on the temporal domain they were lower. This indicated that the time taken by participants to perform a NSOMs task was lesser than that of speech that, which was reflected as NSOMs velocity profile being longer on the temporal domain. Align the figures below in a row.

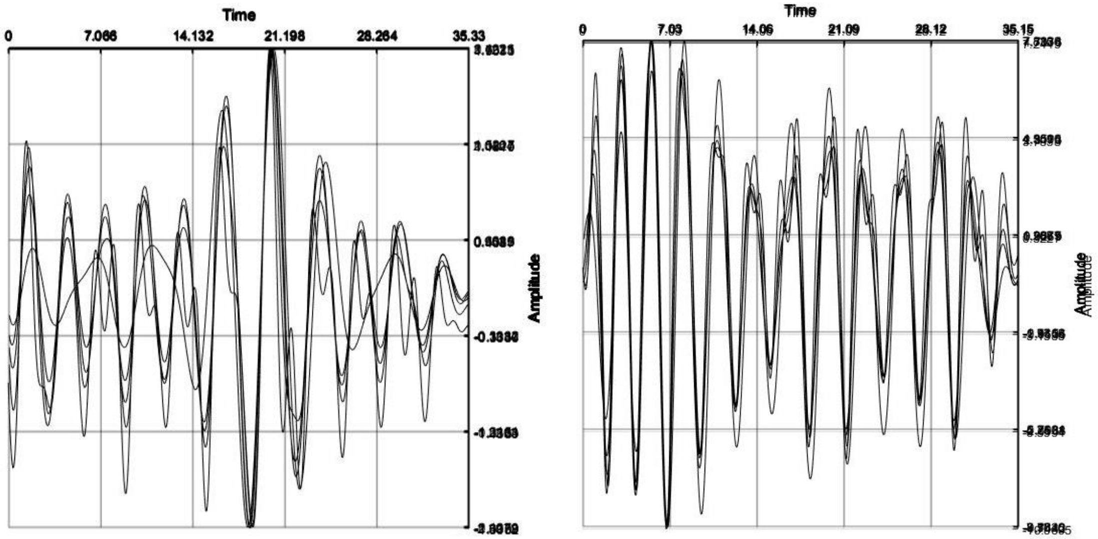

Figure 14: amplitude and time normalized velocity profiles of lower lip in y – axis for speech (left panel) and NSOMs (right panel) for five male participants.

When the performance of the upper and the lower lip were compared, as in figure 13 and 14, it revealed distinct kinematic wave morphology for both the tasks. For the speech task, upper lip and the lower lip were in a relatively less out of phase condition when compared to that of NSOMs. The performance of upper and the lower lip for NSOMs were more robust and high in amplitude compared to that of speech task. The variations of amplitude were high for the NSOMs task compared to that of the speech task. This was reflected through crests and the troughs of the velocity profile of NSOMs being more irregular in amplitude compared to that of speech task. Whereas the velocity profiles of speech task appear more regular and synchronous.

B. Comparison of spatio temporal indices of speech and NSOMs within males in the y – axis (superior - inferior dimension).

Table 7:

Mean, median and standard deviation (SD) of upper lip and lower lip for speech and NSOMs task for males in the y – axis.

	Speech		NSOMs	
	Lower lip	Upper lip	Lower lip	Upper lip
Mean STI	4.67	3.76	4.82	5.64
median	5.44	3.55	5.09	5.76
SD	1.5	0.97	1.38	1.95

Note: STI = Spatio-Temporal Index, NSOMs = Non speech oral movements.

The STIs of NSOMs are higher compared to that of speech task, as revealed from the observation of table 7. This suggested that the variability of speech motor control was higher for non – speech tasks as reflected through higher values of STI. The comparison of STIs of upper lip and lower lip revealed that upper lip showed higher STI values compared to that of lower lip in the both the tasks.

When the tasks were within gender for males, the data did not follow a standard normal distribution. Hence these findings were statistically verified using a non - parametric Wilcoxon sign ranked test. There was no statistically significant difference between speech and NSOMs of the upper lip (Z = |1.48|; p >0.05) and also for the lower lip (Z = |0.4|; p >0.05) in the y – axis within males.

C. Comparison of velocity profiles of speech and NSOMs within males in the z – axis (superior - inferior dimension).

The kinematic wave morphology of upper lip for speech and volitional NSOMs tasks were distinct as revealed in figure 15, that compares speech (left panel) and non – speech (right panel) tasks. The velocity profiles of speech task were more synchronous and clear compared to that of NSOMs. Spatially, the velocity profiles for NSOMs were higher in amplitude compared to that of speech and on the temporal domain they were lower. This indicated that the time taken by the male participants to perform a NSOMs task was lesser than that of speech that, which was reflected as NSOMs velocity profile being longer on the temporal domain within males.

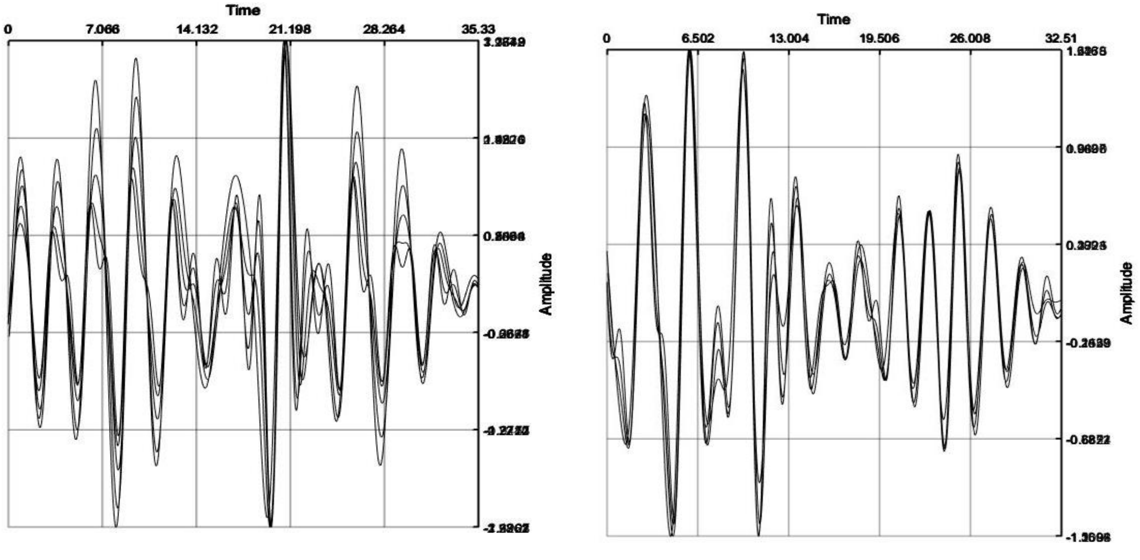

Figure 15: amplitude and time normalized velocity profiles of upper lip in z – axis for speech (left panel) and NSOMs (right panel) for male participants

There was a distinct kinematic wave morphology, even for the lower lip for the two tasks. This has been reflected in figure 16, that compares velocity profile wave morphology of speech (left panel) and non – speech (right panel). The velocity profiles of speech task were more synchronous and clear compared to that of NSOMs. Spatially, the velocity profiles for NSOMs were higher in amplitude compared to that of speech and on the temporal domain they were lower. This indicated that the time taken by participants to perform a NSOMs task was lesser than that of speech that, which was reflected as NSOMs velocity profile being longer on the temporal domain.

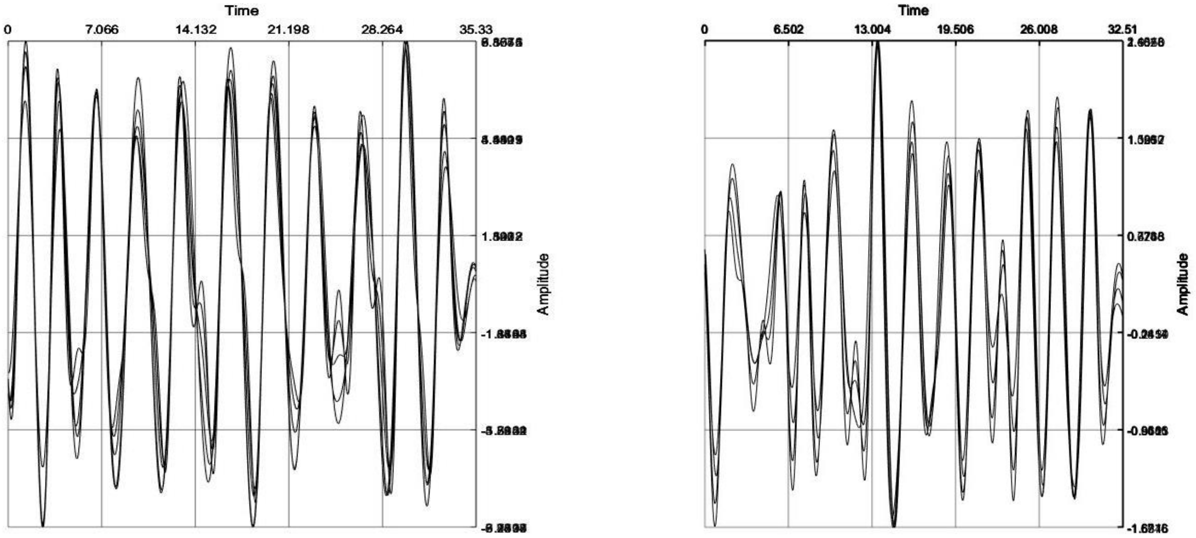

Figure 16: amplitude and time normalized velocity profiles of upper lip in z – axis for speech (left panel) and NSOMs (right panel) for male participants

When the performance of the upper and the lower lip were compared, as in figure 15 and 16, it revealed distinct kinematic wave morphology for both the tasks. For the speech task, upper lip and the lower lip were in a relatively less out of phase condition when compared to that of NSOMs. The performance of upper and the lower lip for NSOMs were more robust and high in amplitude compared to that of speech task. The variations of amplitude were high for the NSOMs task compared to that of the speech task. This was reflected through crests and the troughs of the velocity profile of NSOMs being more irregular in amplitude compared to that of speech task. Whereas the velocity profiles of speech task appear more regular and synchronous.

D. Comparison of spatio temporal indices of speech and NSOMs within males in the z – axis (superior - inferior dimension).

Table 8:

Mean, median and standard deviation (SD) of upper lip and lower lip for speech and NSOMs task for males in the z – axis.

	Speech		NSOMs	
	Lower lip	Upper lip	Lower lip	Upper lip
Mean STI	3.01	2.18	6.01	4.74
median	3.43	2.11	6.25	4
SD	1.08	0.48	0.91	1.3

Note: STI = Spatio-Temporal Index, NSOMs = Non speech oral movements.

The STI of NSOMs are higher compared to that of speech task, as observed from table 8. This suggested that the variability of speech motor control was higher for non – speech tasks as reflected through higher values of STI. The comparison of STIs of upper lip and lower lip revealed that upper lip showed higher STI values compared to that of lower lip in the both the tasks.

When the tasks were within gender for males, the data did not follow a standard normal distribution. Hence these findings were statistically verified using a non - parametric Wilcoxon sign ranked test. There was no statistically significant difference between speech and NSOMs of the upper lip (Z = |2.02|; p >0.05) and also for the lower lip (Z = |2.03|; p >0.05) in the z – axis within males.

E. Comparison of velocity profiles of speech and NSOMs within females in the y – axis (superior - inferior dimension).

The kinematic wave morphology of upper lip for speech and volitional NSOMs tasks were distinct as revealed in figure 17, that compares speech (left panel) and non – speech (right panel) tasks. The velocity profiles of speech task were more synchronous and clear compared to that of NSOMs. Spatially, the velocity profiles for NSOMs were higher in amplitude compared to that of speech and on the temporal domain they were lower. This indicated that the time taken by the female participants to perform a NSOMs task was lesser than that of speech that, which was reflected as NSOMs velocity profile being longer on the temporal domain within females.

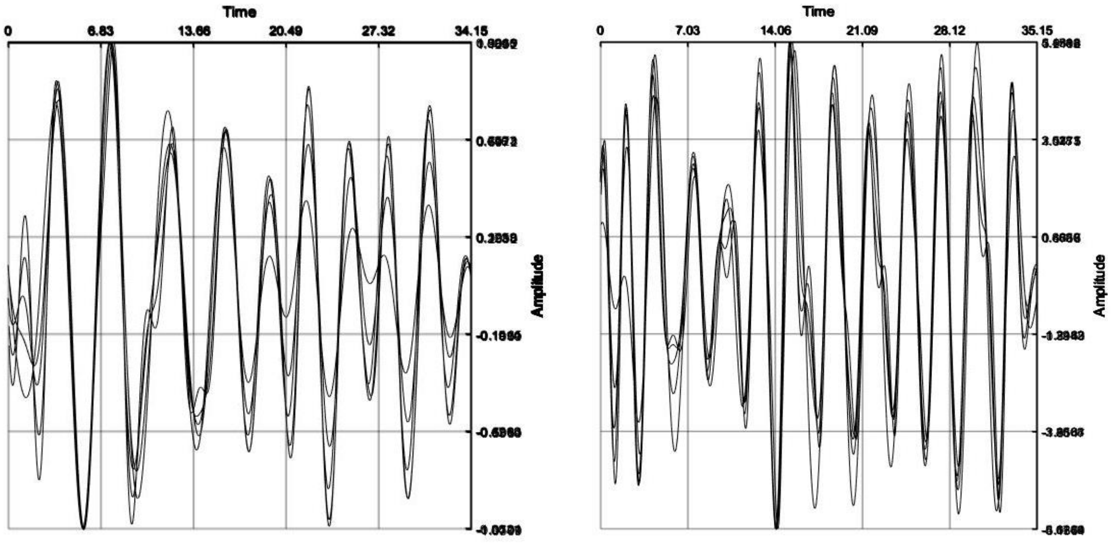

Figure 17: amplitude and time normalized velocity profiles of upper lip in y – axis for speech (left panel) and NSOMs (right panel) for female participants

The kinematic wave morphology of upper lip for speech and volitional NSOMs tasks were distinct as revealed in figure 17, that compares speech (left panel) and non – speech (right panel) tasks. The velocity profiles of speech task were more synchronous and clear compared to that of NSOMs. Spatially, the velocity profiles for NSOMs were higher in amplitude compared to that of speech and on the temporal domain they were lower. This indicated that the time taken by the female participants to perform a NSOMs task was lesser than that of speech that, which was reflected as NSOMs velocity profile being longer on the temporal domain within females.

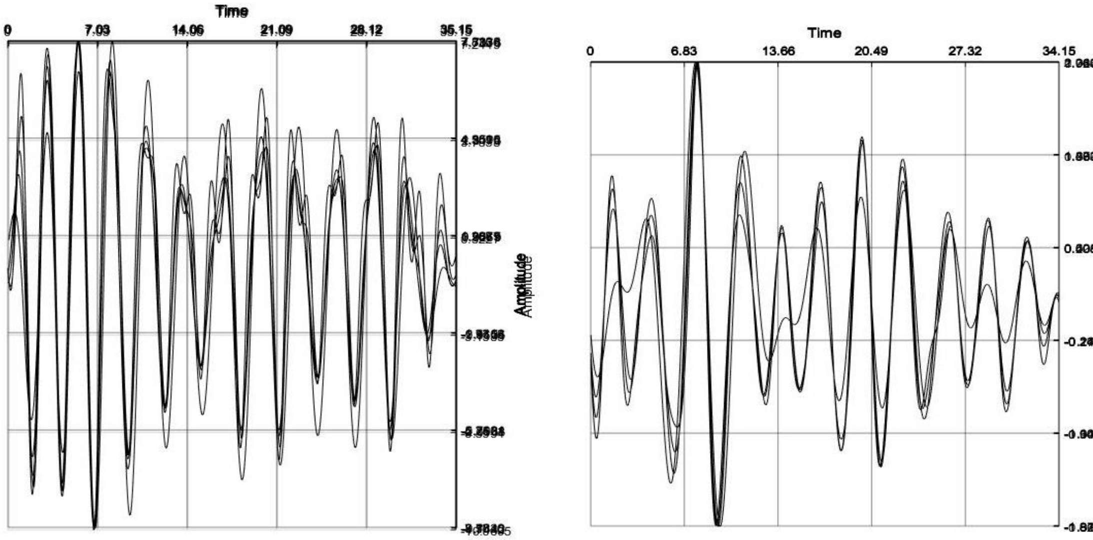

Figure 18: amplitude and time normalized velocity profiles of lower lip in y – axis for speech (left panel) and NSOMs (right panel) for female participants

When the performance of the upper and the lower lip were compared, as in figure 17 and 18, it revealed distinct kinematic wave morphology for both the tasks. For the speech task, upper lip and the lower lip were in a relatively less out of phase condition when compared to that of NSOMs. The performance of upper and the lower lip for NSOMs were more robust and high in amplitude compared to that of speech task. The variations of amplitude were high for the NSOMs task compared to that of the speech task. This was reflected through crests and the troughs of the velocity profile of NSOMs being more irregular in amplitude compared to that of speech task. Whereas the velocity profiles of speech task appear more regular and synchronous.

F. Comparison of spatio temporal indices of speech and NSOMs within females in the y – axis (superior - inferior dimension).

Table 9*:*

Mean, median and standard deviation (SD) of upper lip and lower lip for speech and NSOMs task for females in the y – axis.

	Speech		NSOMs	
	Lower lip	Upper lip	Lower lip	Upper lip
Mean STI	3.64	2.62	6.78	6.79
median	3.76	3	6.46	6.95
SD	0.9	0.6	1.2	1.72

Note: STI = Spatio-Temporal Index, NSOMs = Non speech oral movements.

The STI of NSOMs are higher compared to that of speech task, as observed from table 9. This suggested that the variability of speech motor control was higher for non – speech tasks as reflected through higher values of STI. The comparison of STIs of upper lip and lower lip revealed that upper lip showed higher STI values compared to that of lower lip in the both the tasks.

When the tasks were within gender for females, the data did not follow a standard normal distribution. Hence these findings were statistically verified using a non - parametric Wilcoxon sign ranked test. There was no statistically significant difference between speech and NSOMs of the upper lip (Z = |2.02|; p >0.05) and also for the lower lip (Z = |2.23|; p >0.05) in the y – axis within females.

G. Comparison of velocity profiles of speech and NSOMs within females in the z – axis (superior - inferior dimension).

The kinematic wave morphology of upper lip for speech and volitional NSOMs tasks were distinct as revealed in figure 19, that compares speech (left panel) and non – speech (right panel) tasks. The velocity profiles of speech task were more synchronous and clear compared to that of NSOMs. Spatially, the velocity profiles for NSOMs were higher in amplitude compared to that of speech and on the temporal domain they were lower. This indicated that the time taken by the female participants to perform a NSOMs task was lesser than that of speech that, which was reflected as NSOMs velocity profile being longer on the temporal domain within females.

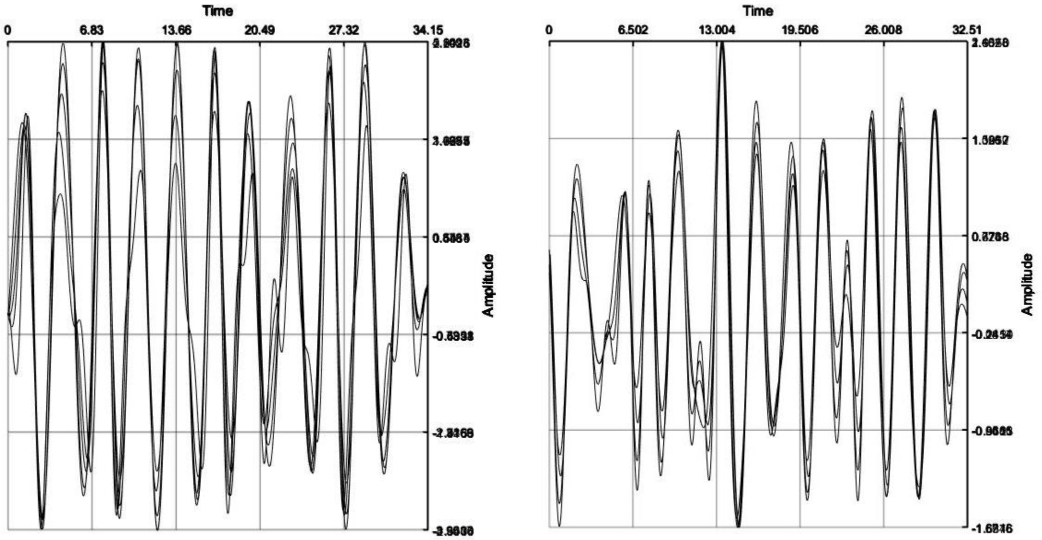

Figure 19: amplitude and time normalized velocity profiles of upper lip in z – axis for speech (left panel) and NSOMs (right panel) for female participants

There was a distinct kinematic wave morphology, even for the lower lip for the two tasks. This has been reflected in figure 20, that compares velocity profile wave morphology of speech (left panel) and non – speech (right panel). The velocity profiles of speech task were more synchronous and clear compared to that of NSOMs. Spatially, the velocity profiles for NSOMs were higher in amplitude compared to that of speech and on the temporal domain they were lower. This indicated that the time taken by female participants to perform a NSOMs task was lesser than that of speech that, which is reflected as NSOMs velocity profile being longer on the temporal domain.

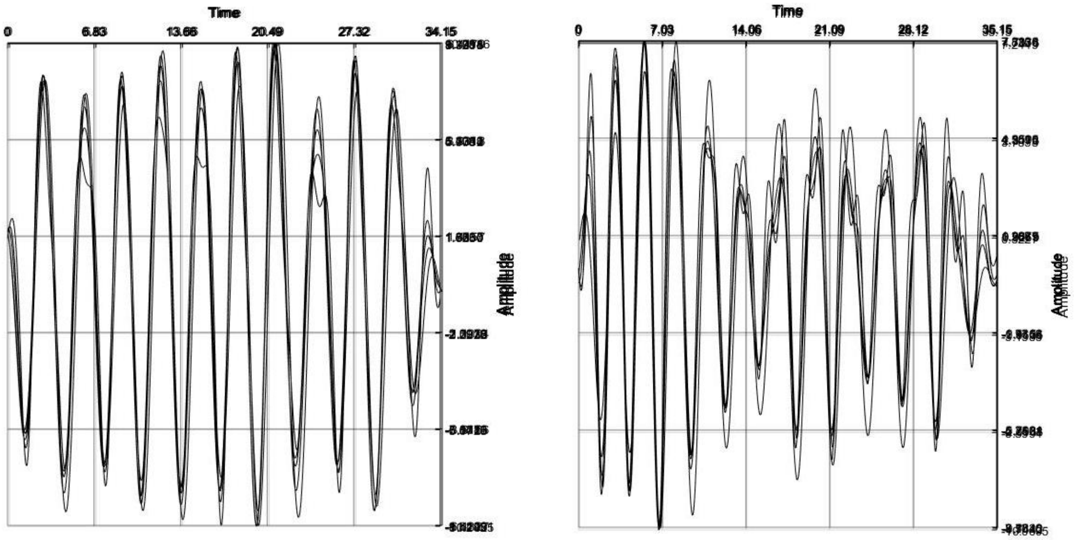

Figure 20: amplitude and time normalized velocity profiles of lower lip in z – axis for speech (left panel) and NSOMs (right panel) for female participants

When the performance of the upper and the lower lip were compared, as in figure 19 and 20, it revealed distinct kinematic wave morphology for both the tasks. For the speech task, upper lip and the lower lip were in a relatively less out of phase condition when compared to that of NSOMs. The performance of upper and the lower lip for NSOMs were more robust and high in amplitude compared to that of speech task. The variations of amplitude were high for the NSOMs task compared to that of the speech task. This is reflected through crests and the troughs of the velocity profile of NSOMs being more irregular in amplitude compared to that of speech task. Whereas the velocity profiles of speech task appear more regular and synchronous.

H. Comparison of spatio temporal indices of speech and NSOMs within females in the z – axis (superior - inferior dimension).

Table 10:

Mean, median and standard deviation (SD) of upper lip and lower lip for speech and NSOMs task for females in the z – axis.

	Speech		NSOMs	
	Lower lip	Upper lip	Lower lip	Upper lip
Mean STI	2.41	4.21	6.48	4.21
median	2.66	4.3	6.32	4.3
SD	0.88	1	1.2	1.8

Note: STI = Spatio-Temporal Index, NSOMs = Non speech oral movements.

The STI of NSOMs were higher compared to that of speech task, as observed from table 10. This suggested that the variability of speech motor control was higher for non – speech tasks as reflected through higher values of STI. The comparison of STIs of upper lip and lower lip revealed that upper lip showed higher STI values compared to that of lower lip in the both the tasks.

When the tasks were within gender for females, the data did not follow a standard normal distribution. Hence these findings were statistically verified using a non - parametric Wilcoxon sign ranked test. There was no statistically significant difference between speech and NSOMs of the upper lip (Z = |2.02|; p >0.05) and also for the lower lip (Z = |2.23|; p >0.05) in the y – axis within females.

The results are discussed in the following chapter.

DISCUSSIONS

The present study was proposed to analyze and compare Velocity Profiles and Spatio Temporal Index (STI) of lips in a selected speech task (utterance of bilabial /pa/ syllable) and volitional non - speech orofacial movements (NSOM) task (bilabial gesture of opening and closing the lips as in /pa/ syllable, but without uttering the /pa/ syllable) across gender in typical adults in the age range of 18 to 25 years, using EMMA (AG -501). The findings of the study which were presented in the previous results chapter are discussed in the following sections below.

I. Comparison across tasks (speech and NSOMs) irrespective of gender

II. Gender wise comparison of tasks

1. Across gender comparison of tasks
2. Within gender comparison of tasks.

I. Comparison across tasks (speech and NSOMs) irrespective of gender

A. Velocity profiles of speech and NSOMs in y and z axes

One of the major issues reported across literature comparing speech and NSMOs; is the difficulty to achieve equivalency between the two tasks (Kent, 2015). In the present study, the equivalency between speech and NSOMs is achieved by operationally defining the speech and NSOMs task, where the tasks are kept identical with respect to their movement characteristics. From the visual inspections of the velocity profiles, following assumptions were drawn and the underlying nature of a motor task were evaluated.

1. If the velocity profiles of speech and NSOMs are similar in their wave morphology, it could be assumed that the speech and NSOMs are brought about by the same motor plan and possibly by the same neural structures.
2. Conversely to this, if the velocity profile wave morphology of the two tasks are different, it can be assumed that speech and NSOMs are not brought about by the same motor plan and are represented differently at the central level.

From the visual inspection of figures 1, 2, 3 and 4, it can be observed that the velocity profiles in the y and z axes for speech are distinct from that of NSOMs. Since the overall wave morphology of the two tasks of the participants are distinct, it can be assumed that the tasks of speech and NSOMs are not brought about the same motor plan and therefore not represented in the same manner at the central level. The data from the present study are in favor of "*the task-specific model*" of motor control proposed by Ziegler (2003). The model proposes that the motor control/functions specialized for the act of speaking are different from those that control non - speech oral motor tasks, thus implying separate sensorimotor control for speech and non - speech tasks (Zeigler, 2003).

There is a dearth of studies that have used kinematic paradigm to investigate possible difference that might exist between speech and NSOMs tasks. A study by Shaiman and Gracco (2002) that utilized static kinematic measure is in support to the findings of the present study. Shaiman and Gracco (2002) recorded kinematic profiles of upper lip and lower lip from 6 typical females in the age range of 18 to 30. The participants of the study performed a speech and speech like NSOMs. The results revealed phasic differences between speech and NSOMs task, indicating not only a difference in neural organization but also in movement properties and sensori motor gating of information.

Contradictory findings are reported by Shaiman, McNeil, and Szuminsky (2001). A static kinematic paradigm utilizing IOWA (Intro Oral Performance Instrument) was used to look into the possible differences that might exist between speech and NSOMs of tongue. The results did not reveal any statistical differences between speech and NSOMs supporting the notion of a common generalized motor program for speech and non - speech behaviors. Sowman et al., (2009) used static kinematic measure such as tongue strength, endurance and intra oral pressure to address the question of similarities or differences that would exist in the motor control for speech versus NSOMs. Their findings are contradictory to that of the present study and suggests that speech and NSOMs have a same sensorimotor representation.

These contradictory findings of Shaiman, McNeil, and Szuminsky (2001), Sowman et al., (2009) might be attributed to the nature of kinematic paradigm used. Both the studies have addressed that question of similarities or differences in the motor control for speech and NSOMs utilizing a static kinematic measure, whereas the present study has utilized a dynamic kinematic paradigm. The static kinematic measures such as tongue strength, endurance and intra oral pressure which are used by Shaiman, McNeil, and Szuminsky (2001), Sowman et al., (2009) may not be sufficient enough to represent the entirety of a motor task. These measures further fail to capture the entire range of motor movements performed during the task as done by dynamic measures.

Further observations of figures 1, 2, 3 and 4, revealed that the velocity profiles of NSOMs are shorter in duration compared to that of speech tasks. This difference between the two tasks, where speech is temporally longer than that of NSOMs can be attributed to the programmed nature of speech. The data from the present study reveals that the motor programming for speech tasks takes longer time than that of volitional NSOMs. The longer durations required for motor planning of speech is reflected as velocity profiles of speech being longer than that of NSOMs. Similar findings have been reported by Kluesk (2010), the authors utilized a static kinematic paradigm and examined thus obtained pressure waveforms of speech and NSOMs tasks. The results of the study revealed that NSOMs were temporally longer than that of speech movements.

Another interesting finding from the present study was that the velocity profiles of speech was more synchronous and rhythmic than that of NSOM task. It can be observed from figures 1, 2, 3 and 4, that velocity profiles for the speech task are smoother and also regular without greater amplitude variations. This difference in the synchronicity of speech and NSOMs tasks can be attributed to the difference in central representation of tasks and also a possible difference in structures being responsible for these two tasks (Riecker et al, 2000).

Riecker et al (2000) using a functional magnetic resonance imaging technique reported that there was a focal activation of cerebellar region for the speech tasks which was absent for the task of NSOMs. This study signifies the important role of cerebellum in speech production tasks, which is reported to be absent during the tasks of NSOMs. The role of cerebellum in timing and coordinating movement function has been reported by several authors (Wildgruber, Ackermann, & Grodd, 2000; Riecker et al, 2000). The synchronous velocity profiles of speech tasks revealed in the present study can be thus attributed to the active role of cerebellum in the speech tasks. Due to the mediation of cerebellum, the tasks of speech are more rhythmic and coordinated in nature. This is reflected as velocity profiles of speech being more synchronous than that of NSOMs.

B. Spatio temporal indices of speech and NSOMs in y and z axes

The measure of spatiotemporal index (STI) uncovers the degree of variability in a core pattern of movement after displacement signals recorded during repeated productions had been amplitude and time normalized. It is an index of how well normalized kinematic waveforms converged onto a single pattern or template (Thelen & Smith, 1999). In the present study, this measure is used to look into the stability and variability of movement patterns of speech and NSOMs.

The measures of variability and stability are directly referred to plasticity of the system (Wohlert & Smith, 1998). If the STI values of a movement is higher, it is said to be more variable and has higher plasticity. Conversely, lower STI values indicate a much stable system which is matured and not readily plastic in nature. The results reported in the previous chapter are discussed with respect to variability of STI values for speech and NSOMs.

From table 1 and 2, it can be observed that the STI values of NSOMs task are higher than that of speech in both y and z axes. Further, there was a statistical significance between the STI measures of two tasks. The findings from the present study indicated that speech task is less variable and more stable than that of the NSOMs task. This is reflected as speech task having lesser STI values compared to that of NSOMs task. This can be attributed to the goal oriented nature of the speech task (Guenther, 2006). Considering the tasks in the study, speech task was operationally defined to be a task where the participants were required to utter a bilabial syllable /pa/ at isolation which was iterated and a the volitional non – speech task which was a movement equivalent to the speech task, where the participants were required to utter a movement equivalent matched to the speech task in terms of bilabial movement pattern of the lips.

In the speech task, the participants had a well – defined goal of producing an acoustically clear iteration of /pa/. But in case of volitional NSOMs task, the goal was to match the movement equivalent of /pa/. This lack of clear goal may have resulted in volitional NSOMs tasks having higher STI values. The present findings of the study are supported by earlier works of Perkell, et al (1997), these authors put forth an internal model of speech production that focuses on acoustic goals and auditory feedback. According to these authors, speech is indeed a goal oriented process. Each act of speech production has a set of desired tasks and completion of these tasks results in achievement of goal. In case of speech production, the goal is producing an acoustic utterance that is perceptually acceptable.

Since, the goals are pre – determined for the speech task, the speech motor system is controlled in such a way that each time a production happens; its desired goals are met. We believe that this goal oriented nature of production is absent in case of NSOMs task. Which is reflected as higher variability in the STI values of volitional NSOMs task compared to that of speech. The important role sensory feedback from the auditory system that helps in monitoring of speech production have been stressed by several authors (Perkell, et al, 1997; Kent, 2003 & Guenter, 2005). In the present study, the effective role of auditory feedback that is present in speech task is not available during the production of volitional NSOMs task.

II. Gender wise comparison of tasks

1. Across gender comparison of task

A. Comparison of velocity profiles of y and z axes across gender:

From the visual inspection of figures 5, 6, 7 and 8, it can be observed that there were no differences in wave morphologies between males and females for both speech and the volitional NSOMs task. But, on a closer inspection of velocity profiles across gender, the following findings were revealed 1) the amplitude of velocity profiles for males was higher in both speech and volitional NSOMs task compared to that of females. 2) the time taken by the male participants to complete the task was much lower than that of females for both speech and volitional NSOMs task.

The findings of greater amplitude in velocity profiles for males is attributed to the physical difference between the speech effectors among males and females. The amplitude of the velocity wave corresponds to the strength of a motor movement. We believe that the differences in physical make of speech effectors between males and females might have contributed to the higher amplitude. These findings are also reflected in the temporal domain of the movement, where the time taken by the male participants is lesser than the female participants.

Within in the knowledge of the investigator, there are no studies that have used kinematic paradigm to look into the possible gender differences that might exist between speech and volitional NSOMs performance of males and females. Few studies that have used paradigms such as DDK, speech language proficiency measured to evaluate the speech and the volitional non - speech motor performance of males and females.

Contradictory findings have been reported by Hyde and Linn (1988) who reported that females have superior speech production abilities compared to that of males.

Further contradicting results of Sadagopan and Smith (2008), Smith and Zelaznik (2004) report that female have better speech and non - speech oral motor abilities compared to that of males. These differences in findings can be attributed to the lesser participants in the present study. Studied by Sadagopan and Smith (2008), Smith and Zelaznik (2004) have considered a much higher number of participants, whereas the present study included only 5 males and 5 females. These studies have utilized DDK as a measure for the volitional NSOMs task, DDK is considered to be more of a performance task whereas the measures of velocity profiles are production based tasks. These differences in the nature of task employed, combined with the factor of lesser participants considered in the present study might have influenced the difference of opinions.

The present study can be replicated by considering a much higher number of participants and can be taken as a future directive. The lesser number of participants in the present study might be considered a draw back and might have influenced the present results.

B. Comparison of spatio temporal indices of y and z axes across gender:

In the present study, the STI values of females were much lower than that of males for both speech and volitional NSOMs task. When these differences were examined for statistical significance, no significant differences were found between STI values of males and females across both the tasks. We attribute, this lack of statistical significance to the lesser number of participants. Further, lower STI values in females indicate a stable motor system in females compared to that of males. This might reflect the superior speech and NSOMs production abilities in females against that of males.

Similar supporting findings have been reported by Sadagopan and Smith (2008), Smith and Zelaznik (2004). These authors report that female have better speech and non - speech oral motor abilities compared to that of males. The superior performance of females in both speech and NSOMs tasks is attributed to the superior language abilities of females. The authors put forth that, since speech is a oral (verbal) manifestation of language, the superior language abilities in females are further reflected as speech and NSOMs abilities being superior in females.

2. Within gender comparison of tasks

One of the aims of the study was to compare the tasks of speech and volitional NSOMs as a factor within each of the gender. When the tasks were compared as a factor within each gender, the following findings were revealed. 1) Males performed better in speech task as compared to that of volitional NSOMs task. This was reflected as synchronous velocity profiles and lower STI values for speech task compared to that of volitional NSOMs task. 2) Females also revealed a similar trend, where they had synchronous velocity profiles and lower STI for speech task as compared to that of volitional NSOMs task.

From these observations, it can be implied that within gender comparison followed the similar trend of group wise comparison. When group wise comparison of tasks was carried out irrespective of gender, we found that speech was more stable that volitional NSOMs and had velocity profiles with higher synchronous patterns. This trend has also been revealed in the within gender comparison of tasks.

When these findings were subjected to statistical verifications, there were no statistically significant differences found. This is again attributed to the lesser number of participants considered in the present study. Within the knowledge of the investigator, there are no earlier studies that have attempted to look into the within gender performance of speech and volitional NSOMs task using a kinematic paradigm. Further studies that aim to look into the within gender performance across tasks of speech and volitional NSOMs task should consider a higher number of participants and is suggested as a future directive.

In summary, the hypothesis of the study which stated that there would be no difference in the STI and velocity profiles in both Y and Z axis across speech and NSOM tasks is defied. There was significant evidence for differences between speech and volitional NSOMs task only in the group wise comparison. Further, the hypothesis of the present study also stated that there would be no difference in the STI and velocity profiles in both Y and Z axis across speech and NSOM tasks for across and within gender comparisons. This hypothesis has been accepted. There were no significant differences in speech and volitional NSOMs across and within gender comparison. This is attributed to the lesser number of participants considered in the present study.

SUMMARY AND CONCLUSION

The present study aimed to analyze and compare Velocity Profiles and Spatio Temporal Index (STI) of lips in a selected speech task (utterance of bilabial /pa/ syllable) and volitional non - speech orofacial movements (NSOM) task (bilabial gesture of opening and closing the lips as in /pa/ syllable, but without uttering the /pa/ syllable) across gender in typical adults in the age range of 18 to 25 years, using EMMA (AG -501). This was a preliminary attempt made to analyze and understand the possible differences that might exist in motor control of speech and volitional NSOMs tasks using a kinematic paradigm. The objective of the study was to compare the Velocity Profiles and Spatio Temporal Index (STI) of lips across task (speech and NSOM) and gender in the following axis of the EMMA (AG -501): a) Y – axis (inferior-superior) b) Z – axis (posterior-anterior).

Ten typical individuals in the age range of 18 – 25 years were included in the present study. These participants performed a speech task (utterance of bilabial syllable /pa/ in isolation) iterated 20 times per participant and a volitional NSOMs task (bilabial gesture of opening and closing the lips as in /pa/ syllable, but without uttering the /pa/ syllable), iterated 20 times. The kinematic traces of the upper lip and lower lip, for both the tasks were obtained using 5 channels (5 sensors: 3 test sensors on upper lip, lower lip and jaw and two reference sensors on the forehead and the mastoid) with a resolution of five degrees of freedom (5 DOF) in 500 mm cube field in the EMMA (AG -501) System. The appropriateness of the position data recorded on the EMMA (AG -501) system was visualized using VisArtico software (Version V.0.9.9 - February 2015) and the data was analyzed using the MATLAB script of the Speech Movement Analysis, Statistics and Histograms (SMASH) tool (version 0.6) developed by Greene, Wang and Wilson (2013).

The results were presented under following sections:

III. Comparison across tasks (speech and NSOMs) irrespective of gender:

- A. Comparison of velocity profiles across tasks in the y – axis (superior - inferior dimension).
- B. Comparison of spatio temporal indices across tasks in the y – axis (superior - inferior dimension)
- C. Comparison of velocity profiles across tasks in the z – axis (anterior – posterior dimension)
- D. Comparison of spatio temporal indices across tasks in the z – axis (anterior – posterior dimension)

IV. Gender wise comparison of task:

1. Across gender comparison of task

- A. Comparison of velocity profiles of speech across males and females in the y – axis (superior - inferior dimension).
- B. Comparison of spatio temporal indices of speech across males and females in the y – axis (superior - inferior dimension).
- C. Comparison of velocity profiles of speech across males and females in the z – axis (superior - inferior dimension).
- D. Comparison of spatio temporal indices of speech across males and females in the z – axis (superior - inferior dimension).
- E. Comparison of velocity profiles of NSOMs across males and females in the y – axis (superior - inferior dimension).

F. Comparison of spatio temporal indices of NSOMs across males and females in the y – axis (superior - inferior dimension).

G. Comparison of velocity profiles of NSOMs across males and females in the z – axis (superior - inferior dimension).

H. Comparison of spatio temporal indices of NSOMs across males and females in the z – axis (superior - inferior dimension).

2. **Within gender comparison of task**

A. Comparison of velocity profiles of speech and NSOMs within males in the y – axis (superior - inferior dimension).

B. Comparison of spatio temporal indices of speech and NSOMs within males in the y – axis (superior - inferior dimension) for NSOM task.

C. Comparison of velocity profiles of speech and NSOMs within males in the z – axis (superior - inferior dimension).

D. Comparison of spatio temporal indices of speech and NSOMs within males in the z – axis (superior - inferior dimension) for NSOM task

E. Comparison of velocity profiles of speech and NSOMs within females in the y – axis (superior - inferior dimension).

F. Comparison of spatio temporal indices of speech and NSOMs within females in the y – axis (superior - inferior dimension) for NSOM task.

G. Comparison of velocity profiles of speech and NSOMs within females in the z – axis (superior - inferior dimension).

H. Comparison of spatio temporal indices of speech and NSOMs within females in the z – axis (superior - inferior dimension) for NSOM task

The results of the present study revealed that the kinematic wave morphology of upper lip and lower lip were distinct for tasks (speech and volitional NSOMs) as well gender (males and females). Overall, the STI values of speech task were significantly lower than that of volitional NSOMs. When, tasks were compared across gender, females had better velocity profile wave morphology and lesser STI values for both the tasks compared to that of males. But there were no significant differences between the STI values of males and females across tasks.

In summary, the hypothesis of the study which stated that there would be no difference in the STI and velocity profiles in both Y and Z axis across speech and NSOM tasks is defied. There was significant evidence for differences between speech and volitional NSOMs task only in the group wise comparison. Further, the hypothesis of the present study also stated that there would be no difference in the STI and velocity profiles in both Y and Z axis across speech and NSOM tasks for across and within gender comparisons. This hypothesis has been accepted. There were no significant differences in speech and volitional NSOMs across and within gender comparison. This is attributed to the lesser number of participants considered in the present study.

Future directions

1) Further studies that consider a larger number of participants shall be taken up provide better understanding of effect of gender on the tasks of speech and volitional NSOMs.
2) Kinematics of jaw shall be considered to better understand the nature and organization of speech and volitional NSOMs.

References:

Ballard, K. J., Granier, J. P., & Robin, D. A. (2000). Understanding the nature of apraxia of speech: Theory, analysis, and treatment. *Aphasiology*, *14*(10), 969-995.

Ballard, K. J., Robin, D. A., & Folkins, J. W. (2003). An integrative model of speech motor control: A response to Ziegler. *Aphasiology*, *17*(1), 37-48.

Ballard, K. J., Solomon, N. P., Robin, D. A., Moon, J. B., Folkins, J. W., & McNeil, M. R. (2009). Nonspeech assessment of the speech production mechanism. *Clinical management of sensorimotor speech disorders*, 30-45.

Bunton, K. (2008, November). Speech versus nonspeech: Different tasks, different neural organization. In *Seminars in speech and language* (Vol. 29, No. 04, pp. 267-275). Thieme Medical Publishers.

Bunton, K., & Weismer, G. (1994). Evaluation of a reiterant force-impulse task in the tongue. *Journal of Speech, Language, and Hearing Research*,*37*(5), 1020-1031.

Clark, H. M., & Robin, D. A. (1998). Generalized motor programme and parameterization accuracy in apraxia of speech and conduction aphasia. *Aphasiology*, *12*(7-8), 699-713.

Dromey, C., & Shim, E. (2008). The effects of divided attention on speech motor, verbal fluency, and manual task performance. *Journal of Speech, Language, and Hearing Research*, *51*(5), 1171-1182.

Folkins, J. W., Moon, J. B., Luschei, E. S., Robin, D. A., Tye-Murray, N., & Moll, K. L. (1995). What can nonspeech tasks tell us about speech motor disabilities? *Journal of Phonetics*, *23*(1), 139-147.

Franz, E. A., Zelaznik, H. N., & Smith, A. (1992). Evidence of common timing processes in the control of manual, orofacial, and speech movements. *Journal of Motor behavior*, *24*(3), 281-287.

Green, J. R., Wang, J., & Wilson, D. L. (2013, August). SMASH: a tool for articulatory data processing and analysis. In *Interspeech* (pp. 1331-1335).

Hageman, C. F., Robin, D. A., Moon, J. B., & Folkins, J. W. (1994). Oral motor tracking in normal and apraxic speakers. *Clinical Aphasiology*, *22*, 219-229.

Hogan, N. (1984). An organizing principle for a class of voluntary movements. *The Journal of Neuroscience*, *4*(11), 2745-2754.

Hyde, J. S., & Linn, M. C. (1988). Gender differences in verbal ability: A meta-analysis. *Psychological bulletin*, *104*(1), 53.

Kent, R. D. (2004). The uniqueness of speech among motor systems. *Clinical linguistics & phonetics*, *18*(6-8), 495-505.

Kent, R. D. (2015). Nonspeech Oral Movements and Oral Motor Disorders: A Narrative Review. *American Journal of Speech-Language Pathology*, *24*(4), 763-789.

Kuehn, D. P., & Moon, J. B. (1994). Levator veli palatini muscle activity in relation to intraoral air pressure variation. *Journal of Speech, Language, and Hearing Research*, *37*(6), 1260-1270.

Loucks, T. M., Poletto, C. J., Simonyan, K., Reynolds, C. L., & Ludlow, C. L. (2007). Human brain activation during phonation and exhalation: common volitional control for two upper airway functions. *Neuroimage*, *36*(1), 131-143.

McClean, M. D., Beukelman, D. R., & Yorkston, K. M. (1987). Speech-muscle visuomotor tracking in dysarthric and nonimpaired speakers. *Journal of Speech, Language, and Hearing Research*, *30*(2), 276-282.

Moon, J. B., Zebrowski, P., Robin, D. A., & Folkins, J. W. (1993). Visuomotor tracking ability of young adult speakers. *Journal of Speech, Language, and Hearing Research*, *36*(4), 672-682.

Nelson, W. L. (1983). Physical principles for economies of skilled movements. *Biological cybernetics*, *46*(2), 135-147.

Ouni, S., Mangeonjean, L., & Steiner, I. (2012, September). VisArtico: a visualization tool for articulatory data. In *13th Annual Conference of the International Speech Communication Association-InterSpeech 2012*.

Perkell, J., Matthies, M., Lane, H., Guenther, F., Wilhelms-Tricarico, R., Wozniak, J., & Guiod, P. (1997). Speech motor control: Acoustic goals, saturation effects, auditory feedback and internal models. *Speech communication*, *22*(2), 227-250.

Robin, D. A., Jacks, A., Hageman, C., Clark, H. M., & Woodworth, G. (2008). Visuomotor tracking abilities of speakers with apraxia of speech or conduction aphasia. *Brain and Language*, *106*(2), 98-106.

Sadagopan, N., & Smith, A. (2008). Developmental changes in the effects of utterance length and complexity on speech movement variability. *Journal of Speech, Language, and Hearing Research*, *51*(5), 1138-1151.

Shaiman, S., McNeil, M. R., & Szuminsky, N. J. (2004). Motor learning of volitional nonspeech oral movements: Intraoral pressure and articulatory kinematics. *The Journal of the Acoustical Society of America*, *115*(5), 2430-2430.

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

Smith, A., Goffman, L., Zelaznik, H. N., Ying, G., & McGillem, C. (1995). Spatiotemporal stability and patterning of speech movement sequences. *Experimental Brain Research*, *104*(3), 493-501.

Solomon, N. P., Robin, D. A., Lorell, D. M., Rodnitzky, R. L., & Luschei, E. S. (1994). Tongue function testing in Parkinson’s disease: Indications of fatigue. *Motor speech disorders: Advances in assessment and treatment*, 147-160.

Sowman, P. F., Flavel, S. C., McShane, C. L., Sakuma, S., Miles, T. S., & Nordstrom, M. A. (2009). Asymmetric activation of motor cortex controlling human anterior digastric muscles during speech and target-directed jaw movements. *Journal of neurophysiology*, *102*(1), 159-166.

Takai, O., Brown, S., & Liotti, M. (2010). Representation of the speech effectors in the human motor cortex: somatotopy or overlap? *Brain and language*, *113*(1), 39-44.

Walsh, B., & Smith, A. (2002). Articulatory Movements in Adolescents: Evidence for Protracted Development of Speech Motor Control Processes. *Journal of Speech, Language, and Hearing Research*, *45*(6), 1119-1133.

Wohlert, A. B. (1993). Event-related brain potentials preceding speech and nonspeech oral movements of varying complexity. *Journal of Speech, Language, and Hearing Research*, *36*(5), 897-905.

Zebrowski, P. M., Moon, J. B., & Robin, D. A. (1997). Visuomotor tracking in children who stutter: A preliminary view. *Speech production: Motor control, brain research and fluency disorders*, 579-584.

Ziegler, W. (2003). To speak or not to speak: Distinctions between speech and nonspeech motor control. *Aphasiology*, *17*(2), 99-105.