ARF project: Short Term Correlations between Speech Motor Variability and Behavioural Dysfluencies in Persons with Stuttering following Fluency Shaping Therapy

Introduction

From a speech motor control point of view stuttering is described as a disorder in timing and coordination of one or more of the speech subsystem such as respiration, phonation and articulation. Van Riper (1982) defined stuttering as a disruption of the simultaneous and successive programming of muscular movements required to produce speech sound or its link to the next sound in a word. Most of the studies that have measured speaking rate and stuttering frequency following behavioural treatment have shown that treatment of stuttering favourably results in a reduction of dysfluencies (e.g., Andrews et al., 1983; Ingham, 1991). These studies, however, do not explain the physiological changes in speech that occur after behavioural treatment, and the majority of them have speculated on the physiological deviations observed in people who stutter (PWS) using mostly the acoustic data.

Few earlier studies used either the paradigms of reaction time or selected acoustic measures to infer the physiological deviations in PWS. Most often, in comparison to typical speakers, these studies have pointed out lengthened reaction times and/or deviated acoustic dimensions studied in PWS (Peters, Hulstijn & Strakweather, 1989; Peters, Hulstijin & Van Lieshout, 2000). Later studies have measured the speech motor physiology using the instrumentation of electromyography (EMG), X-ray microbeam, strain gauge, cineradiography, optotrack, and electromagnetic midsagittal articulography (EMMA).

One of the first groups of studies that measured the articulatory movement parameters and explained stuttering physiologically was by Zimmerman (1980a, 1980b). Using

Cineflourographic analysis, Zimmerman found that Person with Stuttering (PWS) had lower peak velocities and displacement in their utterances compared to typical adults, and additionally, the interarticulator positioning seen in both perceptual and stuttered utterances was dissimilar to those found in the fluent speech of typical adults. It was opined that increasing the peak velocity and displacements would trigger the brainstem reflex pathway, which in turn creates more variability, leading to perceptual disfluencies. Zimmerman offered two explanations for the obtained results: stuttering could be an event occurring due to unstable motor activity or the motor system of PWS shows less tolerance to variability. The findings were unique as for the first time, stuttering was explained based on physiological aspects, which were earlier described using psychological methods.

Few studies in the late 1980s focused on the sequential execution of the lips and jaw, which contended that typical adults could produce a sequential pattern of upper lip, lower lip, and jaw that was not observed in the fluent utterances of PWS (Gracco & Abbs, 1986; Caruso, Abbs & Gracco, 1988). However, the subsequent studies did not show such differences and on contrary it was shown that even adults were shown to deviate from the above observed articulatory sequence patterns (Max, Gracco& Caruso, 2004).

Contrary to past studies, recent studies have focused on analyzing the phrase length data, typically measuring the articulatory variability. The idea behind this is that the co-articulatory boundaries extend beyond the traditional syllable level analysis and also, to understand the deviation in the motor control strategies employed by PWS, a longer syllable sequence needs to be analysed. Increased movement variability for a set of repetitions of the same phrase reflects an inherent deficit in the control of speech motor programming and thereby makes the PWS more susceptible to motoric breakdown. A range of studies have used the articulatory variability pattern of articulators as a metric to understand the physiological deviations in PWS (Kleinow & Smith, 2000; MacPherson & Smith, 2013; Smith & Kleinow, 2000).

The Spatiotemporal Index (STI), introduced by Smith et al. (1995), is one of the most commonly used intra-articulatory variability measures that helps in computing how well the movement trajectories of a given articulator repeated for the same fluent phrase converge as a single motor template. An increase in the STI values is reflected as decreased articulatory stability, and lower STI values are interpreted as an indication of better articulatory motor control. Smith and Kleinow (2000) reported abnormal instability in the articulatory motor control in at least one third of their participant group when STI of the lower lip was measured for the bilabial phrase "Buy Bobby a Puppy". It was also found that asking PWS to reduce their speaking rate decreased the overall stability owing to newer timing relations, and this was suggested to change and achieve stable values only with continuous practice. Additionally, it was also reported that PWS may overlap in the usage of motor control strategies with that of typical adults when the motoric demands placed on their system are low. This was further corroborated in their next study, which showed that adults with stuttering (n = 8) showed decreased articulatory stability when the syntactic complexity of a baseline phrase was increased compared to age and gender-matched controls. It was concluded that the increased linguistic and motor demand would make PWS susceptible to articulatory motor breakdown (Kleinow & Smith, 2000).

Recent studies carried out on the influence of sentence length and syntactic complexity on articulatory stability in children with stuttering (CWS) have confirmed the earlier findings of increased articulatory variability patterns in adults with stuttering (MacPherson & Smith, 2013). This suggests that decreased speech motor stability could be the physiological underpinning of the disorder of stuttering. This supports the fact that adults with stuttering continue to experience motor instabilities despite producing perceptually fluent speech. Interestingly, one of the recent studies has shown a gender effect on the articulatory motor patterning in the early childhood years of stuttering, wherein boys were observed to show greater articulatory variability compared to age matched girls, concluding that poor speech motor control from the time of emergence of stuttering could be the probable reason why boys would persist in stuttering compared to girls (Walsh, Mettel & Smith, 2015).

The majority of studies on articulatory stability patterning in PWS were cross-sectional, and there are few reports on the effect of treatment on speech motor changes (Story, Alfonso, & Harris, 1996; Tasko, McClean, & Runyan, 2007). Story, Alfonso, & Harris (1996) reported the acoustic, respiratory, laryngeal, and articulatory kinematics of 3 adults with stuttering after participating in the Hollins Precision Fluency Shaping Program. Increased acoustic duration, Inspiratory/expiratory volume, and laryngeal opening were reported along with reduced amplitude in lip and jaw movements.

Tasko, McClean and Runyan (2007) reported the pre and post therapy movement data of articulators along with acoustic and respiratory variables on 35 persons with stuttering following a 1-month treatment programme. Participants were observed to have increased the amplitude and duration of speech breaths and reduced the rate of lung volume change during inspiration. The amplitude and speed of lip movements were reduced, whereas the lip and jaw movement durations were increased. The syllable rate was reduced in the post treatment observations. A multiple regression analysis revealed that two respiratory variables and one kinematic variable explained the greatest variance in post-treatment stuttering severity.

Need for the study

Stuttering therapy has always focused on the changes seen in perceptual and behavioral attributes following either fluency shaping or stuttering modification techniques.

Many of the studies which noticed the behavioral changes in speech production of people with stuttering (PWS) have monitored their speech patterns for reasonably long period of time. This ignores a critical question of how long one should take fluency therapy to become fluent. Depending on the perceptual and/or behavioral patterns of fluency for making clinical decision may consume considerable amount of time for PWS. Additionally, some of the physiological studies have shown that the perceptually fluent speech of PWS is not without any motoric aberrations (Smith & Kleinow, 2000; Kleinow & Smith, 2000). Therefore, understanding the short terms changes in behavioral and physiological domains of speech production of PWS would give a better picture on day to day changes in their motor abilities and their capabilities to cope up with the problem.

EMMA has been previously used to investigate speech motor planning/programming breakdown in PWS (Smith & Kleinow, 2000) and suggested that PWS differs from control normal with respect to kinematic measures like Spatiotemporal Index (STI). The STI is an index of how well amplitude and time-normalized kinematic waveforms converge on a single pattern or template. It is designed to uncover the degree of variability in a core pattern of movement (Smith et al., 1995). STI has been investigated in several follow up studies and it has been shown that it helps in understanding the motoric instability in PWS (Smith & Kleinow, 2000; Macpherson & Smith, 2013). As number of investigations on addressing the post therapy changes in articulatory motor control is relatively less reported in the literature, the current study is proposed to examine the short term changes following fluency shaping therapy on physiological measures of articulatory motor variability indexed by mean STI (Spatiotemporal Index) scores and Kinematic duration of lower Lip measured using Articulograph AG501 and behavioral measure of stuttering frequency.

Aim and Objectives

The aim of the study is to examine the short term effects of fluency shaping therapy on selected kinematic measures in native Kannada speakers with stuttering.

a) To investigate the short terms effects [before, at the completion of 5th session and at the completion of 10th session] of Fluency Shaping Therapy in Persons with Stuttering who are native Kannada speakers on mean STI scores of Lower Lip (LL) for bilabial words and phrasal stimuli using Articulograph AG501.

b) To investigate the short term effects of Fluency Shaping Therapy in Persons with Stuttering who are native Kannada speakers on kinematic duration of Lower Lip (LL) for bilabial words and phrasal stimuli using Articulograph AG501.

c) To correlate the short term changes of mean STI scores and kinematic duration of LL with the frequency of stuttering measured for conversational and reading sample of Kannada, in native Kannada speakers with stuttering.

Review of Literature

Humans have the best motor skills in the world when it comes to speaking. For fluent speech output, where movement sequences changes continuously, the coordination of articulation, phonation, and respiratory subsystems becomes crucial (Ward, 2018). One of the most commonly occurring speech disorders that disrupt the smooth coordination of speech apparatus in childhood is Stuttering. As a developmental speech disorder, Stuttering is known to show disruptions in the forward flow of speech and develops during the preschool years, usually between the ages of two and four ( ). American Speech-Language Hearing Association (Special Interest Division 4: Fluency and Fluency Disorders, 1999, p. 31) defines stuttering as "monosyllabic whole word repetitions, part-word repetitions, audible sound prolongations, or silent fixations or blockages. These may or may not be accompanied by accessory (secondary) behaviors (i.e., behaviors used to escape/and or avoid these speech events)". One of the hallmark definition on this disorder stuttering was put forth by Wingate (1964) several year ago, who observed stuttering to be a I. (a) Disruption in the fluency of verbal expression, which is (b) characterized by involuntary, audible or silent, repetitions or prolongations in the utterance of short speech elements, namely: sounds, syllables, and words of one syllable. These disruptions (c) occur frequently or are marked in character and (d) are not readily controllable. II. Sometimes the disruptions are (e) accompanied by accessory activities involving the speech apparatus, related or unrelated body structures, or stereotyped speech utterances III. Also, there are not infrequently (f) indications or report of the presence of an emotional state, ranging from a general condition of 'excitement' or 'tension' to more specific emotions (g) The immediate source of stuttering is some incoordination expressed in the peripheral speech mechanism; the ultimate cause is presently unknown and may be complex or compound".

The epidemiological data of stuttering that explains the Incidence and Prevalence of the disorder is quite variable as methods of defining the behavior and collecting data is different across studies. Prevalence of stuttering was estimated in Kindergarten children to be 2.4% using random sampling method (Beitchman et al., 1986). Though reliable studies on the prevalence data in adults are sparse, it is estimated to be less than 1% by few investigations (Bloodstein & Ratner, 2008). Similar to methodological concerns raised while measuring prevalence, the data on incidence of stuttering is also less straight forward. However, certain studies that reported the incidence figures on stuttering were close to each other, with an estimated incidence of 5% (Andrews, et al., 1983; Mansson, 2000).

Though stuttering is considered primarily a speech disorder, several additional behavioral attributes renders it to a multidimensional problem. Overtime the development of negative self thoughts, frustration, embarrassment, shame and self-doubts related to speaking largely affects the life of persons with stuttering. Avoidance strategies which are frequently observed in this population makes them evade stressful speaking situations (e.g., talking over phone, talking with strangers etc) and thereby affects their social, vocational and occupational participation (Gabel et al., 2008). In some individuals who stutter, anxiety related to speaking is found to be a debilitating symptom that impedes their interpersonal and social relationships (see review by Iverach et al., 2011).

The current methods of managing stuttering largely lies with Speech Language Pathologists (SLPs) who are trained to identify, assess and manage the clinical signs and symptoms using behavioral approaches. Both indirect (modifying environmental variables) and direct (changing the speech behaviour) approaches to treat stuttering is employed in Children with Stuttering (CWS). In adults, the focus is placed either to treat the core features by adjusting their speaking style or to modify the associated behaviours (avoidance, anxiety and acceptance) and facilitating them to stutter in easier ways. The former is called 'fluency shaping'; and sometimes also referred to as 'speech restructuring' or 'prolonged speech' therapies and the later is termed as 'Stuttering Modification'. Since the focus of this project is on speech restructuring treatment, we simply present an overview of stuttering modification in this review.

Stuttering Modification

Stuttering Modification was started largely during 1930s, initiated at Iowa, by the work of Lee Edward Travis and Bryng Bryngelson. Techniques and strategies which were extensively worked on in the later years by other investigators like Johnson (1967), Sheehan (1970, 1979), Van Riper (1973) and Bloodstein (1975) are together termed as 'Stuttering Management' Therapies (Blomgren, 2010). Because nearly all of these early stuttering treatment techniques were developed at the University of Iowa, they've been dubbed the 'Iowa Way' (Zebrowski & Arenas, 2011). In stuttering management approaches, therapy strategies are focused to reduce the muscular tension associated with stuttering episodes, including desensitization to stuttering and stuttering modification procedures. A common goal of stuttering management therapies is to: increase stuttering acceptance, decrease stuttering anxiety and avoidance, and decrease the effort during the moment of stuttering (Blomgren, 2012). Stuttering management therapies are primarily based on two-component models of stuttering (Bloodstein & Ratner, 2008; Prins & Ingham, 2009). This model assumes the first component to be the 'overt stuttering' which precipitate emotional, anxiolytic, and avoidance reactions which constitute the secondary component of the model. As many supporters of stuttering management therapy opine that total elimination of Stuttering is impossible, they propose to treat the second component of stuttering to be the primary goal.

Major concern about the Stuttering management approaches lies in its lack of efficacy data (Bothe et al., 2006). The research on stuttering management approaches were reported during early 1970s and hardly any recent attempts have been made to understand its efficacy on PWS (Boudreau & Jeffrey, 1973; Dalali & Sheehan, 1974; Fishman, 1937; Gregory, 1972; Irwin, 1972; Prins, 1970). Only descriptive research on stuttering management therapy are available in a few cases, and even these studies provide limited data, making it problematic to assess their efficacy on stuttering (Eichstadt et al., 1998). Blomgren et al. (2005) examined the stuttering management therapy offered at the Utah University from 1999 to 2002 on 14 fluency and affective-based measures. Results revealed that stuttering management approaches reduced several anxiolytic features related to stuttering that was maintained till 6 months post-treatment. However, it did not reduce the overall stuttering frequency and severity and it did fail to show any changes in the self perceived severity of Stuttering in the participants.

As stuttering frequency is not an aim targeted in stuttering management therapies, the approach does not teach fluency-facilitating techniques, and as a result, the programme does not lead to a reduction in the frequency of stuttering (Blomgren et al., 2005). As per several studies, focusing primarily on treating the anxiolytic and reactive aspects of stuttering seems to be insufficient, especially in light of the numerous available programmes that report positive results in reducing core stuttering behaviours (Blomgren, 2010; Ingham, 1975; Kroll and Scott-Sulsky, 2010; Kully et al., 2007; Montgomery, 2006; O'Brian et al., 2010). Additionally, it is acknowledged that the counselling skills of the clinician play a major role in making PWS to choose this approach as this involves voluntary disclosure of stuttering by PWS thereby desensitizing them to reduce avoidance and anxiolytic reactions related to speech.

Speech Restructuring

Speech restructuring is one of those approaches which have been largely studied on its effectiveness in reducing stuttering frequency. Here, PWS is modeled to develop a new way of speaking which is devoid of stuttering moments. These procedures are often known as "fluency shaping" or "prolonged speech." Slowing the overall speaking rate either by extending the syllables or providing pauses between the words is the primary ingredient of this approach. Additionally, '*gentle phonatory onsets*' and '*smooth/soft articulatory contacts'* and '*continuous phonation*' is added to the already modeled slower speaking rate. In *gentle phonatory onsets*, contrary to hard vocal cord approximations that are presumed to occur during dysfluencies, a gradually initiated vocal cord vibrations are modeled. Hard articulatory contacts that occur within or between the active and passive articulators are replaced with the *soft articulatory targets*. Finally, PWS is encouraged to *continuously vibrate* the vocal cords by blurring the between word boundaries which is known to reinforce speech fluency. From this point forward, we'll refer 'speech restructuring' process as "fluency shaping' for convenience.

Three primary sources influenced the development of fluency-shaping therapy. The first was the breakthrough of a significant reduction in stuttering followed by fluency inducing conditions (e.g., rhythmic speech, under masking noise, chorus speaking), which implied that careful remediation of speech subsystem processes might increase fluency. Second, as operant conditioning principles were becoming prominent, it was conceived that treatment targets of fluency remediation targeting the speech subsystems could be better achieved with behavioural shaping procedures. The third crucial factor was the discovery by

Goldiamond (1965) who reported increased speech fluency following slow rate of speaking in PWS under delayed auditory feedback.

Most of the fluency shaping treatments does not address anxiolytic and avoidance tendencies of PWS. Furthermore, while speech restructuring therapy can lead to significant reductions in stuttering frequency in the clinic, maintaining consistent fluency in everyday speaking settings can be difficult. Because stuttering is prone to relapse, it is prudent to teach stuttering management strategies to deal with stuttering when it happens. Both short term and long term evidences are available for fluency shaping treatments, particularly in adolescents and adults (Craig et al., 1996; Howie et al. 1981; Ingham, 1982; Ingham & Andrews, 1973; Ingham et al., 2001; Ingham & Packman, 1977; James et al., 1989; Maruthy & Savithri, 2006; Onslow et al., 1996; Perkins et al., 1974; Ryan & Ryan., 1983, 1995).

Howie et al (1981) described a three-week intensive therapy programme for adult stutterers. This treatment evolved from an original programme devised by Ingham and Andrews (1973) that used speech extension techniques, gradual moulding of speech rate to normal, and methodical transfer of clinic abilities to real-life circumstances. Stuttering was virtually gone after extensive treatment, and speech rate and attitudes about communication were returned to normal. When clients were examined in the clinic after two months of treatment in the Maintenance Phase, there was no significant decline in these therapeutic benefits. Most clients exhibited permanent overall improvement in speech and attitude measures gathered outside the clinic 12-18 months after intense treatment, while 40 clients showed modest decrease in fluency from immediate post-intensive treatment levels.

Ingham and Andrews (1973) evaluated the effects of a token economy programme on fluency and its combination with prolongation therapy on small groups (n=4) of patients in a hospital setting. It was found that token economy can be used to control the percentage of syllables stuttered as a response class. Here, the token system's rewards resulted in increased fluency, while the withdrawal resulted in discernible dysfluencies. After that, the token system was combined with delayed auditory feedback and used in conjunction with a prolonged speech pattern to shape normal fluent speech. The results indicated that prolonged speech with contingent feedback resulted in faster fluency improvements than a group that received no contingent feedback during the prolonged speech treatment. While 65% of participants reported stutter-free speech at the ninth month assessment, numerous relapses were observed during the 15-month follow-up.

Few attempts have been made to systematically investigate the processes underlying the stuttering-relieving effects of response-contingent stimulation James et al., (1989). The reductions in stuttering that typically accompany RCS are thought to be the consequence of the stutterer being encouraged to access existing fluent speech that might not be completely apparent during "contingency-free" (CF) situations. A preliminary examination of the idea was undertaken by tracking the frequency and rate of RCS and CF stuttering in 20 adult stutterers before, during, and after a fluency training programme. On the basis of their baseline response to the RCS technique of time-out from speaking, subjects were split into "high" and "low" responders, after which they participated in a 32-hour fluency training programme targeted at minimizing stuttering. High and low responders were shown to be similarly influenced by time-out after displaying a degree of relapse during a subsequent 6-month follow-up. This result contrasted with the two groups' differing responses during the baseline phase, and it is consistent with the idea that improvements in fluency during RCS occur when stutterers access existing fluent speech that is not being fully exploited.

Apart from the above-described studies which used prolongation therapy, several variants of the same technique have been used by many of the investigators who developed ‘treatment packages’ for stuttering from north American and Australian origins. These include Camper-Down programme (O’Brain, Packman & Onslow, 2010), Conversational rate control therapies (Curlee & Perkins, 1969, 1973), comprehensive stuttering program at the University of Alberta (Boberg & Kully, 1985), Intensive Treatment Program at the American Institute of Stuttering (Montgomery, 2006), Precision fluency programme (Webster, 1974), and Prince Henry programme (Andrews. Craig & Feyer, 1983). Most of these studies have documented favourable effects of speech restructuring as a means to reduce the frequency of stuttering across age ranges.

Physiological Deviations in Stuttering: Reaction time and acoustic investigations

Although not on the effects of treatment, some of the earlier studies of stuttering used reaction time paradigms and neuromotor measures to detect physiological abnormalities. Some studies have found physiological deviations between people who stutter and people who don't stutter across multiple speech subsystems. At the respiratory level, physiological deviations were attributed to: respiratory muscle fixations and lack of control over the subglottal air pressure (Zocchi, Estenne, Johnston, Ferro, Ward & Macklem 1990); higher intraoral pressure during fluent and dysfluent speech (Adams, 1974; Hutchinson & Navarre, 1977). Some of these respiratory abnormalities were attributed to the competing inputs from the Metabolic Respiratory Controller (MRC) and the Peri-aqueductal Grey Matter Controller (PGMC), where MRC directs vegetative breathing and PGMC provides the variability required for speech production (Denny & Smith, 1997).

In the early 1970s, laryngeal structures were thought to be a possible basis of disfluent speech. Several investigations found aberrant laryngeal activation during stuttering speech. Using glottography, Chevrie and Muller (1963) found frequent pauses in the rhythm of the vocal fold vibration during stuttering intervals. Disfluent speech had unusually high action potential when recorded by EMG (Bar, Singer, & Feldman, 1969). In a few intrinsic laryngeal muscles, objective evidence demonstrated a synchronous contraction of adductor and abductor muscles before and during stuttering (Freeman & Ushijima, 1975, 1978; Shapiro, 1980).

Acoustic research conducted in the late 1970s and early 1980s, pointed the evidences to the phonatory mechanism as the most likely source of disfluent behaviour. Jitter, shimmer, voice onset time (VOT), voice initiation time (VIT), voice termination time (VTT), vowel duration, and voice quality were all measured in several of the acoustic experiments. Some studies found that PWS had higher VOT than non-stutterers (Hillman & Gilbert, 1977; Metz, Conture & Caruso, 1979; Zimmerman, 1980), while others found no significant difference between PWS and non-stutterers in the VOT task (Hillman & Gilbert, 1977; Metz, Conture & Caruso, 1979; Zimmerman, 1980). PWS have been observed to have slower VIT responses than those who do not stutter in a number of investigations (Adams & Hayden, 1976). Soe of the models that were proposed during this time also pointed the laryngeal abnormalities to be the most likely physiological underpinning of Stuttering (Schwartz, 1974).

Few researchers considered stuttering to be an articulatory abnormality, and several studies supported this hypothesis. Spatial articulatory aberrations such as restricted articulatory movements, low articulator velocities, and poor articulatory stability were reported in PWS (Zimmerman, 1980; Klich & May, 1982; Van Riper, 1982; Jansen, Weineke & Vaane, 1983). Temporal abnormalities such as longer/shorter vowel/consonant durations, longer length between articulatory events, and erroneous timing were discovered using spectrographic analysis (Prosek & Runyan, 1982; Cooper & Allen, 1977). These studies also discovered that the length and utterance complexity of the speech tasks plays a significant role in differentiating stuttering and no-stuttering groups.

Physiological deviations in stuttering: Kinematic Investigations

Apart from analyzing the dysfluent speech pattern, a certain group of investigators favoured the usage of fluent speech in PWS to understand the physiological aberrations (Zimmermann, 1980). Past studies indicate physiologic defects in the fluent speech of PWS, including delayed phonatory initiation, disturbed pressure buildup, and differences in subglottal pressure. The majority of them opined that when physiological abnormalities exceed a predetermined threshold, fluency gets impaired (Peters, Hietkamp & Boves, 1994; Peters & Boves, 1988). The finding of speech motor anomalies in the fluent speech of PWS has paved the way for a better understanding of the disorder's neuromotor basis and has clinical implications for stuttering assessment and therapy. The 'kinematic' approach, in which movements of the articulatory structures are recorded using instruments such as Optotrack, 3 Dimensional Electro Magnetic Midsagittal Articulography (EMMA), and others, is one of the methods used to analyze the physiological deviations associated with fluent speech in PWS.

To understand the articulatory movement parameters, the majority of articulatory kinematic research on stuttering study repeated fluent utterances of PWS. The movement analysis is calculated for single point measures such as peak velocity and/or displacement (Zimmerman, 1980) or complete trajectory measures such as Spatiotemporal Index (STI) and Lip Aperture Variability (LAVAR), which include the entire kinematic trace for measurement (Smith, Goffman, Zelaznik, Ying, & McGillem, 1995; Smith & Zelaznik, 2004). Electro Magnetic Midsagittal Articulography (EMMA) is one of the various instruments available for kinematic studies. It allows for the acquisition of articulatory kinematic data by collecting articulatory movements as well as synchronized acoustic data, which can then be analyzed later. The character of the speech motor act involved in distinct articulatory executions is reflected in the articulatory kinematic metrics. Speech motor variability assessments of fluent utterances of PWS could be used to address the phenomena of 'sub-acoustic' stuttering, in which aberrant muscle activity/coordination is not connected with perceivable dysfluency.

Zimmermann (1980a) reported the spatial and temporal kinematic organization of perceptually fluent speech gestures for six stutterers and seven normal speakers are described using high speed cineradiography. Movement characteristics of the CVCs such as /mam/, /pap/, and /bab/ analyse lower lip and jaw movements. The study group consistently demonstrated longer durations between movement onsets, peak velocity attainment, and voice onsets than normal speakers. Additionally, PWS demonstrated a longer steady state position for the lip and jaw during vowel production, as well as a greater degree of asynchrony between the lip and jaw movements. The findings suggest that the organization of events necessary for speech production varies between groups of stutterers and normal speakers in perceptually fluent utterances.

Cinefluorographic techniques at a high speed (150 fps) were used to record articulatory movements during fluent and non-fluent speech from four PWS and control utterances from a normal speaker (Zimmermann, 1980b). The analyses of only 11 perceptually disfluent utterances were presented. The findings highlighted differential interarticulator positions in both perceptually fluent and disfluent utterances of PWS from those in fluent utterances of a normal speaker along with aberrant interarticular positions before the repetitive movements and static posturing in PWS. Lowering of lip and jaw before the termination of repetition or blocks as well as tongue reshaping resembled to that of a fluent production of normal speakers. The systematic repositioning and other aberrant patterns seen in PWS were attributed to the conflicting afferent and efferent inputs of the brainstem.

A follow up study by Zimmerman and Hanley (1983) failed to replicate their own earlier findings of lengthened articulatory durations, and decreased displacement and velocity in PWS in an adaptation task using cineflourography. Three persons with and without stuttering were studied using cinefluorography while repeating a monosyllable. The passage contained CVC target words of the form /caet/, which were used to analyze the velocities, displacements, and durations of tongue, jaw, and lower lip movements along with examining the articulatory coordination. The study was conducted to see if decreased velocities and displacements, longer movement durations, and shorter delay between the onsets of jaw and tongue tip movements were linked to the repeated measurements. The results did not support the hypothesis. A post hoc analysis revealed that practice was related with a decrease in the variability of instantaneous velocities for PWS compared to normal controls.

Electromyographic (EMG) activity of orofacial muscles was recorded during fluent and dysfluent speech in nine children with stuttering (8 boys and 1 girl) and normal children, ranging in age from 2.7 to 14 years (Kelly, Smith & Goffman, 1995). The digastric (ABD), levator labi superior (Upper Lip), and orbicularis oris inferior (Lower Lip) muscles had surface EMG electrodes inserted on their anterior belly. From the conversational speech samples, twenty segments of stuttering and perceptually fluent speech were extracted. Tremor-like oscillations of EMG activity in the upper lip, lower lip, and ABD muscles during stuttering in three oldest children with stuttering were observed. During stuttered and/or perceptually fluent speech, both younger children who stutter and children who do not stutter displayed primary spectral peaks in the 1 to 4 Hz range. It is hypothesized that the appearance of tremor-like instabilities in children who stutter's speech motor processes may correlate with features of their general brain maturation and the development of stuttering. Jancke, Bauer, Kaiser, and Kalveram (1997) investigated the timing and stiffness aspects of jaw movements in PWS at different speech rates. While producing fluent speech, the past studies indicate that there were prolonged jaw opening and closing durations, decreased peak velocities, and reduced maximal opening and closing displacements, which they reasoned were not due to a motor deficit, but rather compensatory adjustments made by PWS to achieve fluent speech.

PWS was found to have incoordination across many articulatory effectors non other studies (Caruso, Abbs, & Gracco, 1988; De Nil & Abbs, 1991; McClean, Kroll, & Loftus, 1990). For oral opening and closing motions in PWS, Caruso, Abbs, and Gracco (1988) examined the movement coordination of the UL, LL, and Jaw. The movement coordination assessments of dynamic composition and inter-movement motor equivalence between PWS and matched controls indicated no significant differences. UL-LL-Jaw peak velocity sequencing was consistent in matched controls, while it was significantly variable in PWS. The findings of subsequent investigations contradicted this finding, leading to the conclusion that UL-LL-Jaw peak velocity sequencing is not required for fluent speech (De Nil & Abbs, 1991; McClean, Kroll, & Loftus, 1990).

Max, Carusso, and Gracco (2003) compared fluent speech utterances, orofacial movements and finger movements of PWS and Normal controls in order to compare the speech and non-speech motor systems in PWS to delineate the presence of any centralized deficit existing in the motor control. Differences were seen in jaw closing and finger flexion movements. However comparable movements were observed between the groups for the orofacial task, leading to the conclusion that PWS may show a centralized deficit for goal-directed movements across unrelated motor systems. Few behavioral studies carried out on these lines did not reveal consistent relationship between speech and non-speech motor tasks (Smith-Bandstra, De Nil, & Saint-Cyr, 2006).

Single point kinematic measures have been used in studies to address somatosensory deficiencies in stuttering (Archibald & De Nil, 1999; De Nil &Abbs, 1991; Loucks, De Nil & Sasisekaran, 2007). PWS have difficulty monitoring small jaw movements in the absence of visual feedback, which is limited to speech movements and not for non-speech movements, according to De Nil and Abbs (1991). Other studies found larger jaw movement amplitude and jaw-phonatory coordination deficits in PWS in the non-visual condition (Archibald & De Nil, 1999; Loucks, De Nil, & Sasisekaran, 2007), which they attributed to a lack of oral kinesthetic feedback that helped control fine speech movements (Archibald & De Nil, 1999; Loucks, De Nil, & Sasisekaran, 2007). Using biting block articulatory perturbation studies, Namasivayam, Van Lieshout, Mcllroy, and De Nil (2008) and Namasivayam, Van Lieshout, Mcllroy, and De Nil (2009) investigated the somatosensory deficits in PWS and found no differences between PWS and No Stuttering (PNS). As a result, more investigation is necessary to reexamine the findings.

Smith, Goffman, Zelaznik, Ying, and McGillem (1995) employed whole trajectory measures because they considered that typical point measures only offer information about a discrete event on an entire movement trajectory and do not take into account the common features that underpin movement control. One such metric is the 'Spatiotemporal Index (STI),' which provides a composite score for an articulator's spatial and temporal variability of utterances repeated for a specified number of times (Smith, Goffman, Zelaznik, Ying, & McGillem, 1995). Another similar measure that is commonly used in the kinematic literature is Lip Aperture Variability (LAVAR). LAVAR is a composite measure of spatial and temporal variability of repeated utterances that may be determined using a difference signal of UL and LL when they are subtracted mechanically (Smith & Zelaznik, 2004). LAVAR gives information on inter-articulatory coordination, whereas STI is an intra-articulatory stability measure (Chakraborty, Goffman & Smith, 2008; Smith & Zelaznik, 2004).

To better understand the impact of language-related variables on stuttering, STI and LAVAR tests are increasingly being used. A variety of linguistic factors, including phonological complexity (Smith, Sadagopan, Walsh, & Weber-Fox, 2010), utterance length and syntactic complexity (Kleinow & Smith, 2000; Maner, Smith & Grayson, 2000;

Sadagopan & Smith, 2008), and prosody in PWS (Goffman, 1999, 2004; Goffman & Malin, 1999; Goffman, Hiesler & Chakraborty, 2006) influence spatial and temporal measures of speech. Smith et al. (2010) investigated the effects of increased phonological complexity on behavioural and kinematic measures (LAVAR) in PWS and non-stuttering individuals (PNS). Participants were asked to repeat nonsensical syllables ranging in length from one to four syllables. Perceptual accuracy judgement as well as LAVAR were used to evaluate the repetitions. In the behavioural repetition tasks, there were no significant differences between the groups. However, there were variations in LAVAR ratings, with the PWS group scoring higher as the phonological length and complexity of the utterances rose, indicating increasing speech motor instability.

The most common linguistic variables examined in kinematic investigations that deal with language and motor interactions in PWS are utterance duration and linguistic complexity. When the length and complexity of utterances are increased, PWS are at an increased risk of speech motor breakdown, according to several studies (Kleinow & Smith, 2000; MacPherson & Smith, 2013; Maner, Smith & Grayson, 2000). When the length and/or syntactic complexity of a bilabial phrase were increased, Kleinow and Smith (2000) assessed the variability in STI scores. When comparing PWS to PNS, the STI for Lower Lip showed an overall rise in PWS. It was also reported that increasing the length and complexity of utterances, rather than just the length of utterances, impacts PWS movement variability. Maner, Smith, and Grayson (2000) compared the STI scores of stuttering children and adults. Due to maturational considerations, children were shown to be more variable than adults, whereas adults only showed greater STI when both length and syntactic complexity were raised. The LAVAR index is significantly variable in CWS when compared to age and gender-matched typically developing children, according to MacPherson and Smith (2013).

These findings show that linguistic processes have a role in speech motor planning and/or programming in general.

Stuttering treatment and Kinematic Investigations

Story, Alfonso, and Harris (1996) investigated the acoustic, respiratory, laryngeal, and articulatory kinematics of three adults with stuttering after they completed the Hollins Precision Fluency Shaping Program. Additionally, the study included two controls who received no treatment. Participants were asked to repeat the target words in the phrasal context "He see CVC again" at self-selected speaking rates of slow, normal, and fast. Pre and post therapy comparisons revealed that the experimental group's acoustic duration of the entire phrase decreased, whereas the controls' acoustic duration increased. Following therapy, inspiratory and expiratory volumes increased and laryngeal opening was prolonged, whereas this was not the case in control subjects. After therapy, the experimental group's lip and jaw articulatory movements for consonants were significantly reduced in amplitude. All of this evidence indicated that behavioral treatment had an effect on the respiratory, phonatory, and articulatory behaviors of individuals who stutter.

Tasko, McClean, and Runyan (2007) examined the movement of articulators, as well as acoustic and respiratory variables, in 35 individuals with stuttering before and after a one-month treatment programme. The amplitude and duration of speech breaths were observed to be increased, while the rate of lung volume change during inspiration was decreased. Lip movement amplitude and speed were decreased, but lip and jaw movement durations were increased. In post-treatment observations, the syllable rate was decreased. A multiple regression analysis revealed that the greatest variance in post-treatment stuttering severity was explained by two respiratory variables and one kinematic variable.

According to the present literature, there are very few investigations on the treatment-related changes in PWS using kinematic measurements. Because some of the outcome measures in this approach have been systematically shown to reflect changes as a function of age, utterance length and complexity, and phonologic/syntactic variations, which are known to be the key factors that differentiate people who stutter from those who do not, kinematic measures provide an added advantage in understanding the physiological deviations in stuttering. This method is well-known for its reliability, as the measured variables may be easily replicated across investigators, settings, and participants, and kinematic measures have remained rather similar across replications. As a result, the current study aims to better understand the effects of short-term treatment of fluency shaping therapy on kinematic changes in native Kannada speakers with stuttering. To that purpose, this research investigates the measurement of the Spatiotemporal Index (STI) (Smith, Goffman, Zelaznik, Ying, & McGillem, 1995) and the kinematic duration of the Lower Lip (LL) for Kannada language word and phrasal stimuli before and after the fluency shaping treatment.

Method

Participants

A total of 10 persons with stuttering (PWS) in the age range of 18-40 years [Mean age = 25.5 (5.40)] were enrolled in the study. Participants were selected from the Fluency Unit of All India Institute of Speech and Hearing, Mysuru. The diagnosis of Stuttering was carried out by a qualified speech language pathologist who was a native speaker of Kannada language. For this purpose, Stuttering Severity Instrument (SSI -3) (Riley, 1994) was used and a severity score was derived after analyzing the speech samples of the participants across different contexts (monologue and reading) and the same is tabulated in Table 1. All the participants were native Kannada speakers and used Kannada as a language for their day-to-day communications. Only those participants who could read Kannada were included as the samples for this study.

Apart from developmental stuttering none of them had a positive history of delay or deviation in language, oro-facial or structural anomalies, hearing problems and psychological problems. Any PWS under the medication for systemic illnesses were excluded. Additionally, participants who underwent fluency shaping therapy in the past six months were excluded from the study design. Participants signed the written Informed consent before enrolling into the study.

Table 1: Demographic data of Participants

Sl. No	Age	Gender	SSI score	Severity
P1	25 year	Male	17	Very Mild
P2	36 year	Male	32	Severe
P3	25 year	Male	26	Moderate
P4	32 year	Female	33	Severe
P5	24 year	Male	32	Severe
P6	21 year	Male	40	Very Severe
P7	24 year	Male	23	Moderate
P8	20 year	Male	28	Severe
P9	29 year	Male	38	Very Severe
P10	19 year	Male	18	Mild

Materials

Stimuli for kinematic recording

As the effect of fluency shaping therapy was explored on bilabial articulatory movements, stimulus words consisting of bilabial consonants (/pɑ/, /bɑ/ and /mɑ/) were constructed. The stimulus tokens was adapted from previous studies that measured bilabial articulatory movements in typical and disordered speech motor control of Kannada speaking population (Mahesh & Manjula, 2016; Mahesh & Manjula, 2020). The first set of stimuli consisted of 3 bilabial bisyllabic Kannada words (eg: /bombe/). All the words chosen had bilabial consonants across first and second syllables. Despite being matched for number of syllables, the chosen words were mostly identical with their syllable shapes, except for the first word which had an extra bilabial consonant in the second syllable position. As Kannada phonemic repertoire has aspirated voiced bilabial, the third word chosen for the study did include a voiced bilabial aspirant in the syllable initial position. With regard to the phrasal stimuli, though the first two phrases had identical syllable number and structure, they differed in the syllable composition. The first phrase was composed with voiced bilabial consonants whereas the second phrase had only unvoiced bilabial consonants. The third phrase was 6 syllables in length, which differed from the earlier two phrases by including a bilabial voiced aspirant [b^h] in the initial position of the second word of the phrase. The bilabial stimulus tokens were made sure that they were within the vocabulary of the participants. The details of the stimulus words and phrases are presented in Table 2.

Table 2: Details of the bilabial stimuli tokens of the study.

Sl. No.	Stimuli tokens	Meaning	International Phonetic Alphabet (IPA)	Syllable structure	No. of Syllables	No. of bilabial sounds
Words						
1.	ಬೊಂಬೆ	Doll	/bombe /	CVCCV	2	3
2.	ಪೀಪಿ	Whistle	/pɪːpɪ/	CVCV	2	2
3.	ಭೂಮಿ	Earth/Land	/b^hUmɪ/	CVCV	2	2
Phrases						
1.	ಬಾಬನ ಬೊಂಬೆ	The doll of baba	/bɑːbənə bombe/	CVCVCV CVCCV	5	5
2.	ಪಂಪನ ಪೀಪಿ	The toy whistle of pampa	/pəmpənɑ pɪːpɪ/	CVCCVCV CVCV	5	5
3.	ಪಾಪಮ್ಮನ ಭೂಮಿ	Land belonging to Papamma	/pəpəmmənɑ b^hUmɪ /	CVCVCCVCV CVCV	6	7

Stimuli for the behavioral measurement of stuttering.

To correlate the kinematic measures with the behavioral moments of Stuttering, both reading and spontaneous speech samples from persons with stuttering were collected and the percentage syllable stuttered was tabulated. The audio-video samples of the five minutes spontaneous speech and reading were recorded during before therapy (R1), after 5^{th} session (R2) & post 10^{th} session (R3), using Sony HDR-PJ540 Handycam. For reading task, the standard Kannada reading passage developed by Savithri and Jayaram (2005) that comprised of 304 was used (Appendix1).

The percentage of syllable stuttered was defined as the percentage of number of moments of stuttering per 100 syllables or number of stuttered syllables in both reading and spontaneous speech.

Treatment protocol

Fluency shaping approach treats the disorder of stuttering by implementing speech motor control techniques by regulating respiration, phonation, articulation and their coordination, which are then shaped to approximate normal sounding speech (Ward, 2006). It is also considered as 'treatments that focus on increasing fluency rather than decreasing the abnormality of stuttering' (Guitar, 2006, pg-286).

Participants underwent 10 days of fluency shaping therapy. Each therapy session was offered for 45 minutes and the following skills were taught for fluency 'shaping'.

- *Easy voice onsets:* Here, the patient slowly initiated the voicing of vocal folds against sudden voicing commonly observed during hard glottal attack. This is practiced on words that begin with vowels and the transition is gradually progressed to longer units of utterances (phrases etc).

- *Light articulatory contacts:* Here, the client was modeled by the clinician to make light articulatory contacts which was facilitated by relaxed articulators with continuous flow of air/voicing.
- *Continuous airflow/phonation:* Here, the client was asked to connect the syllables with continuous phonation without segmenting the words with pauses.
- *Slowed Speaking Rate:* Here, the participants were monitored with a slowed speaking rate of 40-60 syllables per minute by stretching each syllable irrespective of stuttering severity. This was modeled by the clinician in the beginning by stretching vowels, fricatives, nasals, and semi vowels at syllable level.
- *Proprioceptive Feedback:* Here, the clients were encouraged to feel the movements of articulators while speaking slowly with easy voice onset, light articulatory contacts, and continuous phonation/airflow.

The above skills of fluency shaping was modeled and corrected by the clinician wherever necessary. Participants were not advised to practice the learnt skills at home as this was difficult to monitor by the clinician. The therapy was continued up to the maintenance level of the technique and no attempt was made to generalize the learnt skills across other settings until the participants completed the tenth session of the study.

Apparatus

Articulograph AG501 [Electromagnetic Midsagital Articulograph (EMMA)] was used to capture the movements of Lower Lip (LL). Articulograph AG501 allows the digital recording, presentation and evaluation of the movement of articulators during speech production. It helps in capturing the movements of articulators in real time with a time locked acoustic data. The equipment works on the principle of inductive measurement of distances wherein the receiver/sensor coils glued to the articulators develop voltage when the electromagnetic lines of force impedes on it by a group of 9 electromagnetic transmitters.

The strength of the induced voltage/current on the sensors is inversely proportional to the cube root of the distance from the transmitter coils. By measuring the dynamic variations in voltage, the distance of the sensors from the transmitters were computed and inturn the articulatory positions could be captured in real time. Articulograph AG501 provides data in X (Antero-Posterior), Y (Medio-Lateral) and Z (Superior-Inferior) dimensions. For the purposes of the current study, the vertical movement of the articulators (in Z dimension) is reported. Ultra small sensors (1-4mm in length) captured the articulatory movements with a sampling frequency rate of 250 Hz and the acoustic data was captured at 48 kHz sampling rate. The reading passage and spontaneous speech were audio- video recorded using Sony HDR-CX405 Handycam.

Procedure

A. Kinematic recording

Step 1: Calibration of sensors.

Calibration of the Articulograph AG501 was carried out for a dedicated sensor set up of 5 sensors which were required for an experimental recording. Articulograph system was switched on for 30 minutes before calibration to ascertain that the transmitter coils that emit electromagnetic waves reached stable temperature. During calibration, sensors would be attached to the ‘magazines’ of the ‘circal unit’ which in turn is attached to the main system. Figure 1(a) and (b) shows the circal unit along with the magazines. Figure 2 shows the placement of sensors inside the magazine before the calibration. A total of 5 sensors were calibrated to run the experimental trials.

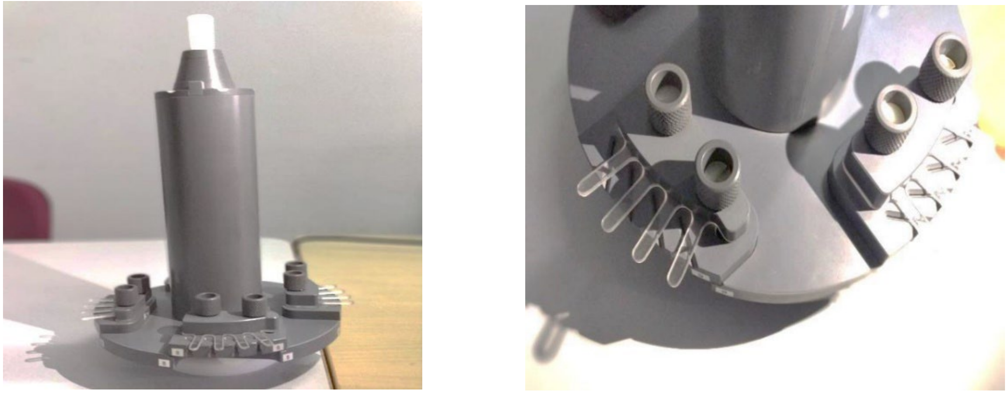


Figure 1(a) Circal Unit of Articulograph AG501 and *1(b)* Magazines used for calibration

Figure 2. Mounted sensors inside the Magazine of Articulograph AG501

Calibration procedures were initiated using the control computer which approximately took 25-30 minutes to calibrate the sensors. After the completion of calibration, the successful number of sensors that were calibrated was automatically displayed on the screen.

Step 2: Experimental Recording.

Skin sites of sensor placement were cleaned using a disinfectant after which sensors were attached using bio adhesive glue (Epiglue). Bio tapes were used on the target skin sites to secure the sensor placements. Four sensors were used, in which two of them acted as reference and the other two as test sensors. Two reference sensors were placed: one on the left mastoid and the other on the nasal bridge. One of the test sensor was placed on mid vermillion border of the Upper Lip (UL), and the other on mid vermillion border of the Lower lip (LL). Figure 3 shows the placement of references and test sensors of the study.

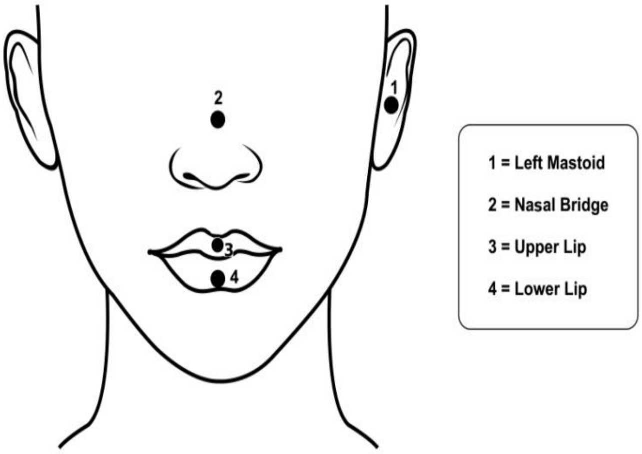


Figure 3. Placements of test and reference sensors of the study

Soon after the calibration, sensors were dipped into a rubber solution (latex milk) and kept for drying fort at least 45 minutes. As the rubber solution formed a thin layer over the sensors, it is easier to remove the glue by peeling the rubber covering after the experimental recording. This reduced the chances of cross contamination of infections across the participants and also made the sensors reusable for next set of experimental trials.

Kinematic and acoustic data of Persons with Stuttering (PWS) was recorded in three time points. First recording was carried out before the participants were enrolled into therapy (R1). Second and third recording was carried out after the fifth (R2) and tenth session (R3) of therapy respectively. Stimuli remained unchanged across the three recordings of kinematic and reading samples but differed for the recording of spontaneous speech. The order of stimuli presentation was counterbalanced for kinematic recording across the sessions. As treatment efficacy was monitored for a short term, only those who were willing to undergo the protocol of fluency shaping therapy for 10 days were included as the participants.

All the participants were instructed to repeat the stimuli in their habitual loudness and speaking rate. An auditory model was provided to the participants for each target stimulus; however, attempts were not encouraged to practice the same before the initiation of experimental trials. During the recording of experimental trials, stimulus tokens were visually presented using Microsoft Power Point on a Personal Computer placed in front of the participant. The participants viewed the written stimuli in Kannada orthography on the computer screen and repeated until 20 fluent iterations were captured.

While recording the speech sample for behavioral analysis of Stuttering, participants were provided with the written handout of the Standard Kannada passage (Savithri & Jayaram, 2005) and were instructed to read in their habitual speaking rate and loudness. Similar instruction was provided while recording the monologue. The order of recording the objective (kinematic) and behavioral (% dysfluency counts) data was counterbalanced across the participants. Participants were instructed to not to use the learnt fluency shaping techniques while recording for kinematic and behavioral analysis of stuttering on 5^{th} and 10^{th} sessions.

Analysis

Kinematic data was processed in two stages. In the first stage, the raw data was fed into 'Calcpos' software which helped in estimating the absolute articulatory positions. The data obtained from the calcpos procedure was further processed using 'Normpos' software (Carstens, Medizenelektronik, Germany) which estimated the relative articulatory positions (with respect to the two reference sensors) by removing the speech independent head movements. In the second stage, kinematic data was imported into the MATLAB software (Math Works, Inc., 2012) for further processing. In the MATLAB environment, baseline drifts and noise were removed using a band pass Butterworth filter. By listening to the acoustic data, only last 10 fluent productions were considered for final analyses.

a) Kinematic analysis

The audio samples of the recorded data were played and any instances of non fluent utterances were noted down. These non-fluent utterances were not included in the kinematic analysis.

Calculation of STI

All the displacement trajectories was filtered to remove low frequency noise component by passing it through a band pass digital Butterworth filter with a cut off frequency of 0.5Hz to 6Hz. The displacement trajectory was differentiated to obtain the velocity signal. The derived velocity signal was band passed to eliminate low frequency noise components. The velocity data was used as the reference to segment the displacement trajectories of individual iterations of LL. During the segmentation, LL displacement trajectory along with LL velocity signal was lined up one below the other, as shown in Figure 4. The initial and final negative velocity peaks from the LL velocity signals were marked for each stimulus repetition as this represented the opening movements of the bilabial consonants (Smith et al., 1995). For instance, the first negative peak associated with the bilabial opening /bɑ/ of /bɑːbənə/and the last bilabial opening movement of /be/ in /bombe/ was used to segment the displacement trajectories of/bɑːbənə bombe/. Following the procedure of segmentation, amplitude and time normalization of the plots was carried out (Smith et al., 1995; Smith, et al., 2000).

The segmented plot was extrapolated to a known factor of 1000 points using cubic spline interpolation and the amplitude was normalized by dividing the mean of the plot by the Standard Deviation (Smith & Goffman, 1998; Smith et al., 1995). On these amplitude-time normalized traces, standard deviations was calculated at every 20th point upto 1000 points making upto 50 standard deviations for 10 fluent iterations and summed up to obtain the Spatiotemporal Index (STI). STI for each stimulus was calculated across the participants of the study. Along with the numerical data, the segmented trajectories of 10 iterations for each stimulus across the participants were saved and these were used in the results section for subjective introspection of the objective findings. In brief, the stability of a given stimulus token is known to be high when the 10 segmented trajectories gets clearly superimposed on one another while the stability is posited to be poor when there is a departure from the above arrangement. An STI plot is a graphic representation of an aggregation of the 10 segmented trajectories superimposed on one another for a given stimulus token of an individual participant.

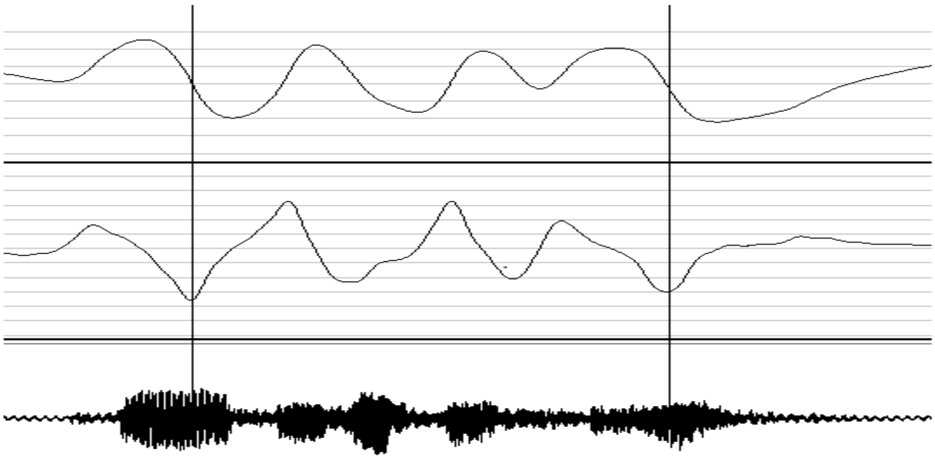


Figure 4: Displacement trajectory of lower lip along with the lower lip velocity trace of the phrase/baːbənə bombe/. Observe the initial and final negative peaks which are used to segment the displacement trajectories.

Calculation of Kinematic Movement Duration of Lower Lip (LL).

Visartico software was used to calculate the LL movement duration (Ouni, Mangeonjean & Steiner, 2012). The displacement trajectory of LL and the velocity of the same were (fluent iterations) lined one below the other. The first and last negative velocity peaks were marked and the corresponding time points were noted down which represented the total duration of LL for a given iteration. Likewise, the duration of 10 fluent iterations for a given stimulus was averaged for each participant.

b) Speech Analysis

Behavioral dysfluencies were analyzed by calculating the percentage syllables stuttered. Stuttering dysfluencies such as repetitions (audible and inaudible), prolongations (audible and inaudible) and blocks were measured separately for reading and monologue samples to calculate the percent syllable stuttered from PWS. The formula to calculate the percent syllable stuttered is:

$$Percentage\ syllable\ stuttered = \frac{Number\ of\ syllables\ stuttered}{Total\ Number\ of\ syllables} \times 100$$

Statistical Analysis

The dependent variables included in the study were LL movement duration, STI of LL and stuttering frequency. The mean measurements of these dependent variables recorded across R1, R2 and R3 sessions for bilabial words and phrases were calculated using SPSS 21 software (IBM Corp. 2012). Normality of the data was examined using Shapiro-Wilk's test which revealed normal distribution for kinematic and non-normal distribution for behavioural data, and therefore, parametric test for kinematic and non-parametric statistical tests were chosen for the final analysis of the data. The mean STI, LL duration and frequency of stuttering data would be compared between the three sessions of recording at 95% confidence intervals. The mean LL duration and STI was checked for its correlation with behavioral frequency of stuttering using a non-parametric correlation test.

Results

The study aimed to analyze the short term effects of fluency shaping therapy on kinematic and behavioral measures for Kannada bilabial words and phrases in Adults with Stuttering (AWS) and to correlate the same with the frequency of stuttering. As the first objective, the study analyzed two kinematic measures recorded using Articulograph AG501 on AWS i.e., Lower Lip (LL) movement duration and Spatiotemporal Index (STI) of LL following short term fluency shaping therapy of 10 sessions. In the second objective, LL movement duration and STI of LL was correlated with the frequency of stuttering (percentage of syllable stuttered) calculated for monologue and reading tasks in Kannada. Short term effects of fluency shaping therapy on dependent variables [LL movement duration, STI of LL and frequency of Stuttering] was measured across 3 instances i.e. before initiating therapy (R1), after 5^{th} session (R2) and after 10^{th} session (R3) of the same.

Lower Lip (LL) movement duration and STI of AWS across the recordings (R1, R2 & R3) were checked for normality using Shapiro-Wilk's method. Results revealed that the movement duration were normally distributed across the three recordings ($p > 0.05$), except for the word /pipi/ in the first recording (R1). With regard to STI, all the data showed normal distribution except for R1 of /babana bombe/, and R2 of /pampana pipi/ ($p > 0.05$). Frequency of Stuttering calculated in terms of percentage syllable stuttered did not show normality across the recordings ($p < 0.05$). Hence, the parametric test of one way repeated measure ANOVA and the non-parametric Freidman's test were used to analyze kinematic and behavioural dysfluencies of stuttering respectively.

To correlate the behavioral and kinematic measures, Spearman's Rank correlation coefficient was utilized. For the ease of reporting the results, the following abbreviations are used for the stimuli of the study: 1) /bombe/ as Word 1 [W1] 2) /pɪːpɪ/ as Word 2 [W2] and

3) /b^hUmɪ/ as Word 3 [W3] 4) /bɑːbənə bombe/ as Phrase 1 [P1] 5) /pəmpənɑ pɪːpɪ/ as Phrase 2 [P2] and 6) /pəpəmmənɑ b^hUmɪ/ as Phrase 3 [P3].

The results of this study are discussed under the following sections

Section 1

1.1. Short-Term Effects of Fluency Shaping on Lower Lip (LL) Movement Duration on Bilabial Kannada Words in AWS

A one way repeated measure ANOVA was performed to compare the short term effects of fluency shaping therapy on Lower Lip (LL) movement duration on bilabial words between R1, R2 and R3 conditions. The results showed that, though the mean score of LL movement duration changed with therapy, it was not statistically significant [W1, F (2, 18) = 2.42; W2, F(2,18) = 0.27; W3, F(2,18) = 0.21] with $p > 0.05$. Table 1 shows the LL movement duration averaged for 10 fluent iterations for each participant of the study.

Table 1

Lower Lip (LL) Movement Duration for Bilabial Kannada Words for R1, R2 and R3 Treatment Phases in AWS.

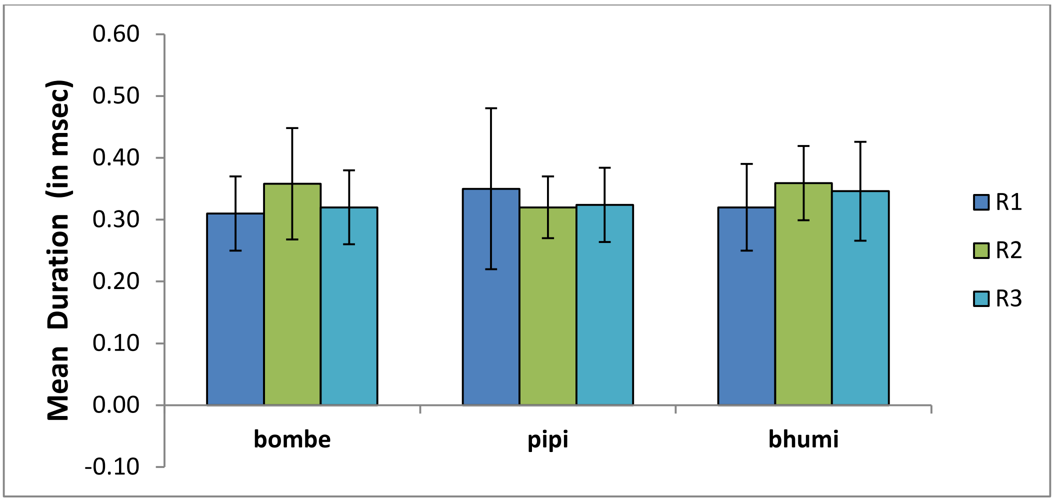
Participants	Lower Lip Movement Duration (in seconds)								
	/ bombe/			/pɪːpɪ/			/b^hUmɪ/		
	R1	R2	R3	R1	R2	R3	R1	R2	R3
P1	0.28	0.30	0.34	0.68	0.30	0.30	0.33	0.29	0.29
P2	0.25	0.31	0.31	0.24	0.32	0.32	0.25	0.34	0.34
P3	0.26	0.31	0.27	0.24	0.35	0.28	0.29	0.32	0.32
P4	0.42	0.39	0.39	0.44	0.41	0.42	0.43	0.45	0.42

P5	0.39	0.43	0.39	0.43	0.37	0.40	0.41	0.42	0.46
P6	0.28	0.54	0.32	0.28	0.37	0.31	0.26	0.42	0.31
P7	0.37	0.42	0.46	0.37	0.25	0.42	0.38	0.39	0.49
P8	0.35	0.37	0.31	0.29	0.38	0.31	0.38	0.38	0.32
P9	0.28	0.27	0.25	0.28	0.27	0.26	0.28	0.32	0.26
P10	0.25	0.25	0.24	0.24	0.25	0.24	0.25	0.26	0.25

Figure 1 represents the mean lower lip movement duration and SDs of bilabial words (W1, W2, & W3) in R1 (Before initiating therapy), R2 (after 5th) and R3 (after 10th). A common trend of increased Mean LL duration in R2 was observed for W1 and W3 whereas an opposite trend of reduced LL duration was seen for W2. For comparison of R1 to R3, both W1 and W3 have shown an increase in duration of lower lip movement with therapy. The word /pipi/ has shown an opposite trend, i.e., a reduction in mean lower lip movement duration with the fluency therapy. These changes did not reach statistical significance at 95% confidence intervals.

Figure 1

Mean Lower Lip Movement Duration and SDs of Words for R1, R2 and R3 Treatment Phases in AWS



1.2 Short-Term Effects of Fluency Shaping Therapy on Lower Lip (LL) Movement Duration on Bilabial Kannada Phrases in Adults with Stuttering

Comparison of LL movement duration of Bilabial Kannada Phrases across R1, R2 and R3 treatment conditions using one way repeated measure ANOVA did not show any statistical significance ($p > 0.05$) [P1, $F(2,18) = 1.60$; P2, $F(2, 18) = 0.13$; P3, $F(2, 18) = 0.72$]. Table 2 shows the LL movement duration averaged for 10 fluent iterations produced by each participant across treatment phases.

Table 2

Lower Lip (LL) Movement Duration for Bilabial Kannada Phrases for R1, R2 and R3 Treatment Phases for Participants of the Study.

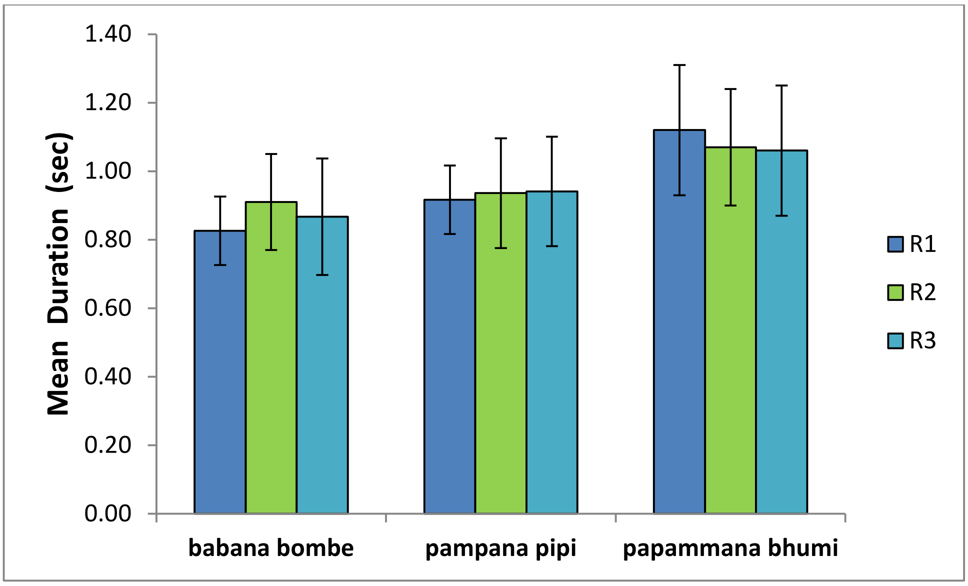
Participants	Lower Lip Movement Duration (in sec)								
	/bɑːbənə bombe/			/pəmpənɑ pɪːpɪ/			/pəpəmmənɑ b^hUmɪ /		
	R1	R2	R3	R1	R2	R3	R1	R2	R3
P1	0.79	1.06	0.75	1.03	0.89	0.91	1.04	0.97	1.05
P2	0.75	0.79	0.74	0.80	0.88	0.88	1.01	1.13	1.12
P3	0.72	0.82	0.75	0.93	0.81	0.80	0.96	0.98	0.91

P4	0.94	0.96	1.09	0.98	1.23	1.09	1.17	1.35	1.20
P5	0.98	1.03	0.96	0.97	1.08	1.13	1.39	1.17	1.19
P6	0.79	1.13	0.80	0.97	1.12	0.86	1.19	1.02	0.93
P7	0.95	0.84	1.19	0.96	0.84	1.26	1.50	1.03	1.50
P8	0.93	1.05	0.96	1.00	0.96	0.99	1.17	1.33	1.05
P9	0.74	0.73	0.68	0.82	0.82	0.74	0.95	0.95	0.90
P10	0.69	0.69	0.75	0.72	0.72	0.77	0.89	0.79	0.81

Figure 2 represents the mean LL movement duration and SDs for bilabial phrases of all the study participants. It could be observed from figure 2 that no clear trends were readily apparent in the mean kinematic duration of LL of AWS following fluency shaping therapy.

Figure 2

Mean Lower Lip Movement Duration and SDs of Phrases for R1, R2 and R3 treatment phases in AWS



1.3 Short Term Effects of Fluency Shaping Therapy on Mean STI of Bilabial Kannada Words in AWS

Table 3 shows the STI computed for each participant for bilabial Kannada words. The data reflected the changes in articulatory stability of LL for 10 AWS that was measured for R1, R2 and R3 treatment phases of therapy. A one way repeated measure ANOVA was conducted to analyze the effect of fluency shaping therapy on speech motor stability as indexed by STI of LL. Change in STI following fluency shaping therapy was not significant ($p > 0.05$) for any bilabial Kannada words of this study (W1, $F(2,18)= 0.36$, $p= 0.69$; W2, $F(2,18)= 0.44$, $p= 0.64$; W3, $F(2,18)= 0.02$, $p = 0.97$).

Table 3

Spatiotemporal Index for Bilabial Kannada Words across R1, R2 and R3 Treatment Phases in AWS

Participants	STI		
	/ bombe/	/pɪːpɪ/	/b^{h}Umɪ/

	R1	R2	R3	R1	R2	R3	R1	R2	R3
P1	61.71	73.70	53.68	45.23	45.42	40.56	26.09	46.82	24.47
P2	65.70	64.60	40.95	67.54	55.72	53.66	44.07	36.71	51.62
P3	34.69	50.05	31.06	18.85	38.66	53.29	45.09	46.62	69.81
P4	33.18	43.35	29.12	28.58	31.55	35.17	28.10	34.11	26.27
P5	42.44	38.97	33.83	26.36	32.10	30.60	30.17	33.32	34.35
P6	52.81	27.79	44.76	42.80	37.82	40.13	73.70	35.63	57.27
P7	53.78	30.10	60.14	35.44	44.42	18.41	52.71	40.76	23.02
P8	44.15	53.51	28.03	33.70	67.31	45.04	37.84	51.49	47.95
P9	55.54	78.29	77.52	68.97	79.46	49.49	107.57	75.28	116.22
P10	36.28	44.93	60.06	47.88	37.77	81.82	53.99	90.78	55.85

The mean STI and their SDs of bilabial words across R1, R2 and R3 treatment phases are represented in Figure 3. The movement data of an individual sample representing the STI is shown in Figure 4. A trend of increased STI was observed following treatment in W2 and W3 whereas a reduction in instability was noticed in W1. The kinematic profile corroborates the mean STI data of PWS as no consistent changes were seen in the kinematic trajectories of this sample when the treatment effect was measured.

Figure 3

Mean STI score of bilabial Kannada words for R1, R2 and R3 treatment phases in AWS

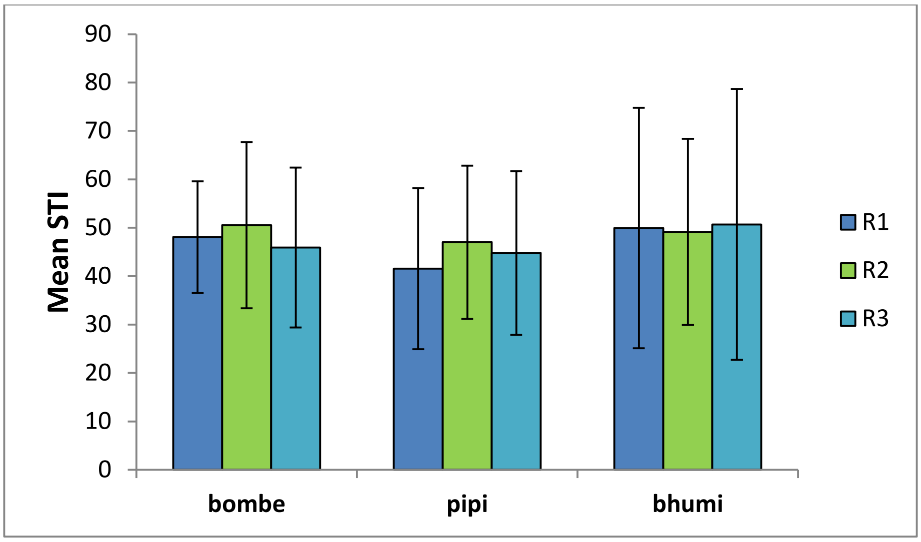
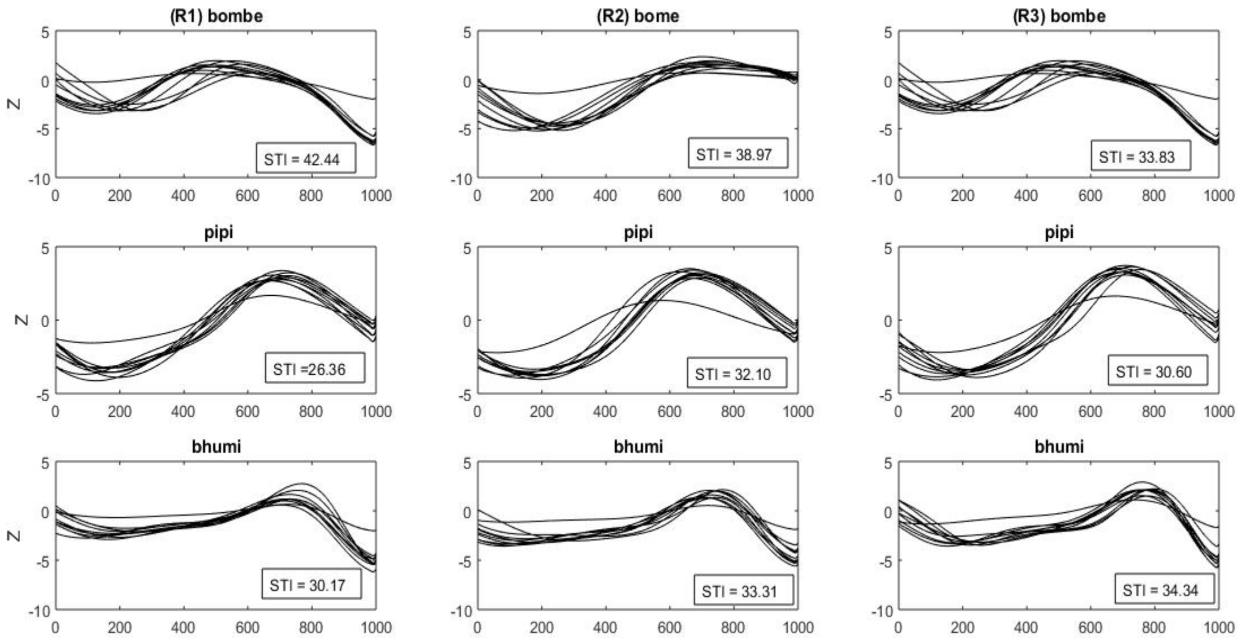


Figure 4

An amplitude-time normalized kinematic profile of an individual with stuttering for bilabial Kannada words across treatment sessions.



1.4 Short Term Effects of Fluency Shaping Therapy on Mean STI of Bilabial Kannada phrases in Adults with Stuttering.

The STI data of each participant across R1, R2 and R3 Treatment phases for 3 Kannada bilabial phrases is tabulated in Table 4. Mean STI of AWS did not change statistically between the treatment phases as observed through Repeated Measure ANOVA analysis [P1, $F(2,18) = 2.75, p = 0.09$; P2, $F(2,18) = 0.78, p = 0.47$; P3, $F(2,18) = 0.04, p = 0.95$].

The Mean STI score of bilabial phrases across three recordings (R1, R2 & R3) is shown in Figure 5. An increasing stability was witnessed for Phrase 1 where the mean STI score decreased from R1 to R3. For the phrase 2, the mean STI score decreased from R1 to R2 and then increased from R2 to R3. No change in mean STI score was observed for phrase 3 across treatment phases.

Table 4

Spatiotemporal Index of AWS for Bilabial Kannada Phrases across R1, R2 and R3 Treatment Phases

Participants	STI								
	/bɑːbənə bombe/			/pəmpənɑ pɪːpɪ/			/pəpəmmənɑ b^hUmɪ /		
	R1	R2	R3	R1	R2	R3	R1	R2	R3
P1	28.33	35.28	15.43	15.35	23.04	24.05	18.29	19.53	21.58
P2	37.47	31.90	32.33	29.27	24.37	26.96	41.53	36.04	34.36
P3	22.99	26.02	27.54	39.90	24.83	40.12	17.31	27.12	22.46
P4	28.29	27.49	20.06	22.08	24.57	33.02	31.20	22.30	22.13
P5	30.93	18.05	29.15	21.25	22.82	20.71	45.49	39.64	30.82
P6	57.27	44.33	31.92	31.63	49.62	31.03	19.15	29.49	62.86
P7	32.32	18.05	17.57	24.69	22.82	17.04	33.03	22.30	15.32
P8	54.14	30.13	34.37	49.93	36.64	37.39	39.76	31.52	38.59
P9	33.70	39.24	24.59	37.55	20.29	34.95	29.35	54.19	21.96

P10	30.56	47.22	42.15	40.72	33.47	59.78	40.28	34.90	34.01

Figure 5

Mean STI and SDs of bilabial Kannada phrases for R1, R2 and R3 treatment phases in AWS

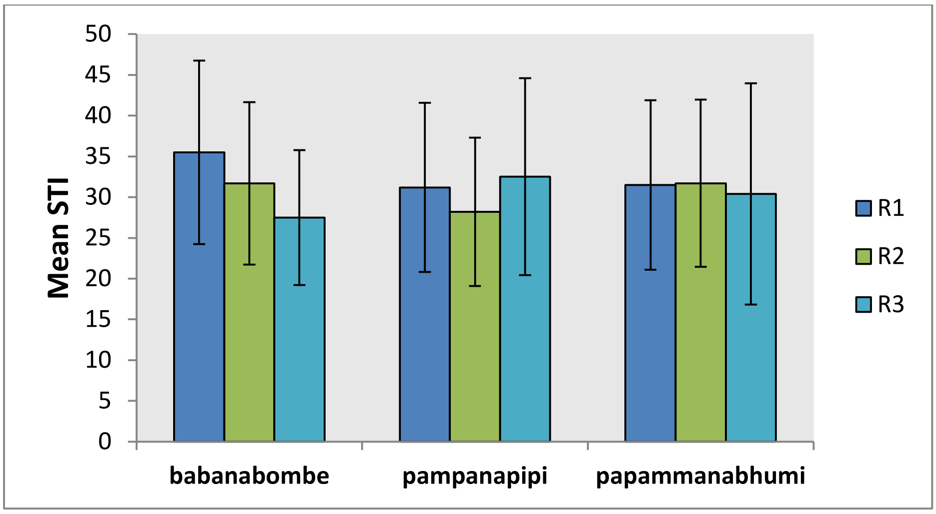
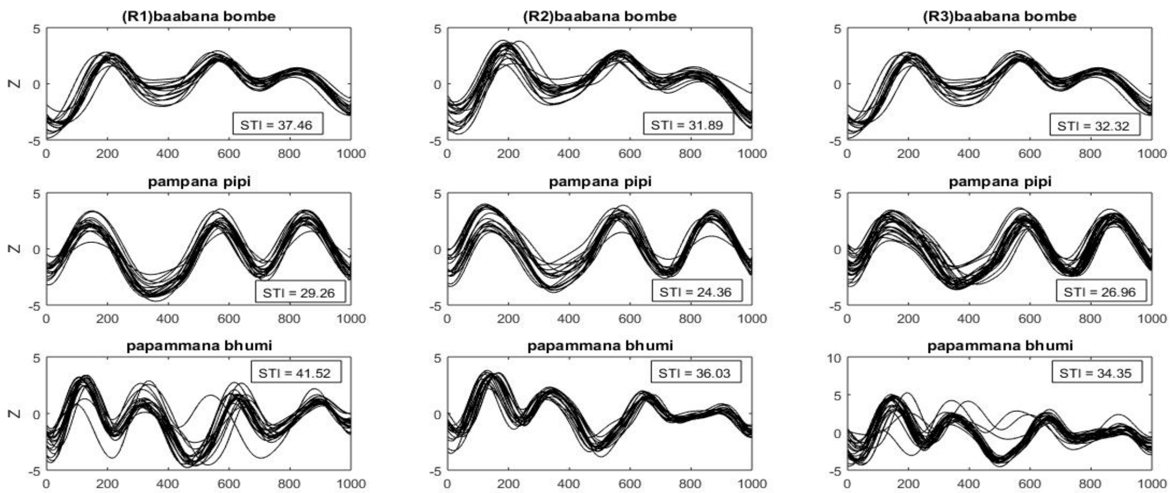


Figure 6 shows a kinematic profile of an AWS. The movement trajectories showed an inconsistent change for bilabial Kannada phrases across treatment sessions.

Figure 6

An amplitude-time normalized kinematic profile of an individual with stuttering for bilabial Kannada phrases across treatment sessions.



Section II.

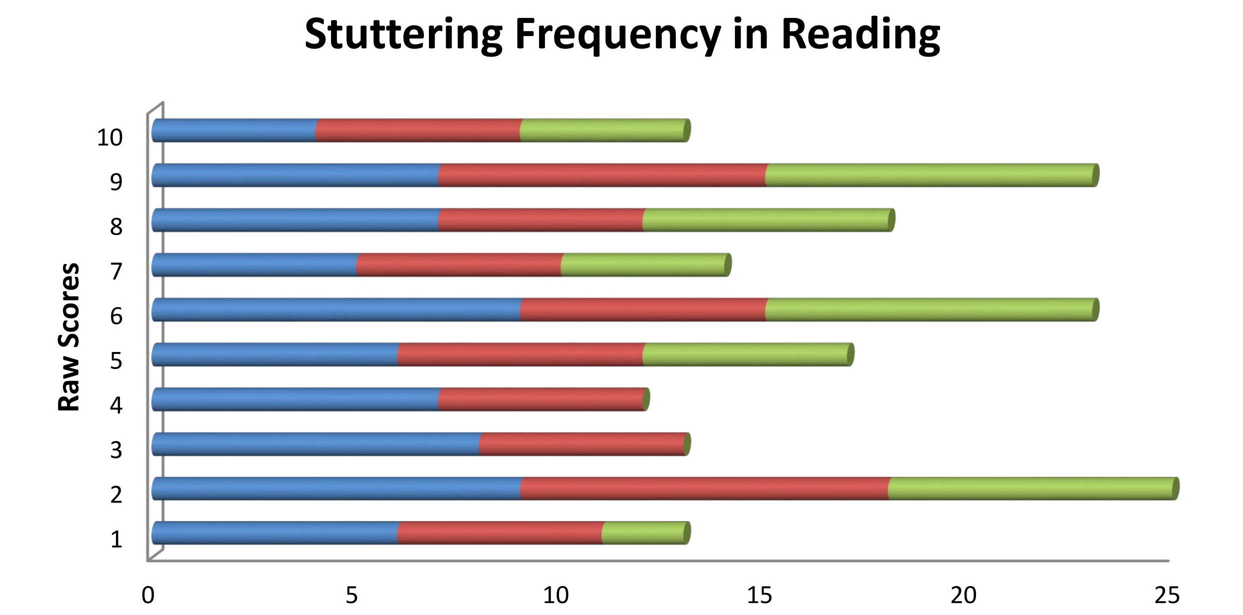
This section deals with the behavioral changes in stuttering frequency following fluency shaping therapy measured for the tasks of reading and monologue.

2.1 Short Term Effects of Fluency Shaping Therapy on Mean Stuttering Frequencies of reading in AWS.

As described earlier, frequency of Stuttering was calculated before (R1), at 5th (R2) and after 10th Session of fluency shaping therapy. The stuttering frequency of AWS in the reading task is shown as Figure 7.

Figure 7

Frequency of stuttering in Reading for R1, R2 and R3 treatment phases in AWS



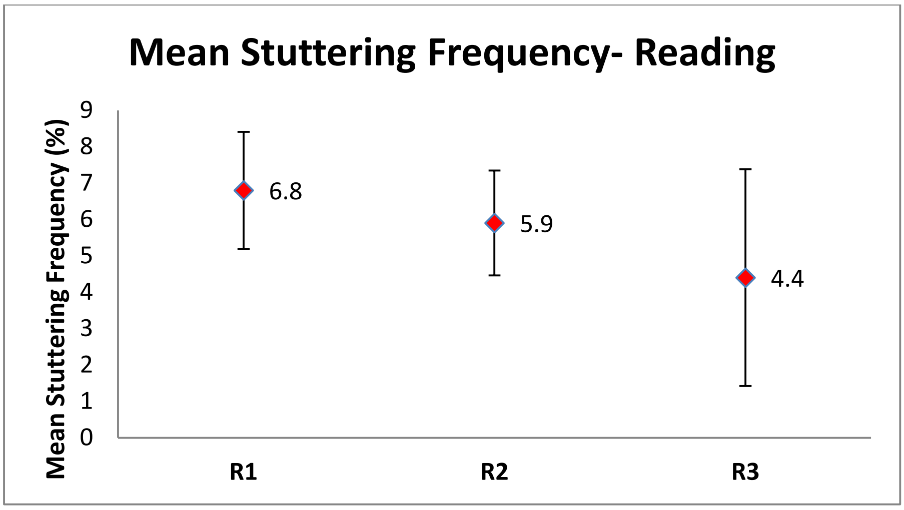
	1	2	3	4	5	6	7	8	9	10
R1	6	9	8	7	6	9	5	7	7	4
R2	5	9	5	5	6	6	5	5	8	5
R3	2	7	0	0	5	8	4	6	8	4

It is inferred from the figure that there was an overall decline in stuttering frequency in second (R2) and third recordings (R3) for reading showing a positive effect of fluency shaping therapy on behavioral dysfluencies. It is worthwhile to note that participants 3 and 4 showed no dysfluencies in the final treatment phase.

Comparison of mean Stuttering frequency between the treatment phases for the reading task was analyzed using Friedman's test. Result were statistically significant for the stuttering frequency in reading [χ^2 (2) = 7.08, p = 0.02]. Wilcoxon Signed Rank test was used to compare the Post hoc analysis of the stuttering frequency between the treatment phases. Results revealed a statistically significant difference in the frequency of stuttering in R1 Vs R3 (/z/= 2.35, *p*= 0.019, *p* = 0.01). Comparison were not significant between R1 Vs R2 (/z/= 1.70, *p*= 0.08) and R2 Vs R3 (/z/= 1.73, *p*= 0.08). Figure 8 shows the mean stuttering frequency for the reading task. It could be inferred from the below data that the percent syllable stuttered showed a declining trend from R1 to R3 but the mean scores were statistically significant only between R1 and R3.

Figure 8

Mean Stuttering Frequency and SDs in Reading for R1, R2 and R3 in AWS

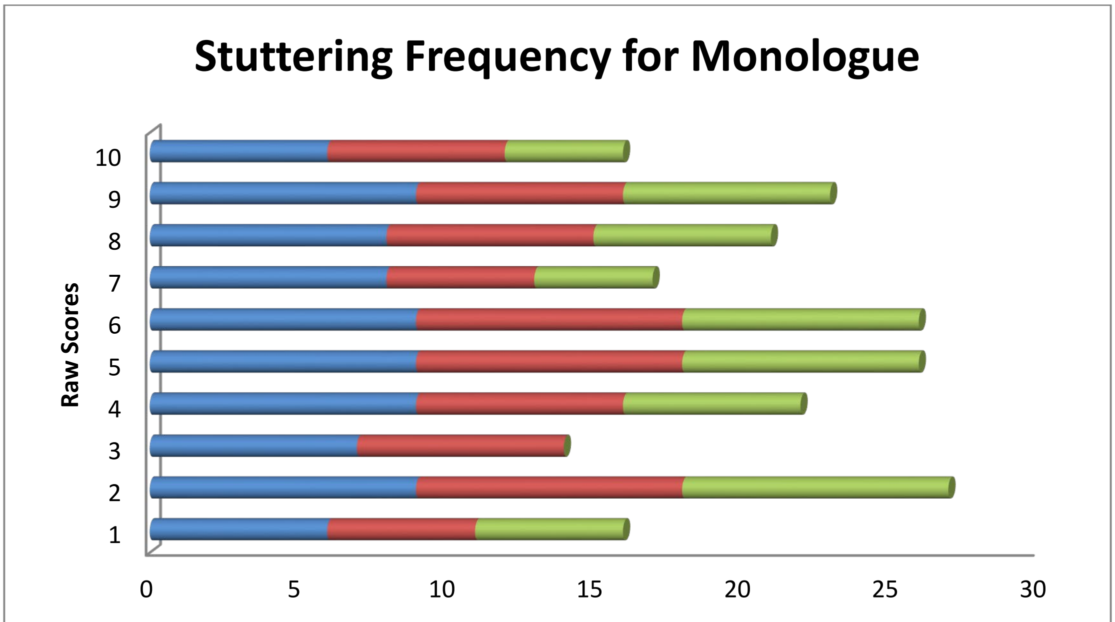


2.2 Short Term Effects of Fluency Shaping Therapy on Mean Stuttering Frequencies of monologue in AWS.

Stuttering frequency shown in Figure 9 depicts the percent syllable stuttered for monologue for each participant (N =10) across the treatment phases. It could be inferred that the stuttering frequency declined among the participants during the monologue after therapy in second (R2) and third (R3) recordings. It could be observed that participant 3 had reduced the dysfluencies to nil in the final phase of the treatment.

Figure 9

Frequency of stuttering in Reading for R1, R2 and R3 treatment phases in AWS



	1	2	3	4	5	6	7	8	9	10
R1	6	9	7	9	9	9	8	8	9	6
R2	5	9	7	7	9	9	5	7	7	6
R3	5	9	0	6	8	8	4	6	7	4

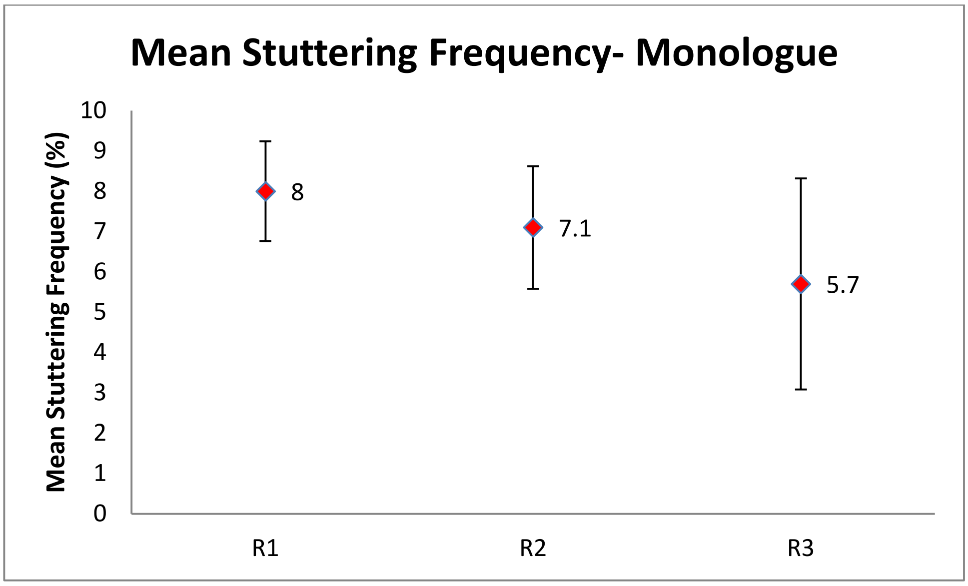
Comparison of mean Stuttering Frequency in monologue between the treatment phases using Friedman's test revealed high statistical significance [χ^2 (2) = 15.20, p = 0.001]. Paired comparison of the treatment phases on stuttering frequency using Wilcoxon Signed Rank test showed high statistical significance between R1 and R3 [/z/= 2.68, p= 0.01, p <

0.01]. Mean stuttering frequency also differed in monologue tasks for R1 Vs R2 [/z/= 2.04, p = 0.04] and R2 Vs R3 treatment phases [/z/= 2.45, p = 0.01].

The data of mean stuttering frequency shown in figure 10 unravels the changes in the behavioral dysfluencies in AWS between the treatment phases. Such changes indicate the impact of fluency shaping therapy on speech dysfluencies in AWS. It is to be noted that the observed behavioral changes in stuttering dysfluencies were robust for monologue in relation to reading tasks.

Figure 10

Mean Stuttering Frequency and SDs in Monologue for R1, R2 and R3 treatment phases in AWS



SECTION 3

In this section, kinematic measures were correlated with the behavioral measures of stuttering dysfluencies in AWS. This was carried out separately for LL movement duration and mean STI scores obtained from the study participants

Spearman correlation coefficient was used to understand the correlation between mean LL movement duration and frequency of stuttering measured for reading and monologue tasks. No significant correlation (p>0.05) was observed between the stuttering frequency and LL movement duration for bilabial Kannada words in R1 and R3 condition. In R2, a borderline correlation (ρ=0.55, p= 0.09) was observed for lower lip movement duration for /pipi/ and frequency of stuttering in monologue. Though results showed positive correlation for bilabial Kannada phrases across three treatment phases (R1, R2 and R3), it was statistically insignificant (p> 0.05).

Correlation analyzed between STI of LL for bilabial Kannada words and behavioral measure of stuttering frequency across reading and monologue tasks. Though most of the correlations were insignificant, the word /bhumi/ in R2, showed marginal negative correlation (ρ = -0.57, p= 0.08) with the stuttering frequency in monologue. No significant correlations were observed between mean STI of LL for Kannada phrases with measures of stuttering frequency across reading and monologue tasks.

Discussion

The present study aimed to find out the short-term effects of fluency shaping therapy on kinematic and behavioral measures for Kannada bilabial words and phrases in adults with Stuttering (PWS) and toexamine the relation between both the measures. To study the kinematic measures, Lower Lip movement duration and mean Spatiotemporal Index (STI) were analyzed and correlated the same with the frequency of stuttering in monologue and reading.

Effects of Fluency Shaping Therapy on Lower Lip (LL) movement duration and STI

By providing fluency shaping therapy, it was expected that the lower lip movement duration would increase, as studies have pointed out longer movement durations following therapy (Zimmerman, 1980; Tasko, McLean &Runyan 2007; Mclean, Kroll & Loftus, 1990). This occurs due to the targeted practise of slowed articulatory executions, which is one of the main elements of fluency shaping procedures. In the current study, statistically we did not see differences in the averaged lower lip movement durations (n=10) after fluency shaping therapy, recorded at two instances, i.e., first after the 5th session (R2) and second after the 10th session (R3). This was true for both words as well as for the phrasal stimuli used in the study. Also, no differences were observed for STI measures when the pre treatment baseline (R1) was compared with the first (R2) and second (R3) post treatment speech recordings. Our findings contradict a few of the handful of studies that reported speech kinematic changes following treatment (Mclean, Kroll & Loftus, 1990; Metz et al. 1983; Samar et al. 1986, Story et al. 1996; Tasko et al. 2007). Story et al. (1996) reported a consistent decrease in the amplitude of the articulatory closure and release gestures for bilabial and labiodental monosyllabic words embedded in a carrier phrase context for 3 AWS following a 19day

Precision Fluency Shaping Programme (PFSP) developed by Webster (1979). Tasko et al. (2007) reported reduced amplitude and speed of lip movements and increased duration of lip and jaw movements following the Walter Reed Stuttering Treatment Program, where the treatment was administered for a 1-month duration. The findings were based on the opening and closing movements of sound /b/ in the word ‘bad’ and only the closing phase of /b/ in ‘daeba’, which was recorded in a non-sense phrase/a bad daeba/.

The differences between our findings and those studies could be due to the measured variable and the treatment duration provided to the participants. First, in the current study, we employed a holistic or global measure of spatial and temporal variability, i.e., the STI of LL, which reflects the overall motoric variability in the patterning of LL for an utterance repeated over time, along with a temporal measure of LL movement duration. In contrast, previous studies have focused on variations in "point measures" such as amplitude, displacement, speed, velocity, and duration that address changes in either spatial or temporal variability of spoken utterances individually but not holistically after treatment. At this point, as per our knowledge, there are no reports suggesting a correlation between point and global measures (such as STI) that reflect articulatory changes following treatment. Therefore, unchanged STI following treatment cannot be directly related to the observed amplitude/displacement and speed differences of the previous studies. Adding complexity to this observation is the inconsistency of measuring these point data on the kinematic trajectories of each articulator compared to the whole trajectory measure (i.e., STI). To further augment our observation, it is to be noted that the peak displacement changes following PFSP treatment in the study of Story et al. (1996) were reported as a cumulative change in the overall displacement of UL, LL, and Jaw for lip closure but not for each articulator separately. Furthermore, because of their consistency, recent studies have favored reporting on global variations in speech motor control as indexed by measures such as STI and Lip Aperture Variability (LAVAR) in normal and disordered populations(Usler, Smith & Weber, 2017; Usler& Walsh, 2018).

Second, in the current study, 10 continuous sessions of fluency shaping were provided and the treatment changes were measured twice i.e., once after the 5th session and the other at the completion of the 10th session.In contrast, previous studies that reported treatment related changes on kinematic measures have followed a treatment package that lasted nearly a month (Story et al., 1995; Tasko et al., 2007). These studies completed the fluency shaping protocols and compared the pre and post treatment effects on selected dependent factors including the kinematic measures. We speculate that our treatment duration, despite targeting every essential skills of fluency shaping to that of the previous studies, was considerably short and this might have reduced the influence to observe any appreciable changes on the selected kinematic variables. Also, as our objective was to report the findings of only short-term changes of treatment, we did not record the data after the initiation of transfer and maintenance phases of treatment that used to occur more or less after 15 sessions of treatment.Additionally, we posit that STI and LL movement duration (for both words and phrases) is not very sensitive for short term treatment effects. It needs to be seen through further investigations on the minimal number of treatment sessions that produces discernible changes on kinematic measures like STI and LL movement duration.

Our finding of no significant differences in LL movement duration is partly in consonance with few of the earlier investigations that measured post therapy acoustic duration in PWS. Onslow, Doom and Newman (1992) investigated the changes in acoustic durations after prolonged speech treatment in 10-year-olds who have not received any similar treatment before.The preand posttreatment acoustic data was collected from spontaneous speech samples. The duration of the acoustic segments did not showany significant change after the treatment.On the other hand, the vowel duration and the articulation rate showed a noticeable reduction in variation. The authors warranted that further studies are required to understand this phenomenon as theirs study explored the spontaneous speech samples which was until then inferred using non spontaneous speech tokens readymade phrases or words. This study indicates that despite no change in acoustic duration changes in speech fluency could still be observed. We hypothesize that this could be the case in our study as it is explained in the upcoming section that we did see a decrease in the reduction of stuttering frequencies with no changes in the kinematic measures.

Finally, our study may also indirectly support the notion of speech motor 'skill limitations' in PWS as documented in some of the previous studies(Ludlow, Siren &Zikria, 1997; Smits-Bandstra, De Nil & Saint-Cyr, 2006).The underlying speech motor skill deficiencies associated with PWS necessitate long-term speech motor'skill training' and'self-monitoring,' which are difficult to attain in a short-term programme like the one used in this study. According to our findings, the initial improvement in the reduction of perceptual dysfluencies following fluency shaping therapy necessitates cautious treatment because clinical decisions are heavily reliant on these measures, which may or may not reflect the subtle speech motor skill inadequacies observed in this population.

Effects of Fluency Shaping Therapy on Stuttering Frequency across monologue and reading tasks

Comparison of the short terms effectsof fluency shaping therapy on behavioral measuresshowed statistically significant difference in the frequency of stuttering in both reading and monologue. In reading task, it was observed that the baseline measurement of stuttering frequency i.e., R1 showed differences with R3, and no other comparisons were statistically significant. In contrast, both R2 and R3 measurements of mean stuttering frequency significantly differed with the baseline measure i.e., R1.These findings of reduced stuttering frequency following short term fluency shaping is in line with few of the earlier investigations who also carried out short term treatments to improve the behavioral dysfluencies in PWS (Howie, Tanner andAndrews, 1981; Laiho&Klippi, 2007).

Variations in stuttering frequencies were observed across the speaking tasks used in the current study. Dysfluency rate in oral reading were significant from baseline only after the end of 10th session i.e., no changes in stuttering frequency for reading was seen during the first assessment following treatment (R2). Reduced syntactic or semantic flexibility that are inherent to reading tasks may have reduced the overall changes in the stuttering frequencies while reading. On contrary, as per the EXPLAN theory, the upcoming speech motor plans has to be ready for continuous speech execution in monologue(spontaneous speech) tasks (Howell, 2004).As semantic and syntactic formulation of the utterance construction here depends on the person, an instantaneous generation of speech motor plans/programs needs to be created for continuous speech delivery. As speech motor planning/programming is a challenging task for a person who stutter, even a slightest aberration in creating such plans could lead to dysfluencies. We opine that, fluency shaping therapy addresses such challenges and thereby reduces the dysfluency rate as it provides additional time in planning and executing the utterances in PWS. Therefore, positive changes that reduced the dysfluencies in monologue tasks were continuously seen throughout the therapy in this study which was observed during our first (R2) and second (R3) post therapy evaluations. Although our data suggests that dysfluency rates were greater in monologue than in oral reading, it was not our objective to compare dysfluency rates between the tasks.

Correlation between LL movement duration and STI with LL movement duration and behavioral measure of stuttering frequency

Largely it was observed that there was no statistically significant correlation observed between kinematic measures and stuttering frequency. It needs to be observed that, compared to the baseline, the behavioral measures of stuttering showed changesafter treatment. This trend was more consistent for the task of monologue than for oral reading. By now it is known that fluency shaping did not influence the measuredkinematic parameters of our study. Therefore, we speculate here that the lack of correlation between the two measures could be due to the unchanging STI and LL movement duration across the words and bilabial phrases undertaken in the study. Apart from that, we suggest that the type of the tasks employed to collect kinematic data and stuttering frequency may have altered these associations in unforeseen ways. It is known that kinematic measures were calculated for repeated iterations of bilabial words and phrases whereas the frequency of stuttering was calculated on a common template of continuous running speech. While it is well established that kinematic tests accurately capture subtle speech motor instabilities, the extent to which this correlates with a behavioural measure such as stuttering frequency is largely unknown in the literature. Very few studies have reportedbehavioral and the kinematic measures following a fluency treatment, but did not use correlation methods to examine their association (Tasko et al.,2007; Story et al., 1996). Tasko et al. (2007) reported a significant reduction in the stuttering frequency following a 1 month long Hollins precision fluency programme in 35 individuals with stuttering. Reduced amplitudeand speed of lip movements with prolonged lip and jaw movement durations were observed which coincided with reduced speaking rate in PWS. Similar study by Story et al (1996) revealed consistent reduction in summated amplitude and their displacements of Upper Lip, Lower Lip and Jaw following Hollins Precision Fluency Shaping programme. It needs to be noted that Tasko et al., and Story et al's study used the 'point measures' to correlate with the behavioural changes of stuttering frequency and in our study we have used a global measure (STI) of speech motor variability to address the same. Given the lack of association between behavioural and kinematic measurements in this investigation, it remains to be seen whether a change may be noticed with a greater number of sessions and how global measures of speech motor stability, such as STI, correspond with behavioural variations in future studies.

References

Adams, M. R., & Hayden, P. (1976). The ability of stutterers and nonstutterers to initiate and terminate phonation during production of an isolated vowel. *Journal of Speech and Hearing Research*, *19*(2), 290-296.

Adams, M. R., & Reis, R. (1974). Influence of the onset of phonation on the frequency of stuttering: A replication and reevaluation. *Journal of Speech and Hearing Research*, *17*(4), 752-754.

Andrews, G., Craig, A., & Feyer, A. M. (1983). Patient's manual for the stuttering treatment programme. *Sydney: Prince Henry Hospital*.

Andrews, G., Hoddinott, S., Craig, A., Howie, P., Feyer, A. M., & Neilson, M. (1983). Stuttering: A review of research findings and theories circa 1982. *Journal of speech and hearing disorders*, *48*(3), 226-246.

Archibald, L., & De Nil, L. F. (1999). The relationship between stuttering severity and kinesthetic acuity for jaw movements in adults who stutter. *Journal of Fluency Disorders*, *24*(1), 25-42.

Bar, A. & Singer, J. & Feldman, R. G. (1969). Subvocal muscle activity during stuttering and fluent speech: A comparison. *South African Journal of Communication Disorders*, *16*(1), 9-14.

Beitchman, J. H., Nair, R., Clegg, M., & Patel, P. G. (1986). Prevalence of speech and language disorders in 5-year-old kindergarten children in the Ottawa-Carleton region. *Journal of Speech and Hearing Disorders*, *51*(2), 98-110.

Blomgren, M. (2010, November). Stuttering treatment for adults: an update on contemporary approaches. In *Seminars in speech and language* (Vol. 31, No. 04, pp. 272-282). © Thieme Medical Publishers.

Blomgren, M. (2010, November). Stuttering treatment for adults: an update on contemporary approaches. In *Seminars in speech and language* (Vol. 31, No. 04, pp. 272-282). © Thieme Medical Publishers.

Blomgren, M. (2012). Stuttering Management Program.

Blomgren, M., Roy, N., Callister, T., & Merrill, R. M. (2005). Intensive stuttering modification therapy.

Bloodstein, O., & Ratner, N. B. (2008). *A handbook on stuttering (6th ed.).* Clifton Park, NY: Delmar Learning.

Bloodstein, P. (1975). A handbook of stuttering. Chicago: National

Boberg, E., & Kully, D. (1985). *Comprehensive stuttering program*. San Diego: College-Hill Press.

Bothe, A. K., Davidow, J. H., Bramlett, R. E., Franic, D. M., & Ingham, R. J. (2006). Stuttering treatment research 1970–2005: II. Systematic review incorporating trial quality assessment of pharmacological approaches.

Boudreau, L. A., & Jeffrey, C. J. (1973). Stuttering treated by desensitization. *Journal of Behavior Therapy and Experimental Psychiatry*, *4*(3), 209-212.

Carey, B., O'Brian, S., Onslow, M., Block, S., Jones, M., & Packman, A. (2010). Randomized controlled non-inferiority trial of a telehealth treatment for chronic stuttering: the Camperdown Program. *International journal of language & communication disorders*, *45*(1), 108–120.

Caruso, A. J., Abbs, J. H., & Gracco, V. L. (1988). Kinematic analysis of multiple movement coordination during speech in stutterers. *Brain, 111,* 439–455

Chakraborty, R., Goffman, L., & Smith, A. (2008). Physiological indices of bilingualism: Oral–motor coordination and speech rate in Bengali–English speakers.

CHEVam-MULLEa, C., A study of laryngeal function in stutterers by the glottal-graphic method. In Proc. VI1 e Congrds de la Societd Frangaise de M~decine de la Voix et de la Parole, Paris (1963

Connally, E. L., Ward, D., Pliatsikas, C., Finnegan, S., Jenkinson, M., Boyles, R., & Watkins, K. E. (2018). Separation of trait and state in stuttering. *Human brain mapping*, *39*(8), 3109–3126.

Cooper, M. H., & Allen, G. D. (1977). Timing control accuracy in normal speakers and stutterers. *Journal of Speech and Hearing Research*, *20*(1), 55-71.

Craig, A., & Hancock, K. (1996). Anxiety in children and young adolescents who stutter. *Australian Journal of Human Communication Disorders*, *24*(1), 28-38.

Curlee, R. F., & Perkins, W. H. (1969). Conversational rate control therapy for stuttering. *Journal of Speech and Hearing Disorders*, *34*(3), 245-250.

Curlee, R. F., & Perkins, W. H. (1973). Effectiveness of a DAF conditioning program for adolescent and adult stutterers. *Behaviour Research and Therapy*, *11*(4), 395-401.

Dalali, I. D., & Sheehan, J. G. (1974). Stuttering and assertion training. *Journal of Communication Disorders*, *7*(2), 97-111.

De Nil, L. F., & Abbs, J. H. (1991). Influence of speaking rate on the upper lip, lower lip, and jaw peak velocity sequencing during bilabial closing movements. *The Journal of the Acoustical Society of America*, *89*(2), 845-849.

DE NIL, L. F., & ABBS, J. H. (1991). Kinaesthetic acuity of stutterers and non-stutterers for oral and non-oral movements. *Brain*, *114*(5), 2145-2158.

Denny, M., & Smith, A. (1997). Respiratory and laryngeal control in stuttering. *Nature and treatment of stuttering: New directions*, 128-142. Easter Seal Society.

Eichstädt, A., Watt, N., & Girson, J. (1998). Evaluation of the efficacy of a stutter modification program with particular reference to two new measures of secondary behaviors and control of stuttering. *Journal of Fluency Disorders*, *23*(4), 231-246.

Fishman, H. C. (1937). A study of the efficacy of negative practice as a corrective for stammering. *Journal of Speech Disorders*, *2*(2), 67-72.

Freeman, F. J., & Ushijima, T. (1975). Laryngeal activity accompanying the moment of stuttering: a preliminary report of EMG investigations. *Journal of Fluency Disorders*, *1*(2), 36-45.

Freeman, F. J., & Ushijima, T. (1978). Laryngeal muscle activity during stuttering. *Journal of Speech and Hearing Research*, *21*(3), 538-562.

Gabel, R. M., Hughes, S., & Daniels, D. (2008). Effects of stuttering severity and therapy involvement on role entrapment of people who stutter. *Journal of Communication Disorders*, *41*(2), 146-158.

Goffman, L. (1999). Prosodic influences on speech production in children with specific language impairment and speech deficits: Kinematic, acoustic, and transcription evidence. *Journal of Speech, Language, and Hearing Research*, *42*(6), 1499-1517.

Goffman, L. (2004). Kinematic differentiation of prosodic categories in normal and disordered language development.

Goffman, L., & Malin, C. (1999). Metrical effects on speech movements in children and adults. *Journal of Speech, Language, and Hearing Research*, *42*(4), 1003-1015.

Goffman, L., Heisler, L., & Chakraborty, R. (2006). Mapping of prosodic structure onto words and phrases in children's and adults' speech production. *Language and Cognitive Processes*, *21*(1-3), 25-47.

Goldiamond, I.,(1965). Stuttering and fluency as manipulable operant response classes. In L. Krasner and L. Ulmann (Eds.), *Research in Behavior Modification.* New York: Holt, Rinehart, and Winston (1965)

Gracco, V. L., & Abbs, J. H. (1986). Variant and invariant characteristics of speech movements. *Experimental Brain Research, 65,* 156–166.

Gregory, R. L. (1972). Cognitive contours. *Nature*, *238*(5358), 51-52.

Guitar, B.(2006) *Stuttering: An integrated approach to its nature and treatment.* , Third edition, U.S.A, Lippincott Williams and Wilkins, 19-29

Hillman, R. E., & Gilbert, H. R. (1977). Voice onset time for voiceless stop consonants in the fluent reading of stutterers and nonstutterers. *The Journal of the Acoustical Society of America*, *61*(2), 610-611.

Hillman, R. E., & Gilbert, H. R. (1977). Voice onset time for voiceless stop consonants in the fluent reading of stutterers and nonstutterers. *The Journal of the Acoustical Society of America*, *61*(2), 610-611.

Howie, P. M., Tanner, S., & Andrews, G. (1981). Short-and long-term outcome in an intensive treatment program for adult stutterers. *Journal of Speech and Hearing Disorders*, *46*(1), 104-109.

Howie, P. M., Tanner, S., & Andrews, G. (1981). Short-and long-term outcome in an intensive treatment program for adult stutterers. *Journal of Speech and Hearing Disorders*, *46*(1), 104-109.

Hutchinson, J. M., & Navarre, B. M. (1977). The effect of metronome pacing on selected aerodynamic patterns of stuttered speech: Some preliminary observations and interpretations. *Journal of Fluency Disorders*, *2*(3), 189-204.

Ingham R. J. (1991). Alleviation of acquired stuttering with human centremedian thalamic stimulation. *Journal of neurology, neurosurgery, and psychiatry*, *54*(1), 93–95.

Ingham, R. J. (1975). A comparison of covert and overt assessment procedures in stuttering therapy outcome evaluation. *Journal of Speech and Hearing Research*, *18*(2), 346-354.

Ingham, R. J. (1982). The effects of self-evaluation training on maintenance and generalization during stuttering treatment. *Journal of Speech and Hearing Disorders*, *47*(3), 271-280.

Ingham, R. J., & Andrews, G. (1973). An analysis of a token economy in stuttering therapy 1. *Journal of Applied Behavior Analysis*, *6*(2), 219-229.

Ingham, R. J., & Andrews, G. (1973). Details of a token economy stuttering therapy programme for adults. *Australian Journal of Human Communication Disorders*, *1*(1), 13-20.

Ingham, R. J., & Packman, A. (1977). Treatment and generalization effects in an experimental treatment for a stutterer using contingency management and speech rate control. *Journal of Speech and Hearing Disorders*, *42*(3), 394-407.

Ingham, R. J., Kilgo, M., Ingham, J. C., Moglia, R., Belknap, H., & Sanchez, T. (2001). Evaluation of a stuttering treatment based on reduction of short phonation intervals.

Irwin, R. B. (1977). Judgments of vocal quality, speech fluency, and confidence of southern black and white speakers. *Language and Speech*, *20*(3), 261-266.

Iverach, L., Menzies, R. G., O'Brian, S., Packman, A., & Onslow, M. (2011). Anxiety and stuttering: Continuing to explore a complex relationship.

James, J. E., Ricciardelli, L. A., Rogers, P., & Hunter, C. E. (1989). A preliminary analysis of the ameliorative effects of time-out from speaking on stuttering. *Journal of Speech, Language, and Hearing Research*, *32*(3), 604-610.

Jäncke, L., Bauer, A., Kaiser, P., & Kalveram, K. T. (1997). Timing and stiffness in speech motor control of stuttering and nonstuttering adults. *Journal of Fluency Disorders*, *22*(4), 309-321.

Janssen, P., Wieneke, G., & Vaane, E. (1983). Variability in the initiation of articulatory movements in the speech of stutterers and normal speakers. *Journal of Fluency Disorders*, *8*(4), 341-358.

Johnson, W. (1967). Stuttering. In W. Johnson, S. Brown, J. Curtis, C. Edney, & J. Keaster (Eds.), Speech handicapped school children (pp. 229-329). New York: Harper & Row.

Kelly, E. M., Smith, A., & Goffman, L. (1995). Orofacial muscle activity of children who stutter: A preliminary study. *Journal of Speech, Language, and Hearing Research*, *38*(5), 1025-1036.

Kleinow, J., & Smith, A. (2000). Influences of length and syntactic complexity on the speech motor stability of the fluent speech of adults who stutter. *Journal of speech, language, and hearing research*, *43*(2), 548-559.

Klich, R. J., & May, G. M. (1982). Spectrographic study of vowels in stutterers' fluent speech. *Journal of Speech, Language, and Hearing Research*, *25*(3), 364-370.

Kully, D., Langevin, M., & Lomheim, H. (2007). Intensive treatment of stuttering in adolescents and adults. *Stuttering and related disorders of fluency*, 213-232.

Loucks, T. M., Luc, F., & Sasisekaran, J. (2007). Jaw-phonatory coordination in chronic developmental stuttering. *Journal of Communication Disorders*, *40*(3), 257-272.

MacPherson, M. K., & Smith, A. (2013). Influences of sentence length and syntactic complexity on the speech motor control of children who stutter.

MacPherson, M. K., & Smith, A. (2013). Influences of sentence length and syntactic complexity on the speech motor control of children who stutter.

MacPherson, M. K., & Smith, A. (2013). Influences of sentence length and syntactic complexity on the speech motor control of children who stutter.

MacPherson, M. K., & Smith, A. (2013). Influences of sentence length and syntactic complexity on the speech motor control of children who stutter.

Mahesh, B.V.M., & Manjula. R. (2020). *Influence of Second Language (English) Proficiency on Speech Motor Control in Kannada-English Bilinguals with Stuttering*. Unpublished Doctoral Thesis, All India Institute of Speech and Hearing. University of Mysuru, Mysuru.

Mahesh, B. V. M., & Manjula, R. (2016). The effects of English (L2) language proficiency on speech motor indices for bisyllabic bilabial word utterances in typical Kannada (L1)–English (L2) bilinguals. *Speech, Language and Hearing*, *19*(3), 171-179.

Maner, K. J., Smith, A., & Grayson, L. (2000). Influences of utterance length and complexity on speech motor performance in children and adults. *Journal of Speech, Language, and Hearing Research*, *43*(2), 560-573.

Maner, K. J., Smith, A., & Grayson, L. (2000). Influences of utterance length and complexity on speech motor performance in children and adults. *Journal of Speech, Language, and Hearing Research*, *43*(2), 560-573.

Månsson, H. (2000). Childhood stuttering: Incidence and development. *Journal of fluency disorders*, *25*(1), 47-57.

Maruthy, S., & Savithri, S. R. (2006). *Some Perceptual and Acoustical Correlates of Stuttering: A Pre-Post Therapy Comparison.*Unpublished Doctoral Thesis, All India Institute of Speech and Hearing. University of Mysuru, Mysuru.

Max, L., Caruso, A. J., & Gracco, V. L. (2003). Kinematic analyses of speech, orofacial nonspeech, and finger movements in stuttering and nonstuttering adults.

Max, L., Gracco, V. L., & Caruso, A. J. (2004). Kinematic event sequencing in stuttering and nonstuttering adults. In *Proceedings of the 4th World Congress on Fluency Disorders* (pp. 315-322).

McClean, M. D., Kroll, R. M., & Loftus, N. S. (1990). Kinematic analysis of lip closure in stutterers' fluent speech. *Journal of Speech, Language, and Hearing Research*, *33*(4), 755-760.

Metz, D. E., Conture, E. G., & Caruso, A. (1979). Voice onset time, frication, and aspiration during stutterers' fluent speech. *Journal of Speech, Language, and Hearing Research*, *22*(3), 649-656.

Montgomery, C. S. (2006). The treatment of stuttering: From the hub to the spoke. *Current issues in stuttering research and practice*, 159-204.

Namasivayam, A. K., Van Lieshout, P., & De Nil, L. (2008). Bite-block perturbation in people who stutter: Immediate compensatory and delayed adaptive processes. *Journal of communication disorders*, *41*(4), 372-394.

Namasivayam, A. K., Van Lieshout, P., McIlroy, W. E., & De Nil, L. (2009). Sensory feedback dependence hypothesis in persons who stutter. *Human movement science*, *28*(6), 688-707.

Onslow, M., Costa, L., Andrews, C., Harrison, E., & Packman, A. (1996). Speech outcomes of a prolonged-speech treatment for stuttering. *Journal of Speech, Language, and Hearing Research*, *39*(4), 734-749.

Ouni S., Mangeonjean L. & Steiner I. (2012), "VisArtico: A visualization tool for articulatory data", *13th Annual Conference of the International Speech Communication Association – Interspeech 2012*, Portland (OR), United States. [

Perkins, W. H., Rudas, J., Johnson, L., Michael, W. B., & Curlee, R. F. (1974). Replacement of stuttering with normal speech: III. Clinical effectiveness. *Journal of Speech and Hearing Disorders*, *39*(4), 416-428.

Peters, H. F., & Boves, L. (1988). Coordination of aerodynamic and phonatory processes in fluent speech utterances of stutterers. *Journal of Speech, Language, and Hearing Research*, *31*(3), 352-361.

Peters, H. F., Hulstijn, W., & Starkweather, C. W. (1989). Acoustic and physiological reaction times of stutterers and nonstutterers. *Journal of Speech, Language, and Hearing Research*, *32*(3), 668-680.

Peters, H. M., Hulstijn, W., & Van Lieshout, P. H. (2000). Recent developments in speech motor research into stuttering. *Folia phoniatrica et logopaedica*, *52*(1-3), 103-119.

Peters, H., Hietkamp, R., & Boves, L. (1994). Aerodynamic and phonatory processes in disfluent speech utterances of stutterers. *Journal of Fluency Disorders*, *19*(3), 199.

Prins, D. (1970). Improvement and regression in stutterers following short-term intensive therapy. *Journal of Speech and Hearing Disorders*, *35*(2), 123-135.

Prins, D., & Ingham, R. J. (2009). Evidence-based treatment and stuttering—historical perspective.

Prosek, R. A., & Runyan, C. M. (1982). Temporal characteristics related to the discrimination of stutterers' and nonstutterers' speech samples. *Journal of Speech, Language, and Hearing Research*, *25*(1), 29-33.

Riley, G. D. (1994). *Stuttering severity instrument for children and adults* (3rd ed.). Austin, TX: PRO-ED.

Ryan, B. P., & Ryan, B. V. K. (1983). Programmed stuttering therapy for children: Comparison of four establishment programs. *Journal of Fluency Disorders*, *8*(4), 291-321.

Ryan, B. P., & Ryan, B. V. K. (1995). Programmed stuttering treatment for children: Comparison of two establishment programs through transfer, maintenance, and follow-up. *Journal of Speech, Language, and Hearing Research*, *38*(1), 61-75.

Sadagopan, N., & Smith, A. (2008). Developmental changes in the effects of utterance length and complexity on speech movement variability.

Savithri, S. R., & Jayaram, M. (2005). *Rate of Speech/Reading in Dravidian Languages.* Departmental Project, All India Institute of Speech and Hearing, Mysuru.

Schwartz, M. F. (1974). The core of the stuttering block. *Journal of Speech and Hearing Disorders*, *39*(2), 169-177.

Shapiro, A. I. (1980). An electromyographic analysis of the fluent and dysfluent utterances of several types of stutterers. *Journal of Fluency Disorders*, *5*(3), 203-231.

Sheehan, J. (1979). Current issues on stuttering and recovery. *Controversies about stuttering therapy*, 175-208.

Sheehan, J. G. (1970). Reflections on the behavioral modification of stuttering. In *EDRS PRICE MF-$0.65 HC-$6.58 DESCRIPTORS* Behavior Change; Conference Reports;* Exceptional Child Education;* Learning Theories; Operant* (p. 123).

Smith, A., & Goffman, L. (1998). Stability and patterning of speech movement sequences in children and adults. *Journal of Speech, Language, and Hearing Research*, *41*(1), 18-30.

Smith, A., & Kleinow, J. (2000). Kinematic correlates of speaking rate changes in stuttering and normally fluent adults. *Journal of Speech, Language, and Hearing Research*, *43*(2), 521-536.

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

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., & Stark, R. (1995). Speech Motor Development. *Seminars in Speech and Language, 16,* 87-99

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.

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.

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.

Smith, A., Sadagopan, N., Walsh, B., & Weber-Fox, C. (2010). Increasing phonological complexity reveals heightened instability in inter-articulatory coordination in adults who stutter. *Journal of fluency disorders*, *35*(1), 1-18.

Smith, A., Sadagopan, N., Walsh, B., & Weber-Fox, C. (2010). Increasing phonological complexity reveals heightened instability in inter-articulatory coordination in adults who stutter. *Journal of fluency disorders*, *35*(1), 1-18.

Smits-Bandstra, S., De Nil, L. F., & Saint-Cyr, J. A. (2006). Speech and nonspeech sequence skill learning in adults who stutter. *Journal of fluency disorders*, *31*(2), 116–136.

Story, R. S., Alfonso, P. J., & Harris, K. S. (1996). Pre-and posttreatment comparison of the kinematics of the fluent speech of persons who stutter. *Journal of Speech, Language, and Hearing Research*, *39*(5), 991-1005.

Tasko, S. M., McClean, M. D., & Runyan, C. M. (2007). Speech motor correlates of treatment-related changes in stuttering severity and speech naturalness. *Journal of Communication Disorders*, *40*(1), 42-65.

Van Riper, C. (1973). *The treatment of stuttering*. Prentice Hall.

Van Riper, C. (1982). *The nature of stuttering*. Prentice Hall.

Walsh, B., Mettel, K. M., & Smith, A. (2015). Speech motor planning and execution deficits in early childhood stuttering. *Journal of neurodevelopmental disorders*, *7*(1), 1-12.

Webster ,R.(1975). *The Precision Fluency Shaping Program* Client Manual, Vol. II (1975)

Webster, R. L. (1974). A behavioral analysis of stuttering: Treatment and theory. *Innovative treatment methods in psychopathology*, 17-61.

Wingate, M. E. (1964). A standard definition of stuttering. *Journal of speech and hearing disorders*, *29*(4), 484-489.

Zebrowski, P. M., & Arenas, R. M. (2011). The "Iowa Way" revisited. *Journal of fluency disorders*, *36*(3), 144-157.

Zimmerman, G. N. (1980). Articulatory behaviors associated with stuttering: A cineradiographic analysis. *Journal of Speech, Language, and Hearing Research*, *23*, 108-121.

Zimmerman, G. N. (1980a). Articulatory behaviors associated with stuttering: A cineradiographic analysis. *Journal of Speech, Language, and Hearing Research*, *23*, 108-121.

Zimmermann, G. (1980). Stuttering: A disorder of movement. *Journal of Speech, Language, and Hearing Research*, *23*(1), 122-136.

Zimmermann, G. (1980a). Stuttering: A disorder of movement. *Journal of Speech, Language, and Hearing Research*, *23*(1), 122-136.

Zimmermann, G. (1980b). Articulatory behaviors associated with stuttering: A cinefluorographic analysis. *Journal of Speech, Language, and Hearing Research*, *23*(1), 108-121.mmermann, 1980b

Zimmermann, G. N., & Hanley, J. M. (1983). A cinefluorographic investigation of repeated fluent productions of stutterers in an adaptation procedure. *Journal of Speech, Language, and Hearing Research*, *26*(1), 35-42.

Zocchi, W., Estenne, M., Johnston, S., Del Ferro, L., Ward, M. E., & Macklem, P. T. (1990). Respiratory Muscle Incoordination in Stuttering Speech, 1-3. *American Review of Respiratory Disease*, *141*, 1510-1515.